

The copyright of this thesis rests with the University of Cape Town. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Energy policies for sustainable development in South Africa's residential and electricity sectors

Implications for mitigating climate change

by

HARALD WINKLER

Thesis presented for the Degree of
DOCTOR OF PHILOSOPHY

in the Energy Research Centre
UNIVERSITY OF CAPE TOWN

June 2006

TABLE OF CONTENTS

ABSTRACT	VI
ACKNOWLEDGEMENTS	VIII
ABBREVIATIONS, ACRONYMS AND UNITS	X
PART I: INTRODUCTION TO ENERGY, SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE	1
1. INTRODUCTION	1
1.1 ENERGY, SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE IN SOUTH AFRICA	1
1.2 RESEARCH QUESTION	3
1.3 METHODOLOGY	3
1.4 OUTLINE OF THE THESIS	8
2. SUSTAINABLE DEVELOPMENT, ENERGY AND CLIMATE CHANGE	9
2.1 WORKING DEFINITION OF SUSTAINABLE DEVELOPMENT	9
2.2 ENERGY FOR SUSTAINABLE DEVELOPMENT IN SOUTH AFRICA	12
2.3 SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE	13
2.4 MAKING ENERGY DEVELOPMENT PATHS MORE SUSTAINABLE AS AN APPROACH TO CLIMATE CHANGE MITIGATION	18
2.5 CONCLUSION	21
PART II: ISSUES AND CONTEXT	22
3. DEVELOPMENT OBJECTIVES	22
3.1 THE BROADER CONTEXT: SOUTH AFRICA'S DEVELOPMENT OBJECTIVES	22
3.2 THE POLICY ENVIRONMENT IN THE ENERGY SECTOR	25
3.3 ROLE OF ELECTRICITY IN DEVELOPMENT	30
3.4 ECONOMIC AND INSTITUTIONAL ASPECTS	40
3.5 SOCIAL DIMENSIONS AND THE RESIDENTIAL SECTOR	46
3.6 ENVIRONMENTAL IMPACTS	50
3.7 CONCLUSIONS: COMPARING AND ASSESSING	55
4. POLICY OPTIONS IN THE ELECTRICITY AND RESIDENTIAL SECTOR	58
4.1 FURTHER EXTENDING AFFORDABLE ACCESS TO ELECTRICITY	59
4.2 ENERGY GOVERNANCE – TO PRIVATISE OR NOT ?	64
4.3 MANAGING ENERGY-RELATED ENVIRONMENTAL IMPACTS	66
4.4 ECONOMIC DEVELOPMENT AND INSTRUMENTS	70
4.5 SECURING ELECTRICITY SUPPLY THROUGH DIVERSITY	80
4.6 CONCLUSION	90
PART III: MODELING ENERGY POLICIES	91
5. TOOLS FOR MODELING ENERGY POLICIES	91
5.1 PURPOSE OF MODELING IN THIS THESIS	91
5.2 DEVELOPING POLICY CASES FOR ENERGY FUTURES	91
5.3 MODELING TOOLS	92
5.4 CRITICAL ANALYSIS OF MODELING TOOLS FOR ENERGY POLICIES	94
5.5 CONCLUSION	97
6. MODELING ENERGY POLICIES	98
6.1 FOCUS OF POLICY MODELING	99
6.2 DRIVERS OF FUTURE TRENDS AND KEY ASSUMPTIONS	103
6.3 THE BASE CASE	112
6.4 OVERVIEW OF POLICY CASES	120
6.5 RESIDENTIAL ENERGY POLICIES	121
6.6 ELECTRICITY SUPPLY OPTIONS	132
6.7 CONCLUSION	142

7. DISCUSSION AND INTERPRETATION OF RESULTS	143
7.1 RESIDENTIAL ENERGY POLICIES	143
7.2 ELECTRICITY SUPPLY OPTIONS	156
7.3 CONCLUSION	165
PART IV: SUSTAINABLE DEVELOPMENT, ENERGY AND CLIMATE CHANGE POLICIES	166
8. EVALUATING ENERGY POLICIES AGAINST INDICATORS OF SUSTAINABLE DEVELOPMENT	166
8.1 INDICATORS OF SUSTAINABLE DEVELOPMENT	166
8.2 ECONOMIC	169
8.3 ENVIRONMENTAL	177
8.4 SOCIAL	184
8.5 COMPARISONS AND CONCLUSIONS	191
PART IV: ENERGY FOR SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE.....	200
9. POLICY ANALYSIS	200
9.1 ENERGY POLICIES TO MAKE DEVELOPMENT MORE SUSTAINABLE	200
9.2 IMPLICATIONS OF SUSTAINABLE ENERGY DEVELOPMENT PATHS FOR CLIMATE CHANGE MITIGATION POLICY	218
9.3 CONCLUSION	226
10. CONCLUSION.....	228
APPENDICES	233
REFERENCES.....	236

List of Tables

TABLE 3.1: SOUTH AFRICAN ENERGY POLICY PRIORITIES AND PROGRESS	29
TABLE 3.2: LICENSED CAPACITY, MAXIMUM POWER, PEAK DEMAND AND CALCULATED 'EXCESS CAPACITY' FOR ESKOM, SELECTED YEARS	37
TABLE 3.3: NET ELECTRICITY SENT OUT (MWh) BY FUEL	39
TABLE 3.4: ELECTRICITY INTENSIVE SECTORS OF THE SA ECONOMY.....	44
TABLE 3.5: ESTIMATED ELECTRIFICATION LEVELS OF RURAL AND URBAN HOUSEHOLD BY INCOME QUINTILE	48
TABLE 3.6: EMISSION FROM ESKOM POWER STATIONS, 2001.....	52
TABLE 3.7: ENERGY SECTOR CARBON DIOXIDE EMISSIONS INTENSITY AND PER CAPITA IN 2002 AND CUMULATIVE EMISSIONS 1950-2000	52
TABLE 3.8: ENERGY AND ELECTRICITY CONSUMPTION, 2000	55
TABLE 3.9: ELECTRIFICATION RATES IN 2000	56
TABLE 3.10: NATIONAL ENERGY INTENSITIES BETWEEN 1993 AND 2000.....	56
TABLE 4.1: MEAN HOUSEHOLD EXPENDITURE ON ELECTRICITY AND OTHER FUELS AND ENERGY AS A PERCENTAGE OF TOTAL HOUSEHOLD EXPENDITURE	61
TABLE 4.2: EXTERNALITIES ASSOCIATED WITH ELECTRICITY SUPPLY BY CLASS.....	66
TABLE 4.3: SUMMARY OF EXTERNAL COSTS OF ESKOM COST-FIRED ELECTRICITY GENERATION PER UNIT (1999 RANDS)	69
TABLE 4.4: POTENTIAL FUTURE SAVINGS FROM ENERGY EFFICIENCY AND DEMAND SIDE MANAGEMENT (CUMULATIVE CAPACITY EQUIVALENT IN MW)	75
TABLE 4.5: INTERNATIONAL COST DATA FOR RENEWABLE ENERGY TECHNOLOGIES.....	82
TABLE 4.6: ESTIMATES OF THEORETICAL POTENTIAL FOR RENEWABLE ENERGY SOURCES IN SOUTH AFRICA	82
TABLE 4.7: TOOLS THAT GOVERNMENTS CAN USE TO PROMOTE RENEWABLE ELECTRICITY	83
TABLE 4.8: OPTIONS FOR NEW ELECTRICITY SUPPLY	87
TABLE 6.1: ACTION IMPACT MATRIX SCOPING THE IMPACT OF POLICY INTERVENTIONS ON DEVELOPMENT GOALS	100
TABLE 6.2: SA POPULATION PROJECTIONS FROM VARIOUS SOURCES, MILLIONS.....	106
TABLE 6.3: NUMBER AND SHARE OF HOUSEHOLDS, ESTIMATED FOR 2001 AND PROJECTED FOR 2025	108
TABLE 6.4: FUEL PRICES BY FUEL AND FOR SELECTED YEARS.....	110
TABLE 6.5: COST DEFLATORS BASED ON GROSS VALUE ADDED.....	111
TABLE 6.6: TOTAL PRIMARY ENERGY SUPPLY BY FUEL GROUP IN BASE CASE	113
TABLE 6.7: ENERGY DEMAND BY HOUSEHOLD TYPE AND END USE FOR SELECTED YEARS	119
TABLE 6.8: SUMMARY OF POLICY CASES IN RESIDENTIAL AND ELECTRICITY SUPPLY SECTORS.....	120
TABLE 6.9: INCOME AND EXPENDITURE IN URBAN AND NON-URBAN AREAS IN 2000 MARKET VALUES, GROUPED BY 1995 QUINTILE	122
TABLE 6.10: NUMBERS AND SHARES OF RURAL AND URBAN HOUSEHOLDS, ELECTRIFIED AND NOT.....	123
TABLE 6.11: SIX HOUSEHOLD TYPES, WITH TOTAL NUMBERS IN 2000, SHARES AND ASSUMPTIONS	123
TABLE 6.12: ENERGY DEMAND BY HOUSEHOLD TYPE FOR EACH END USE	126
TABLE 6.13: KEY CHARACTERISTICS OF ENERGY TECHNOLOGIES IN THE RESIDENTIAL SECTOR	127
TABLE 6.14: CHARACTERISTICS OF ELECTRICITY SUPPLY TECHNOLOGIES IN POLICY CASES	133
TABLE 6.15: TECHNICALLY FEASIBLE POTENTIAL FOR RENEWABLE ENERGY BY TECHNOLOGY	135
TABLE 6.16: CURRENT CAPACITY, INCREASES AND PROGRESS RATIOS FOR RE TECHNOLOGIES.....	137
TABLE 7.1: OVERVIEW OF RESULTS FOR RESIDENTIAL ENERGY POLICIES	143
TABLE 7.2: REDUCTION IN MONTHLY EXPENDITURE ON ELECTRICITY WITH EFFICIENT HOUSES BY HOUSEHOLD TYPE.....	145
TABLE 7.3: ENERGY SAVED AND COSTS FOR CLEANER WATER HEATING.....	149
TABLE 7.4: FUEL CONSUMPTION IN THE RESIDENTIAL SECTOR ACROSS POLICY CASES, 2014 AND 2025 ...	154
TABLE 7.5: ENERGY CONSUMPTION BY END USE FOR HOUSEHOLD TYPES, 2025	155
TABLE 7.6: SHARE OF HOUSEHOLDS WITH ACCESS TO ELECTRICITY IN 2025 FOR ALL POLICY CASES.....	158
TABLE 8.1: INDICATORS OF SUSTAINABLE DEVELOPMENT FOR ENERGY POLICIES.....	168
TABLE 8.2: TOTAL ENERGY SYSTEM COSTS ACROSS RESIDENTIAL POLICIES	170
TABLE 8.3: TOTAL COST OF ENERGY SYSTEM FOR ELECTRICITY SUPPLY OPTIONS	172
TABLE 8.4: GWh ELECTRICITY GENERATED BY TECHNOLOGY IN ITS POLICY CASE.....	173
TABLE 8.5: COSTS OF ELECTRICITY SUPPLY TECHNOLOGIES PER CAPACITY AND UNIT OF GENERATION....	173
TABLE 8.6: SHADOW PRICE OF ELECTRICITY FOR POLICY CASES	175
TABLE 8.7: DIVERSITY OF FUEL MIX FROM DOMESTIC SOURCES FOR ELECTRICITY SUPPLY OPTIONS BY 2025	176

TABLE 8.8: LOCAL AIR POLLUTANTS IN RESIDENTIAL POLICY CASES, 2025	177
TABLE 8.9: GHG EMISSIONS IN RESIDENTIAL POLICIES CASES	178
TABLE 8.10: LOCAL AIR POLLUTANTS IN ELECTRICITY POLICY CASES, 2025.....	179
TABLE 8.11: GHG EMISSIONS FOR ELECTRICITY SUPPLY OPTIONS	181
TABLE 8.12: ESTIMATE OF ABATEMENT COST IN POLICY CASES.....	183
TABLE 8.13: RESIDENTIAL FUEL CONSUMPTION BY POLICY CASE	185
TABLE 8.14: SHADOW PRICES OF ELECTRICITY AND OTHER FUELS ACROSS POLICY CASES.....	186
TABLE 8.15: INITIAL INVESTMENT IN TECHNOLOGY IN ITS POLICY CASE.....	187
TABLE 8.16: ELECTRICITY CONSUMPTION BY HOUSEHOLD TYPE	188
TABLE 8.17: MONTHLY EXPENDITURE ON ELECTRICITY BY HOUSEHOLD TYPE AND POLICY CASE	189
TABLE 8.18: AVERAGE ANNUAL EXPENDITURE PER HOUSEHOLD BY QUINTILE GROUP, PLACE OF RESIDENCE AND TYPE OF DWELLING.....	190
TABLE 8.19: DERIVED AVERAGE ANNUAL AND MONTHLY EXPENDITURE BY HOUSEHOLD TYPE	190
TABLE 8.20: ELECTRICITY BURDEN: SHARE OF MONTHLY HOUSEHOLD EXPENDITURE SPENT ON ELECTRICITY	191
TABLE 8.21: EVALUATION OF ALL POLICIES ACROSS THREE DIMENSIONS OF SUSTAINABLE DEVELOPMENT	193
TABLE 9.1: SUBSIDY REQUIRED FOR MAKING EFFICIENT HOUSING AS AFFORDABLE FOR POORER AS FOR RICHER HOUSEHOLDS	204
TABLE 9.2: COST OF SAVED ENERGY FOR SWH AND GEYSER BLANKETS	205
TABLE 9.3: ORDER OF MAGNITUDE OF CARBON REVENUES FOR DIFFERENT CARBON PRICES	221
TABLE 10.1: MONTHLY EXPENDITURE ON ELECTRICITY BY HOUSEHOLD TYPE AND POLICY CASE, 2001... 235	

List of Figures

FIGURE 1.1: METHODOLOGY FOR THE THESIS	4
FIGURE 2.1: ELEMENTS OF SUSTAINABLE DEVELOPMENT	10
FIGURE 2.2: COMPARISON OF SRES REFERENCE EMISSIONS SCENARIOS (WITHOUT CLIMATE POLICY) AND 'POST-SRES' CLIMATE CHANGE MITIGATION SCENARIOS	17
FIGURE 2.3: EMISSIONS PATHS RELATIVE TO DEVELOPMENT LEVEL AND POSSIBILITY OF 'TUNNELLING' ...	20
FIGURE 3.1: ENERGY DEMAND, 1992-2000.....	32
FIGURE 3.2: SECTORAL CONTRIBUTION TO ECONOMY, 1967-2003.....	32
FIGURE 3.3: SHARE OF TOTAL PRIMARY ENERGY SUPPLY, 1999.....	33
FIGURE 3.4: TOTAL SALEABLE PRODUCTION, LOCAL SALES AND EXPORTS OF SOUTH AFRICAN COAL, 1992 TO 2001.....	34
FIGURE 3.5: SHARE OF FINAL ENERGY CONSUMPTION, 2000.....	35
FIGURE 3.6: PERCENTAGE CHANGES IN ESKOM ELECTRICITY SALES AND CHANGE IN REAL GDP AT MARKET PRICES	35
FIGURE 3.7: ESKOM LICENSED CAPACITY AND PEAK DEMAND (MW)	37
FIGURE 3.8: MAP OF SA POWER STATIONS BY FUEL AND OWNERSHIP.....	38
FIGURE 3.9: ENERGY FLOW THROUGH THE ELECTRICITY SUPPLY INDUSTRY IN SOUTH AFRICA.....	40
FIGURE 3.10: SHARE OF FINAL ENERGY DEMAND BY ENERGY CARRIER	42
FIGURE 3.11: ELECTRICITY DEMAND, 1986-2000	43
FIGURE 3.12: FINAL INDUSTRIAL ENERGY CONSUMPTION BY SUB-SECTOR	45
FIGURE 3.13: FINAL RESIDENTIAL ENERGY DEMAND BY ENERGY CARRIER	47
FIGURE 3.14: EMPLOYMENT IN COAL-BASED ELECTRICITY GENERATION IN SOUTH AFRICA.....	50
FIGURE 3.15: SOUTH AFRICA'S GREENHOUSE GAS INVENTORY BY SECTOR, 1994.....	54
FIGURE 3.16: CHANGES IN ENERGY INTENSITY, 1993 – 2000	57
FIGURE 4.1: WELFARE ECONOMIC BASIS FOR POVERTY TARIFF.....	62
FIGURE 6.1: TRENDS IN GDP, 1946 - 2000.....	104
FIGURE 6.2: POPULATION PROJECTIONS BY ASSA MODEL.....	107
FIGURE 6.3: LEARNING CURVES FOR NEW AND MATURE ENERGY TECHNOLOGIES	109
FIGURE 6.4: ELECTRICITY GENERATION (GWh) IN THE BASE CASE, GROUPED BY FUEL.....	115
FIGURE 6.5: ELECTRICITY CAPACITY (GW) IN THE BASE CASE	115
FIGURE 6.6: PROJECTED ENERGY DEMAND BY SECTOR IN THE BASE CASE	116
FIGURE 6.7: TRENDS IN ELECTRIFICATION OF HOUSEHOLDS IN SA, 1995-2002.....	117
FIGURE 6.8: PROJECTED CHANGES OF HOUSEHOLD NUMBERS IN THE BASE CASE, 2001 – 2025.....	118

FIGURE 6.9: TRENDS IN FUEL SHARES IN THE RESIDENTIAL SECTOR IN THE BASE CASE	125
FIGURE 6.10: SCHEMATIC DESCRIPTION OF ASSUMED PBMR COSTS IN REFERENCE AND POLICY CASES ...	138
FIGURE 7.1: IMPLICATIONS OF EFFICIENT HOUSES ON DEMAND FOR SPACE HEATING IN UHE HOUSEHOLDS	145
FIGURE 7.2: CHANGES IN LIGHTING TECHNOLOGIES IN THE CFL POLICY CASE	147
FIGURE 7.3: INVEST COSTS FOR SWH AND GEYSER BLANKETS BY HOUSEHOLD TYPE	149
FIGURE 7.4: EQUIVALENT OF FOSSIL FUEL USE FOR SOLAR WATER HEATING, BY HOUSEHOLD TYPE (PJ) ..	150
FIGURE 7.5: ENERGY USED FOR WATER HEATING BY URBAN LOW-INCOME ELECTRIFIED HOUSEHOLDS	150
FIGURE 7.6: FUEL SWITCH TO LPG FOR THREE HOUSEHOLD TYPES.....	152
FIGURE 7.7: RENEWABLE ENERGY FOR ELECTRICITY GENERATION BY POLICY CASE	156
FIGURE 7.8: CONTRIBUTION OF RENEWABLE ENERGY TECHNOLOGIES TO MEETING THE TARGET BY 2013	157
FIGURE 7.9: NUCLEAR ENERGY (PBMR) FOR ELECTRICITY GENERATION BY POLICY CASE	159
FIGURE 7.10: UNUSED CAPACITY OF THE PBMR IN THE POLICY CASE	159
FIGURE 7.11: MARGINAL INVESTMENT REQUIRED FOR MORE PBMR CAPACITY	160
FIGURE 7.12: IMPORTS OF HYDRO-ELECTRICITY AND IMPORT COSTS IN POLICY AND BASE CASE	161
FIGURE 7.13: ANNUALISED INVESTMENT IN COMBINED CYCLE GAS IN THE POLICY AND BASE CASE.....	162
FIGURE 7.14: ELECTRICITY GENERATION WITHOUT FLUIDISED BED COMBUSTION.....	163
FIGURE 8.1: UNDISCOUNTED TOTAL INVESTMENT IN TECHNOLOGIES, SUPPLY AND DEMAND	169
FIGURE 8.2: INVESTMENT REQUIRED FOR RESIDENTIAL POLICIES IN THE RESPECTIVE POLICY CASE.....	171
FIGURE 8.3: ANNUALISED INVESTMENTS IN ELECTRICITY SUPPLY TECHNOLOGIES BY POLICY CASE.....	174
FIGURE 8.4: SO ₂ EMISSIONS IN ELECTRICITY POLICY CASES OVER TIME.....	179
FIGURE 8.5: CO ₂ EMISSIONS FOR ALL CASES OVER TIME	182
FIGURE 8.6: RENEWABLE ENERGY USE IN RESIDENTIAL POLICY CASES	185
FIGURE 8.7: SHADOW PRICES OF ENERGY CARRIERS OVER TIME	187
FIGURE 8.8: ELECTRICITY SUPPLY OPTIONS RANKED BY ECONOMIC, SOCIAL AND ENVIRONMENTAL INDICATOR	197
FIGURE 8.9: ELECTRICITY OPTIONS RANKED AGAINST MORE INDICATORS	198
FIGURE 8.10: RESIDENTIAL POLICIES RANKED BY ECONOMIC, SOCIAL AND ENVIRONMENTAL INDICATOR	199
FIGURE 9.1: MARGINAL INVESTMENTS REQUIRED FOR EFFICIENT HOUSES AT 30% AND 10% DISCOUNT RATES.....	203
FIGURE 9.2: DIVERSITY OF FUEL MIX FROM DOMESTIC SOURCES FOR ELECTRICITY SUPPLY OPTIONS BY 2025	216
FIGURE 9.3: TOTAL CAPACITY FOR ELECTRICITY GENERATION AND ADDITIONS PER YEAR	217
FIGURE 9.4: WEDGES OF ELECTRICITY CAPACITY EQUIVALENT TO ONE 'SIX-PACK' EACH OVER 20 YEARS	218
FIGURE 9.5: GHG EMISSIONS AVOIDED IN RESIDENTIAL POLICY CASES	219
FIGURE 9.6: GHG EMISSIONS AVOIDED IN ELECTRICITY POLICY CASES	220
FIGURE 10.1: ELECTRICITY GENERATION FROM ALL PLANTS IN THE BASE CASE	233
FIGURE 10.2: ELECTRICITY CAPACITY IN THE BASE CASE, ALL POWER PLANTS	234

Abstract

Harald Winkler's thesis examines "Energy policies for sustainable development in South Africa's residential and electricity sectors: Implications for mitigating climate change". The research question asks whether there are energy policies that will make South Africa's energy development more sustainable economically, socially and environmentally, especially in the context of the local environment. Energy policies for sustainable development are explored as an approach to mitigating climate change.

A methodology combining three major components is developed - modeling, evaluation of indicators of sustainable development and policy analysis. The analysis explicitly starts from development objectives. 'Backcasting' from development objectives has been not been implemented in national energy models in developing countries. Within the modeling component, the residential sector is disaggregated into six household types for the first time in a national energy model for South Africa.

Energy policies for sustainable development in two sectors are identified to meet the country's development objectives. Making residential energy more sustainable includes cleaner and more efficient ways of providing energy services - lighting, water heating, cooking and heating. The thesis also analyses four major electricity supply options – renewable energy, nuclear, importing hydro or natural gas. The thesis develops an analytical approach that for considering energy policies that incorporates environmental concerns.

Identified policies are quantified in an energy-economic modeling framework. A wide variety of data sources is used, drawing on statistical information, official energy data, utility statistics, journal articles and research reports. Indicators of sustainable development provide a framework for assessing the suitability of suggested policy cases, while policy analysis considers their implementation for both energy and climate policies. A contribution of the thesis lies in combining these analytical tools to identify energy policies that promote both local sustainable development and mitigate climate change.

The thesis finds solar water heating and efficient housing rank higher than alternatives in all dimensions of sustainable development for the residential sector. These policies provide cleaner energy services, reduce fuel use and yield cost savings for households. The latter is significant in reducing the electricity burden, particularly for poorer households. A more equitable *distribution* of energy services favours social sustainability and reduces inequalities..

Emissions in the order of 1- 10 Mt CO₂-equiv / year can be avoided. The investment requirement is relatively modest. However, the residential sector will not deliver the largest absolute energy savings and associated emission reductions.

Sustainable energy policies in the electricity sector will also be important for climate policy. In this sector, the challenges are longer-term and more trade-offs are required, with no single option preferable in all dimensions of sustainable development. The two import options require the least domestic cost, while the two domestic options are found to increase diversity, albeit in different ways. The challenge for electricity supply options, the thesis argues, is to diversify rather than to pick a single energy source to supply all future needs.

In reducing greenhouse gases, the abatement cost of renewable energy appears to be lower. Combining the suggested electricity supply options could avoid emissions up to 50 Mt CO₂ / year – although a combined case has the highest costs of all. A transition to a more sustainable electricity supply sector will take several decades, but needs to be enabled by short-term changes. Based on the findings, the thesis contends that the appropriate starting point – conceptually and methodologically – for both energy and mitigation policy is sustainable development. Climate change mitigation policy, it is argued, should start with *local* sustainable development, rather than goals set in climate terms.

The thesis demonstrates that there are indeed policies that meet local sustainable development objectives, and reduce greenhouse gases as a co-benefit. Combining residential and electricity policies would offer a mix that overall provides a durable balance of economic development, social sustainability, and both local and global environmental benefits. Energy policies suggested in this thesis would assist South Africa in sustainable development of its energy sector.

Acknowledgements

The work in this thesis is substantially my own. Yet it would not have been possible without a number of people and organisations, whom I wish to acknowledge and thank.

My co-supervisors, Prof Ogunlade Davidson and Prof Sue Parnell, motivated me to embark on this thesis in the first place and helped me sustain the effort needed to write it. I thank them both for their insight and wise guidance.

My colleagues at the Energy Research Centre and the former Energy & Development Research Centre helped me learn much of what I know about energy in South Africa. A special thanks to Randall Spalding-Fecher, the foil for much of my early thinking informing this thesis. Gisela Prasad gave generously of her time and advice on the process of working through a thesis. As an organisation, ERC has been a place in which I have been able to explore the pursuit of knowledge – for the sake of making a difference. The cited works of many of my former and current colleagues – too numerous to mention individually – bear testimony to their contribution.

The Munasinghe Institute for Development (MIND) in Sri Lanka offered me a place to consolidate and write up a large part of the thesis. Their warm hospitality and the depth of experience of the MIND director and staff are deeply appreciated as is the contribution of UNITAR in providing the resources to make my stay in Sri Lanka possible.

Parts of this thesis have previously been published. Parts of chapter 4 relating to renewable energy have been published in: Winkler, H 2004. Renewable energy policy in South Africa: Policy options for renewable electricity. *Energy Policy* 33 (1): 27-38. The funding of the Sustainable Energy & Climate Change Partnership for the underlying research is gratefully acknowledged.

Chapter 6, in particular the analysis of the residential sector, was informed by work of the author published in: Winkler, H, Spalding-Fecher, R, Tyani, L & Matibe, K 2002. Cost-benefit analysis of energy efficiency in urban low-cost housing. *Development Southern Africa* 19 (5): 593-614. Although I was the lead author in the published work, the inputs of my colleagues added significant value. The work for this thesis substantially elaborated the previous cost-benefit analysis, adding new data and placing the residential sector in the context of a national energy model. National energy modeling has been developed by the Energy Research Centre's modeling group. With respect to chapter 6, I led a recent project funded by the IAEA (Winkler et al. 2005a), but acknowledge with thanks the valuable learning on the use Markal, and work on the database by my colleagues Mark Howells and Thomas Alfstad. The work in the thesis extends the previous analysis, particularly in my own focus areas of residential demand and renewable energy in the electricity supply sector.

The ‘sustainable development policies and measures’ (SD-PAMs) approach is outlined in chapter 9 and informs the methodology of the thesis, described in chapter 1. The SD-PAMs concept was originally conceived and published as a peer-reviewed book chapter: Winkler, H, Spalding-Fecher, R, Mwakasonda, S & Davidson, O 2002. Sustainable development policies and measures: starting from development to tackle climate change. K Baumert, O Blanchard, S Llosa and J F Perkaus (Eds). *Building on the Kyoto Protocol: Options for protecting the climate*. Washington DC, World Resources Institute: 61-87. I was the lead author and primary developer of the approach. The support of the World Resources Institute in undertaking the conceptual work and publishing is gratefully acknowledged. The SD-PAMs approach has since been elaborated in further case studies and publications, some which I have contributed to (Winkler et al. 2002a; Bradley et al. forthcoming; Winkler et al. 2005b).

Thanks to my mother, Ruth Winkler, for her unwavering support, and my brother and sister-in-law, Gunter and Gisela Winkler, for many conversations and hand-holding.

Finally, my warmest thanks to my children, Kristy and Ally Winkler, and my wife, Janet Small, who gave me the time and space to do this work. Without their loving support, this thesis would not have been written.

Abbreviations, acronyms and units

AGAMA	Agama Energy (company)
AIM	Action Impact Matrix
ANC	African National Congress
c/kWh	Cents per kilowatt-hour
CCGT	Combined cycle gas turbine
CCT	City of Cape Town
CDM	Clean Development Mechanism
CFLs	Compact fluorescent lamps
CGE	Computable general equilibrium
CO ₂	Carbon dioxide
COP	Conference of the Parties (to the UNFCCC)
CSD	Commission on Sustainable Development
DBSA	Development Bank of Southern Africa
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DoH	Department of Housing
DPE	Department of Public Enterprises
DTI	Department of Trade and Industry
DSM	Demand side management
DWAF	Department of Water Affairs and Forestry
EBSST	Electricity basic support services tariff ('poverty tariff')
EDI	Electricity distribution industry
EDRC	Energy & Development Research Centre – now part of ERC
ERC	Energy Research Centre – University of Cape Town
ERI	Energy Research Institute – now part of ERC
EE	Energy efficiency
EIA	Environmental Impact Assessment
ELI	Efficient lighting initiative
FBC	Fluidised bed combustion

FGD	Flue gas desulphurisation
GB	Geyser blanket
GDP	Gross Domestic Product
GEAR	Growth Employment and Redistribution (macro-economic strategy)
GEF	Global Environment Facility
GHG	Greenhouse gasses
GJ	Gigajoule (10^9 J)
GW	Giga-watts (10^9 W)
GWh	Gigawatthour
HVAC	Heating, ventilation and air conditioning
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEP	Integrated energy plan
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
J	Joule
kW	Kilowatts (power measurement)
kWh	Kilowatt-hour
LEAP	Long-range Energy Alternatives Planning system
LFG	Landfill gas
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MARKAL	MARKet ALlocation (modeling framework)
MDG(s)	Millennium Development Goal(s)
MW	Megawatt (10^6 W)
MWh	Megawatthour (10^6 Wh, or 10^6 kWh)
NAAQS	National ambient air quality standards
NECC	National Electrification Coordinating Committee
NEPAD	New Partnership for Africa's Development
NER	National Electricity Regulator
NCCC	National Committee on Climate Change
NIRP	National Integrated Resource Plan (for electricity)

NGO	Non-governmental organisation
NMVOC	Non-methane volatile organic compounds
NO _x	Nitrogen oxides (plural, since they refer to nitrogen dioxide (NO ₂) and nitric oxide (NO))
NPV	Net present value
O&M	Operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PAMs	Polices and Measures
PBMR	Pebble bed modular reactor (nuclear)
PF	Pulverised fuel (coal)
PJ	Petajoules (10 ¹⁵ J)
PPP	Purchasing power parity
PWC	Price Waterhouse Coopers
PWR	Pressurised water reactor (nuclear)
PV	Photovoltaic
R&D(&D)	Research and development (and demonstration)
RDP	Reconstruction and Development Programme
RE	Renewable energy
RETs	Renewable electricity technologies
REDs	Regional electricity distributors
RIDCs	Rapidly Industrialising Developing Countries
SA	South Africa
SADC	Southern African Development Community
SANEA	South African National Energy Association
SAPP	Southern African Power Pool
SARB	South African Reserve Bank
SD-PAMs	Sustainable development policies and measures
SEA	Sustainable Energy Africa
SECCP	Sustainable Energy and Climate Change Partnership
SHS	Solar Home Systems
SO _x	Sulphur oxides
SRES	Special Report on Emission Scenarios (of the IPCC)

SSA	Statistics South Africa
SSN	SouthSouthNorth (organisation)
SWH	Solar water heaters
Toe	Tons of oil equivalent
TOR	Terms of Reference
TPES	Total primary energy supply
TSP	Total suspended particulates
UCT	University of Cape Town
UNFCCC	United Nations Framework Convention on Climate Change
W	Watt
WCED	World Commission on Environment and Development
WCD	World Commission on Dams
WRI	World Resources Institute
WSSD	World Summit on Sustainable Development

Household types defined for the thesis:

RHE	Rural higher-income electrified
RLE	Rural lower-income electrified
RLN	Rural lower-income non-electrified
UHE	Urban higher-income electrified
ULE	Urban lower-income electrified
ULN	Urban lower-income non-electrified

PART I: INTRODUCTION TO ENERGY, SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE

CHAPTER 1

1. Introduction

1.1 Energy, sustainable development and climate change in South Africa

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

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

The local environment is affected by the particular features of the South African energy system. At the point of use, electricity may be a clean energy carrier. But upstream environmental impacts of coal mining and combustion mean that electricity supply and use does have significant environmental impact. Outdoor air pollution is associated with burning of coal (often of a poor quality) for electricity production. Indoor air pollution in South Africa is associated with energy carriers other than coal. Transport fuels contribute to the 'brown haze' of local air pollution; paraffin use results in burns, deaths and poisoning (Mehlwana 1999a; Lloyd 2002; Biggs & Greyling 2001); and indoor use of coal and wood contributes to respiratory disease (Qase et al. 2000; Van Horen 1996a; Spalding-Fecher et al. 2000a) (see section 3.6).

The connection between sustainable development and climate change works in two directions. On the one hand, unmitigated growth in emissions has the potential to undermine sustainable development. On the other hand, making development paths more sustainable can contribute to climate change mitigation (Munasinghe & Swart 2005). In South Africa, the two-way connection is particularly marked in the energy sector, the major source of GHG emissions.

Under the United Nations Framework Convention on Climate Change (UNFCCC 1992) and its Kyoto Protocol (UNFCCC 1997), industrialised countries adopted targets for climate change mitigation framed in terms of reducing greenhouse gas emissions. However, asking for similar targets for developing countries has been opposed as it is perceived as placing a limit on their development (Agarwal & Narain 1991; Mwandosya 2000). A different approach is needed, one that puts development first. The thesis investigates whether such an approach – starting from making energy development more sustainable in local terms – is viable for South Africa and could form the basis for both future energy and climate change policies.

The thesis therefore takes as its starting point development objectives, rather than climate change targets. The form of climate action which it investigates is sustainable development policies and measures (Winkler et al. 2002b). While sustainable development measures might in practice be similar to climate change policy, the motivation is different – the one pursues emission reductions, the other local development. Making development more sustainable locally is a higher policy priority for most developing countries than addressing a global problem such as climate change, particularly since the latter has been caused mainly by industrialised countries. South Africa has a rather atypical emissions profile for a developing country – high emissions per capita and per GDP. A development-focused approach seems more likely to be implemented than the imposition of GHG targets by the international community – especially as the country has adopted development targets such as the Millennium Development Goals (UN GA 2000) and the Johannesburg Plan of Action (WSSD 2002).

Historically, greenhouse gases have been emitted mostly by industrialised countries; however, the *annual* emissions of developing countries are growing rapidly (WRI 2005) – as they develop (Pan 2002). However, emissions for some industrialised countries, e.g. the US, Japan, Norway and Canada, continue to grow. The current multi-lateral framework under the UNFCCC and its Kyoto Protocol sets emission targets only for industrialised countries. There is growing realisation that the climate change problem is global and requires participation by all countries, including action by developing countries that does not limit their development prospects. The urgency for some developing countries to take on some kind of commitments is growing. In this context, demonstrating *at a national level* that energy policies can both promote local sustainable development and also reduce GHGs can make a major contribution to climate change mitigation.

This thesis seeks to demonstrate energy policies for sustainable development in South Africa. Are there obvious solutions that solve both energy and climate change problems, or do priorities have to be traded off – and if so, where? Is there such a thing as an optimal solution, or do considerations of durability (or sustainability) mean that multiple objectives must be balanced?

This chapter outlines the research question, the methodology developed to investigate it and describes the structure of the thesis.

1.2 Research question

The research in this thesis explores whether there is a locally sustainable path of energy development in the South African residential and electricity sectors that also reduces GHG emissions. Making the development paths more sustainable would require increases in a set of 'development indicators' over time, without negative social, economic and environmental feedback (see chapter 2 for a working definition of sustainable development).

The research thus addresses as its central question:

Are there energy policies to make the development in South Africa's residential and electricity sectors more sustainable economically, socially and in terms of local environment, and that also reduce GHG emissions?

To investigate the research question, the development objectives for the energy sector need to be understood. The residential sector is particularly significant for social sustainability (see chapter 8), while the electricity supply makes the largest contribution of a single sector to South Africa's total greenhouse gas emissions (calculated from RSA 2004a). Together, the two sectors are key testing grounds for both local sustainable development and climate change mitigation in South Africa.

The issues of sustainable development and climate change are of broader concern, especially for a group of 'rapidly industrialising developing countries' (RIDCs) (Ott et al. 2004). Sustainable development is acknowledged as an important problem by other RIDCs such as India (IIM 2003; Vajpayee 2002) and China (Pan 2002; Shukla et al. 2002) whose emissions are rising as they seek to provide basic services.

This thesis argues that making energy development more sustainable can, in the first place, achieve important development objectives, and secondly, is the most appropriate approach to achieve climate change mitigation. A combination of methods is used to test the hypothesis of the research question.

1.3 Methodology

Set against a survey of international and local literature and experiences in assessing energy and sustainable development, three major components are combined in the methodological framework for this thesis – modeling, indicators of sustainable development and policy analysis. The sequence of methodological steps is illustrated in Figure 1.1.

The methodology begins by locating policy options in the energy sector within the broader context of development objectives. The starting point both conceptually and methodologically lies with development, rather than climate change. Energy is understood as a necessary, but not sufficient condition for development. Policy options are identified making energy development in the residential and electricity sectors more sustainable, and are implemented in an energy-economic model. The results of modeling are analysed against indicators of sustainable development, laying the basis for the policy analysis that answers the research question.

Figure 1.1: Methodology for the thesis



To explore to what extent policies can make energy development more sustainable, the methodology integrates across economic, social and environmental dimensions. Two broad approaches to integration are those emphasizing the concepts of optimality and durability (Munasinghe & Swart 2005).

The methodology combines modeling, which is at its core an energy-economic tool, with a broader interpretation of indicators of sustainable development. Economic methods are typically optimization tools, as is the case with the Markal modeling framework which is used in this thesis. Its objective function is to minimize costs. Environmental and social variables can be introduced as side constraints. Constraints are necessary particularly where the other objectives are not easily monetized, for example, where ecological impacts are irreversible or high levels of inequality reduce social capital. The constraints can be introduced under weak or strong concepts of sustainability, i.e. maintaining overall non-decreasing stocks of capital, or each type (economic, human, social, environmental) separately (Daly & Cobb 1989). Multiple objectives can, in principle, be included even where monetary valuation is difficult, using multi-criteria analysis and resulting trade-off curves (Munasinghe & Swart 2005).

Durability favours development paths that permit growth, but does not insist on economic optimality. There is more willingness to trade off some economic optimality for greater safety, or for a system that has higher resilience to external shocks. The difference, however, is one of emphasis and perspective - optimality and durability have different emphases, but can complement one another (Munasinghe & Swart 2005). The approach taken in this thesis is to use both modeling and indicators to provide quantitative input for policy analysis – the analysis of the research question.

The steps shown in Figure 1.1 can be elaborated a little further in a number of steps below. The further elaboration makes clear how and where in the thesis modeling, indicators and policy analysis are combined:

1. Describe the development objectives of the country (chapter 3)
2. Locate the energy sector within the broader development pathway (chapters 3 and 4)
3. Identify energy policies that can make development more sustainable (chapter 4)
4. Model cases of policies that meet development objectives (in a least-cost framework) (chapters 5 and 6)
5. Analyse results of policy cases (chapter 7) against indicators of sustainable development (chapter 8)
 - a. Including local environmental, social and economic dimensions
 - b. Examine co-benefits of GHG emission reduction
6. Policy analysis (chapter 9), combining quantified results with discussion of
 - a. implications for energy policy
 - b. climate change mitigation policy

The practical approach taken in this thesis starts with development objectives. It starts from development objectives, not climate change targets. The policy options identified for inclusion in the modeling all have important development benefits. Development drives both emissions and the capacity to mitigate climate change. The least-cost model tool (Markal) establishes an optimized reference case. The model is used to examine policy cases, some of which are designed in a way that 'forces in' particular energy policy interventions (step 3), beginning to introduce considerations of durability. Step 4 lets the model choose the most economically efficient path of meeting this constraint, amongst all the other constraints built into the model (e.g. matching energy supply and demand). Environmental and social side constraints are introduced, and hence indicators of sustainable development can be examined in the results, providing a 'bridge' to policy analysis. Policy analysis is treated as a distinct activity (step 6), not only drawing on the quantitative results from the modeling, but also examining important areas where quantification reaches its limits. It is in this final step that durability is examined most fully.

Modeling is used to explore the implications of electricity and residential energy policies in a systematic, quantitative framework. The modeling tool used is Markal, which derives least-cost solutions, so that policy cases are implemented in the most cost-effective and economically sustainable way. A critical analysis of modeling tools – both optimization and simulation tools – is presented in chapter 5, introducing the modeling chapters of the thesis.

The thesis focuses on policies in particular sectors – residential demand and electricity supply – but places these within the broader context of the energy sector. Analysis of electricity supply builds on similar approaches to those taken for national energy and electricity planning. The modeling of the residential sector introduces significant changes, in that households (not individuals) are the unit of analysis. A key innovation in the context of national energy system modeling is disaggregating households into six categories, based on income, electrification status and geographical location. The approaches to the two focus sectors are described in more detail in chapter 6.

The results are evaluated against a broader set of indicators of sustainable development. Indicators are chosen to represent key dimensions of sustainable energy development. A fundamental indicator for access, for example, would be increasing electricity consumption per capita over time, where the increase is not threatened by 'feedback' from either biophysical impacts (local air pollution, greenhouse gas emissions), social impacts (social disruption) or economic consequences (unaffordable tariffs, impaired economic development). Considering policies against multiple objectives will show where policies are ranked higher in all dimensions (economic, social and environmental) and where trade-offs are required. Projecting indicators

over time can assist policy-makers in assessing contributions to making energy development more sustainable.

The thesis demonstrates the importance of residential energy policies in contributing to social sustainability. In assessing modeling results against indicators, it ranks policies that rank higher in all three dimensions of sustainable development. But not all sectors show clear 'winners' – finding durable electricity supply options probably require trade-offs. Diversifying energy sources is a long-term challenge that requires changes in the near future.

Together, the findings from modeling and indicators lay the basis for policy analysis – implementation in energy policy and implications for climate policy. Since the approach is rooted in energy for sustainable development, several options for national climate policy that are at the same time sound energy policies. On this basis, implications for South Africa's participation in the international climate change negotiations under the UN Framework Convention on Climate Change and its Kyoto Protocol are examined (see chapter 9). The realization that all countries need to act to solve the climate change problem places increasing pressure on some developing countries to take on quantified emissions limitation targets. Non-Annex I countries like South Africa, with high absolute and relative GHG emissions, may be expected to act early (Ott et al. 2004; Winkler et al. 2001, 2002c). The thesis locates South Africa's policies on energy, sustainable development and climate change in the broader context of multi-lateral climate agreements.

The thesis contributes to knowledge by implementing a methodology that works back from development objectives. The methodology is an elaboration of my approach previously published as Sustainable Development Policies and Measures (Winkler et al. 2002b). While 'backcasting' from development objectives has been outlined as a conceptual approach internationally, it has not been implemented in national energy models in developing countries, and not in South Africa. To conduct such an analysis, a methodology combining modeling, evaluation of indicators of sustainable development and policy analysis is developed. Within the modeling component, the residential sector is disaggregated into six household types for the first time in a national energy model for SA. The thesis contends that the appropriate starting point - conceptually and methodologically – for both energy and mitigation policy is sustainable development. The thesis argues that a sustainable development approach to energy policy is the most appropriate approach for climate change mitigation in South Africa. Climate change mitigation policy should start with *local* sustainable development, rather than goals set in climate terms.

The thesis draws on a wide variety of sources, from statistical information, government publications of official energy data (e.g. published by the DME and NER), utility statistics (Eskom), journal articles, book chapters, research reports and other sources. Where modeling

data are used, the original data sources are referenced where they could be established, or reference is made to the published plans (e.g. IEP and NIRP).

Having outlined the research question and the methodology proposed to investigate it, the outline of the thesis is presented in the next section.

1.4 Outline of the thesis

The thesis is organized in four major parts, comprising ten chapters. Part I includes this introduction and a literature review. Since the research question presented in this introduction integrally involves sustainable development, the literature review in chapter 2 develops a working definition, applied to the energy sector. Energy for sustainable development is the particular component of the linkages between climate change and sustainable development most relevant to this thesis, and so the literature on energy for sustainable development is also reviewed. .

Part II sets out the context and key issues. Chapter 3 outlines the development objectives for SA as a whole, before focusing in objectives for the energy sector. Chapter 4 identifies policy options in the residential demand and electricity supply sectors, using the five major goals of energy policy as a framework (DME 1998). In this part, the first step of policy analysis is taken, by identifying options that can make energy development more sustainable.

The implications of future energy policies are examined in a modeling framework in Part III. Chapter 5 outlines the purpose of modeling in the overall thesis and critically evaluates available modeling tools. The strengths and limitations of using an optimizing tool such as Markal are highlighted, particularly in the context of sustainability. Chapter 6 first outlines the key drivers of energy development and the base case. It explains the model implementation of policies in the electricity supply and residential demand sector. Results are discussed and interpreted for each policy in chapter 7.

Part IV synthesizes the analysis of sustainable development, energy and climate change policy. Chapter 8 evaluates the policies, drawing on modeling results, against a set of indicators of sustainable development. Policy analysis in Chapter 9 starts with considerations of what is required to shift energy policy that look good in analysis to implementation. The thesis concludes with a consideration of the implications for domestic climate policy and South Africa's engagement in the international climate change negotiations.

CHAPTER 2

2. Sustainable development, energy and climate change

The research question (outlined in chapter 1) implies that the concept of sustainable development can be applied to South Africa's energy sector. This chapter explores *how* sustainable development can be applied to energy, through a review of the literature relating the concept to both energy and climate change. Sustainable development for the residential and electricity sectors is conceived in all three of its dimensions – economic, social and environmental.

This chapter develops a working definition of sustainable development, firstly in the context of energy and secondly in relation to climate change. More sustainable energy development is the approach to climate change mitigation taken in this thesis. It lays the conceptual basis for developing indicators of energy for sustainable development, which are used to evaluate different energy policies in the remainder of this thesis.

2.1 Working definition of sustainable development

Sustainable development is a term widely used with many different associations and multiple definitions.¹ The concept emerged from concerns about a sustainable society and the management of renewable resources (Brown 1981). Early debates on 'green issues' focuses on preservation or conservation of natural resources and developed concepts such as maximum sustained yield (Wilson 1989; Nash 1982). Another strand of the debate focused on 'brown issues' such as pollution, population growth and the limits of resources (Ehrlich 1968; Meadows et al. 1972). Questions were raised about the limits to growth, and sustainability conceived by some as keeping society within ecological limits. In the 1980s, the concept of sustainable development emerged in attempts to link concerns about ecological limits with those about poverty and development (IUCN et al. 1980; WCED 1987). The concept was popularised by the Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: 8). The implication was that ecological sustainability could not be achieved if poverty was not addressed, requiring action on both environment and development (Robinson 2004a). Perhaps it is in implementing – the process of making development more sustainable – that the concept becomes more clearly defined for a particular context, rather than in abstract definition.

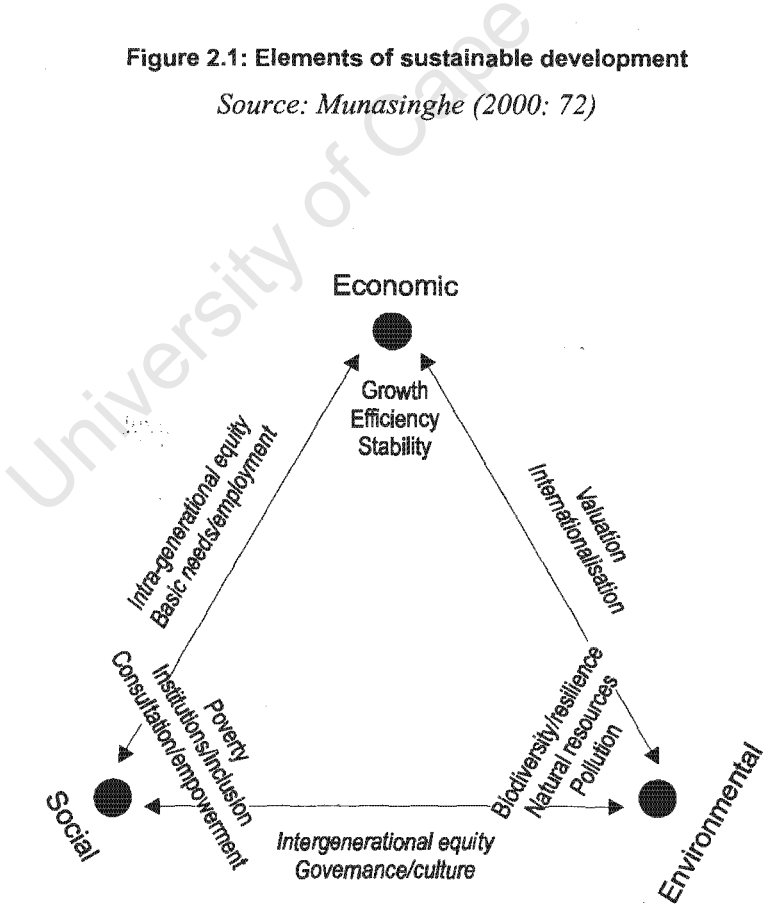
¹ For more extensive overviews of the concept of sustainable development, its history and the debate around it, see for example Pezzoli (1997), Guha & Martinez-Alier (1997) and Robinson (2004a).

While the Brundtland definition is commonly cited, there is no consensus in academic or policy circles on the concept or how to apply it in practice (IPCC 2001a: 93). Despite the absence of any single authoritative definition, in practice many people would recognise development that is *not* sustainable. For the purposes of this thesis, a working definition of sustainable development is required for the energy sector, not least because the South African government is committed to this principle. Having hosted the World Summit on Sustainable Development (WSSD) in 2002, and ensured that the outcome took the form of an action plan, government has a vested interest in realising at least some of the WSSD goals – after all, it is the *Johannesburg Plan of Implementation*.

There does, however, appear to be consensus that sustainable development has three broad dimensions - economic, social and environmental. Sustainable development at its simplest is “development which lasts” (Munasinghe 2000: 71). In Figure 2.1, the economic dimension is related to growth, efficiency and stability; key social issues include poverty, participation and empowerment; while the environmental corner of the triangle is concerned with issues such as pollution, biodiversity and natural resources. The concepts are further defined in 2.3 below.

Figure 2.1: Elements of sustainable development

Source: Munasinghe (2000: 72)



The concept of sustainability has been further defined in relation to non-declining stock of capital, or wealth. "Any growth path characterised by non-decreasing stocks of assets (or capital) is sustainable" (Munasinghe 2000: 76). This broad definition has been refined by Daly, distinguishing between 'weak' and 'strong' forms of sustainability (Daly & Cobb 1989). Capital, or assets capable of generating flows of goods and services, comes in different forms: natural and human-made capital (the latter often being further sub-divided into manufactured, human and socio-cultural sub-categories). Natural capital refers to natural resource assets, durable structures or equipment are manufactured by human beings, human capital is the productive potential of human beings, while social capital captures the norms and institutions that influence human interactions (Banuri & Weyant 2001:94). Development may be considered sustainable if capital is non-decreasing. Accumulating the various kinds of capital increases the resilience of an economy, society and its environment to external shocks.

Weak sustainability assumes that different forms of capital are substitutes and can be traded off against one another; strong sustainability assumes they are complements (Daly & Cobb 1989). Weak sustainability requires only that capital stocks are maintained across all types, but a deficit in one kind of capital can be made up in another. Strong sustainability, on the other hand, requires that all kinds of capital increase. One implication is that increases in human-made capital stocks cannot make up for losses of natural capital under strong sustainability.

A working definition of sustainable development needs to incorporate the concept of maintaining or enhancing stocks over time, with assets relating to economic, social and environmental dimensions. One approach that incorporates the concerns of sustainability and development is provided by Munasinghe:

"[A]n approach that will (inter alia) permit continuing improvements in the present quality of life at a lower intensity of resource use, while leaving behind for future generations enhanced stocks of assets (i.e. manufactured, natural and social capital) that will provide undiminished opportunities for improving their quality of life" (Munasinghe 2000: 71).

This conception is used as a working definition of sustainable development in this thesis. While any definition of energy for sustainable development may be contested in abstract, it is possible to identify which energy development paths are more sustainable than others. Sustainable energy development is treated in this thesis not as an end-state, but rather different policy options are compared to see which are more sustainable. Making development more sustainable does not so much require a precise definition of some ideal state of sustainable development – what is important is addressing those parts of current development trends that are clearly unsustainable. In this sense, a working definition of energy for sustainable development is needed for the thesis.

2.2 Energy for sustainable development in South Africa

Sustainable development has as its primary aim the search for a path of economic progress which does not impair the welfare of future generations (Pearce et al. 1989: 28). A sustainable *energy* development path for the electricity sector would need to be socio-economically viable as well as meeting local and global environmental criteria. A key global environmental impact of electricity production and use is its likely impact on climate stability, while air pollution is a significant local environmental impact of electricity supply and use (see chapter 3). The social welfare of future generations will be determined in no small measure by employment and income distribution. Sustainable development for the sector must therefore reduce energy poverty,² by promoting affordable access to modern energy services.

Sustainable energy development is more than sustainable energy growth. An energy growth path may deliver increase in energy consumption per capita, but energy development should also improve - or at least maintain - social and environmental quality. This has implications for the *pattern* of energy development. Several studies document issues of energy and poverty in South Africa (for some examples, see Eberhard & Van Horen 1995; for some examples, see Bank et al. 1996; Jones et al. 1996; Mehlwana & Qase 1998). In the context of a society where large sections of the population still suffer from energy poverty, growth in energy services is an essential first step to energy development. Put in different terms, sustainable growth is a necessary, but not sufficient condition for sustainable energy development. The Reconstruction & Development Programme balanced social goals (electricity for all) with environmental concerns (promoting diverse energy sources and energy efficiency) (ANC 1994: 2.7 Energy and Electrification). The working definition of sustainable development above suggests that sustainable energy development requires more than simply growth in energy consumption.

Some further working definitions are elaborated below (Adapted from Pearce et al. 1989: 33):

- *Energy growth* means that energy consumption per capita is increasing over time. However, observation of such a trend does *not* mean that growth is sustainable.
- *Sustainable energy growth* means energy consumption per capita is increasing over time *and* the increase is not threatened by 'feedback' from either biophysical impacts (local air pollution, greenhouse gas emissions) or from social impacts (social disruption, e.g. if services are unaffordable).
- *Sustainable energy development* means that a set of 'development indicators' is increasing over time. Indicators would be drawn from social, economic and

² Energy poverty is taken in this thesis to mean the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development. For discussions of energy poverty in the African and South African context, see Karekezi (2002), Eberhard (1995), Mehlwana (1998) and Davidson (2002).

environment dimensions, but different stakeholders might emphasise various criteria. The same feed-back requirements apply.

The definition could similarly be extended to the electricity sector, suggesting that growth in electricity consumption per capita alone is necessary, but not sufficient to demonstrate sustainable development. Growth in electricity consumption must not undermine its own achievement by contributing to social disruption, and therefore have to remain affordable. Social sustainability is particularly relevant in the residential sector, where affordable access to modern energy services is a key goal. A core development indicator that needs to increase is access to energy services. To meet criteria of strong sustainability, increasing electricity supply and more affordable services should be achieved while minimizing local air pollution and global environmental pollution. In this context, efficient use of energy is a necessary condition for sustainable development. The debate on energy for sustainable development is integral to the linkages between sustainable development and climate change.

2.3 Sustainable development and climate change

The concept of sustainable development is widely applied in the climate change debate (Banuri & Weyant 2001; Byrne et al. 1998; Davidson & Nakicenovic 2001; Markandya & Halsnaes 2002; Metz et al. 2002; Munasinghe 2001; Sachs 2000). Most simply, mitigating climate change is part of the broader sustainable development agenda. Unchecked growth of GHG emissions due to development is not sustainable, as it exceeds the capacity of the atmosphere to absorb pollutants. The linkage between climate change and sustainable development is seen as working in both directions - sustainable development is a key component of mitigating climate change, while the impacts of unmitigated climate change threaten to undermine any possibility of sustainable development (Munasinghe & Swart 2005; IPCC 2001a).

In the literature on energy and climate change, environmental, economic and social dimensions were initially analysed separately and sustainability treated as their sum. More recently and particularly in relation to climate change, the focus has shifted to analysing the potential areas for synergies - as well as trade-offs - in realising sustainable development (Banuri & Weyant 2001; Byrne et al. 1998; Metz et al. 2002; Munasinghe 2001; Sachs 2000; Davidson 1996). The IPCC's Third Assessment Report identifies three broad approaches to climate change: efficiency and cost-effectiveness; equity and sustainable development; and global sustainability and societal learning. It noted that consensus appeared limited to acceptance that three broad dimensions must be integrated to achieve sustainable development – economic prosperity (development), ecological integrity (sustainability) and social justice (equity) (Banuri & Weyant 2001: 93). This broader discussion (compared to a focus on poverty reduction, as in the Millennium Development Goals) is used in this thesis to analyse the three dimensions of

sustainable development: development (primarily economic), sustainability (environmental) and equity (social). This is an analytical distinction, recognising that all three dimensions are inter-related.

2.3.1 Development

Development is often associated with economic prosperity. In the first instance, economic prosperity may be measured in total output. However, the concept of economic development implies not only increase in total output over time (economic growth), but also progress towards some set of social goals. In South African macro-economic policy GEAR, growth is allied to goals of job-creation and redistribution of income (DTI 1996). More detailed development objectives, however, are spelled out in the Reconstruction & Development Programme (ANC 1994).

If economic development is to be sustainable, its impact on the environment - human and natural, social and ecological - must be limited. In the social context, the distribution of income is as important as economic output (see discussions on equity below), otherwise social crises that might arise from inequality may undermine economic development. Societies with high levels of inequality - approximated by the Gini coefficient, for example - may struggle to maintain the social stability needed for economic development. Environmental concerns require that economic development should not undermine its own basis - ecosystems and their natural resources and services. Sustainable development broadens the concept of development from its narrow focus on economic growth to include human development, poverty eradication, and social equity (Banuri & Weyant 2001: 93). The social dimension of development should include measures that reduce vulnerability, improve equity and meet basic human needs (Munasinghe 2000: 73).

2.3.2 Sustainability

Sustainability in simple terms means that something lasts over time. Sustainability is linked to *durability*. But durability does not mean that no change takes place over time. In economic and ecological systems, sustainability relates to its *resilience*, the ability to adapt to change, as well as its vigour and level of organisation (Munasinghe 2000). It is often assumed that greater *diversity* in ecological and economic systems makes them more resilient to shocks and stresses (Pearce et al. 1989: 43). For development to be sustainable, it must improve the health of ecological and socio-economic systems and their ability to adapt to change. "Policies must address simultaneously the goals of social equity and ecological resilience" (Tellus 2001: 40). Similarly in the economic dimension, greater resilience to external shocks and surprises is important for sustainability.

2.3.3 Equity

Does development with sustainability add up to sustainable development? Many argue that a higher degree of social equity is also required by the standards of sustainable development (Byrne et al. 1998; Nakicenovic 2000: 336; Sachs et al. 1998; Kartha et al. 1998). This is consistent with a concept of development that does not undermine itself by causing disruption through social inequality.

Developing countries have frequently expressed the concern that their development should not be constrained by considerations of climate change (Mwandosya 2000; Sari 1998; Zhou 2001; Agarwal 2000). This is considered unfair, given that industrialised countries bear most of the responsibility for cumulative historical greenhouse gas emissions. For developing countries, mitigation efforts might focus on de-linking economic growth from rising GHG emissions (Banuri & Weyant 2001; Baumert et al. 1999).

Equity in the context of climate change requires "that neither the impact of climate change nor that of mitigation policies exacerbates existing inequities both within and across nations" (Banuri & Weyant 2001: 87). Given the time-frames of climate change, equity between generations is part of this discussion. Clearly both mitigation and adaptation have implications for equity.

Four central issues in the climate change negotiations have strong implications for equity:

- Fair allocation of costs to prevent further climate change;
- Sharing the costs of adapting to climate change impacts;
- Fair process to determine the previous two issues; and
- Fair allocation of greenhouse gases in the long term and the transition (Toth & Mwandosya 2001: 669).

While mitigation can be enhanced by sustainable development, strict mitigation targets may place a limit on sustainable development, especially in developing countries. The link is explicit in Article 2 of the Framework Convention, which places three conditions on the ultimate objective of stabilising greenhouse gas concentrations in the atmosphere – allowing ecosystems to adapt naturally, avoiding threats to food production and enabling “economic development to proceed in a sustainable manner” (UNFCCC 1992). This is reinforced in Article 3.4, which recognises as one of its guiding principles that “Parties have a right to, and should promote sustainable development”.³

³ The other principles are equity, common but differentiated responsibilities, precaution, cost-effective measures and support for an open international economic system (UNFCCC 1992: Article 3).

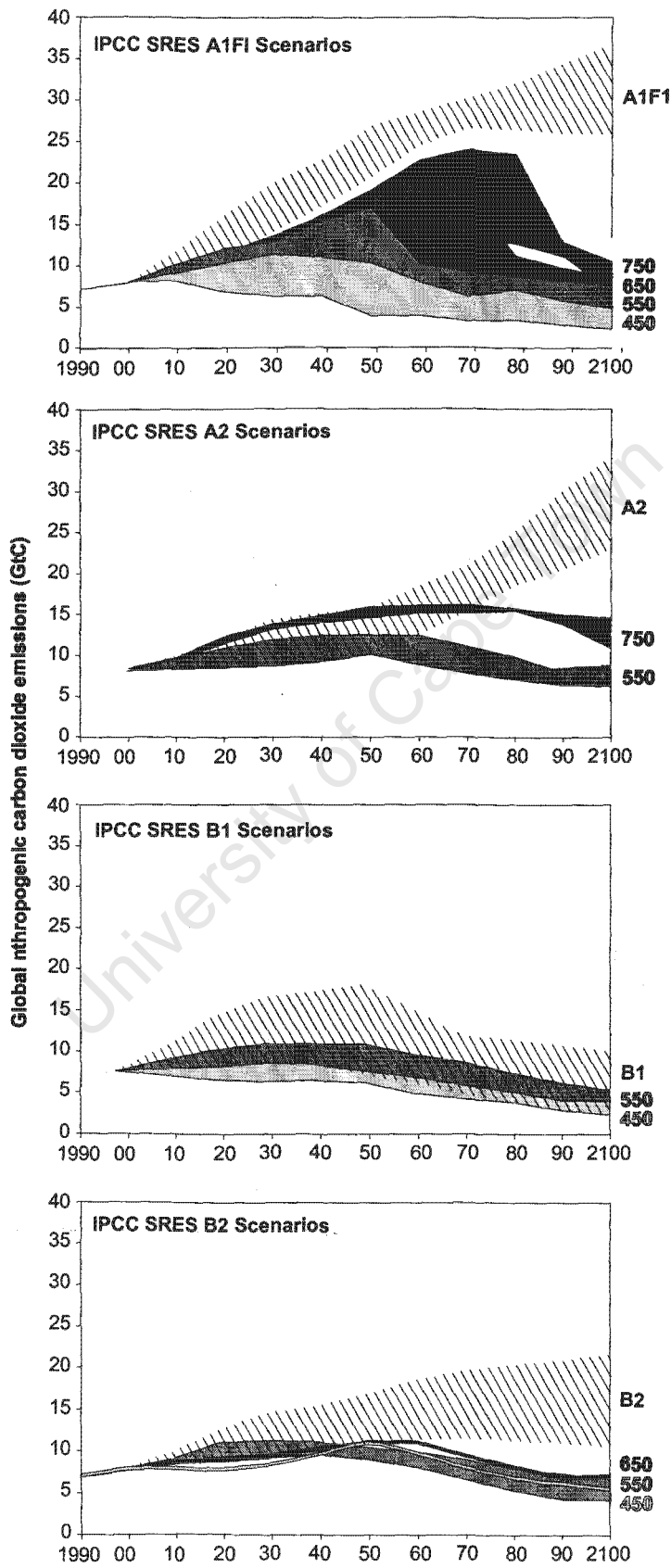
Equity is framed in the Convention process both in terms of greater historical responsibility of industrialised countries, but also the limited capability of developing countries to divert resources to climate change mitigation. These differences have become known as 'common but differentiated responsibilities' of developed and developing countries in the climate change regime. Non-Annex I countries (developing countries) do not currently have binding commitments to reduce greenhouse gas emissions, to allow them to continue developing. Their voluntary mitigation programmes under the Convention are to be enabled by funding and technology transfer from Annex I countries (UNFCCC 1992: Article 4.1b). Under the Kyoto Protocol, they may participate in the Clean Development Mechanism, which has sustainable development as one of its two major goals (UNFCCC 1997: Article 12)

The emphasis in this thesis is on equity in mitigating climate change. Approaches that meet local development needs (e.g. energy services) are presumed to be more equitable for developing countries, since developed countries industrialised in the absence of climate constraints (Mwandosya 2000). Hence an approach that starts from energy development objectives is more appropriate and equitable for developing countries. The argument is that more equitable approaches will help generate support for mitigation (see, for example, Agarwal 2000). Promotion of more sustainable development in developing countries both contributes to international equity and enhances mitigation efforts by reducing emissions of the reference case (Winkler et al. 2002b; IPCC 2001b). This has important implications for the economic analysis, given the finding - in analysing the economics of the Kyoto Protocol - that "[i]n general, other things being equal, the higher the reference case emissions, the higher the costs of implementing the Protocol" (Weyant & Hill 1999: xxxv).

Figure 2.2 shows four of the families of scenarios from the IPCC's Special Report on Emission Scenarios (SRES). Each of the striped scenario families represents a different storyline of how global emissions might evolve in future. The SRES scenarios deliberately do not consider policies explicitly aimed at combating climate change. The striped reference scenarios shown in Figure 2.2 do not include climate policy and are shown together with mitigation scenarios resulting in atmospheric concentrations of CO₂ ranging from 450 to 750 ppmv (various shades).

Figure 2.2: Comparison of SRES reference emissions scenarios (without climate policy) and ‘post-SRES’ climate change mitigation scenarios

Source: (Morita & Robinson 2001: 151, fig. 2.14)



Choosing a sustainable development path means that the baseline - or reference - GHG emissions are lower than in other possible futures. Put differently, a more sustainable development path has lower emissions, *even without* any explicit climate policy. The IPCC's Third Assessment Report found that this choice of future 'world' more important than the drivers determining GHG emissions (Morita & Robinson 2001: 142).

The corollary is also true - development objectives can be met in more or less emission-intensive ways. Beginning with one or more future development ambitions it would be possible to describe paths towards those goals (Winkler et al. 2002b; Metz et al. 2002; Berk et al. 2001). The selected scenarios show clearly that to reach the same atmospheric concentrations, significantly less effort is required if reference emissions are low (in the B family) than if the future world had higher emissions (in the A scenarios).⁴ A key challenge for South Africa's contribution mitigating GHG emissions is to make energy development paths more sustainable.

2.4 Making energy development paths more sustainable as an approach to climate change mitigation

The starting point for developing countries is development, and ways can be sought to make energy development in particular more sustainable. Sustainable development policies are likely to be more attractive as an approach to mitigation for developing countries, being closer to their most important policy objectives than climate change (Winkler et al. 2002b). "The best climate policies for some nations over the foreseeable future may have nothing specific to do with climate" (Yohe 2001: 261). *The approach taken in this thesis, therefore, seeks paths that meet development objectives in a more sustainable manner, rather than emission reduction objectives.*

Focusing on policy for sustainable development raises the question how this differs from climate policy. The motivation or intent of the policy is more relevant in distinguishing the two, rather than the kind of action taken. Climate change mitigation policy focuses primarily on reducing atmospheric GHG concentrations (Banuri & Weyant 2001: 85). Similarly, one could say that sustainable development policies are primarily motivated by the aim of delivering development services (water, housing, food, energy, etc) with due regard to social and environmental impacts. These are more pressing concerns than conventional approaches to climate change for most people (Berk et al. 2001: 11). In practice, however, climate and sustainable development measures are often the same or similar, even if they are motivated by different reasons.

⁴ The difference in emissions between the reference case in A1FI and 550 ppmv is much larger than the corresponding difference between B1 reference emissions and a path stabilising at the same level.

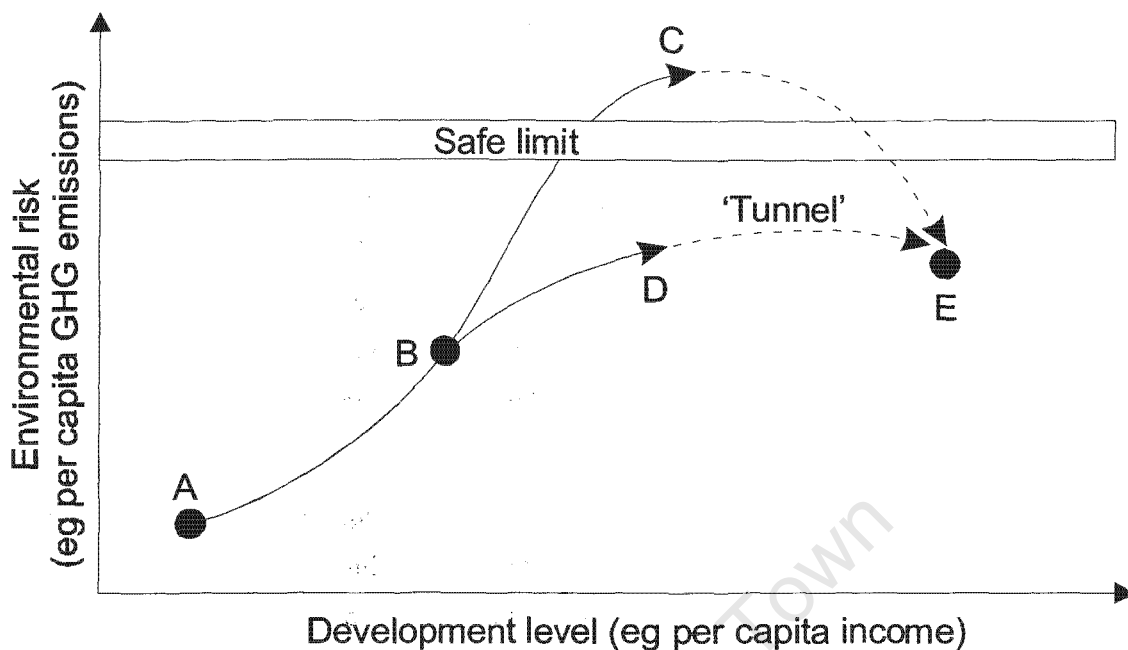
The IPCC's Third Assessment Report draws a distinction between climate and non-climate policies (Morita & Robinson 2001: 122). Climate policies have GHG emission reductions as a primary goal, while non-climate policies do not aim at this. The confusion arises when non-climate policies nonetheless reduce emissions. Sustainable development policies are a classic example - energy efficiency in low-cost housing may be motivated by sustainable development, but have the effect of reducing the emissions compared to the baseline - the development path that would have happened otherwise. Clear separation is not always possible, since many policies have multiple goals.

The approach taken in this thesis focuses on non-climate policies, with GHG emission reductions as a co-benefit. Supply options are examined that can make electricity generation more sustainable. The South African electricity sector, which accounted for 40% of South Africa's greenhouse gas emissions in 1994 (calculated from RSA 2004a), implying that the potential for climate co-benefits of cleaner electricity development is large. On the demand side, residential energy policies are examined that make social development more sustainable. This will entail not only increased access, but also making energy services more affordable for households, in particular the poor.

South Africa's development path in the electricity sector needs to 'tunnel' under a conventional electricity development path (Munasinghe 1995). Figure 2.3 shows how a country's emissions might change with its level of development, as illustrated by the proxy of GDP per capita. In the initial stages, emissions tend to increase for a number of reasons – economies tend to be built around more energy-intensive primary sectors, and the fuel-mix may include fossil fuels, as with coal in South Africa's case. If South Africa's development path for the electricity sector were purely growth-oriented – without any change in the fuel mix on the supply side, or efficiency on the demand side - then emissions will increase.

Figure 2.3: Emissions paths relative to development level and possibility of 'tunnelling'

Source: (Munasinghe 2001: 45)



South Africa, with high emissions per GDP and per capita, is already high on the curve AB. The main reasons for this emissions profile – and a similar picture for local pollutants – are due to the coal-dominated fuel mix, energy-intensive primary and secondary economic sectors and relatively inefficient use of energy (see section 3.6 further discussion). Depending on how one defines a safe limit (not quantified in this heuristic diagram), South Africa perhaps already lies above such a limit, on segment BC. South Africa's per capita emissions were 6.91 tCO₂ (1.88 tC) per person in 2000, which is well above the global average of 3.89 tCO₂ (1.06 tC) (IEA 2002a). Even more than for other developing countries, South Africa needs to de-couple emissions from economic growth. The main opportunities for de-coupling lie in using energy more efficiently, and in changes in the fuel mix. While coal continues to be used, increased beneficiation – adding more value within the country – will be needed, as well as reducing emissions through 'cleaner coal' technologies. In the longer-term, changes to less energy-intensive economic sectors – typically secondary and tertiary sectors – can reduce emission further, at a time when per capita incomes are also higher.

To stabilise the climate – which is the ultimate objective of the UNFCCC – the global average needs to decrease. What is needed is a technological, infrastructural and institutional transition to a sustainable electricity economy in SA that also reduces GHG emissions. It is for this reason that the issue of climate change mitigation is approached from the perspective of energy for sustainable development.

2.5 Conclusion

The approach taken in this thesis puts development objectives first, focuses the analysis on means of making development more sustainable, and considers reductions of GHG emissions as co-benefits. The aim of this chapter was to examine the relevant literature on sustainable development, energy and climate change.

A working definition of sustainable development embraces the economic, social and environmental dimensions. *Sustainable energy development* means that a set of 'development indicators' is increasing over time, contributing to economic welfare. The increase is not threatened by 'feedback' from either biophysical impacts, social disruption, making it durable or sustainable. Chapter 8 will define in more detail indicators to evaluate whether policies make energy development more sustainable.

The literature on sustainable development and climate change focused on issues of development, equity and sustainability. An important finding underpinning the approach taken in this thesis is that reducing emissions in the reference scenario may be as important as climate change policy. Making energy development more sustainable will have co-benefits in terms of climate change mitigation. Pursuing a goal motivated by development policy is more appropriate for countries like South Africa where development objectives are defined around basic needs – issues such as reconstruction and poverty alleviation.

Part II: Issues and context

CHAPTER 3

3. Development objectives

3.1 The broader context: South Africa's development objectives

This chapter outlines electricity development objectives for South Africa. It does not relate these explicitly to climate change, but rather starts from an analysis of the energy sector and its relationship to broader development. The broad development objectives of the country are reconstruction, development and poverty alleviation. These objectives were framed in the Reconstruction and Development Programme (RDP) as targets for specific sectors. A review of these sectoral targets sets the energy sector in its context of broader development objectives.

The energy development path of South Africa is assessed not only in terms of its own objectives, but also in terms of sustainability in its economic, social and environmental dimensions. To be sustainable, electricity development objectives must contribute to the broader developmental goals of South African society. The chapter therefore assesses the historical contribution of the electricity sector to social and economic development, as well as considering the impacts of electricity supply and use on the environment. In so doing, it provides a starting point for analysis of climate change mitigation that is firmly rooted in understanding the objectives of the energy sector on its own terms. Considering the history and current status of the electricity sector through the lens of sustainable development sets the framework for stories about how electricity development can become more sustainable.

3.1.1 Development objectives in South Africa

South Africa's development objectives have been shaped deeply by Apartheid – a history of racial oppression and patterns of economic exploitation. Apartheid systematically underdeveloped black working-class communities and left a deep legacy of backlogs of basic services in rural and urban areas.⁵ A central driver for policy since 1994 has been the redress of the imbalance of Apartheid and the promotion of socio-economic development of poor communities. A core document capturing the major objectives is the RDP. However, the imperatives of reconstruction and development have been in tension with a macro-economic framework that emphasises economic growth as the driver of development – the Growth,

⁵ Given South Africa's history of Apartheid, racial categories remain significant. In presenting statistical information related to household energy use, categories of 'black', 'white', 'coloured', 'Indian' and 'African' are used as found in the literature. In defining household types, however, income categories ('richer' and 'poorer') are found to be more relevant.

Employment and Redistribution (GEAR) strategy (2002). Sectoral targets have had to be pursued in a changing macro-economic framework.

Many of the detailed socio-economic development objectives were set out in the African National Congress' RDP (ANC 1994). It outlined job creation through public works and meeting a range of basic needs as key priorities. Quantified goals were set for delivery of several basic services. For instance, the RDP proposed to address the housing backlog of some 2-3 million houses by aiming to build 300 000 units each year for the first five years. In the same period, 30% of the land was to be redistributed. In providing basic services of water and sanitation, a short-term target of 25 litres of water per person per day was identified. In the energy sector, the main aim of the RDP was 'electricity for all'. The target of connection 250 000 households per year is one of the few that has been exceeded (Borchers et al. 2001).

These aspirational goals serve to illustrate the importance of socio-economic development, conceived around delivery of basic services, in the broader context of South African policy. While the status of RDP has become uncertain and lives in tension with macro-economic policy, these overall development objectives continue to provide an important context for energy policy as well. As the country has gained experience with implementation, new challenges – technical, social, economic – have arisen and targets have had to be reformulated and refined.

The energy sector has performed well – relative to other sectors – in meeting such targets. Significant progress has been made in extending access to electricity in particular, although affordability and productive use remain difficult issues. Yet more remains to be done, and the challenge of delivering energy in a sustainable manner. Sustainable development needs to take into account not only the development objectives of the RDP, but also the economic imperatives of GEAR.

3.1.2 Energy and development

The GEAR framework sets macro-economic policy from approximately 1997 onwards. As the name suggests, GEAR emphasised growth, employment and redistribution. Accelerated economic *growth* is a key objective of government's macro-economic policy. Key aims have been to reduce the budget deficit (which has grown to 7% of GDP under the Apartheid government), accelerate tariff reduction, tighten monetary policy, reach inflation targets (between 3 and 6%), and limit increases in private and public sector wage increases (DTI 1996).

While explicit development goals are commonly associated with the RDP, the long-term vision of GEAR includes a number of economic and social goals:

- a competitive, fast-growing economy which creates sufficient jobs for all work-seekers;
- a redistribution of income and opportunities in favour of the poor;

- a society in which sound health, education and other services are available to all; and
- an environment in which homes are secure and places of work are productive.

GEAR thus at least in principle includes some of the social development objectives of the RDP; however, its focus in explicitly macro-economic and social goals is referenced to the earlier document.

A major component of government's macro-economic strategy is the *privatisation of state-owned enterprises*. The main focus of these efforts is the four big parastatals: Eskom (electricity utility), Transnet (transport), Telkom (telecommunications) and Denel (arms). In the energy sector, the corporatisation of Eskom has already taken place, changing it from a parastatal to a public company.

Some key themes have carried through the policy changes since 1994. Unemployment and the creation of jobs have had high priority throughout the last ten years. With unemployment at 26% in 2004 according to the official definition⁶ (SSA 2005), this will remain a major priority. Concerns about reducing poverty, at least in the sense of narrowing the gap in income distribution, are part of both the RDP and GEAR, although less explicit in the latter.

The budget for 2005 again highlighted economic development, job creation, poverty alleviation and social services as key issues. "We are acutely aware of the extent of need – for employment, for broader participation in economic activity, for relief from the trap of persistent poverty, for housing, better education and reliable health services" (Manuel 2005). As far as development objectives go, the RDP objectives still enjoy wide support, both in government and civil society. The vision of reconstruction of a country scarred by Apartheid emphasises the importance of socio-economic development. The core of this notion of development is the delivery of basic services.

While the budget deficit has been reduced substantially to about 1.5% of GDP (Manuel 2005), several of GEAR's targets, both macro-economic and social development oriented, have proved elusive (Streak 2004). The strategy of privatisation as a means of delivering social benefits has been re-examined. The ANC has accepted that GEAR is a 'necessary, but not sufficient condition' for creating employment and redistribution (Streak 2004). With debt relatively low and a declining interest burden, government has increasing scope for social expenditure (Eberhard 2003). Some of the socio-economic goals have moved back into the mainstream of

⁶ The official definition is that unemployed are "those people within the economically active population who: (a) did not work during the seven days prior to the reference day, (b) wanted to work and were available to start work within two weeks, and (c) had taken active steps to look for work or to start some form of self-employment in the four weeks" (SSA 2005). The most recent statistics only include the official definition, and no longer an expanded one. The expanded unemployment rate excludes criterion (c), in other words it includes discouraged job seekers. Earlier statistics reported unemployment figures according to both definitions, e.g. by the stricter official definition, unemployment was 29.5% in 2001, while a broader definition put it at 40% (SSA 2003c).

policy. In 2004, the target of universal electrification was presented as being achieved by “our integrated system of government, with a strengthened local government working with our state enterprise, ESKOM” (Mbeki 2004a). Mention of sale of state-owned enterprises was notably absent, replaced by indications of government returning to a focus on RDP-like service delivery and a state intervening in development. Explicit reasons for this reportedly include that state-owned enterprises are needed for job creation and economic growth (Robinson 2004b). Mbeki himself wrote in an open letter that “the market is incapable of totally eradicating poverty and underdevelopment” (Mbeki 2004b). The context of development policy in 2005, therefore, still reflect macro-economic concerns (as in GEAR), but has increasingly returned to delivery of social services (the priority in the RDP).

While tensions between RDP goals and macro-economic priorities continue, the overall development objectives provide important background for energy policy. Policy in the energy sector more broadly, and electricity in particular, must address not only access to energy services, but also contribute to social goods – housing, jobs, water – and economic development.

3.2 The policy environment in the energy sector

The major objectives of government policy for the *energy* sector are spelled out in the 1998 White Paper on Energy Policy (DME 1998):

- Increasing access to affordable energy services;
- Improving energy governance;
- Stimulating economic development;
- Managing energy-related environmental impacts; and
- Securing supply through diversity.

Electrification has been a major way of *extending access* and universal access to electricity continues to be a goal. Historically, provision of electricity in South Africa was limited to established towns and areas of economic activity. In 1993, only some 36% of the total population had access to grid electricity. Initiated by Eskom in 1991 under the slogan ‘electricity for all’, it was included as a RDP programme after the 1994 elections.

The first phase National Electrification Programme (1994-99) was implemented by Eskom and municipalities. It was financed internally at a total cost of about R7 billion (Borchers et al. 2001), increasing electrification to about 66% nationally by 1999 (46% in rural areas, 80% in urban areas) (NER 1999). The aim of Phase I was to provide access to electricity for an

additional 2.5 million households, mainly in previously disadvantaged and rural areas, and for all schools and clinics without electricity. These targets have been met and exceeded, with a total of 2.75 million connections in Phase 1 (Borchers et al. 2001) and an estimated 3.75 million connections by 2004. During 2003, a further R 1.1 billion was spent on electrification, now financed by government through the Department of Minerals and Energy. However, a third of the country's population still remains without electricity, with rural areas being the most difficult and costly to electrify. Average costs per connection have declined over time, with learning and diminishing infrastructure costs for Eskom (Borchers et al. 2001).

Increasing access to affordable energy services has to a large degree been interpreted as access to electricity, even though other fuels play important roles as well (e.g. LPG for cooking; liquid fuels for transport). Recognising the importance of rural energy, an off-grid rural concessions programme has been launched, aiming to provide up to 50 000 Solar Homes Systems in 7 concession areas (Kotze 2001). Proposals have been made to extend the concept to a package that would also include LPG for cooking and other uses. Other energy goals in the RDP are improved rural electrification, a low-smoke coal programme, energy efficiency and the regulation of liquid fuels.

A major change in the *governance* of the energy sector is the *reform of the electricity industry*. Broader national development policy, as outlined above, interacts with global trends to reform in the electricity sector. The way in which restructuring happens in the electricity sector will have significant impact on delivery of services, as well as the future role of energy efficiency and renewable energy (Winkler & Mavhungu 2001). Opportunities exist for independent power producers to sell renewable energy (DME 2003b), but entry into the market is difficult (DME 2000a; Davidson & Turkson 2001).

Major changes in governance are also taking place in the liquid fuel sector, with the establishment of a Gas Regulator. The first pipeline from Mozambique began delivering natural gas in the first half of 2004 (Sasol 2004). The pipeline can supply 120 million Gigajoules per annum and potentially raises the contribution of natural gas to primary energy supply from 1.5 percent to just over 4 percent.⁷ The natural gas is marketed by Sasol in Gauteng and Kwa-Zulu-Natal to industries; with a domestic market operated by eGoli Gas. The option of introducing liquefied natural gas (LNG) into South Africa is presently being examined (CEF 2005). The amended Petroleum Products Act will change the licensing rules for petrol stations to give government more influence, and the Petroleum Pipelines Bill is expected to establish pricing and access rules for oil and gas pipelines. These will be the first major changes in petroleum

⁷ <http://www.dme.gov.za/home.asp?menu=main>

sector regulations in many years – and are revisions of regulations rather than full-scale deregulation of the oil industry.

Energy-related *environmental impacts* are governed by environmental legislation. Of particular note are the National Environmental Management Act and, for air pollution, the Atmospheric Pollution Prevention Act (Act 45 of 1965). DEAT has published sulphur dioxide standards for comment, which are part of an initiative to establish a National Ambient Air Quality Standard (RSA 2001a). A Vehicle Emission Strategy (DEAT & DME 2003) could make a major contribution to improved air quality, since transport energy has been identified as a major source of local air pollutants in cities such as Cape Town (Wicking-Baird et al. 1997). Institutional requirements are probably the key constraint to effective implementation – the lack of people to effectively enforce existing regulations. The co-ordination and effective communication between different national departments (DME, Transport and DEAT) as well as different levels of government will also be necessary. Without compliance and enforcement mechanisms, regulations are not meaningful. Accurate monitoring of emissions may soon be required through the mechanisms created in the National Air Quality Management Bill, as well as ensuring that such information is widely disseminated.

Diversity of supply is a major goal of energy policy. The Energy Minister made clear that South Africa intends ‘to use every energy source optimally: coal, gas, oil, nuclear and renewable energy’ (Mlambo-Ngcuka 2003). Starting from a coal-dominated base, the initial focus in terms of securing supply through diversity has been on importing natural gas from Mozambique and possibly Namibia, as well as more recent finds off South Africa (Marrs 2000a, 2000b; DME 2001a). Gas has been imported by pipeline from Mozambique since 2004, but its preferred use has been for feedstock at SASOL’s chemical and synfuel plants (Sasol 2004). The first gas was delivered via a pipeline from the Pande and Temane fields in Mozambique to Sasol’s plant in Secunda. These investments – US\$1 200 million in the Mozambique project alone (Venter 2001) – could promote a significant shift away from coal as a primary energy source, and provide feedstock for high value added chemicals and the synfuels plants.

Renewable energy sources are another major option for increasing diversity. The focus has been primarily on increased imports of hydro-electricity from within the Southern African Power Pool (SAPP), if political stability is achieved in the country hosting a major possible source. Despite some ongoing conflicts over the price of importing electricity, the region’s utilities are working on a combined regional power expansion plan. Eskom has identified more than 9 000 MW potential for regional imports, even without the massive potential of the Grand Inga scheme in the Democratic Republic of Congo. Grand Inga could potentially provide capacity of up to 100,00 MW in the long term and over 40 000 MW in the medium term (Eskom 1997). Regional co-operation on energy development is also a major drive within NEPAD.

In promoting greater *diversity in supply*, increasing the percentage of renewable energy in the electricity generation mix is a particular goal. In 2003, the Department of Minerals & Energy published a White Paper on Renewable Energy. The new policy document intends to

“give much needed thrust to renewable energy; a policy that envisages a range of measures to bring about integration of renewable energies into the mainstream energy economy. To achieve this aim Government is setting as its target **10 000 GWh** (0.8 Mtoe) renewable energy contribution to final energy consumption by 2013, to be produced mainly from biomass, wind, solar and small-scale hydro. The renewable energy is to be utilised for power generation and non-electric technologies such as solar water heating and bio-fuels. This is approximately **4%** (1667 MW) of the projected electricity demand for 2013 (41539 MW). This is in addition to the estimated existing (in 2000) renewable energy contribution of 115 278 GWh/annum (mainly from fuelwood and waste)” (DME 2003c).

The last sentence makes it clear that this amount is additional to current use of renewable energy, most of which biomass. In contrast to earlier drafts, the focus is not exclusively on renewable energy for electricity generation, but also for solar water heating and biofuels. However, the total energy is then converted to a percentage of electricity demand (not total energy demand). Biomass data is very unreliable, since fuelwood and waste are mostly not traded commercially, so that the error in the data on biomass energy could be larger than the target.

The Energy Minister's 2003 budget speech had indicated that renewable energy policy would “lead to the subsidization of Renewable Energy and develop a sustainable market share for clean energy” (Mlambo-Ngcuka 2003). Following the approval of policy by Cabinet, the DME is now developing a strategy to achieve the target. Several studies (some commissioned directly by government, others by the NGO community) have analysed in some detail aspects of renewable energy policy, including economic and financial analysis (DME 2004a), developing market rules for renewable energy, in particular independent power producers (Sad-elec 2003), policies and measures for renewable energy and energy efficiency (EDRC 2003a), and the potential of renewable energy technologies to create jobs (AGAMA 2003). Non-governmental organisations have called for significantly higher targets than the 4% in the final policy document, viz. “10 % of electricity generation by renewable energy technologies by 2012 and 20% by 2020” (Energy Caucus 2002). However, analysis indicates that achieving the more modest government target by 2013 will require substantial additional investment (Alfstad 2004a).

Government intends to take the results of these national-level studies and develop practical projects that bring together developers and financiers (Otto 2004). The design of systems for an

office to administer subsidies for renewable energy projects is under way. Subsidies are expected to be once-off for three years (2004-06), after which the approach will be evaluated.

3.2.1 Assessing overall progress against energy development objectives

The five major energy policy goals spelled out in the 1998 White Paper remain current, with some changes in emphasis over time. In the budget speech for 2005, the Energy Minister interpreted these goals in the following way (Mlambo-Ngcuka 2005):

- “attaining universal access to energy by 2014;
- access, affordable and reliable energy especially for the poor;
- diversifying primary energy sources and reducing dependency on coal;
- good governance which must also facilitate and encourage private sector investments in the energy sector;
- environmentally responsible energy provision”.

The Minister has consistently linked all these to the overall government goal of “pushing back the frontiers of poverty” (Mlambo-Ngcuka 2003).

Overall progress against the five major objectives of energy policy was assessed in a 2002 study as shown in Table 3.1. Within the major objectives, different policy priorities have emerged and progress is assessed against these more detailed priorities.

Table 3.1: South African energy policy priorities and progress

Source: (Spalding-Fecher 2002a)

Objective	Priorities	Progress to date
Increased access to affordable energy services	• Electrification policy and implementation • Address off-grid electrification	• Initiate second phase of electrification programme, including renewable energy for off-grid electrification
	• Affordability	• Zero-rating of VAT on paraffin • Poverty tariff
	• Facilitate management of woodlands • Promote improved fuel wood stoves • Establish thermal housing guidelines	• No activity
	• Promulgate electricity regulatory bill • Manage deregulation of oil industry	• Voluntary guidelines only • Postponed to 2002
Improving energy governance	• Implement new regulation of nuclear • Restructure state energy assets	• No petroleum regulator; Petroleum Products and Pipelines Bills in 2002 • Nuclear regulator established
	• Restructure DME budget • Establish energy policy advisory board • Establish information systems and research strategy	• Eskom conversion bill passed • PetroleumSA formed • iGas formed • Limited activity

<i>Objective</i>	<i>Priorities</i>	<i>Progress to date</i>
Stimulating economic development	• Encourage black economic empowerment in energy sector	• Two multinational oil companies have sold 25% of business to BEE firms
	• Manage electricity distribution industry restructuring	• Plan for REDs agreed; implementation in 2002
	• Remove energy trade barriers & facilitate investment in energy sector	• Only Gas Bill to encourage investment in natural gas
	• Introduce special levies to fund regulators & other energy agencies	• Implemented in all sub-sectors except nuclear
	• Introduce competition in electricity	• Outline of long term plans agreed by cabinet
	• Establish cost-of-supply approach to electricity pricing	• Cost-of-supply and wholesale electricity tariff piloted
	• Promote energy efficiency and voluntary appliance labelling programme	• Limited activity outside of commercial building standard
Managing energy-related environmental impacts	• Improve residential air quality	• Pilot programmes to improve air quality through low smoke fuels
		• Proposals on ambient air quality standards under debate
	• Monitor reduction on candle/paraffin fires resulting from electrification	• Hazards still very significant
	• Introduce safety standards for paraffin stoves	• Under discussion
	• Develop policy on nuclear waste management	• Under discussion
	• Investigate options for coal discards	• Significant research, but no programmes
	• Investigate environmental levy	• Not investigated
Securing energy supply through diversity	• Evaluate clean energy technology	• Participation in Climate Change debate
	• Develop Southern African Power Pool	• SAPP regional co-ordination centre established and some joint planning
	• Pursue international and regional co-operation	• SADC Regional Regulator's forum and NEPAD
	• Develop gas markets	• Mozambique gas to Sasol, and Namibia also under discussion
	• Stimulate use of new & renewable energy sources	• Piloting several programmes, Renewable Energy White Paper in 2002
	• Stimulate energy research	• Declining research funds

The table makes clear that the sectoral goals set for energy by the RDP in 1994, have had to be refined and modified for policy reasons and technical reasons. Experience with electrification showed that while the targets of physical connections were met and exceeded, additional policy – the poverty tariff – was needed to make use of electricity affordable. Like all development targets, energy objectives had to be achieved within a changing macro-economic framework.

Overall, although the sector has done relatively well, substantial work remains to be done and the high standard of sustainability has not been reached.

3.3 Role of electricity in development

Energy in general and electricity in particular have been central to South Africa's development path in the past. While energy on its own is not sufficient for development to occur, it is

certainly a necessary ingredient. Energy and particularly electricity will continue to be shaped by future social and economic development.

3.3.1 Energy and electricity development in SA

The South African energy sector has historically been at the centre of the country's development. The origins of the electricity supply industry in the first years of the twentieth century, for example, were driven by the needs of the booming mining industry. Energy was a critical ingredient in major investments in mining. Electricity supply, too, was shaped by the demand from the mining industry as it emerged in the early twentieth century. The mining sector in turn produces coal, South Africa's pre-dominant fuel⁸ for electricity generation and direct use in industry.

As manufacturing became more important in the economy than mining and agriculture, energy continued to be a major driver of development. Much of the manufacturing sector is also linked to mining activities through minerals beneficiation and metals production. Mining and the various processes of beneficiation are all energy-intensive. In the South African context, the availability of inexpensive coal and electricity were critical to the establishment of these industries. The 'minerals-energy complex' (Fine & Rustonjee 1996) fundamentally formed the energy economy of the country.

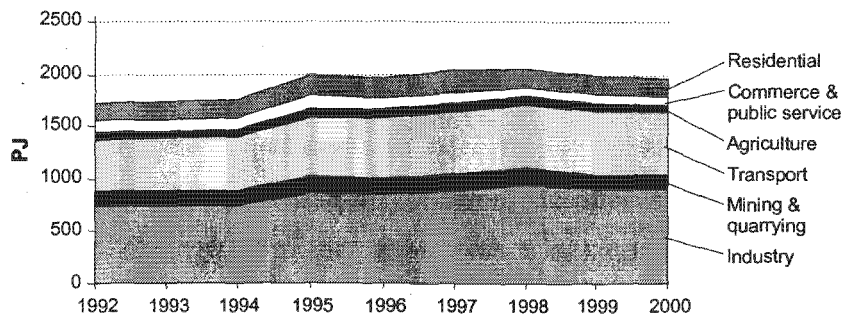
In the 1950s, the then apartheid government decided to develop a synthetic petroleum industry and local nuclear capacity, reflecting concerns for energy security. With local fuels, it could meet demand for liquid fuels and lessen its dependence on energy imports. The 1960s and '70s saw large investment in electricity generation, resulting in excess capacity through the next two decades (see 3.3.1 and Figure 3.7).

Under the democratic government after 1994, the focus shifted from supply to address demand, and particularly broadened to include household access to electricity and making energy services more affordable for the poor. The earlier period focused primarily on economic development – in the sense of the growth of mining and manufacturing industries. Productive activity was central to energy development.

⁸ Coal is currently most widely used, as illustrated in various graphics in this chapter. In terms of the total resource, however, it is smaller than uranium and certainly than solar energy, which is renewable each year.

Figure 3.1: Energy demand, 1992-2000

Source: Based on data in energy balances (DME 2002a)



Note: does not include consumption of renewable energy and waste, due to data uncertainties

Energy consumption has contributed primarily to industry, mining and transport. In the two key economic sectors, industrial demand has been the major source of recent growth across all energy carriers (see Figure 3.1). Some growth can be seen in the transport sector, while mining production declined slightly towards the end of the past decade. These sectors make major contributions to the economy, as seen in Figure 3.2. The manufacturing and commercial sector have increased in importance over time, with mining and agriculture remaining fairly constant in real terms and mining declining in recent years. If earlier time series were available, they would show mining and agriculture contributing most economic output in the early 1900s.

Figure 3.2: Sectoral contribution to economy, 1967-2003

Source: Various issues of the SA Reserve Bank Quarterly Bulletin

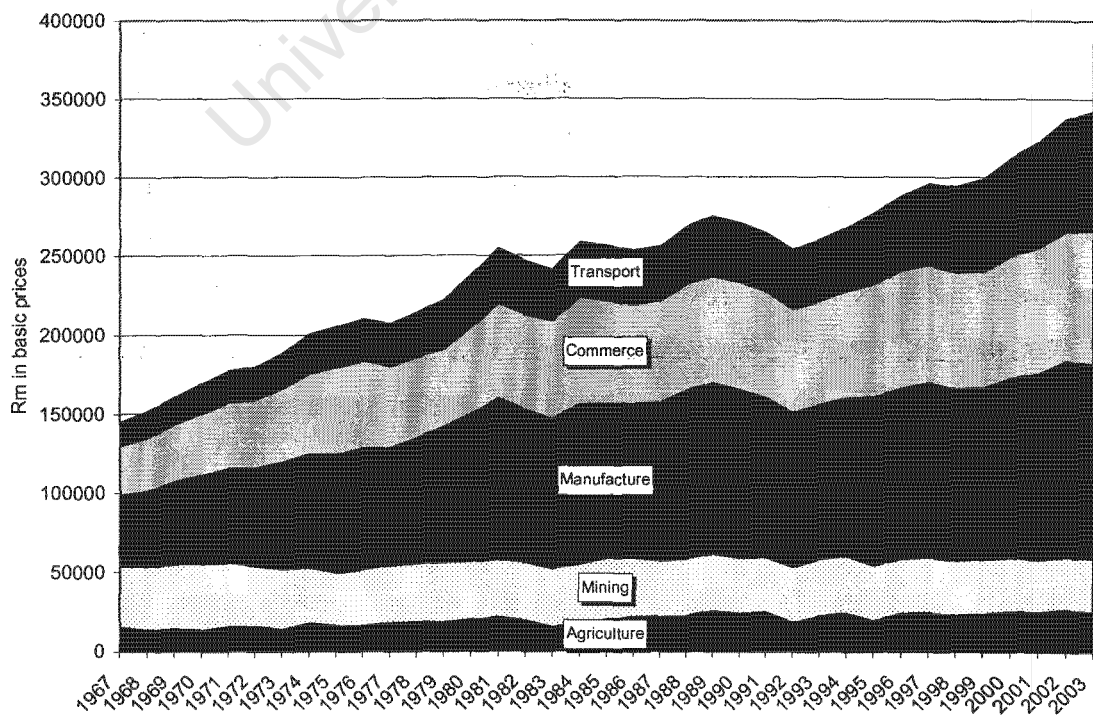
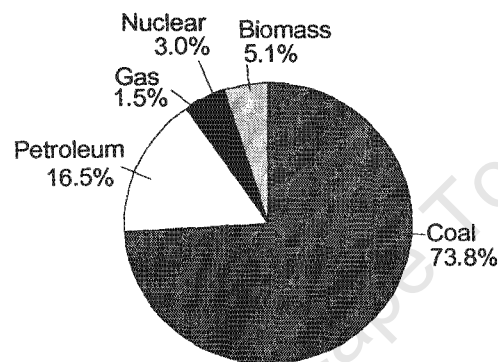


Figure 3.2 includes only selected primary and secondary sectors. Numbers represent gross value added at basic prices of the sector.

Most of the energy used in the major economic sectors is produced from coal. Figure 3.3 illustrates the coal-dependence of the economy, with 73.8% of total primary energy supply (TPES) coming from coal (DME 2001a). This compares to a share of 20% for the OECD and a world average of 24% (IEA 2001).

Figure 3.3: Share of total primary energy supply, 1999

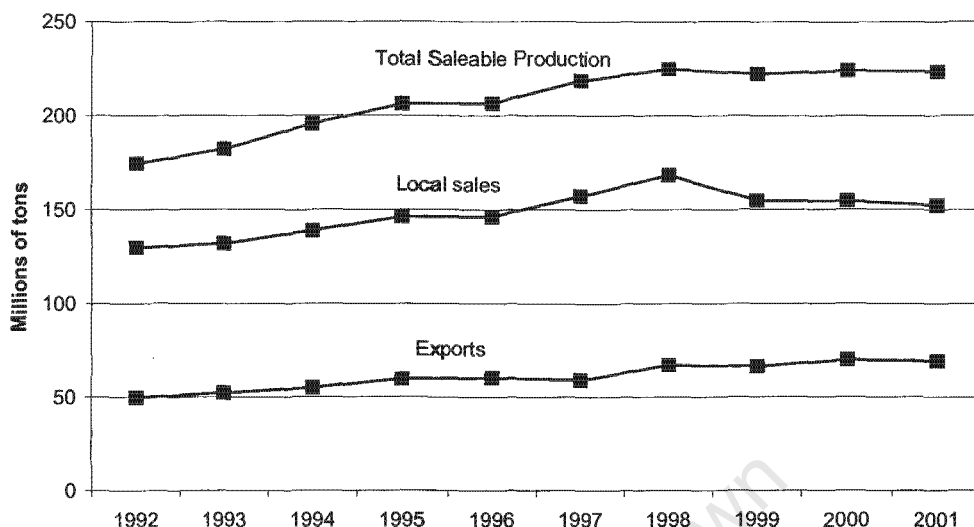
Source: (DME 2001a)



South African coal reserves are large, with the best current estimate being 38 billion tons (ERC 2004a). This gives South Africa the world's sixth biggest reserves after China, the USA, India, Russia and Australia. Annual production of coal is around 230 million tons per year (see Figure 3.4), giving a life of about 165 years of production at current rates. Pinheiro's detailed technical analysis gives an estimated life of 139 to 151 years, assuming that coal producers find profitable markets for their products, not only supply coal for electricity generation. (Pinheiro 1999: 31). In 2001, Eskom burned 94.1 million tons of coal in their power stations (Eskom 2001: 126).

Figure 3.4: Total saleable production, local sales and exports of South African coal, 1992 to 2001

Source: (DME 2002b)



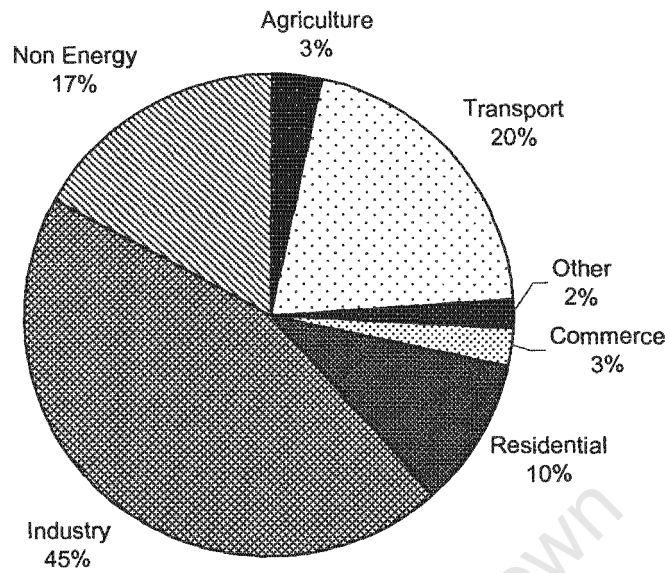
The high levels of energy and electricity consumption in SA, based as they are largely on coal, have led to high GHG emissions relative to other developing countries (see section 3.6.2). In the official GHG inventory (part of South Africa's initial national communication to the UNFCCC), the energy sector – both production and use – contributed 78% of GHG emissions in 1994, in absolute amounts 297 564 Gg⁹ out of 379 842 Gg CO₂ equivalent (RSA 2004a). Most of South Africa's greenhouse gas emissions are related to the production and consumption of energy. Electricity generation contributes the largest part of the emissions from 'energy industries', contributing over 40% of the total GHG emissions, almost exclusively in the form of CO₂.¹⁰

Broken down by the economic sectors which consume final energy, Figure 3.5 illustrates the dominance of the industrial and transport sectors. Non-energy refers to resources that could be used for energy, but which are converted to other products like coal into chemicals and wood into paper (SANEA 2003). Clearly major economic and social development would not be possible without this energy.

⁹ One Gg equals 1 000 tons, so multiply Gg by 1 000 to get million tons. To adjust tons of CO₂ to tons of carbon, divide by a factor of 44/12 or 3.66.

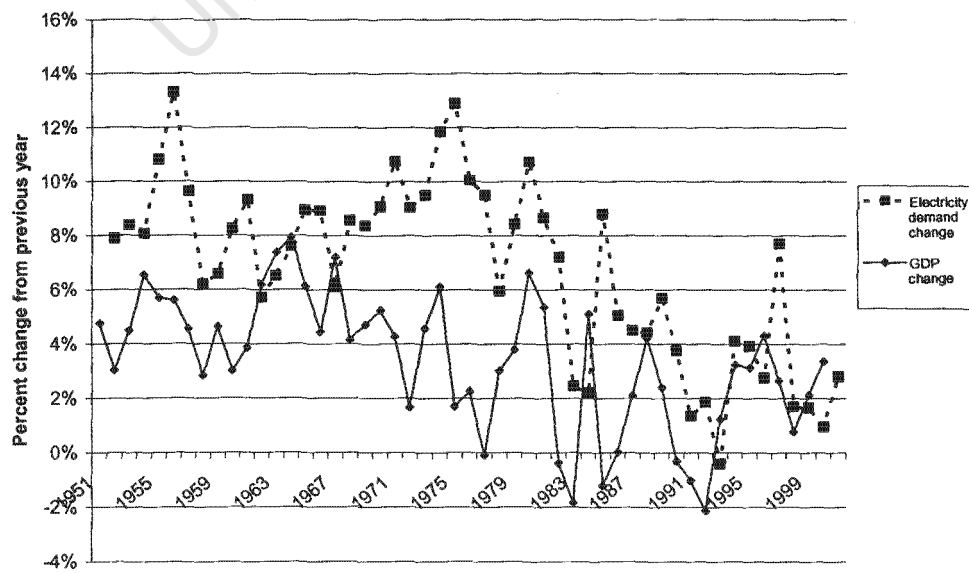
¹⁰ Eskom reported emissions of 2,154 tons of N₂O in 2001, compared to 169,3 million tons of CO₂ (Eskom 2002a). Converted by the Global Warming Potential of N₂O, this means that nitrous oxide accounts for 0.4% of CO₂-equivalent emissions, a factor that has remained constant for since 1997.

Figure 3.5: Share of final energy consumption, 2000
Source: Based on SANEA (2003)



The link between electricity and economic development is shown in similar growth rates. Growth rates for electricity consumption and economic output (approximated by GDP growth rates) have been roughly correlated, as shown in Figure 3.6. Total electricity sales are a good proxy for consumption, and have grown fairly consistently for the second half of the twentieth century. The figure shows the percentage change from the previous year, with higher growth rates between 6 and 13% for the 1950s to 1970s, but between 1 and 4% in the 1980s to 1990s. Economic growth was noticeably lower than electricity demand growth around the 1970s, although in general at lower percentage rates than electricity.

Figure 3.6: Percentage changes in Eskom electricity sales and change in real GDP at market prices
Source: (Eskom 1987, 1996; NER 2000; SARB 2002)



The focus of energy development has recently broadened to include social development. Improving the quality of life for South Africans by ensuring access to energy services is one part of this. The residential sector has seen growth in access to electricity in particular, as noted above, but access to transport services are important in relation to the liquid fuel sector. Energy for economic development remains central, however, including the delivery energy that can enable productive activity, particularly industry, commerce and agriculture. The history of development of the electricity sector provides the back-drop for understanding its current status and future potential.

3.3.2 Development of the electricity supply industry

The pattern of electricity demand was briefly outlined above (see Figure 3.1). By 1948, the industry was consolidated into a large and powerful state-owned, vertically integrated monopoly, Escom. Massive power station projects were initiated in the 1960s and 1970s (mostly coal-fired stations, but also including local nuclear capacity), in response to high economic growth and assuming continued rapid increases in electricity demand – up to 16% growth in peak demand between 1972 and 1982 (Eberhard 2003). By 1973, the transmission grid was interconnected and controlled centrally. As in other sectors (transport, telecommunications, water, iron & steel, synfuels, nuclear energy), the state assumed a dominant role and owned Eskom (renamed in 1987) as a parastatal. With the isolation of the Apartheid government, energy security has an important driver of policy and contributed to the development of synthetic fuels, uranium production and nuclear power, as well as the overcapacity of power plants (Steyn 2001).

By the 1980s, economic growth slowed down, but the long lead times of building power stations meant that the programme continued. This left the national utility with large excess capacity in the 1980s and 1990s. Construction of new plants was put on hold and plans for the final station eventually cancelled (Eberhard 2003). Older plants with about 5000 MW capacity were ‘mothballed’. Eskom promoted growth in demand, particularly in minerals-beneficiation in aluminium and ferrochrome. Nonetheless, maximum generating capacity still exceeded peak demand by 63% in 1992 (Steyn 2001). Table 3.2 shows the gap between licensed capacity and peak demand as ‘excess capacity’ between 1975 and 2000. The net maximum power produced was lower than licensed capacity over the period, but still exceeded peak demand by a substantial margin.

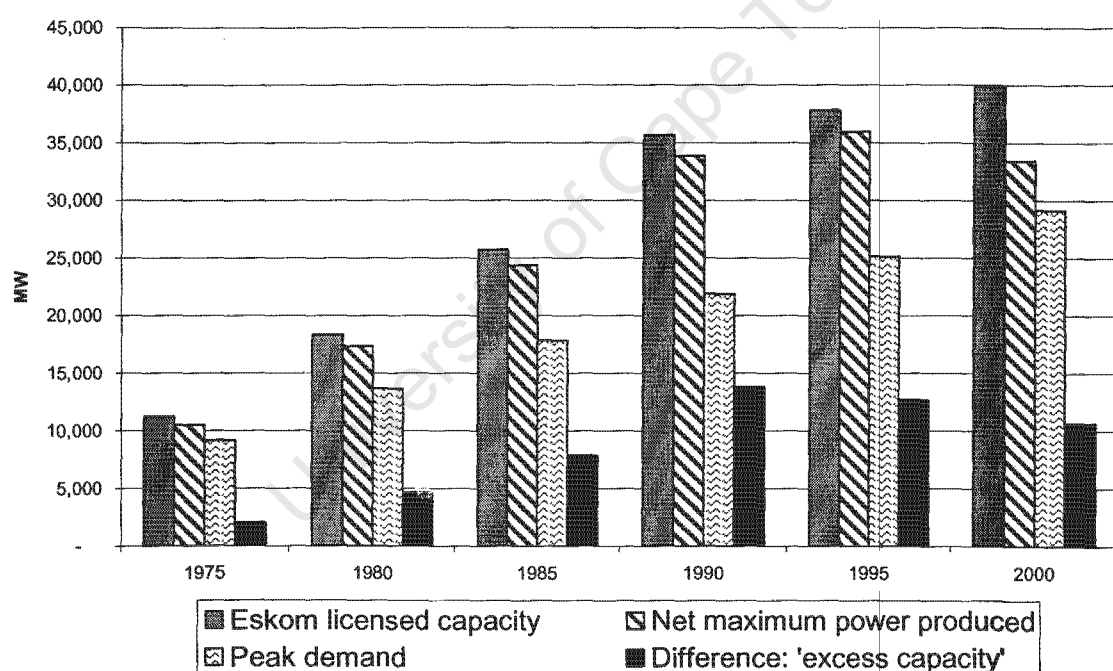
Table 3.2: Licensed capacity, maximum power, peak demand and calculated 'excess capacity' for Eskom, selected years

	1975	1980	1985	1990	1995	2000
Eskom licensed capacity	11,242	18,349	25,716	35,673	37,840	39,870
Net maximum power produced	10,522	17,339	24,359	33,843	35,951	33,461
Peak demand	9,185	13,668	17,852	21,863	25,133	29,188
Difference: 'excess capacity'	2,057	4,681	7,864	13,810	12,707	10,682

Excess capacity has helped to keep electricity prices low, although this excess capacity will be exhausted within the coming three to five years (Eskom 2000a). This excess capacity is illustrated as the difference between total licensed capacity and peak demand in Figure 3.7. Note that net maximum power is slightly lower than licensed capacity, but still significantly higher than peak demand.

Figure 3.7: Eskom licensed capacity and peak demand (MW)

Sources: (Eskom 1987, 1996; NER 2000)



With little need for new investment in recent decades, debt has been reduced as most of the capacity has already been paid off. When new investments have to be made, costs and electricity prices are expected to rise. The presence of low energy prices, including coal-generated electricity, has been one of South Africa's key competitive advantages and continues to drive much of new investment in industry (Eberhard & Van Horen 1995; Visser et al. 1999). It has, however, given little incentive for efficient use of energy and contributed to local and global environmental problems (Spalding-Fecher et al. 2000a; Davis & Steyn 1999; Van Horen 1996b).

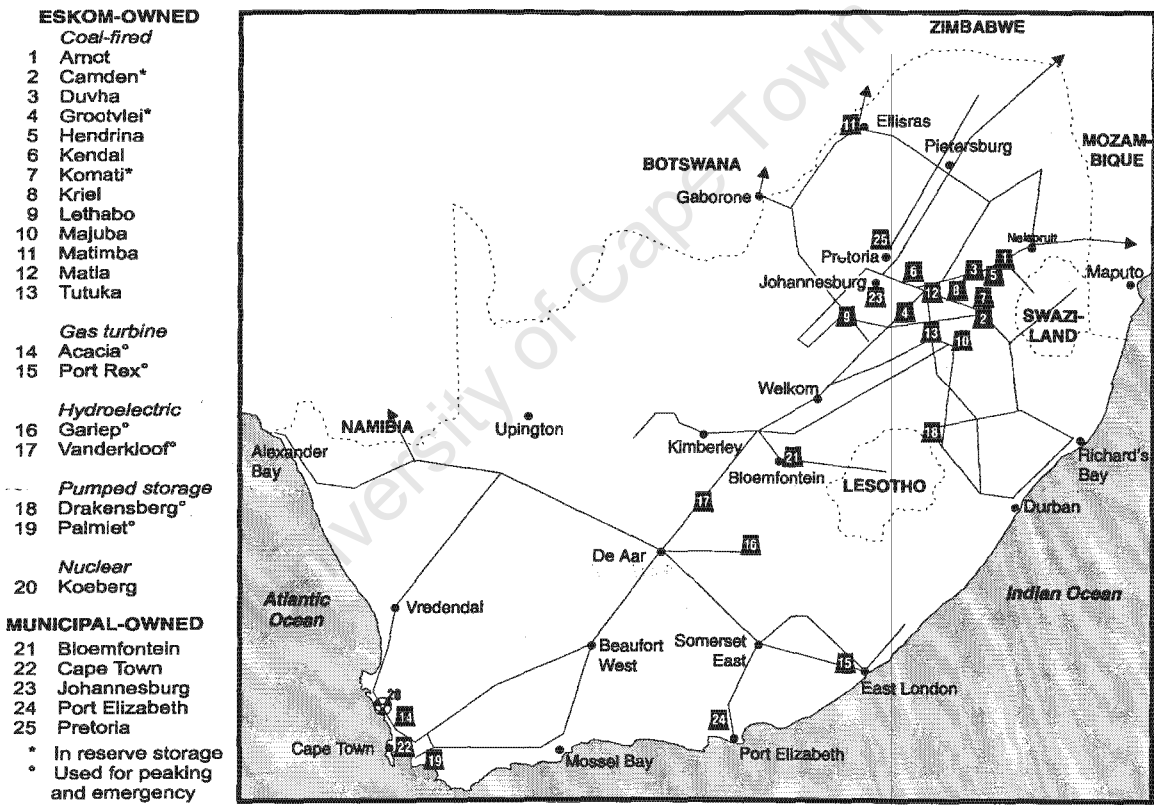
3.3.3 Current status of electricity sector

Most generation and transmission of electricity in South Africa is derived from Eskom. The utility generated 95.9% of electricity sent out in 2002, with municipalities and private auto-generators¹¹ contributing 0.6% and 3.5% respectively. The total quantity of electricity generated in 2002 was 203.6 TWh (NER 2002a).

South Africa's generating technology is based largely on coal-fired power stations, mostly concentrated near and to the east of Johannesburg – close to the main coal-mining areas as well as the major demand centre. To avoid transport costs, all the large coal power stations are concentrated around the coalfields in Mpumalanga, Gauteng and the Northern Province (see Figure 3.8).

Figure 3.8: Map of SA power stations by fuel and ownership

Source: (Spalding-Fecher et al. 2000a)



At the end of 2000, there were 50 power stations in the country, of which 20 are coal-fired, accounting for 90% of the total licensed capacity of 43 142 MW (including capacity in reserve and under construction). Three older coal stations are currently in reserve because of excess capacity, and constitute 3 556 MW. Net maximum power produced was lower than licensed capacity at 35 324 MW. The only non-coal stations of significance are the Koeberg nuclear

¹¹ Autogenerators are industries that generate electricity for their own use, including SASOL, sugar companies and the pulp & paper industry.

station (4.6% of operational capacity) and three pumped storage facilities (collectively 4.0 %) (NER 2001a). These stations are the only ones that are not located in the northeast of the country and assist with grid stability in the Western Cape.

Table 3.3 shows the share of electricity sent out by fuel type (note that percentages of capacity and electricity generation can differ, depending on load factors).

Table 3.3: Net electricity sent out (MWh) by fuel

Source: (NER 2001a)

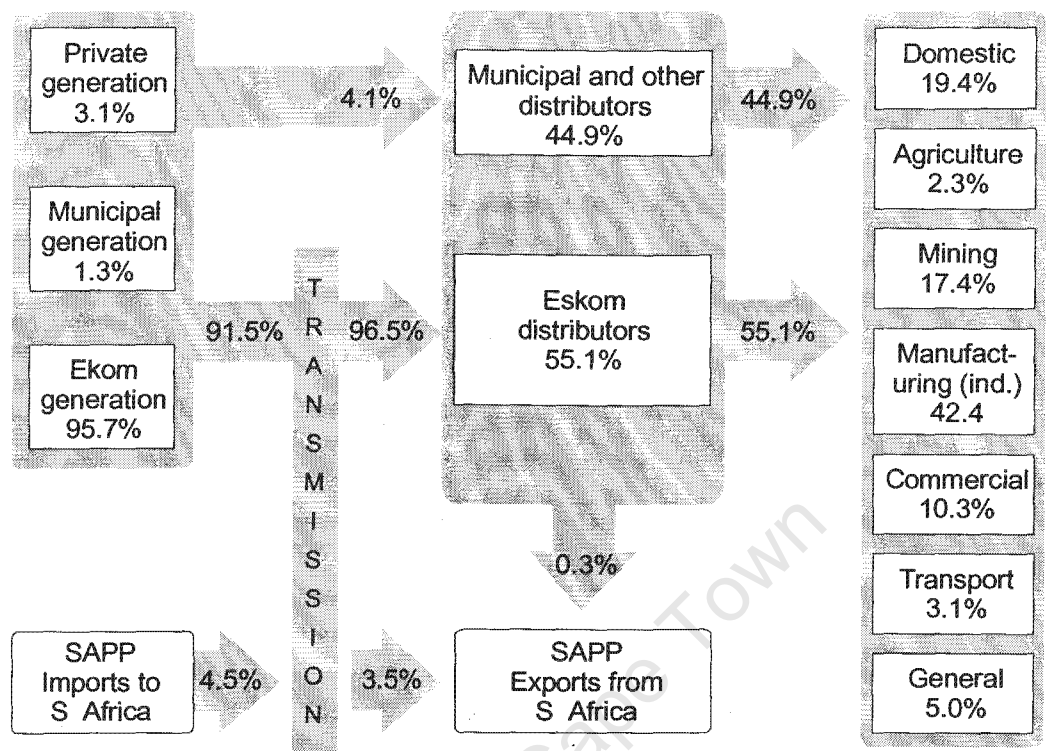
	<i>Eskom</i>	<i>Municipal</i>	<i>Private</i>	<i>Total</i>	<i>Share of total energy sent out</i>
Coal	175 222 884	609 676	7 440 075	189,900,811	93.2%
Nuclear	10 718 623	-	-	11,961,744	5.9%
Pumped storage	-769 295	-67 545	-	-816,755	-0.4%
Hydro	2 194 071	9 690	14 288	2,382,048	1.2%
Bagasse	-	-	306 878	259,317	0.1%
Gas	-725 *	5 710	-	5,557	0.003%
Total	195,324,579	1,143,657	7,224,486	203,692,722	

* Negative values: Pumped storage uses more electricity in pumping water up than it generates, and hence is a net consumer. For gas (using aeronautical diesel fuel in jet turbines), Acacia station consumed more for own use in its generation process than it generated in 2000. This is not always the case.

The flow of electricity from production, through distribution and to end use customers is shown in Figure 3.9. In addition to domestic resources, imports (primarily hydro-electricity) are shown. Note that the shares for different sectors in this figure are for electricity only, while those in Figure 3.1 were for all energy.

Figure 3.9: Energy flow through the electricity supply industry in South Africa¹²

Source: NER (2001a)



3.4 Economic and institutional aspects

How sustainable is South Africa’s energy *economy*? To answer this question, one needs to consider how financially sustainable the sector is, but also what contribution it makes to overall economic development. Sustainability in the energy sector is not only about the internal dynamics of the sectors, but also about its relationship to the broader economy.

One of the features of South Africa’s energy economy that receives much attention is the relatively low price of electricity. There are multiple reasons for this, and the price is low from a utility perspective rather than affordable for all customers.

As a parastatal for most of its life, Eskom has received support from government over the years. While it has contributed significantly to social development (notably electrification), this has been made possible by a range of factors - low coal prices, utilising power station technologies that maximize economies of scale and exploit the lowest value (and cost) of coal, exemption from taxation and dividends, financing subsidies and over-capacity (Eberhard 2000: 13; Steyn 2000: 6-8; Clark 2001a: 128).

¹² The original diagram gives no percentages for imports and exports. For 2000, however, 5 294 GWh were imported from SAPP utilities and 3 967 GWh exported. As a percentage of gross energy sent out of 198 206 GWh, imports constituted 2.6% and exports 2.0%. It is not exactly clear how this would change the percentages above, but the

South Africa has taken advantage of large economies of scale in coal mining and power generation, and the power stations are situated near the mines and benefit from long term coal contracts (Chamber of Mines 2001). Municipal distributors and large industrial and mining customers contribute more than 80% of Eskom's sales, which reduces overhead costs per unit of sales (NER 2000). Given that power plants need to be near coalfields to avoid transport costs, electricity generation is concentrated in the northeast of South Africa. Electricity has to be transmitted to other major centres such as Richards Bay, Durban and East London.

Investments have effectively been subsidised with public money, for example through Reserve Bank providing forward cover protecting Eskom against changes in exchange rates. As a parastatal for most of its existence, Eskom did not have to pay tax and dividends, even after these investments had been paid off. The estimated benefit to Eskom was R22 579 million between 1986 and 1998 (Steyn 2000: 7). Even with this subsidy, Eskom's debt burden was high in the 1980s, but over time the loans have been paid off. Large investments were made in previous decades led to significant overcapacity, so that Eskom has been able to pay off debt, reduce financing costs, and price electricity at a very low marginal cost (Eberhard 2000; Van Horen & Simmonds 1998; Davis & Steyn 1998)

Eskom's high debt-equity ratio¹³ in 1986 at 2.93 declined to 0.85 in 1998 (Steyn 2000), and was reduced further by 11.5% per year to 0.63 in 2000 (Eskom 2000b). In a commercial firm, lower debt repayments would have been replaced by higher payments of dividends to shareholders, but this did not happen with Eskom as a public company. With the capital costs having been paid off, consumers are currently paying only for energy costs.

Over-investment in coal-fired power plants in the 1980s led to excess capacity, so that Eskom has not had to invest significantly in new power stations for some years, which reduces overall costs. In fact, three power stations are 'mothballed', and the debt for constructing power plants has largely been paid off. When new investments have to be made (by ca. 2007), costs and electricity prices will rise. Eskom expects that R100 billion of new investment will be required over the next 25 years (Chalmers 2001a), for an estimated capacity of 15 000 – 25 000 MW (Chalmers 2001b). In 2004, government announced that a tender for new generating capacity needed by 2008, although in the same speech aiming that "administered prices do not unnecessarily add to the general costs of production and inflationary pressures" (Mbeki 2004a).

impact of 1 327 GWh difference between imports and exports is unlikely to result in changes in front of the decimal point.

¹³ A debt-equity ratio of 1.00 would show equal debt and equity. In other words, only half of the liabilities of the company would be financed by borrowing (debt), the rest from other provisions, such as capital development funds, loans redeemed and other capital receipts that reflect the use of retained earnings of the company to support assets. A ratio greater than 1.00 shows more reliance on debt to finance operations, below 1.00 the operations are financed from retained earnings.

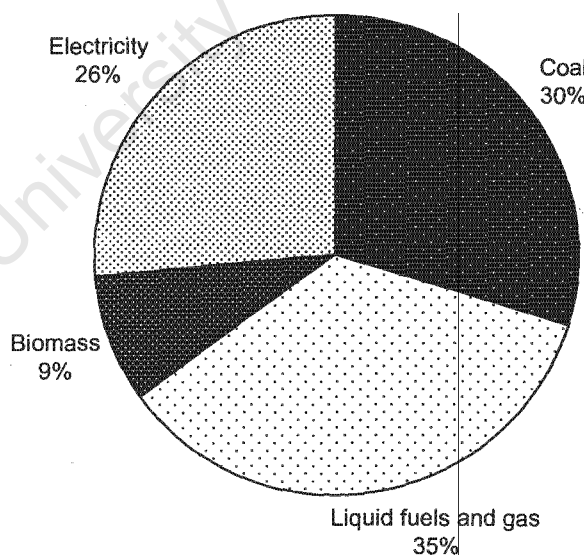
The overall effect is that the price of electricity does not reflect true costs (the value of the inputs used to produce electricity): the full capital costs are not reflected (tariffs are not 'cost-reflective'), nor are externalities priced. Cheap electricity has had a large opportunity cost to South Africa as a whole.

With the restructuring of the electricity supply industry, investment will not come exclusively from Eskom. Independent power producers can enter the market. Eskom has been corporatised, and up to 30% of its assets may be sold off. While previously tax-exempt, Eskom will have to pay tax and dividends in future. Since the passing of the Eskom Conversion Act (2000), it has made provision for future tax payments. The value of Eskom's assets for tax purposes is specified in the Act at R41 827.8 million at 1 January 2000 (DPE 2000: 8).

Having considered several internal dynamics affecting the economics within the energy sector, we now consider the contribution of energy – and electricity in particular – to the broader economy and its various sectors. To understand the role of electricity in productive activity, it is useful to put electricity in the context of other major energy carriers. Figure 3.10 breaks down final energy demand by carrier, and shows that liquid fuels and gas make up the largest single share, followed by coal and electricity.

Figure 3.10: Share of final energy demand by energy carrier

Source: Based on data from (DME 2002a)



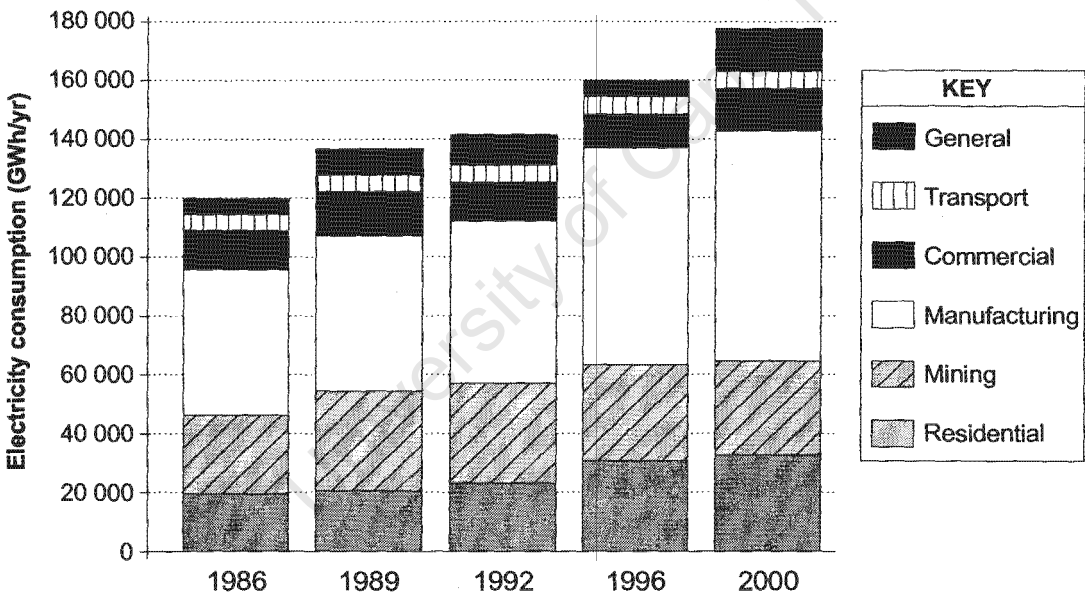
Electricity makes up 26 per cent of final energy demand in South Africa, following coal and liquid fuels (DME 2000b). This share underestimates the role that electricity plays, however, as a high quality energy carrier and as a critical input to key economic sectors and productive activity. At the point of final demand, electricity is efficient to use – the thermal losses have already occurred upstream in the power stations and lines. Similarly, pollutants from electricity

generation are emitted where the coal is burned, but at the point of use electricity is a clean ‘fuel’. Other fuels, by contrast, are typically burned directly in industrial equipment – or indeed in household appliances. Efficiency losses and pollution occur on site.

To understand the contribution of electricity to economic sectors, we need to investigate what electricity is used *for* and how these uses contribute to productive activity. Figure 3.11 shows the trends in electricity consumption for major economic sectors from 1986-2000 (ignoring other energy carriers). The growth in aggregate demand in the sector is clearly evident. By 2000, manufacturing and mining together make up more than half of electricity demand, and both sectors are also major contributors to economic growth and exports. Together with the transport and commercial sectors all are essential to production, and together account for about three-quarters (74%) of final energy consumption.

Figure 3.11: Electricity demand, 1986-2000

Source: Davis (1998), NER (2000)



The input-output tables for the SA economy were used to establish the sectors in which electricity contributed the highest share of input costs.

Figure 3.4 was based on the 1995 input-output tables and identified sectors with above national average (7%) share of electricity as intermediate input cost. The mining and minerals beneficiation sectors are at the top of the list, with cement and chemicals also paying a major share of their input costs to electricity.

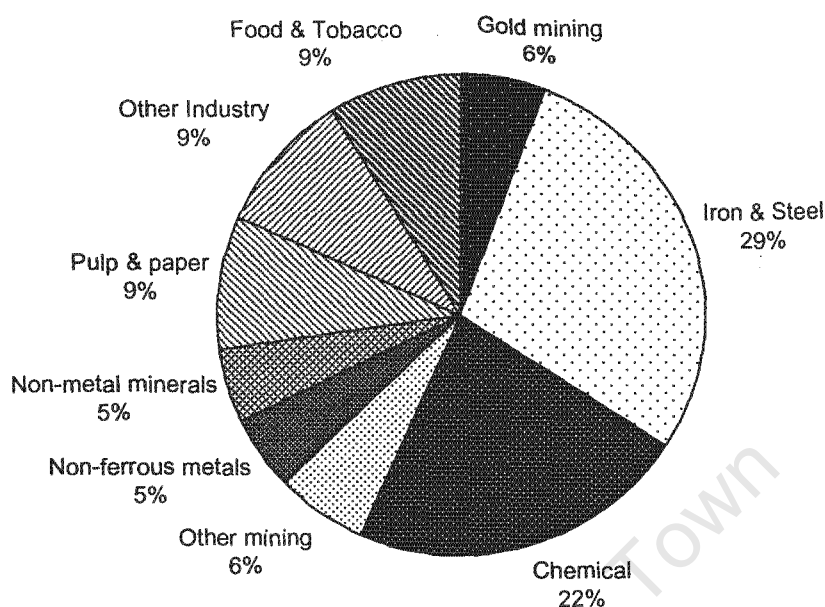
Table 3.4: Electricity intensive sectors of the SA economy*Source: Consult 101, EC & IDC (2001)*

<i>SIC Sector</i>	<i>Sector description</i>	<i>Electricity costs as percentage of total intermediary input costs</i>
2400	Gold Mining	31.8%
3710	Iron & Steel Basic Industries	18.9%
3610	Pottery	18.1%
3720	Non-Ferrous Metal Basic Industries	17.1%
2800	Other Mining (Diamonds & Other)	16.7%
4200	Water Supply	14.9%
3692	Cement	14.9%
3511	Industrial Chemicals	14.6%
3691	Bricks	12.2%
3513	Synthetic Resins	11.9%
2100	Coal Mining	11.8%
3620	Glass & Glass Products	11.7%
9800	Other Services, Non-Profit Seeking	10.3%
8310	Real Estate	9.5%
7100	Transport & Storage	9.0%
3411	Pulp & Paper	8.5%
6300	Catering & Accommodation Services	7.3%
	AVERAGE FOR THE SA ECONOMY	6.8%

The contribution to productive activity can be understood in more detail by considering characteristics of the major electricity-using sectors. The sub-sectors that consume the most energy are manufacturing, mining, iron & steel and chemical industries are major energy users.

Figure 3.12: Final industrial energy consumption by sub-sector

Source: SANEA;(2003) 2001 total: 1302 PJ



Industry (including both mining and manufacturing) is perhaps the classical sector of productive activity. The sector includes energy- and electricity-intensive industries – e.g. minerals beneficiation like aluminium smelting, as well as mining itself. It uses primarily coal (57% of its final energy demand) and electricity (35%) (DME 2002a).

Few productive activities are possible without transport. Unsurprisingly, electricity plays a relatively small role in a sector dominated by liquid fuels, notably petrol and diesel. Petroleum products account for 97% of consumption; electricity is mostly used in rail transport. While rail is important to production, it is overshadowed by road transport.

Electricity is the predominant form of energy carrier in the commercial sector. Government and office buildings, financial services, information technology, educational institutions and recreational sub-sectors primarily use electrical appliances, e.g. lights, air conditioning, heaters and office equipment. The services offered by the commercial sector are an increasingly important part of Gross Domestic Product. If energy-efficiency standards were made mandatory for commercial buildings, significant savings – of electricity and money – could be made.

While agriculture has declined in terms of economic output (as approximated by GDP¹⁴), the sector remains important for food production and as a source of rural employment. Data on agricultural energy use is poor even for commercial farms, and almost non-existent for dense

¹⁴ As first mining and then manufacture increased their influence in the economy, agriculture has declined in its share of economic output, contributing 9.1% of GDP in 1965, for example, but only 4.0 % by 1998 (NDA 2000)

rural settlements and 'subsistence farming'. For both sub-sectors, there is little data on energy use, except of isolated studies (Auerbach & Gandar 1994). Most energy in this sub-sector is used for land preparation and water pumping, with minor contributions from crop processing, transport and lighting. The larger energy users are commercial farms, which are tending to increase in size but decrease in number. Energy is used primarily in the form of diesel, followed by electricity and coal (SANEA 2003; ERC 2003).

In summary, then, the electricity sector is characterised by relatively low tariffs, although this has multiple reasons examined in this section. Although electricity is not the largest energy carrier in South Africa, it makes an essential contribution to the full range of productive and income-generating activities. The sector has contributed to economic development through the provision of low-cost, reliable electricity supply.

Turning to social dimensions, the residential sector takes centre stage. Figure 3.11 illustrates that the residential sector makes the third largest contribution to electricity demand. The share of electricity demanded by this sector has grown in the last decade, as targets for development have been pursued in energy and other sectors. The following section considers in more detail how electricity relates to social development.

3.5 Social dimensions and the residential sector

One of the most ambitious goals of the RDP was connecting a quarter of a million households to electricity each year. Achieving this goal has made a major contribution to social development. Has this contribution been achieved in a sustainable manner, and can it be extended more broadly and deeply?

Electricity services are important in improving the quality of life for the previously disadvantaged majority. As described above (section 3.2), electrification has been a key means of delivering access to commercial energy services, increasing the share of connected households from roughly one-third to two-thirds during the 1990s. By the same token, however, every third household is still without electricity – every second one in rural areas. So while major strides towards social sustainability have been made, more remains to be done. And the experience of electrification has shown that numbers of connections are not the only parameter. Finally, the question of affordability of energy services raises a critical question of sustainability in its social dimension.

3.5.1 Electrification and multiple fuel use

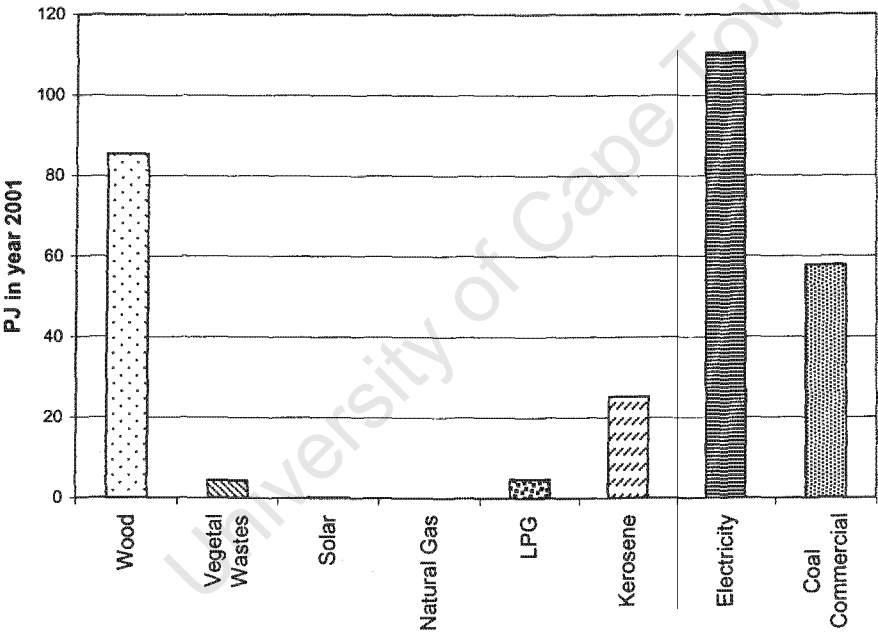
The National Electrification Programme, as described in section 3.2, has been the major vehicle thus far for meeting the target of universal access to affordable energy services. It has contributed to quality of life in several ways. Benefits included increased access to a modern energy carrier, improved health care in clinics and adult education in evenings at schools. Small

retailers were able to extend business hours, and use electrical appliances. Reduced use of coal in Gauteng improves indoor air quality, while less use of paraffin in the Western Cape reduces the risk of fires. Access to electricity has increased not only for richer households, but also poorer ones – 31% of those earning less than \$1 per day had access to electricity in 2000, compared to 20% in 1995 (SARPN 2005).

However, multiple fuel-use persist for many years after electrification (Borchers et al 2001). Energy use in poor households continues to be characterised by the use of multiple fuels, with paraffin, coal, fuel-wood and LPG often being used long after a household has been connected (see Figure 3.13).

Figure 3.13: Final residential energy demand by energy carrier

Source: Based on SANEA (2003) and ERC (2003); 2001 total: 288 PJ



Patterns of household energy demand differ significantly in rich and poor, urban and rural households (Mehlwana & Qase 1998; Simmonds & Mammon 1996; Mehlwana 1999b). Middle- and high-income households use a much higher share of electricity. For poor households, the issue is not simply one of physical connection – access is also limited by affordability. Not only are poor areas often the last to be electrified (ERC 2004a), but electricity is used only for lighting and media, not for cooking and space heating. Multiple fuel use persists many years after electrification, highlight the importance of *affordable use* of modern energy for cooking, lighting, space heating and media.

When modern energy sources are not available or are not affordable, many households use traditional biomass fuels. Used indoors, burning of wood, dung or other biomass causes high

levels of indoor air pollution and this in turn impacts respiratory health. Electrification is desirable for its social benefits, but needs to be affordable both for the utility and for customers.

There is a distinct rural-urban divide in electrification rates, and across income groups. The national average electrification rate in 2003 of 69% obscures the fact that almost half the rural population (54%) remains without grid electricity and other convenient fuels, while 79% of urban households are connected to the grid (NER 2003a). Very poor households (quintile 1) in rural areas have the lowest electrification rates at 41% (see Table 3.5). The largest difference between rural and urban households is found between in the second quintile.

Table 3.5: Estimated electrification levels of rural and urban household by income quintile

Source: UCT (2002) , based on data from October Household Survey (1999)

	Q1	Q2	Q3	Q4	Q5
Rural households	41%	45%	59%	68%	76%
Urban households	63%	78%	87%	91%	98%

Eskom’s industrial and residential electricity tariffs are amongst the world’s lowest (SANEA 1998), made possible by economies of scale, effective subsidies, low debt ratios and non-payment for external costs (see section 3.3.3). From the perspective of poor households, however, electricity remains expensive, especially when used for cooking and heating. High cut-off rates and community protests against cut-offs illustrate the problem of affordability.

3.5.2 ‘Low tariffs’ and affordability

Even for electrified households, the benefits from cooking and heating with electricity were lower than expected by planners, due to affordability. A physical connection to the grid does not ensure the electricity is actually used, finance is also required. Many poor households use electricity primarily for lighting and entertainment. Instead of the planning estimate of 350 kWh / month, consumption remained between 100-150 kWh per household per month. Low levels of consumption, together with other factors (high operating and capital costs, high levels of losses and high cost of capital) (NECC 2000) have meant that electrification has not been financially viable and requires major cross-subsidies (Borchers et al. 2001)

However the non-use of electricity among *electrified* low-income households (for cooking, etc) is quite surprising, at current costs. Recent case studies show that 56% of households in South Africa connected to the national grid in Eskom-licensed areas consume less than 50 kWh of electricity per month (Prasad & Ranninger 2003). Implementing a ‘poverty tariff’ would make electricity a cheaper cooking option than other commercial fuels (see further discussion of the poverty tariff in chapter 4).

3.5.3 Off-grid electrification programme

Remote rural areas are more costly to electrify than denser urban settlements closer to the grid. Building on a school & clinic off-grid electrification programme and an Eskom-Shell joint venture which installed 6 000 solar home systems (SHS), a major off-grid electrification programme that began in 2002 (Afrane-Okese 2003). The programme is targeting 350 000 homes for SHSs. Operational challenges early in the programme led to a shift from a concession approach to a fee-for-service model (Afrane-Okese 2003).

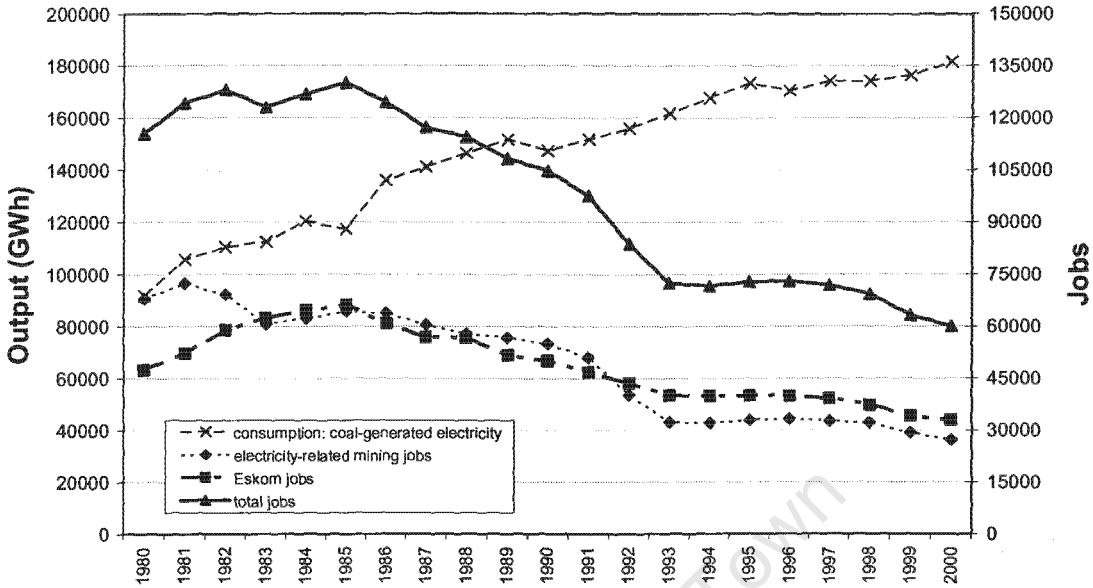
Seven concessionaire companies were to provide non-grid electricity services for an agreed fee to be paid by the customer – the fee-for-service. The companies retained ownership of the systems they install and serviced them regularly. Government provided the concessionaires with a capital subsidy of R 3 500 per system.

Initially, a flat monthly fee of R58 was paid for the service, regardless of the amount used. A solar panel provides on average 62 kWh/year, so that even after the capital subsidy and the poverty tariff, customers are paying 193c/kWh. This is five times the amount a grid-connected customer pays without any subsidy (Spalding-Fecher 2002b). In reaction to this discrepancy and the poverty tariff, government agreed to a monthly service subsidy of R48 as the equivalent of the poverty tariff to grid-connected customers. The subsidy is paid to concessionaires, leaving households paying R10 per month. However, problems with this approach led to the withdrawal of the subsidy. The fluctuation of tariffs led to the near-collapse of the off-grid programme in early 2004. By mid-2005, some companies providing a service were in operation, with three service providers having signed agreements to install 8 000 systems each (Banks 2005).

3.5.4 Electricity and job losses

As shown in Figure 3.14, employment in Eskom and electricity-related mining has declined, even as consumption of electricity (predominantly coal-based) has increased. The number of employees in Eskom declined from 40 128 in 1993 to 29 359 in 2000 (Eskom 2002b). Coal-mining shed more than half its jobs, from about 100 000 in 1986 to 49 000 in 2001 (SANEA 2003). In Figure 3.14, a share of job losses in coal mining is attributed to electricity generation (AGAMA 2003), based on the 53% of non-export coal being consumed for electricity generation (DME 2002a).

Figure 3.14: Employment in coal-based electricity generation in South Africa
Source: (AGAMA 2003) ¹⁵



Increasing mechanisation and capital-intensive production meant that the consumption of electricity and production of coal increased in the respective industries at the same time as employment was reduced (AGAMA 2003). The job losses in Eskom may not take into account increasing outsourcing of some services. As shown earlier in Figure 3.7, excess capacity increased through the 1980s and peaked in the mid-1990s, suggesting that some job losses may have been in constructing power plants. Perhaps the outstanding remaining challenge for electricity’s contribution to social development is that of job creation.

This section has shown how the electricity sector has contributed to social development through increasing access on and off the grid. Issues of affordability, while not easily resolved, have been partially addressed by the policy of a ‘poverty tariff’. Yet the production and consumption of electricity has significant environmental impacts. It is to this dimension of sustainable development that the thesis now turns.

3.6 Environmental impacts

The electricity sector has undoubtedly made major contributions to economic and social development. The heavy dependence of SA on coal, shown earlier in Figure 3.3, means that the way in which electricity is supplied and used has major environmental implications. Changing

¹⁵ Underlying data from (DME 2002a; Eskom 1996; NER 2001a; Eskom 1989; DME 2002c)

the fuel mix for electricity generation, and introducing safer, cleaner fuels for use in households, transport and industry, remain major challenges.

At the point of use, electricity is a clean energy carrier. This is not true of many other energy carriers, resulting in substantial energy-related environmental impacts not related to electricity. Paraffin use has severe health and safety impacts (poisoning from ingestion, burns and deaths from fires, destroyed housing), and is wide-spread in the Western Cape (Mehlwana 1999a; Lloyd 2002; Biggs & Greyling 2001). In Gauteng, where locally available coal is burned indoors, respiratory disease resulting from indoor air pollution is prevalent (Qase et al. 2000). In rural areas, indoor wood fires have similar effects, as pollutants are confined in the house (see Van Horen 1996a; Spalding-Fecher et al. 2000a). Switching from wood, paraffin, coal, candles, batteries and various other fuels to electricity may have environment *benefits* at the local level (Spalding-Fecher 2000a, 2005).

3.6.1 Local air pollution

Environmental impacts occur upstream, in the generation of electricity and the mining of coal. The impacts of electricity supply can be considered on two levels, the local and global environment. Indoor air pollution is generally associated with other energy carriers. Electricity can displace these fuels in theory and contribute to a healthier indoor environment. But with the persistence of multiple fuel use even after electrification (see 3.5.1), serious environmental health issues remain.

Outdoor air pollution is largely contributed to by the burning of coal (often of a poor quality) for electricity production (and brown haze from the transport sector). Coal-fired power plants generate 93% of South Africa's electricity (NER 2001a) and this fuel mix changes only slowly, as investments in this sector have life-times of 30 years and more. Investments made in energy technologies today lock the country into a particular path for a generation. A key issue for environmental sustainability of the electricity sector is the mix of energy technologies that will be used to meet growing demand - renewable energy, nuclear power, petroleum, coal, natural gas and others – see chapter 4).

South African coal has high ash, low sulphur and low calorific value. While Eskom has developed considerable expertise in burning poor quality coal (including coal with a heating value lower than 16 MJ/kg), it has not installed the costly equipment (e.g. flue gas desulphurisation, bag filters) to reduce emissions. Coal-fired power stations produce large amounts of pollutants, including local pollutants such as particulates and sulphur, as well as the greenhouse gases (contributing to anthropogenic climate change) carbon dioxide and nitrous oxide.

Table 3.6: Emission from Eskom power stations, 2001

Source: Eskom (2002a)

Particulate emissions, kt	59,64
Sulphur dioxide (SO ₂), kt	1 500
Nitrogen oxide (NO _x) as NO ₂ , kt	684
Nitrous oxide (N ₂ O), t	2 154
Carbon dioxide (CO ₂), kt	169 300

Probably the major *local* environmental impact associated with electricity is on outdoor air pollution. The pollutants listed in Table 3.6 contribute to health impacts such as respiratory ailments resulting from air pollution (Spalding-Fecher & Matibe 2003). Sulphur emissions are associated with acid rain; and particulates have impacts on visibility in Mpumalanga where most of the coal-fired stations are located. Mining the coal is associated with dust and methane; and social impacts in the form of injuries and deaths in the coal-mining sector.

Water consumption per unit of electricity has been reduced by newer stations, which are dry-cooled. Kendal and Matimba stations require 0.1 litres of water per kWh, compared to 1.8 l to 2.0 l per kWh for wet cooling through the conventional cooling towers. However, with the wet-cooled stations still in operation, total water consumption has increased slightly, from 225 699 MI in 1997 to 239 233 MI in 2001 (Eskom 2002a).

3.6.2 Global greenhouse gas emissions

In terms of *global* environmental impacts, South Africa is one of the most carbon emissions-intensive countries in the world, due to the energy-intensive economy and high dependence on coal for primary energy. South African per capita emissions are higher than those of many European countries, and more than three and a half times the average for developing countries (see Table 3.7).

Table 3.7: Energy sector carbon dioxide emissions intensity and per capita in 2002 and cumulative emissions 1950-2000

Sources: (IEA 2004a; WRI 2003)

	CO ₂ /cap	CO ₂ /GDP	CO ₂ /GDP PPP	Cumulative energy CO ₂ emission from 1950 to 2000	
	tonnes/capita	Kg/1995 US\$	kg/1995 PPP US\$	MtCO ₂	% of world total
South Africa	6.65	1.65	0.75	10,165	1.29%
Africa	0.89	1.16	0.45	13,867	1.75%
Non-OECD	1.65	1.33	0.45	318,117	40.23%
OECD	10.96	0.44	0.56	472,635	59.77%
World	3.89	0.68	0.56	790,753	100%

South Africa is a semi-industrialised country with an emissions profile that in some respects is not typical of other developing countries. Some key characteristics of its economy and energy sector are not favourable in terms of GHG emissions.

Among major developing countries South Africa's emissions intensity is relatively high, in that it emitted 0.75 kg CO₂ per \$ GDP (PPP)¹⁶ in 2002 (IEA 2004a), compared to averages 0.45 kg CO₂ / \$ for non-OECD and African countries. South Africa is also well above the OECD and world averages (see Table 3.7).

Similarly, emissions per capita are high at 6.65 tons of CO₂ (tCO₂) per capita, four times higher than the non-OECD value of 1.65 tCO₂ and higher than several OECD countries (IEA 2004a).¹⁷ The values including other GHG emissions are higher, since IEA statistics include only for CO₂ from fuel combustion.

South Africa's share of historical cumulative emissions (1950 – 2000) is somewhat lower (1.17 percent) than its share of 2000 annual emissions (1.51 percent), reflecting more recent industrialisation than in the North (Winkler et al. 2001).

While GDP per capita¹⁸ lies below the world average (\$3,160 per capita compared to the global average of \$4,890 per capita¹⁹), this figure hides the gap between black and white, rich and poor within the country.

Reliance on coal energy sources is the main reason behind South Africa's high emissions. On the supply side, major sources of greenhouse gases associated with electricity are coal mining and power generation. Other major emission sources from energy – but not electricity – include oil refining, production of synthetic liquid fuels, gas extraction, wood burning and the burning of coal and oil to produce heat. On the demand side, high emissions stem from energy-intensive industries such as iron and steel, aluminium, ferrochrome and chemicals – the same sectors that make up a large share of South African exports. Energy is not used efficiently in these sectors, by international comparison (DME 2003d; Hughes et al. 2002).

South Africa's emission profile – somewhat atypical for a developing country – means that its responsibility to mitigate is higher. It also implies that major changes in energy systems will be needed over time, given the high proportion of energy-related GHG emissions. According to

¹⁶ Power-purchasing parity; US\$ using 1990 prices and exchange rates.

¹⁷ A previous version of the IEA data, for 1998, showed a more dramatic difference, with SA at 1.81 kg CO₂ per \$ GDP (PPP), compared to a non-OECD average of 0.70 kg CO₂. One reason for the difference may be a change from 1990 to 1995 base year.

¹⁸ GDP per capita is not directly part of the emissions profile, but a key characteristic shaping a country's ability to pay for mitigation and adaptation.

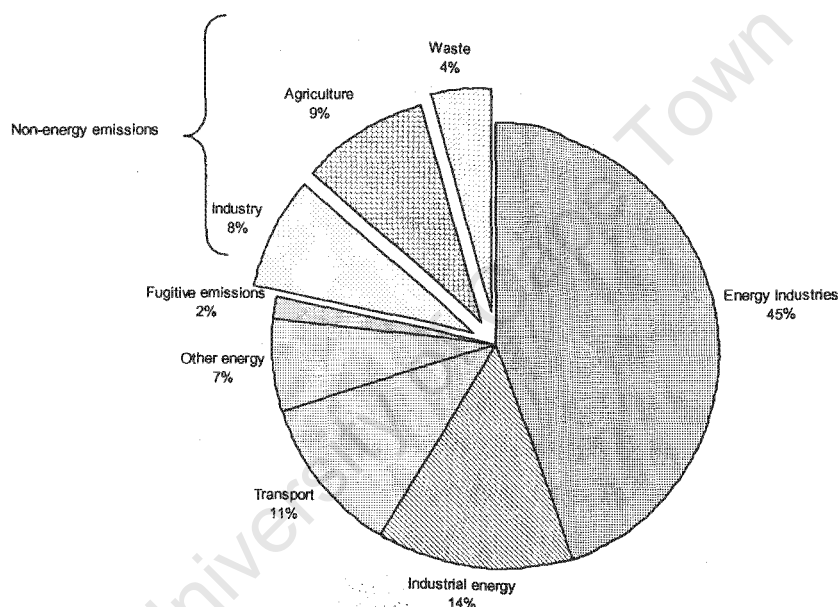
¹⁹ Reported as GNP per capita using exchange rates, based on 1999 dollars, by the World Bank Atlas method (World Bank 2000). South Africa was ranked 86th by this method; 69th when power purchasing parity is used.

South Africa's draft Initial National Communication, total emissions of CO₂, CH₄ and N₂O were 379 842 Gg²⁰ CO₂ equivalents in 1994 (RSA 2004a). This converts to 103.6 million tons carbon, which can be attributed to major sectors of energy, industry, agriculture and waste.

The energy sector, including energy production and use, contributed 78% of GHG emissions (297 564 Gg CO₂ equivalent), agriculture 9.3%, industrial processes 8.0% and waste 4.3%. Comparing the three greenhouse gases in the inventory, carbon dioxide contributed by far the most, 83.2% in 1994. Methane contributed 11.4% and nitrous oxide 5.4% respectively. Given the predominance of carbon dioxide, this analysis focuses on CO₂ emissions.

Figure 3.15: South Africa's greenhouse gas inventory by sector, 1994

Source: (RSA 2004a)



The energy sector is a key source of emissions (see Figure 3.15), which include a number of critical energy related activities such as: energy industries (45% of total gross emissions), energy used in manufacturing an industry (14%), energy used in transport (11%), fugitive emissions from fuels (2%), and other energy related activities (6.6%), which include commercial (0.2%), residential (2.0%) and agricultural (4.4%) use of energy (calculated from RSA 2004a).

The future of energy development in South Africa is integrally related to climate change mitigation. Having placed SA in the international context in this respect, the chapter concludes by comparing the country to others in relation to energy.

²⁰ One Gg equals 1,000 tons, so multiply Gg by 1,000 to get million tons. To adjust tons of CO₂ to tons of carbon, multiply by 12/44.

3.7 Conclusions: Comparing and assessing

To assess how far South Africa has come in terms of energy development, some comparison to other countries is helpful. Other developing countries have the same broad challenge of development, but different energy and electricity sectors. Looking at levels of energy consumption, access to electricity and energy intensity are particularly relevant to energy development paths.

Compared to other developing countries, South Africa’s total primary energy supply (TPES) per person is relatively high (see Table 3.8). The exceptions are other rapidly industrialising countries, with some, such as South Korea, have higher consumption per capita. Total electricity consumption for South Africa is high, particularly in the African context. The two-thirds of South Africa’s population with access to electricity consumes close to 50% of Africa’s electricity with only 5% of its population.

Table 3.8: Energy and electricity consumption, 2000
Source: IEA (2002a)

	Total primary energy supply /capita	Electricity consumption
	Toe/capita	TWh
South Africa	2.51	194
Africa	0.64	399
South Korea	4.10	279
Indonesia	0.69	82
Non-OECD	0.96	5 038
OECD	4.78	9 077
World	1.67	14 115
Note: TPES is shown per person, while electricity is in total consumption for whole countries or regions		

Consumption levels of energy, particularly electricity, in South Africa are significantly higher than in many other developing countries, mainly because of its strong industrial base. However, this also reflects electrification rates that are now exceeding the average for developing countries (see Table 3.9).

Table 3.9: Electrification rates in 2000*Source: IEA (2002b)*

	<i>Electrification rate</i>	<i>Population without electricity</i>	<i>Population with electricity</i>
	<i>%</i>	<i>million</i>	<i>million</i>
South Africa	66.1	14.5	28.3
Africa	34.3	522.3	272.7
Indonesia	53.4	98.0	112.4
Developing countries	64.2	1 34.2	2 930.7
OECD	99.2	8.5	1108.3
World	72.8	1644.5	4 390.4

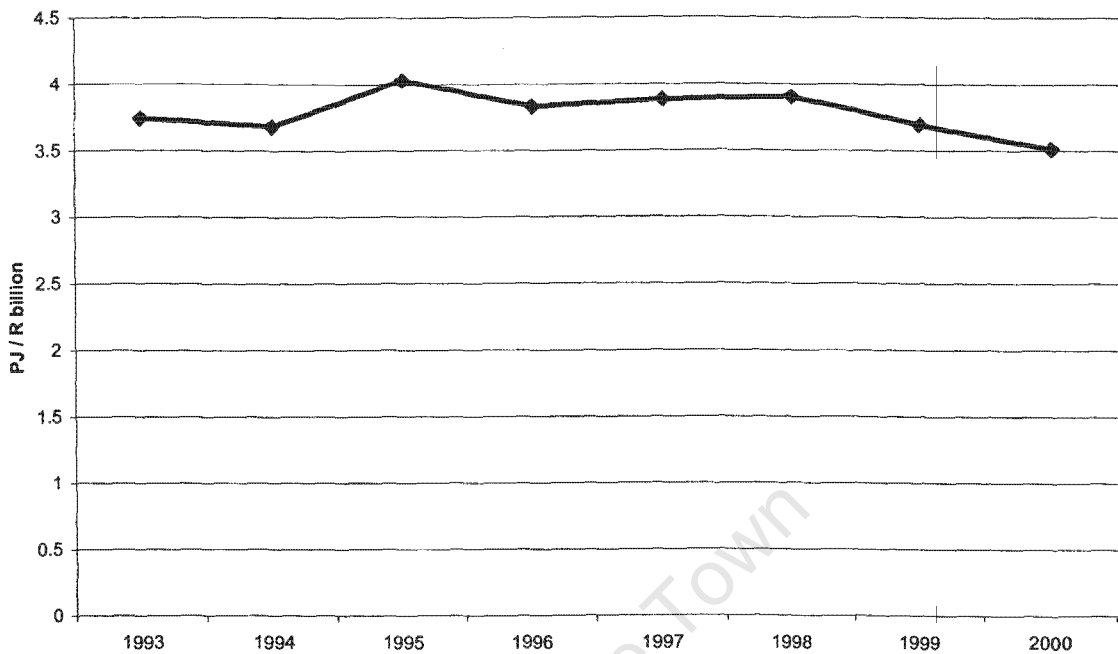
These relatively high levels of consumption also reflect high energy intensity, that is, a high energy input per unit of gross national product (GDP). The Integrated Energy Plan (DME 2003) acknowledged that by “international standards, South Africa has a high energy intensity. South Africa’s history, shaped as it is by the minerals-energy complex, has seen the abundance of mineral deposits converted to low energy costs, but also an emphasis on primary extraction and processing. These economic activities are highly energy intensive. The changes of GDP and final energy consumption are reported in Table 3.10

Table 3.10: National energy intensities between 1993 and 2000*Source: DME (2003d)*

		1993	1994	1995	1996	1997	1998	1999	2000
GDP- All industries at basic prices	R billion (constant 1995 prices)	472	486	500	521	534	538	549	571
Total Final Energy Consumption (renewable and waste excluded)	PJ	1766	1789	2016	1996	2071	2098	2026	2003
Energy intensity (Total energy consumption / GDP)	PJ / R billion	3.74	3.68	4.03	3.83	3.88	3.90	3.69	3.51

Figure 3.16 graphs South Africa’s energy intensity between 1993 and 2000, where post 1995, GDP rises and final energy consumption falls resulting in a lowering of energy intensity over that period. Improving energy intensity has been related to achieving the Millennium Development Goals (MDGs) in South Africa, measured in energy per unit of GDP (SARPN 2005).

Figure 3.16: Changes in energy intensity, 1993 – 2000
Source: based on DME (2003d)



This chapter has considered the development objectives for electricity nested within the broader energy sector, and framed by the overall development objectives of the country. Reconstruction and development in the energy sector have to a significant degree been interpreted as universal access to electricity – and the country is roughly half the way towards achieving this goal. Electricity has contributed to social development through increasing access on and off the grid.

Yet sustainable development of the electricity sector does not begin and end with access to electricity. Dealing with the legacy of Apartheid and the systematic underdevelopment of large sections of the population remains challenging. Issues of affordability, while not easily resolved, have been partially addressed by the policy of a ‘poverty tariff’.

In terms of economic development, the electricity sector has provided relatively low tariffs, although this has multiple reasons as examined in this chapter. Electricity makes an essential contribution to the full range of productive and income-generating activities.

Achieving economic development and delivering basic social services is complicated by the tension with macro-economic parameters, as well as the ongoing challenge of achieving all this while limiting environmental impacts. The emissions intensity of the energy and electricity sectors, both strongly shaped by coal, mean that the environmental sustainability is particularly challenging for South Africa. The next chapter examines policy options that might help to meet this challenge.

CHAPTER 4

4. Policy options in the electricity and residential sector

This chapter²¹ examines the policy options that can move South Africa's electricity sector from its current position towards a more sustainable development path. While there are constraints to policy choices in the electricity and residential sectors – notably privatization and non-negotiable policy commitments – it is possible for SA to shift towards greater sustainability. Policy options need to start from the current reality of energy and development (described in chapter 3), but identify key levers that can move the sector towards a more sustainable future. Scenario planning for the electricity sector involves the creative tension between current reality and future possibility.

An essential input to the scenario modeling of the following chapters is a suite of policy options that could enhance sustainable development in the electricity sector. Scenarios (essentially combinations of policy options) will allow evaluation of the implication of electricity policy for sustainable development in all its dimensions - economic, social and environmental.

Important policy and technology choices to be examined in this chapter include energy efficiency in the near-term; investing in a cleaner, more diverse fuel mix; and new industrial policies to make the economy less energy-intensive over time. Different instruments can be used to achieve policy objectives, falling into two broad types - economic and regulatory instruments. To reduce environmental impacts of electricity, for example, taxes can be used to internalize external costs, or regulatory standards can be set. Such more specific policy and technology options within the broader choices are described in this chapter, laying the basis for modeling policy options in future scenarios in the following chapters.

Extended affordable access to modern energy services is a policy imperative which other initiatives will have to follow. As outlined in chapter 3, affordable access to energy services has been advanced primarily through electrification, both through the grid and some off-grid programmes. Universal access to electricity is to be achieved by “a strengthened local government working with our state enterprise, Eskom ... within the next eight years”, i.e. by 2012 (Mbeki 2004a). The commitment is so strong that policy-makers take it as a given. At the same time, policy has dictated that energy tariffs – not only for industry, but also for households – should be kept low. The challenge of affordability has been partly addressed through the

²¹ Parts of this chapter relating to renewable energy have been published in: Winkler, H 2004. Renewable energy policy in South Africa: Policy options for renewable electricity. *Energy Policy* 33 (1): 27-38.

'poverty tariff' which provides 50 kWh of free electricity (DME 2004b). Any scenarios for the electricity sector will need to contribute to affordable access to electricity.

The Energy Policy (DME 1998) goal of improving governance – including the introduction of competition – sets constraints for electricity policy options. Privatisation is not the only aspect of governance, but it is the one that determines the macro-economic framework for other policies. Indeed, the role of the regulator is likely to change with the restructuring of the distribution industry, and possible privatisation on the supply side (Eberhard 2003). From licensing and setting tariffs for a virtual monopoly, the role would shift to setting rules for a competitive market. This chapter considers the prospects of power sector reform, and the implications for electricity policy that promotes sustainability.

Current electricity policy shares the five major goals of the White Paper on Energy Policy (DME 1998: see ch 3 for details). *Access* to electricity is a particularly strong policy imperative. Future policy options for the electricity sector will be framed by *governance* arrangements in the sector, with the future of privatisation setting major parameters. Some of these options contribute to reducing the *environmental* impact of energy supply and use. Major policy shifts are possible in changing the energy *economy*, but are also a long-term process. Forward-looking policy will seek *security by diversifying* the fuel mix, examining various fuel and technology options.

4.1 Further extending affordable access to electricity

Universal access to affordable electricity will remain a corner-stone of policy for the sector and treated as a 'given' in considering policy choices. In urban areas, close to 100% of households may be connected. The challenge for the future will be to achieve universal access in rural areas, where half²² of the households were still without access to grid electricity by 2001 (NER 2001a). Governments commitment to achieving universal access has been reiterated in many policy speeches (Mbeki 2004a; Mlambo-Ngcuka 2003, 2002a, 2004). With the rationalisation of the electricity distribution industry, electrification will be carried out by the six new Regional Electricity Distributors (REDs) – still combining Eskom and municipal distributors, but in a new institutional configuration. All REDs are to be operational by 2006 (RSA 2005).

4.1.1 Electrification policy

One challenge for the policy of electrification lies in the fact that the areas where electrification is cheaper – urban areas and denser settlements – were electrified first. Even in this context, electrification is not viable in financial terms (Borchers et al. 2001). As the programme reaches the 'deep rural' areas, longer distribution lines are needed to connect more widely dispersed

²² National average rate of rural grid electrification was 49.1%, but some provinces were lower, with rural KwaZuluNatal only 35.6% electrified and Eastern Cape 37.7%

customers with lower consumption, and the cost per connection increases. The prospects for the off-grid concessions programme, despite its heavy subsidies for solar home systems, are currently not good (see chapter 3, section 3.5.3).

Financing of continued electrification will most likely remain an important policy issue. Government has already decided that the second phase of electrification will not be funded by Eskom and channelled to municipalities, but will be paid for directly by national government departments. In principle these funds might be balanced by the taxes and dividends which the corporatised Eskom started to pay from 2003 (Eskom 2005). However, electrification will now have to compete with other social expenditure in the budget for the first time. The medium-term expenditure framework allocates R 1.1 billion to electrification in 2005/6 out of a total departmental budget of R2.1 billion (DME 2004c) (see also 4.4.2). Electrification funding is smaller than planned expenditure on housing of an average R4.5 billion per year for 2004-07 and comparable to capital programmes for basic water and sanitation of R 1 billion per year (National Treasury 2003a: 180, 226). Operation of water services, however, requires another R 900 million per year.

Financing of the costs of connecting households is an issue for financial policy. Another is whether there will be on-going subsidies for the provision of basic services. For electricity, the poverty tariff has been the primary response to affordability so far (see sections 3.5.2 and 4.1.2).

4.1.2 Tackling affordability

Even for households that have been connected to the grid, the affordability of using electricity remains a major issue. Some municipalities across the country had already introduced free electricity since July 2001, varying from 20 kWh to 100 kWh per month (Fowles 2004: 28). In an attempt to address the question of affordability, national government committed itself to implementing a free supply of electricity between 50 kWh per household per month (DME 2003e, 2003f).

The 'poverty tariff'²³ stipulates a uniform electricity basic support services tariff (EBSST) of 50 kWh at zero cost to all grid-connected poor customers. While reducing the energy burden of poor households, the lifeline tariff is considered sufficient for lighting, ironing, water heating, TV and radio (National Treasury 2003a), and could make cooking and heating more attractive. By subsidising the use of electricity for some basic needs, government is seeking to increase the social benefits of electrification (Gaunt 2003).

President Mbeki noted that the poverty tariff was not achieving its aims "if the benefits of free basic electricity are accruing mainly to those who are relatively well off" (Mbeki 2005). A key

challenge of a poverty tariff is identifying the poor, since means testing is administratively expensive. One policy option that has been proposed is a 'weak grid approach', using a lower-capacity grid e.g. 2.5A supply rather than typical urban 20A or 60A (UCT 2002). Such systems reduce costs by using smaller transformers, lower capacity medium voltage T&D lines and local lines. The system is designed for lower ADMD ('after diversity maximum demand')²⁴ across a whole community. While more communities can be connected for the same budget, the weak grid will only meet some energy services and not all peak demand. Other fuels, e.g. liquefied petroleum gas (LPG), will be needed for cooking and heating (ERC 2004a). This is what is meant by using a broader set of energy carriers for 'energisation' rather than only electrification. The EBSST is popularly known as a 'poverty tariff'. The extent to which it alleviates poverty depends on the energy burden (the percentage of the total household budget spent on energy).

Table 4.1: Mean household expenditure on electricity and other fuels and energy as a percentage of total household expenditure

Source: (Prasad & Ranninger 2003)

<i>Expenditure on</i>	<i>Before subsidy</i>	<i>After subsidy</i>	<i>Difference</i>	
Electricity (R/month)	38	31	7	18%
Fuels excluding electricity (R/month)	70	59	11	16%
Energy as % of household expenditure	18%	12%	6%	

The energy burden of poor households in remote rural villages can be 18% of the total household budget, according to data from a case study reported in Table 4.1 (Prasad & Ranninger 2003). The 50 kWh provided by the poverty tariff would reduce the energy burden by two-thirds (6 percentage points). Monthly expenditure on electricity and other fuels decline by 18% and 16% respectively, due to the poverty tariff.

A reduced energy burden means that the poverty tariff makes sense for the economics of households. At a national level, some consideration of an economic rationale for the poverty tariff can help to make clear what the economy-wide benefits can be.

²³ Official names include electricity basic support services tariff (EBSST). The national policy indicates 50kWh, although some municipal distributors are providing lower amounts, 20-50 kWh / household / month. Households in Eskom distribution areas receive 50 kWh.

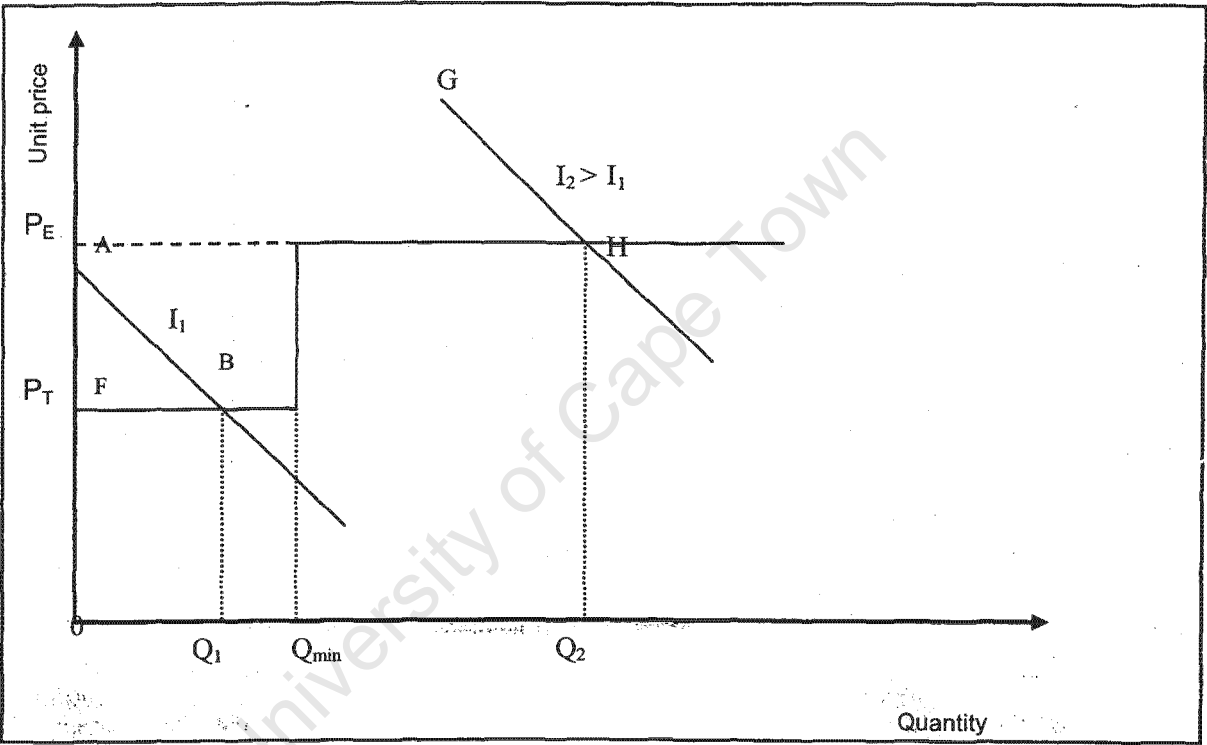
²⁴ Electricity demand is used here in the technical sense, where maximum demand is the maximum power consumed by customers. Individual consumers may require peak power at different times of day, so this 'diversity' effect can bring down the average peak power requirement for a community of consumers. Unfortunately, if a major electricity use occurs at the same time of day for many of the consumers (for instance, cooking meals) there is less demand diversity, and the average peak power requirement rises. The load factor then falls, indicating that the supply capacity required to cover the peak demand is severely under-utilised at other times of day, or seasonally (ERC 2004a).

4.1.2.1 Theory of poverty tariff

The social benefits of a poverty tariff are clear, but the level of such a tariff can be justified in using economic theory. Figure 4.1 shows two demand curves AB and GH, representative of lower (I_1) and higher (I_2) income households; the poverty tariff P_T over the minimum consumption block from 0 to Q_{min} . If the economic tariff based on the long-run marginal cost is at P_E , the higher-income households will be consuming the optimal level Q_2 , but the poorer households will not be able to afford the service (Munasinghe 1992).

Figure 4.1: Welfare economic basis for poverty tariff

Source: (Munasinghe 1992)



Government attaches weight to social benefits to poor households, so the consumer surplus ABF is increased. Although A lies below P_E , the weighted distance OA could be greater than the marginal cost of supply. Adopting the poverty tariff P_T for the first block, followed by P_E , allows the capture of the weighted consumer surplus. The richer households still consume close to optimum, apart from the slight change due to their reduced expenditure for the first block. A means of identifying the magnitude of Q_{min} should be based on criteria for identifying 'lower-income' groups, and establishment of consumption levels. In developing countries, it is typically around 50 kWh / month (Munasinghe 1992). A simple welfare model suggests that

$$P_T = LRMC \times (\text{poor persons' income} / \text{critical income})$$

where critical income is a nationally established poverty line (Munasinghe 1992). In South Africa, $Q_{\min}$ has been set at 50 kWh, but the tariff has been set at zero.

4.1.2.2 Funding continued electrification

Within the electricity sector, funding for both electrification and the use of electricity will remain a high priority. Direct government subsidies will have to increase as more remote areas are connected and as central government takes over funding. The National Electrification Co-ordinating Committee (NECC) recommended that capital costs be covered within the DME budget, with income from Eskom taxes and dividends after corporatisation (NECC 2000). Operational shortfalls were to be borne by the electricity distribution industry, which would initially not earn a return on electrification assets, but only provision for future refurbishment. The DME has funded the Integrated National Electrification Programme (INEP) since 2001/2, with future expenditure for 2004-7 expected to be around R 1.1 billion per year.²⁵ Transfer are made to Eskom and conditional grants will be allocated to municipalities, with responsibility for the latter to be shifted to the Department of Provincial and Local Government (DPLG) in 2006/7 (DME 2004c).

Historically, Eskom has played an important role in distribution and has effectively funded the first phase of electrification (Borchers et al. 2001). With funding in future from National Treasury, Eskom will remain responsible for electrification in its supply areas, and will receive a grant (National Treasury 2003a: 234). However, the relationship between municipalities and Eskom has to be formalised in service level agreements from 2003 onwards (National Treasury 2003a: 237). These agreements will give effect to municipalities' role as service authorities and regulate Eskom's activities within their areas.

As the price of electricity is expected to rise in future – with new capacity soon required and restructuring and / or privatisation imminent – the affordability of using electricity is likely to become an even greater issue. With the restructuring of the distribution industry, REDs will be required to undertake local integrated resource planning (local IRP) – and if they supply small customers who cannot negotiate tariffs, they will have to also show increases in tariff over the next five years (NER 2002b: 12).

Government has allocated R300 million for poverty tariff nationally as part of the local government equitable share of nationally raised revenue (National Treasury 2003a: 233). The equitable share allocation contains an energy component (DME 2004b), but the funding is unconditional and is typically absorbed into the general municipal income pool (Fowles 2004:

²⁵ The medium-term expenditure estimates were R1 067 million for 2004/5; R 1 126 million for 2005/6; and R920 million for 2006/7 (DME 2004c). National Treasury gives a total of R3.3 billion over the period 2004-07 (National Treasury 2003a: 234)

24). The largest transfer from national to local government is for a Consolidated Municipal Infrastructure Programme; electrification falls into the second-largest group, making up 41.9% of the 'S grant' (R 228 million out of an equitable share of 7 698 million for 2005/06 (National Treasury 2003a: 38-39). Funds will be allocated to municipalities, who allocate funds to deliver services to poor households (National Treasury 2003a: 235). Where Eskom is the distributor, the municipality is invoiced at a rate of 34.5c/kWh (excluding VAT), a rate lower than the standard 'Homelight' tariff (Fowles 2004: 27). Eskom only will provide 50 kWh to customers using a 20A supply and who consume less than 150 kWh per month (Fowles 2004: 27).

How poor households are identified varies across municipalities, with one proposal being self-targeting - consumers agreeing to use a reduced 10A level of supply (UCT 2003), the other requiring municipalities to identify indigent households (Fowles 2004: 25). Government considered both approaches, as well as a broad-based approach where all households would receive the benefit (DME 2003f). The average cost of 50 kWh of free electricity is about R25 (National Treasury 2003a: 233), depending on tariffs.

Affordability is obviously shaped by electricity prices. Electricity prices (or tariffs) have been strongly regulated in the past. The further the sector goes along the path of privatisation, the more prices should be set by supply and demand. The extent to which markets should play a role in energy governance is a major policy issue in its own right – the debate around privatisation in the energy sector.

4.2 Energy governance – to privatise or not ?

Reform of the electricity industry has been a major policy issue for the last decade globally. If carried through to its full extent, it would re-shape the context in which all electricity policy takes place. Before considering the impacts of privatisation on environmental and social benefits (such as affordable tariffs), we first outline what privatisation is and why it is on the agenda.

Privatisation²⁶ of the electricity industry relates to *generation* (producing electricity at power stations), *transmission* (at high voltage over long distances) and *distribution* of electricity (at lower voltage over shorter distances). The process aims to increase competition, by changing industry structure to include both more generators (wholesale competition) and more distributors (retail competition).

The debates extend well beyond the electricity sector, with the restructuring of state-owned enterprises in transport, telecommunications and defence also being re-considered (Robinson

²⁶ Also referred to as 'restructuring' or 'power sector reform'. Privatisation implies a change from public to private ownership, whereas restructuring suggest a process of rationalisation that may be independent of ownership (Clark

2004c; Erwin 2004). Broader ideological debates on the role of markets and the state influence the debate on restructuring in the power sector (Bond 2000). The South African debate on feeds into a broader international discussion on the advantages and disadvantages of power sector reform, particular its effect on the poor (Jannuzzi 2005; Wamukonya 2003a; Karekezi & Kimani 2002; Dubash 2002; TNI 2002; Johansson & Goldemberg 2002). The results of power sector reform in other parts of Africa have been mixed at best (Clark 2001a; Turkson 2000; Wamukonya 2003b).

While there are positive motivations for power sector reform, there is also substantial opposition to privatisation in South Africa. Municipal government has objected to restructuring, fearing loss of revenue and citing their constitutional rights to distribute electricity (NER 2001b). The unions have been arguing strongly that the state should retain a role in development, in particular in sectors delivering basic services (COSATU 2001). While the blueprints for privatization make provision for continued electrification (PWC 2000), the fact that connections have not been financially viable in the past makes their future in a highly competitive environment uncertain. Electricity consumers have raised an important concern about rising electricity prices, with tariffs set to increase anyway as new capacity needs to be financed.

Policy on privatisation is not fixed. The liberalisation agenda so strongly promoted at the beginning of the GEAR macro-economic framework may not be realised, or only partially (Streak 2004). After the 2004 elections, national government itself appeared more ambivalent on privatisation. The Minister of Minerals & Energy cited negative experiences with power sector reform in California and elsewhere in her 2004 budget speech. She drew the conclusion “that the state has to put security of supply above all and above competition especially” (Mlambo-Ngcuka 2004). The President drew lessons from experience in fighting poverty in Europe to recognise that markets on their own are not sufficient to eradicate poverty and that “public sector investment in social and economic infrastructure as well as productive capacity” is needed (Mbeki 2004b).

In practice, power sector reform has proceeded piece-meal. On the supply side, Eskom has been corporatised. The Eskom Conversion Act (Act 13 of 2001) gave effect to the commercialisation and corporatisation of Eskom (RSA 2001b). Eskom is to be run more like a business, subject to performance contracts. While still wholly owned by government, the corporation will now pay taxes and dividends. Transmission remains a ‘natural monopoly, to be run by a separately owned state company. The electricity *distribution* industry is in need of reform, due to the several problems (Clark 2001a: 127-8). A key issue is the lack of financial viability, with many

2000a). The World Bank tends to promote power sector reform, with reform having the most positive association (Newbery 1995). All three terms are used in this chapter, depending on the context.

municipalities close to bankruptcy and not paying Eskom for bulk supplies (NER 2001b). The first Regional Electricity Distributor, Red One, was launched in Cape Town in mid-2005.

Policy on privatisation sets an important framework for future policy options in the residential and electricity sectors. If power sector reform is not to undermine sustainability, public benefits (both environmental and social public goods) need to be maintained or enhanced. Policy has been proposed to continue funding for electrification, as a major social benefit, in a liberalised electricity supply industry (Clark & Mavhungu 2000).

The impact on managing energy-related environmental impacts is ambivalent (Winkler & Mavhungu 2001). On the one hand, privatisation opens up the market to IPPs, some of which may use renewable energy sources (e.g. the Darling wind farm, DarlIPP). On the other hand, private investors are arguably less likely to invest in renewable energy technologies due to their higher upfront costs. Policies to promote renewable IPPs include standard contracts for IPPs and non-discriminatory access to the grid (Dubash 2002).

4.3 Managing energy-related environmental impacts

The major environmental impacts associated with energy in general were outlined in chapter 3 (see section 3.6). Electricity in particular is associated with impacts of outdoor air pollution in the local environment, and emissions of greenhouse gases, contributing to global climate change (Van Horen 1996b). Other issues relate to water consumption in the coal cycle, as well as fiscal subsidies and other impacts of the nuclear cycle (Spalding-Fecher et al. 2000a). Significant positive externalities are improved health from reduced indoor air pollution, which adds to the socio-economic benefits of electrification (Spalding-Fecher & Matibe 2003). Table 4.2 classes the major impacts as Class One (serious and measurable), Class Two (potentially serious but not readily measurable), and Class Three (unlikely to be serious).

Table 4.2: Externalities associated with electricity supply by class
Source: (Spalding-Fecher & Matibe 2003)

	Class One	Class Two	Class Three
Coal cycle			
Air pollution and health	•		
Air pollution and acidification		•	
Air pollution and visibility		•	
Water quality impacts			•
Water consumption and pricing		•	

	<i>Class One</i>	<i>Class Two</i>	<i>Class Three</i>
<i>Nuclear cycle</i>			
Fiscal subsidy			•
Other impacts (risk of accidents, waste)		•	
<i>Electrification</i>			
Health benefits	•		
Socio-economic benefits		•	

South Africa's GHG emissions are high by international comparison, both per person and in proportion to economic output (see Table 3.7). Similarly, energy intensity is relatively high – and both realities are recognised by government (DME 2003d; RSA 2003). Policy instruments need to be applied to minimize environmental impacts of electricity generation.

4.3.1 Regulatory policies

Some policies to manage impacts of electricity supply have been discussed in the sections above. Cleaner coal technologies can produce more electricity for the same amount of coal burned and therefore emissions. More efficient use of electricity (see section 4.4.3) reduces demand and hence indirectly emissions.

To directly address impacts of coal-fired electricity on outdoor air pollution, standards can be set. The initial development of regulations for national ambient air quality standards (NAAQS) have focused on sulphur dioxide (RSA 2001a), which would necessitate the use of flue gas desulphurisation. Technical standards are being developed for common local pollutants (SO₂, NO₂, CO, PM-10, O₃, lead, benzene and dust), volatile organic compounds and air toxics (Standards SA 2004a). The framework for regulation establishes *limit values* which are to be attained over a period of time; lower *target values* which should be attained through long-term planning to minimize impacts on environmental health; and higher *alert thresholds*, beyond which there is an immediate risk to human health from brief exposure (Standards SA 2004b). The new Air Quality Act (No. 39 of 2004) provides a regulatory framework that can address both local air pollutants and global pollutants such as greenhouse gases (RSA 2004b). The Act includes mechanisms in domestic legislation that can be used to implement international obligations as well, by listing priority pollutants and activities, as well as requiring pollution prevention plans to be submitted and controlling the use of certain fuels.

Another end-of-pipe solution, carbon capture and storage may become an option for policy-makers in the longer-term (IPCC 2005). All these options, however, reduce the levels of pollution *per unit of electricity*, although this might still lead to rising emissions depending on the rate of growth of total electricity demand.

Standards for GHG emissions – which are not included in the NAAQS - would be one policy approach, in which case direct caps on power stations and other point sources might be more cost-effective. Domestic emissions trading schemes could be set up as ‘cap-and-trade’, allowing polluters to either meet targets in their own facility, or to sell excess reductions or buy from others to meet shortfalls.

As with other technologies, a key policy question is who pays for incremental cost, given that many advanced technologies have higher upfront capital costs than conventional coal. While government require utilities to make investments, costs will ultimately be passed on to consumers. As outlined in chapter 3, low tariffs are a major energy policy priority, both for industrial competitiveness and to widen access to electricity. Dedicated funding mechanisms are needed, with one possibility being the recycling of revenue from environmental taxes on energy use.

4.3.2 Funding options

A source of funding receiving much attention is the Clean Development Mechanism (CDM) under the Kyoto Protocol. The CDM allows industrialised countries to invest in projects in developing countries, in return for the emissions reductions generated. Industrialised countries use these credits towards their quantified mitigation commitments under the Protocol, while the CDM project should contribute to sustainable development in the developing country. CDM investment is seen by government as an important source for funding the implementation of the renewable energy target. The scale of funds allocated for CDM investment internationally had reached \$ 800 million (Ellis et al. 2004), but the funds are to be spent over several years. What share of such investment will come to South Africa remains to be seen and depends in part on the promotion of the country as an investment destination.

Use of economic instruments such as emissions trading and taxation would generate more financial flows that are more directly linked to the scale of emissions in the country. Domestic emissions trading would result in trading of certificates between facilities included under the cap. An alternative policy option is tradable permits for electricity from low-emission sources, such as the Tradable Renewable Energy Certificates (see section 4.5.1). In this case, it is the ‘good’ of clean electricity that is traded, rather than the ‘bad’ of emissions.

4.3.3 Pollution taxes

Taxes could be levied either on GHG emissions (a ‘carbon tax’ as implemented in some European countries) or on air pollutants. There has been some initial consideration of environmental taxes by Treasury, including a focus on electricity (see 4.4.2). A carbon tax in principle internalises the externalities of GHG emissions, a pollution tax may be more politically acceptable. An air pollution tax could be associated with the regulatory framework established by the National Air Quality Management Bill. It would have the effect of making

coal energy-intensive products more expensive, and thus send price signals through the economy that a shift to less pollution-intensive production and consumption is favoured (EDRC 2003a).

The risk of a tax on pollution, however, is that it could disadvantage the poor. In principle, South Africa might follow the Dutch example of using a consumption threshold to protect low-income groups from proportionally higher tax burdens (Nedergaard 2002: 28). Given the policy objective of promoting *affordable* access to modern energy services, this is critical in South Africa. Another means of dealing with the tension in policy objectives would be to recycle revenue generated from pollution taxes, directing them toward reducing the general tax burden on the poor (e.g. reducing VAT on basic food-stuffs) and promoting investment in cleaner technologies and services (Winkler 2005). Recent analysis suggests that a reduction in food prices may pay ‘triple dividends’ in mitigating unwanted effects of environmental taxes (Van Heerden et al. 2006).

The tax should reflect the damage costs of power generation, industrial use of fuels, and commercial and agricultural use of fuels. From an economic point of view, the tax should be set so as to adjust the private marginal cost to the social marginal cost. In practice, the tax may be adjusted based on negotiations between government and various stakeholders, and in response to the observed effectiveness of the tax.

A considerable amount of research has been devoted to estimating the social and environmental *costs* of energy supply and use in South Africa (Van Horen 1996a, 1996b; Spalding-Fecher & Matibe 2003; Spalding-Fecher et al. 2000b; Spalding-Fecher 2000b). Such research faces serious difficulties – absence of local epidemiological studies establishing dose-response relationships; controversies about the ‘value of a statistical life’; broad estimates for morbidity. Nonetheless, the most recent power sector study (Spalding-Fecher & Matibe 2003). summarises low, central and high estimates of local and global pollution (see Table 4.3).

Table 4.3: Summary of external costs of Eskom cost-fired electricity generation per unit (1999 Rands)

Source: (Spalding-Fecher & Matibe 2003)

1999 c/kWh	Per unit of coal-fired power produced		
	Low	Central	High
Air pollution and health	0.5	0.7	0.9
Climate change	1.0	4.3	9.8
Total	1.5	5.0	10.7
Note: this excludes the benefits of electrification from avoided use of dangerous household fuels.			

Externality costs for energy were consolidated as damage estimates per unit of pollutant were reported more fully in EDRC (EDRC 2003a), including damages from Eskom power stations, industrial and commercial energy use, household energy use, from municipal power stations²⁷. Cost estimates of negative externalities such as those described above can be used to set a reasonable level for a pollution tax.

Economic instruments such as taxes and subsidies are important tools for managing the environmental impacts of electricity supply. The next section further considers the use of such instruments, as well as the contribution that future electricity policy can make to economic development.

4.4 Economic development and instruments

Economic policy sets the overall context for electricity policy options. At the same time, policy-makers can make use of economic instruments to promote particular policy objectives. Changes to electricity prices – such as taxes or subsidised tariffs – are examples of market-based policy tools. Beyond individual policy interventions, however, lies the question of the energy structure of the economy, and its intensive use of electricity in particular.

4.4.1 Changing the energy structure of the economy

Chapter 3 outlined the history of the South African economy, with the ‘minerals-energy complex’ at its centre (section 3.3). Driven in part by low-cost coal and electricity, energy-intensive industries make up a large portion of the economy – mining itself, but also the beneficiation of minerals.

Policy on industrial development has promoted electricity-intensive investments, such as the smelting of aluminium at Coega or steel at Saldanha. Low electricity tariffs for industry are seen as a competitive advantage in attracting aluminium smelters to SA rather than other countries (Bond 2000). The marketing of investment opportunities highlights the availability of electricity at “very favourable rates” as one of the attractions (CDC 2004)²⁸

The risk of the current approach is that, while they may promote industrial development in the short run, they carry a high risk of ‘locking in’ the economy into energy intensive industries, when environmental, economic and social pressures may push South Africa in the opposite direction (Spalding-Fecher 2001). The reason for the ‘lock in’ effect is that, once a major investment like a smelter is made, there are very limited opportunities to improve the energy

²⁷ Municipal power stations, because they are older, in urban areas, and have lower stack heights, will likely have much higher damages than Eskom power stations (Spalding-Fecher & Matibe 2003). For this reason, Eskom power station emissions are referred to as “high level” emissions in this study, while industrial and commercial emissions, as well as municipal power stations emissions, are referred to as “low level” emissions.

²⁸ “There are sufficient electricity and water resources to meet the future demands within the Industrial Development Zone. These utilities are available in bulk at very favourable rates” (CDC 2004)

efficiency or also the production process. Recent investments in steel and aluminium bear this out – while the processes may be optimized for that technology, the wholesale switch to a more efficient technology is very costly after construction (Visser et al. 1999).

Forward-looking economic and industrial policies could target less energy-intensive economic sectors. “An active industrial policy is required to diversity the economy forward from South Africa’s mineral-energy complex into capital and intermediate goods” (Michie & Padayachee 1998: 634).

Some Spatial Development Initiatives have been built around eco-tourism, for example in Lebombo (DTI 2002), focusing on service delivery and job creation (Jourdaan 1998). In general, service-oriented sectors, while still consuming substantial amounts of electricity, are less energy-intensive than mining or minerals beneficiation. This would represent a major shift in industrial policy and would take decades to complete, given large investments in infrastructure. However, given the ‘lock-in’ effect, short-term decisions (the next power station, the next smelter or not) are critical in changing the trajectory of South Africa’s energy development path. ‘Bending the curve’ requires a long-term perspective, but also involves policy changes in the immediate future (Raskin et al. 1998).

A policy for an economy with lower energy-intensity would require a very different approach to competitiveness. As CO₂ emissions from fossil-fuel combustion are priced in the emerging international carbon market, electricity from lower-emissions sources is likely to become more attractive. Rather than promoting SA as an investment destination due to low electricity tariffs and the absence of emissions constraints, policy-makers would anticipate the future competitive advantage of lower energy- and emissions-intensity.

It is perhaps fortuitous that DEAT combines environment and tourism, which environmental concerns for lower emissions being consistent with tourism as a less energy-intensive sector. However, DEAT’s promotion of tourism is not articulated as an approach to industrial policy. Active promotion of lower-emissions sectors could limit the growth of negative environmental externalities. In so far as external costs of electricity generation might be internalised in future, this would dampen upward pressure on electricity prices – at least from environmental factors.

4.4.2 Policy on electricity prices, tariffs and taxes

Electricity tariffs in South Africa have been low by international standards, although not necessarily affordable to all customers. There are multiple reasons for low tariffs, as described in chapter 3, including excess capacity, low debt and tariffs that do not reflect all costs, certainly not external costs. The short-term marginal cost of generating electricity has been low, and large customers have paid tariffs around 13-14 c/kWh – industry 12.88 c/kWh; mines 14.14 c/kWh and redistributors (mainly municipalities) 14.09 c/kWh (Eskom 2002b: 135). Residential tariffs

are higher per unit, at an average of 33.43 c/kWh in 2002 (*ibid*). Tariffs are likely to increase in future, as new electricity generation capacity is needed (Eberhard 2003).

However, this rising trend is in tension with the established policy goal of keeping electricity prices low. In reiterating the policy position of universal access to electricity, the President qualified it with an acknowledgement that new power plants are needed with the concern that “administered prices do not unnecessarily add to the general costs of production and inflationary pressures in our economy” (Mbeki 2004a). The Energy Minister also reflects the tension that while the “progressive rise of energy prices cannot be avoided South Africa still intends to keep low electricity prices” (Mlambo-Ngcuka 2003).

Different drivers of tariff policy work in opposite directions, some favouring price increases and others keeping them low. The NER, which regulates electricity tariffs, aims at multiple objectives in developing a pricing policy for the future. Such policy “must balance affordable electricity prices for households, low cost electricity for industrial consumers, efficient market signals by accurately reflecting cost of supply and generate a price level that ensures the financial sustainability of utilities” (NER 2003b). The first two priorities aim to keep prices low, whereas the latter two could raise tariffs.

One of the key motivating factors to keep electricity prices low is affordability of residential tariffs for poor households. Continued electrification makes little sense if customers are not able to afford using their connections. Government is subsidising some limited use through the poverty tariff (see 4.1.2), effectively setting the price of the first 50 kWh to zero. The second main driver is industrial competitiveness and the policy of attracting energy-intensive industry.

In future, electricity prices are likely to be pushed upwards as the building of new generation capacity will raise the cost of supply. A study considering the potential of renewable energy predicted a future average tariff of 24-40c/kWh by 2010 (DME 2000a: 18). While previously the NER had kept increases of electricity tariffs below inflation, Eskom has since 2001 applied for above-inflation increases (but these have not always been approved) (Ensor 2001).

While competition theoretically should reduce prices, international experience has generally been that privatisation has often led to higher prices (Dubash 2002). In the South African context, the corporatisation of Eskom already requires payment of taxes and dividends, costs that will eventually be passed on to customers. Without the financial cover that Eskom enjoyed as a parastatal, private investors are likely to have higher financing costs and expect higher rates of return than typical in public sector investment.

If the privatisation process extends to retail competition, some customers (contestable customers) would be eligible to choose the company from which they purchase electricity

(PWC 2000: 10). Contestable customers are defined as those using more than 100 GWh/year.²⁹ Once competition between generators is established, these customers could be supplied by any distributors. Smaller customers are confined to the distributor into whose area they fall and are known as captive customers. They are unlikely to benefit from competitive supply and hence require regulatory protection through control over tariffs and quality of service (PWC 2000: 12).

Policy options for future electricity tariffs will have to make choices in resolving the tension between maintaining low tariffs for energy-intensive users, and internalising some costs of supply and raising prices. A wholesale electricity pricing policy (WEPS) has been developed for large customers, such as municipalities and energy-intensive industries (Ellman 2001). The first phase of WEPS was implemented within Eskom by 2003 (Eskom 2003), with the second phase to be extended to other wholesale customers (including municipalities). WEPS-3 is to be introduced when Eskom is unbundled and REDs have been established (NER 2003c). Previous tariffs have not been cost-reflective and cross-subsidies have been implicit and not transparent.

The WEPS takes a cost-of-supply approach (NER 2003c), unbundling the electricity bill of wholesale customers into direct costs (e.g. energy, networks, transport, reliability) and more indirect cost (taxes, levies, billing, administrative costs) (NER 2003c: 5). If wholesale customers were to buy at cost-reflective tariffs, their current contribution to cross-subsidies could stop (NER 2003c: 3). Moderately subsidised tariffs are needed for poor households benefit from electrification (NER 2003b: 5).

A major objective of WEPS is to make making cross-subsidies transparent. Cross-subsidisation of tariffs included geographic considerations (higher costs for transmitting electricity); subsidies across different tariffs and within tariff classes (averaging); and electricity levies (NER 2003c: 7-9). Large customers will continue to pay their electricity levies for electrification and electricity supply to rural areas. (NER 2003c: 9). Thus the WEPS falls within the overall NER pricing policy, which seeks to balance the long-term sustainability of suppliers, affordable prices for the poor and cost-of-supply pricing for industrial customers (NER 2003b: 2). Establishing a tariff agreement forms part of government's programme of action (RSA 2005).

Policy instruments to internalise the social and environmental costs of electricity generation (Van Horen 1996a; Spalding-Fecher et al. 2000a; Van Horen 1996b; Spalding-Fecher 2000a) would be taxes or subsidies. Taxes could be levied either directly on air pollution, or on energy to include the external costs of fossil fuel use in the fuel price. Carbon and pollution taxes have been extensively implemented in Europe, but also proposed for South Africa (EDRC 2003a). Taxes on local air pollutants may be more politically acceptable in developing countries than a carbon tax, since responsibility for climate change rests primarily with industrialised countries.

²⁹ A middle-class household uses about 0.01 of a GWh/year, 10 000 times too little to qualify.

Given the central role of energy in development, there may similarly be reluctance to tax energy for global environmental reasons. Taxes that relate more directly to local environmental damage, such as the health impacts of air pollution, address local concerns more directly (EDRC 2003a). In order not to place an increased burden on poor households, they could either be exempted from such taxes or the tax revenue be recycled to reduce other taxes affecting the poor. Examples would be zero-rating of VAT on essential food-stuffs or financing the poverty tariff.

Initial work has been conducted for the National Treasury on environmental fiscal reform (Eunomia & UP 2004) and a discussion document was developed (National Treasury 2003b). An internal government policy paper was released for public comment in 2006 (National Treasury 2006). The initial documents suggest that the energy sector is likely to receive attention in future developments, particularly in relation to electricity generation and air pollution. An input tax on fossil fuels used for electricity generation may be considered, as might an electricity consumption tax. Such taxes would be likely to generate significant revenues, larger than the loss in sales revenue to Eskom. Net revenues could be used to compensate municipalities for their lost revenues under restructuring; to support transitions of affected sectors; or to promote specific projects with environmental benefits such as end-use energy-efficiency and renewable energy. Of particular interest are 'tax shifting' programmes that use revenues from environmental taxes to offset taxes on labour. Taxes would have to be levied at the bulk level and explicitly exclude poor households (EDRC 2003a; Nedergaard 2002).

Recent analysis using a computable general equilibrium (CGE) model to analyse environmental taxes on energy investigated the potential for recycling. Taxes considered were on GHGs, fuel inputs, electricity use, or energy. Revenue recycling could occur through in one of three ways: (i) a direct tax break on both labour and capital, (ii) an indirect tax break to all households, or (iii) a reduction in the price of food. The study concluded that with a "food tax handback", all four policies had the potential to reduce CO₂ emissions, grow GDP and reduce poverty (Van Heerden et al. 2006). However, in establishing an updated GHG inventory, the authors depart from the standard IPCC methodology and rely entirely on energy balances. Future work with combine the analysis in this thesis with the complementary work in the article (Van Heerden et al. 2006), improving the rigour of GHG analysis while adding the benefit of indirect economic effects from CGE modeling.

In summary, tariff policy in future faces choices between continuing to promote low-cost electricity, or making the services more reflective of costs – financial, social and environmental. A variety of other economic policy instruments are available, including subsidies for renewable energy (described in section 4.5) and policies promoting the efficiency in electricity use.

4.4.3 Policies promoting the efficient use of electricity

In meeting the goal of the 1998 White Paper of stimulating economic development, energy efficiency plays a particular role. Energy efficiency and economic concepts of the efficiency of the market are quite distinct (Jochem 2000). Yet clearly producing higher levels of energy efficiency allow more economic production for the same amount of energy. By reducing the costs of a key input to many productive activities, efficiency contributes to economic development. Some of the menu of policy options available to promote electricity efficiency in is outlined in this section.

There is great potential for energy efficiency in South Africa, across a range of sectors from industry, commercial, transport to residential. Interventions for energy efficiency in the residential sector can contribute significantly to development for households – improved quality of life at reduced cost (Winkler et al. 2000; Simmonds 1997; Clark 1997; Spalding-Fecher et al. 1999). The residential policies analysed in the thesis (see chapter 6-9) will examine the potential for savings, in the framework of a national energy model.

Significant savings are also possible in the industrial sector, both through end-use efficiency and load management (see Table 4.4). The National Electricity Regulator (NER) included estimates of potential future savings in its *Integrated Electricity Outlook* (2002) and *Integrated Energy Plan* (NER 2004a). Savings from energy efficiency are expressed as equivalent cumulative electricity generation capacity (in MW) that would be avoided by efficiency programmes up to 2010 and 2020. Since the market penetration of energy efficiency is critical to the results, estimates reflecting different assumption are summarised above.

Table 4.4: Potential future savings from energy efficiency and demand side management (cumulative capacity equivalent in MW)

Source: NER (2002c)

	Low penetration		Moderate penetration		High penetration	
	2010	2020	2010	2020	2010	2020
Industrial and commercial energy efficiency	567	878	889	1270	890	1270
Residential energy efficiency	171	514	537	930	537	930
Industrial and commercial load management	355	444	428	535	510	535
Residential load management	222	735	443	936	669	936
Total	1315	2571	2297	3671	2607	3671

Experience exists with innovative technologies and programmes for energy efficiency and demand-side management. Eskom's DSM programme has focused on three key areas: load management, industrial equipment and efficient lighting. Such interventions include both load

management, typically carried out by the utility, and energy efficiency improvements by end-users. More detailed technologies and policies for electrical efficiency are examined below.

4.4.3.1 Energy efficiency in low-cost housing

Many interventions can be introduced in low-cost housing to improve energy efficiency, save households money and improve the environment (Spalding-Fecher et al. 2002a). A possible package of interventions in a standard 30m² Reconstruction and Development Programme (RDP) house could include a ceiling, roof insulation, wall insulation, window size, and partition. All of these measures pay for themselves in short periods of time (Winkler et al. 2000).

Several government departments have been investigating a framework for regulation of environmentally sound building for some time (DEAT et al. 1998). A recent decision to include an additional R1 024 for damp-proofing in the housing subsidy may have the effect of providing better efficiency cavity walls, plastering and ceilings. It applies in the 'Southern Condensation Area', covering large parts of the Western and Southern Cape and some of the Eastern Cape. An extension of this policy is modeled in section III, and chapter 9 picks up the policy implications of making standards mandatory.

4.4.3.2 Building codes for commercial and residential buildings

Policy support for energy efficiency in buildings need not be limited to low-cost housing. Residential and commercial building codes can require higher efficiency standards in middle- and upper-income houses and commercial buildings. Since wealthier customers can afford to pay the upfront cost to benefit from the long-term savings, regulation can be used rather than outright subsidy. Government may still consider options for financing the initial costs through concessionary loans. Local governments could finance efficiency measures and recoup the outlay, by structuring tariffs to include the saved energy costs as repayments.

4.4.3.3 Concessionary loans for efficient industrial equipment

Industry, like richer households and commercial buildings, should be able to invest in more efficient use of electricity. Measures often payback within periods of months or a few years (for case studies, see ERI 2000a) and have significant potential for job creation (Jefftha 2003). Lack of awareness and information is a key barrier that could be overcome by programmes promoting energy efficiency. Technical interventions with large potential for energy efficiency savings across many industries include variable speed drives, compressed air and HVAC (heating, ventilation and air conditioning) systems (ERI 2000b).

The overall potential for greater efficiency of electricity use in industry is large (Spalding-Fecher et al. 2004). A study using an input-output model of the SA economy, has shown that a 5% increase in electricity efficiency in 2010 would lead to a net increase of some 39 000 jobs

and labour income of about R 800 million (Laitner 2001). The primary reason is that spending is diverted away from sectors with lower wage and salary multipliers towards construction, finance and manufacturing, which have higher income multipliers. The study did not specify particular equipment to be replaced, but gave a sense of the benefits of across-the-board efficiency improvements.

Industrial equipment still bears a higher upfront cost, and while government may not need to pay for capital costs in full, concessionary finance can make investments more attractive. Concessionary loans would offer lower than commercial repayment rates, and to be used introduce more efficient technologies and production facilities. The focus of such a policy should be on the most electricity-intensive equipment and industrial process. Loans in the range of 10-20% of the incremental capital would likely be enough in many cases to tip the balance in favour of energy efficiency investments (EDRC 2003a).

4.4.3.4 Efficient appliances: Labelling, regulation and financial incentives

A first step to promoting the use of more efficient electrical equipment is to provide information to users through labelling. Household appliances that might be labelled include lighting, refrigerators/freezers, air conditioners, water heaters (electric or gas), cooking equipment, clothes and dishwashers, and electronic equipment like TV, stereos and computers. Commercial equipment will include HVAC (heating, ventilation and air conditioning) systems, water heating systems, and electronic office equipment like computers, printers, copiers.

Equipment-labelling involves indicating a certain performance standard on the equipment based on pre-testing appliances for their efficiency and may include estimated operating costs. Appliance-labelling can be a voluntary programme, where government develops the guidelines and testing procedures, but companies choose whether they wish to use the label. Labelling could also be mandatory: all products would have the label, but with or without restrictions on their efficiency.

The most stringent approach would be mandatory labelling, together with prescribed minimum performance standards. Regulations would specify performance for different kinds of appliances and equipment, and restrict the use of equipment that fails to meet the prescribed standard. Generally such standards would be applied only to new appliances.

Using financial incentives rather than regulation, government can offer tax credits or direct subsidies to tax payers for installing efficient electrical appliances. Financing, either in the form of direct subsidies or in small-scale, affordable loans, for equipment and technical upgrades, could be provided (EDRC 2003a).

Smaller appliances, e.g. compact fluorescent lights (CFLs) have lower first-cost barriers to overcome than buildings. Nonetheless, prices need to be brought down, which has already

happened to some extent under Eskom's Efficient Lighting Initiative, which aims to install 18 million CFLs (Eskom 2000c). Municipal government can play a key role in promoting the wider dissemination of CFLs, which reduce the power used for the same lighting by 75-80%.

Promoting solar water heaters

Solar water heaters (SWHs) deliver hot water from a renewable energy source, save energy by displacing use of electricity and therefore avoid emissions. It combines energy efficiency and use of renewable energy. The potential for SWHs is large, as acknowledge in the White Paper on Renewable Energy, which assesses the savings as 18% of urban residential consumption³⁰ or equivalent to a large coal-fired power station (900 MW) (DME 2003c).

However, SWH projects have not been widespread, with the only significant project being in Lwandle township (Thorne et al. 2000; Ward 2002; Lukamba-Muhiya & Davidson 2003). despite DME announced support from the Global Environmental Facility project on a National Solar Water Heating Programme (DME 2001a).

Possibly other models of delivery than grant-funded development projects are needed. Electricity service companies might install SWH in institutions (e.g. hotels) in return for a fee for the hot water service. In middle- and upper-income markets, financing for the higher upfront cost could be facilitated through bonds. A barrier remains low public awareness of the technology or its economic benefits (DME 2003c). Policies are need to create larger markets and economies of scale, which would help bring down the relatively high capital costs. A larger market for solar water heating in turn could build a local manufacturing industry and increased employment opportunities (DME 2003c)

4.4.3.5 Encouraging utility demand side management

Demand-side management (DSM) encompasses a set of measures by electric utilities that save energy and also reduce GHG emissions. Strategic growth of off-peak demand, load shifting, geyser ripple control, interruptible load agreements, time-of-use tariffs and other measures enable DSM in both the industrial and residential sector. The utility benefits by reducing the peaks of consumption ('shaving the peak'), reducing the need for installed capacity. DSM can benefit the national economy by delaying the need to invest in supply-side capacity, at a lower cost.

Eskom has a DSM programme, but further measures are needed to promote investment in these technologies and to ensure that they continue as the electricity distribution industry is restructured (Clark 2000b, 2001b). The structure of tariffs is important in this regard.

³⁰ Assuming that some 30% of total domestic electricity consumption is used for water heating and that 60% of this electricity can be replaced by solar energy by using a hybrid solar-electric water heating system, then the potential savings for urban residential households come to 5 900 GWh (Thorne et al. 2000; Spalding-Fecher et al. 2002b).

Regulated tariffs often link energy sales (kWh) with utility revenues and profits, with little incentive for the utility to engage in DSM. Eskom is not exception in this regard, with the DSM programme battling against the perception that it represents lost revenue. Tariffs can be structured differently, de-coupling revenue from sales. Regulated tariffs are linked to some other measures of service (EDRC 2003a).

If implementation of efficiency programmes were linked to revenue, this would directly encourage investment in DSM measures. In USA, many state regulatory boards chose in the 1980s to base utility profits on a return on capital invested, including demand-side capital, rather than a margin on each unit sold (Eto et al. 1998; Swisher et al. 1997). Utilities that can show efficiency improvements may be allowed to earn higher profits and/or a higher rate of return. In the design of this system, it is important that the DSM incentive is not offset by a rate formula that rewards increased sales. In other words, the incentive only works where revenues, not tariffs, are subject to regulated caps (EDRC 2003a).

Such regulatory policies may be needed to promote energy efficiency under power sector reforms, since privatised utilities have little incentives to invest in measures that reduce their sales revenues (Clark & Mavhungu 2000; Barberton 1999; Tyani 2000). Regulatory policy can make energy efficiency investment a licensing requirements. The REDs, for example, could be required by the NER to implement DSM, which would be consistent with the framework for integrated resource planning (NER 2002d: 7, 13).

4.4.3.6 Turning the potential of efficiency into practice

While the more efficient use of electricity has great potential, achieving wide-spread implementation requires effort. Theoretical gains are not always realised in practice, for either technical or economic reasons. Removing key barriers – informational, institutional, social, financial and market, and technical – is critical to the full realisation of energy efficiency measures (EDRC 2003a). Important success factors to implement efficiency measures include government policy (standards, incentives, recovery of programme costs), electricity pricing mechanisms that do not penalise efficiency, and the effectiveness of DSM delivery agencies (NER 2002c).

To put the wide variety of energy-efficiency measures together in a policy framework, the DME recently published an ‘energy efficiency strategy’. The strategy set a goal for an improvement in energy efficiency of 12% by 2014 (DME 2005a). While the DME document covers all energy, the NER has approved policy for efficiency in the electricity sector in particular, with an ‘energy efficiency and demand side management policy’. However, the policy does not set specific numerical targets. Its focus is on captive customers (i.e. small customers), under the assumption that large contestable customers will respond efficiently to price signals (NER 2004b).

Energy efficiency measures such as those outlined in this section are critical near-term measures. Because they save energy costs and pay back on their investment in short periods, they can be adopted quickly. Changing the fuel mix that generates electricity is a long-term endeavour. Yet increasing diversity of supply not only gives greater energy security, it is central to long-term sustainability.

4.5 Securing electricity supply through diversity

Environmental concerns relate directly to another major energy policy objective, that of securing supply through diversity. As described in chapter 3, the current fuel mix for electricity generation is heavily dominated by coal. Moving to a more diverse mix of electricity generation sources can both increase energy security – since diverse systems are more resilient to external shocks – and at the same time reduce environmental impacts of electricity supply and use.

Cleaner fuels have less environmental impact, for industrial use as well as for electricity generation. In 2003, government adopted a new policy paper on renewable energy (DME 2003c), with earlier drafts indicating that a further policy position on other ‘cleaner energy technologies’ were to be developed. Government has made it clear that it intends using all energy sources and not choosing winners amongst technologies (Mlambo-Ngcuka 2003). Which technologies are used will shape the electricity sector for several decades, given the long life-times of energy technologies.

The excess capacity that the electricity sector has experienced for the last three decades of the twentieth century (see chapter 3) is ending. In his 2004 State of the Nation speech, the President acknowledged this by announcing that a tender would be awarded in the first half of 2005, to deliver “new generating capacity to provide for the growing energy needs from 2008” (Mbeki 2004a). The key policy questions are who will supply new power stations, and what energy sources will they use? (ERC 2004a)

The former question will be shaped by the framework of privatisation (see section 4.1). Eskom’s market power will continue, but to some degree will be supplemented by independent power producers (IPPs). Assuming that IPPs are profit-making firms, they will require higher rates of return on their investment (say 15%) than typical of public utilities (ERC 2004a). This would force electricity tariffs up, making the use of electricity less affordable.

In the light of the long life-times of energy infrastructure, choices made in the near-term will shape the system for several decades, including the mix of fuels used to generate electricity. As outlined in chapter 3, the current mix is dominated by coal for electricity (93%), with three-quarters of total primary energy supply (all energy carriers, not just electricity) coming from comparatively cheap coal. Given the priority given to industrial competitiveness and access to

affordable electricity, achieving the Energy Policy White Paper goal of diversity of supply requires substantial effort. Determined policy interventions will be required to initiate a transition to a cleaner fuel mix for the electricity supply industry.

Three major options of diversifying fuels for electricity generation domestically are examined – renewable energy sources, gas and nuclear. Major opportunities are already being set up within the Southern African region for the import of hydro-electricity. Finally, since coal will continue to dominate the sector for several decades, policies promoting cleaner technologies using the ‘old’ fuel are considered.

4.5.1 Renewable energy technologies for electricity generation

The Minister of Minerals and Energy has recently re-stated that “renewable energy plays an important role in the energy mix and increases supply security through diversification” (Mlambo-Ngcuka 2002b). In practice, renewable electricity technologies (RETs)³¹ have remained in the research, development and demonstration phase. In 2003, government adopted a target of 10 000 GWh renewable energy consumption (DME 2003c). Although this is not limited to electricity but also includes solar water heating and biofuels, the policy document explicitly calculates that this would be 4% of expected *electricity* demand in 2013. The key challenge is to implement this policy at scale, beyond pilot projects.

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

Perhaps the key factor limiting the potential of renewable energy technologies (RETs) globally is cost. Table 4.5 shows international cost data for RETs, according to the World Energy Assessment. Investment costs for coal or gas plants are under \$ 1000 / kW, while the energy cost in SA is below 2 c / kWh (although likely to rise in future).

³¹ For convenience, renewable electricity technologies are abbreviated as RETs, as short-hand for technologies using renewable energy sources. However, it is not the electricity that is renewable, but the energy source. RETs is often used for renewable *energy* technologies, not only those using electricity.

Table 4.5: International cost data for renewable energy technologies*Source: UNDP (2000)*

Technology for electricity generation	Operating capacity, end 1998	Capacity factor		Turnkey investment costs		Current energy cost of new systems		Potential future energy cost	
	GWe	%		(US\$ per kW)		US c/kWh		US c/kWh	
		Low	High	Low	High	Low	High	Low	High
Biomass	40	25	80	900	3 000	5	15	4	10
Wind	10	20	30	1 100	1 700	5	13	3	10
Solar PV	0.5	8	20	5 000	10 000	25	125	5	25
Solar thermal	0.4	20	35	3 000	4 000	12	18	4	10
Small hydro	23	20	70	1 200	3 000	4	10	3	10
Geothermal	8	45	90	800	3 000	2	10	1	8
Tidal	0.3	20	30	1 700	2 500	8	15	8	15

South Africa's potential for renewable energy lies overwhelmingly with solar energy, equivalent to about 280 000 GW (Eberhard & Williams 1988: 9). Technological and economic potentials would be lower than the theoretical potentials – by various estimates – shown in Table 4.6. Other renewable energy sources – wind, bagasse, wood, hydro, and agricultural and wood waste – are much smaller than solar.

Table 4.6: Estimates of theoretical potential for renewable energy sources in South Africa*Sources: (DME 2000a; Howells 1999; DME 2002d)*

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

The most recent estimates of the potential of renewable energy are being compiled for the South African Renewable Energy Resource Database.³² More detailed GIS maps will be sold, with revenues used to update the data (Otto 2003). In estimating economic potential, there is even

³² www.csir.co.za/environmentek/sarerd/contact.html

less data. With little commercial use of renewable energy, there is not sufficient experience regarding local costs and markets to provide estimates of much accuracy.

Demonstration projects will in future need to be scaled up to meet the renewable energy target. The international literature suggests a variety of policy tools could be used by the SA government to promote renewable energy (Winkler 2005). *Feed-in tariffs* guarantee prices for developers, but lack certainty on the amount of renewable electricity such laws would deliver under local conditions. This shortcoming would be addressed by a *renewable portfolio standard* which sets a fixed share of renewable energy in the supply mix. The question for this instrument would focus on the incremental upfront costs compared to future health and environmental benefits. A *renewables obligation*, following the UK model, combines the setting of a target with a tendering process, but may be bureaucratic to administer (Winkler 2005).

Neither setting targets or regulating prices alone, however, will be sufficient. More detailed policies are needed, including power purchase agreements, access to the grid and creating markets for green electricity. Given that renewable electricity technologies have to compete with relatively low electricity tariffs, funding will be needed. The extent to which these are utilised will determine the future mix of renewable energy in South Africa (Winkler 2005). An overview of possible policies for electricity from renewable energy sources is provided in Table 4.7.

Table 4.7: Tools that governments can use to promote renewable electricity

Source: Oliver (2001)

Tool	Advantages	Disadvantages
Power purchase agreements	Long-term, standard agreements help developers and facilitate investment	May require continuing unit subsidy to make the cost attractive
Investment incentives	Overcome high first-cost barriers	Encourage investment, not production
Production incentives	Encourage renewable electricity production	Do not address high first-cost barrier and require continuing subsidies over the long term
Renewable set-asides / mandated market shares	Competitive bidding encourages cost reductions	Can be bureaucratic
Externality adders	Allow for full-cost accounting in power planning	Implementation does not always follow planning
Environmental taxation	Correct energy prices including costs of environmental impacts provide a more level playing field for renewable energy	Taxes are often politically unfavourable
Research, development and demonstration	Builds long-term foundation for technological and industrial development	Difficult to pick a technological winner for R&D investment
Government-assisted business development	Builds market infrastructure	May become too bureaucratic
Green marketing	Allows choice in power purchases	May be under-subscribed

The new policy has effectively set aside a market share, moving beyond research, development and demonstration (RD&D). In practical implementation, some initial progress has been made on green electricity. The approach taken to modeling renewable energy is described in more detail in section 6.6.2.

4.5.2 Switching fuels from coal to gas

Energy security through diversity of supply is a well-established goal of energy policy. In the electricity sector, this goal is being pursued largely through developing the Southern African Power Pool, planning increased imports of hydro-power and developing gas markets. A transition away from coal to cleaner fuels will in the short- to medium-term most likely include natural gas imported by pipeline and / or liquefied natural gas. One of the technologies that can further diversify the mix is gas-fired power, with environmental advantages for the country (Graeber & Spalding-Fecher 2000)

The initial use of gas from Mozambique will probably not focus on electricity generation. Energy plans by Eskom, DME and the NER, however, consider the use of natural gas in power plants (DME 2003d; NER 2004a). Gas-fired plants can have simple cycles, with efficiencies around 32-35%, or combined cycle – producing both heat and power – with efficiencies ranging between 47 and 55%. Beyond their greater efficiencies, gas-fired power has further advantages in being commercially mature, having short installation times, relatively low capital costs (although gas prices influence variable costs), and low emissions levels of (including NO_x). Natural gas is about 60% cleaner than coal in terms of carbon dioxide emissions; however, fugitive emissions (leaks of gas from the pipeline)-need to be minimized.

4.5.3 Developing new nuclear technologies

Uranium and gold are found together in mineral deposits and South Africa produces uranium as a by-product of gold mining, with an estimated 261 000 tons of uranium in ‘reasonably assured resources’ (205 000 tons) and ‘estimated additional resources’ of 56 000 tons (DME 1998). In the apartheid era, South Africa manufactured finished fuel for the Koeberg nuclear power station near Cape Town. Currently, however, the finished fuel is imported because it is cheaper to do so (ERC 2004a).

National government has repeatedly stated its intention to develop all energy sources, including nuclear (Mlambo-Ngcuka 2003, 2004, 2002c). The country currently has one nuclear light-water reactor at Koeberg (1840 MW_e), but Eskom is developing the Pebble-Bed Modular Reactor (PBMR), further developing an earlier German design (Loxton 2004). The designers claim it is ‘inherently safe’, using helium as the coolant and graphite as the moderator (PBMR Ltd 2002). The fuel consists of pellets of uranium surrounded by multiple barriers and

embedded in graphite balls ('pebbles'). Cabinet has endorsed a 5 -10 year plan to develop the skills base for a revived nuclear industry (Mlambo-Ngcuka 2004). The intention is to produce this technology not only for domestic use, but also for export.

One of the conditions of approval of the Environment Impact Assessment for the first PBMR demonstration module – to be built at Koeberg – was that a "Radioactive Waste Management Policy and Strategy" be completed. This was published for comment during 2004 and was to lead to a Nuclear Waste Management Policy and Strategy (Mlambo-Ngcuka 2004). This would set the policy framework to deal with one of the key issues faced by nuclear technology, the long-term disposal of high-level waste.

4.5.4 Importing hydro-electricity from the region

One of the major options for diversifying the fuel mix for electricity is to meet growing demand by importing hydro-electricity from Southern Africa. Hydroelectricity is generated using the flow of water in a river or from a storage reservoir. SA itself has only small hydro resources (0.8% of generation) (NER 2002a), and already imports electricity from the Cahora Bassa dam in Mozambique. Further developments could add to imports of hydro-electricity. A promising site is at Mepanda Uncua in Mozambique about 60 km downstream of the existing Cahora Bassa Power Station on the Zambezi River. In the first stage of this project, which is being considered, is the installation of capacity at the HV terminals with an 1300 MWe.

The scale of this is dwarfed by the potential at Inga Falls in the Democratic Republic of Congo (DRC), estimated to range between 40 000 MW for run-of-river to 100 000 MW for a storage reservoir (Games 2002; Mokgatle & Pabot 2002). Even the run-of-river capacity would equal South Africa's current total generation capacity.³³

The Southern African Power Pool (SAPP) facilitates the trading of electricity. SAPP was formally launched in Harare during 2003 (Mlambo-Ngcuka 2003). Southern African countries agreed that an integrated electricity market can provide economies of scale and benefits from shared resources. An operational control centre facilitates trading, and a short-term energy market (STEM) began in 2001. STEM is currently trading three types of futures contracts for electricity, namely daily, weekly and monthly contracts, although most trade still occurs through fixed contracts (Spalding-Fecher 2002a). Contracts on a 'take-or-pay' basis lead to ongoing tensions relating to the price of imported electricity, which at an average of 2.15 c / kWh is well below the cost of generating electricity in SA (NER 2001a).

³³ While licensed capacity was 43 165 MW, the total operational was 39 568 MW (NER 2001a), the difference mainly being accounted for by three moth-balled coal stations.

4.5.5 Cleaner coal technologies

Advanced and cleaner coal technologies will not diversify the *fuel* mix for electricity generation, which is dominated by coal (see chapter 3 and 6). However, even under the most progressive scenarios of shifting to renewable energy, coal continues to constitute the largest share.

A first step includes modifications to the existing pulverised fuel (PF) plants. Future plants are likely to be dry cooled (reducing specific water use) and install flue gas desulphurisation (removing SO₂). Both have cost implications, with dry cooling reducing efficiency by about one percentage point, and desulphurisation adding some 30% of the capital cost of stations (EDRC 2003a). Other options, such as super-critical and IGCC plants, together with carbon capture and storage, are considered likely only in the medium- to long-term future.

The Integrated Resource Plan considers fluidised bed combustion (FBC) as the key cleaner coal technology. FBC plants mix coal with limestone and air is blown through it in a moving bed of particles. This 'fluidised bed' keeps the coal in the combustion zone longer and therefore poorer quality coal can be used. The process reduces local pollutants - sulphur emissions as the sulphur combines with limestone and can be removed, and nitrous oxides due to lower temperatures. The major economic advantage lies in the ability to use discard coal, of which SA produces about 60 million tons per year (Howells 2000). The IRP base case envisages 466 MW of FBC by 2013 (NER 2004a, 2001/2).

The promotion of advanced technologies for coal-fired electricity can contribute to more diversity in technologies, albeit not fuels. Coal is the fuel with the highest GHG emissions per unit of energy, so that such changes will always remain marginal improvements. Policy support for cleaner coal technologies therefore needs to be part of a set of options that changes the fuel mix. But given the importance of coal in the SA energy economy, this partial approach can make an important contribution to managing the environmental impacts of electricity supply.

4.5.6 Summary of electricity supply options

The major options for ensuring security of electricity supply through diversity have been examined above. Scenarios to examine the options for future electricity generating capacity are being examined for the next National Integrated Resource Plan (NIRP). A draft reference case for the NIRP has been prepared by Eskom, the Energy Research Institute and the National Electricity Regulator (NER 2004a). Table 4.8 summarises energy and cost characteristics of the technologies being considered for this 'base case'.

Table 4.8: Options for new electricity supply

Source: (NER 2004a, 2004c)

	Type of station	No. of units	Total capacity	Unit size	Life-time	Nominal capital costs	Capex / installed capacity	PV of capex at 10% disc rate	Lead-time	Fixed O&M costs	Variable O&M costs	Fuel Price	Efficiency (higher heat values)
			MW	MW	Years	Rm	R/Kw	R/Kw	Years	R/kW/a	R/MWh	R/t or GJ	%
New coal-fired plants													
												R/ton	
CF 1 Dry excl FGD	Baseload	6	3942	657	30	35338	8964	11274	4	121.93	R 5.70	60	35.52
CF 1 Dry + FGD	Baseload	6	3850	642	30	37723	9799	12324	4	125.28	R 7.51	60	34.59
Pumped Storage													
Braamhoek	Peaking	4	1330	333	40	4200	3158	5179	7	90.00	9.00	ms*	76
Generic	Peaking	3	998	333	40	7182	7200	8857	7	90.00	9.00	ms*	76
Gas Turbines													
												R/GJ	
CCGT without trans benefits pipe	Baseload	5	1935	387	25	9797	5063	5659	3	175.26	10.58	20	47.04
CCGT with trans benefits pipe	Baseload	5	1935	387	25		4405	4925	3	156.48	9.45	20	47.04
CCGT without trans benefits LNG	Baseload	5	1935	387	25	9797	5063	5659	3	175.26	10.48	32	47.04
CCGT with trans benefits LNG	Baseload	5	1935	387	25		4405	4925	3	156.48	9.45	32	47.04
GT open cycle kerosene	Peaking	2	240	120	25	920	3833	3949	2	79.80	65.88	72	32.26
GT open cycle LNG	Peaking	2	240	120	25	920	3833	3949	2	79.80	65.88	32	32.26
GT open cycle Sasol gas	Peaking	2	240	120	25	920	3833	3949	2	79.80	65.88	28	32.26
GT open cycle LPG	Peaking	2	240	120	25	920	3833	3949	2	79.80	65.88	56	32.26
New coal (fluid. bed)													
												R/ton	
Greenfield FBC	Baseload	2	466	233	30	4508	9669	11511	4	206.49	19.24	10	36.65

	Type of station	No. of units	Total capacity	Unit size	Life-time	Nominal capital costs	Capex / installed capacity	PV of capex at 10% disc rate	Lead-time	Fixed O&M costs	Variable O&M costs	Fuel Price	Efficiency (higher heat values)
			MW	MW	Years	Rm	R/Kw	R/Kw	Years	R/kW/a	R/MWh	R/t or GJ	%
Imports													
Imported hydro	Baseload	2	1200	300	30	17044	14203	19948	6.5	2151.23	0	n/a	N/A
Renewables													
Solar Thermal	Peaking	3	300	100	30	10043	33477	34589	3	147.29	0.13	0	N/A
Wind	Peaking	20	20	1	20	154	7714	7768	2	167.02	0	0	N/A
Nuclear													
PBMR 1st MM incl transmission benefits	Baseload	8	1320	165	40		16533	17340	4	157.65	6.75	45	40.54
PBMR 1st MM excl transmission benefits	Baseload	8	1320	165	40	24693	18707	19651	4	157.65	6.75	45	40.54
PBMR series MM excl transmission benefits	Baseload	8	1364	171	40	14678	10761	10853	4	161.2	6.75	45	44.50
PWR incl transmission benefits	Baseload	2	1747	874	40	27944	15995	15139	4	507.22	0	45	31.58
PWR excl transmission benefits	Baseload	2	1747	874	40	25389	14532	15290	4	507.22	0	45	31.58

New coal-fired plants account for 29% of new capacity in the NIRP's base case. Most of this is made up of conventional coal plants, some with flue-gas desulphurisation (adding about 10% to capital costs) and some without. Only two units are envisaged with fluidised bed combustion. Shift to make coal technologies cleaner would require that more plants with FGD are constructed.

Renewable energy technologies are represented by wind and solar thermal electricity (STE) in the base case, but account just over 1% of total new capacity. The main reason is high upfront costs – STE capital cost is almost three times the present value of a new coal-fired plant with flue-gas desulphurisation (FGD). Wind is closer to competitive, with some 40% more costly in capital costs, but with no variable operating and maintenance (O&M) or fuel costs, and only slightly higher fixed O&M costs. Investment decisions that focus on initial capital costs will not favour renewable energy, but if the longer-term variable costs are given more weight become economically more attractive, even before considering externalities.

Imported hydroelectricity in the 'base case' only accounts for 4% of new capacity, which would be built outside of the country. Capital costs are some 60% higher than coal plants in SA.

New nuclear options include the Pebble Bed Modular Reactor (PBMR) and Pressurised Water Reactor (PWR). A total of 26% of new capacity is expected, made up of initial PBMR demonstration modules, PBMR developed at scale and PWR. Demonstration plants are some 60% more expensive than a reference coal station, but this drops to around 40% additional cost if the benefits of avoided transmission losses are taken into account. Assuming that costs reduce by learning in the commercialisation process, the PBMR would eventually have lower capex. The PBMR has O&M costs comparable to new coal, while the PWR has a fixed component, but no variable O&M costs.

A significant proportion of new capacity uses gas-fired turbines, which represents a shift from coal to gas given that current generation capacity is 88% coal (NER 2002a). Together gas plants make up just over 30% of total new capacity, mostly (27%) combined cycle and some (3%) open cycle. Fuel costs depend strongly on international markets, but capital costs are significantly lower – half of coal plants for combined cycle, and under 40% with the open cycle (although the latter has much higher variable O&M costs). Cost factors, together with shorter lead times in construction new plants, make it attractive to address the immediate urgency of new capacity.

The options presented above are the National Electricity Regulator's plan. The supply options of a cleaner fuel mix for electricity generation will be examined in the policy scenarios to be

modelled in chapter 6. Chapter 5 briefly outlines the modeling framework through which the quantitative analysis for the policy cases is conducted.

4.6 Conclusion

This chapter has argued that options exist for a transition from current constraints to a more sustainable future for the electricity and residential sectors. Chapter 3 had outlined the development objectives as the starting point of the analysis. Rather than making development fit climate objectives, climate change mitigation is located in the context of sustainable energy development. Such an approach would implement the policy options suggested in this chapter as a basis for climate policy.

In identifying policy options for the future, the chapter lays the basis for scenario modeling in the next section, which will combine different technological and policy options and examine their implications for meeting energy development objectives and implications for climate change.

Part III: Modeling energy policies

CHAPTER 5

5. Tools for modeling energy policies

5.1 Purpose of modeling in this thesis

This chapter, together with chapters 6 and 7, uses modeling as a tool to examine policy cases in South Africa's energy sector. A variety of policy cases are constructed, focusing on the residential demand and electricity supply sectors. In the methodology outlined in chapter 2, modeling provides an important step in quantifying the implications of energy policies identified.

Models provide a systematic framework to examine such policy cases in quantitative terms. The potential and limitations of using models are discussed in section 5.4. The results of the modeling will be interpreted in chapter 8 in economic, social, environmental terms – against criteria of sustainable development. The interpretation of model results will inform the analysis of implementation of policies in chapter 9. The modeling is therefore an important part of the methodology, but not the only aspect of the methodology.

5.2 Developing policy cases for energy futures

Energy models allow the construction of policy cases in a quantified way. The implications of policy interventions can be tested. Developing more than one policy case allows comparisons of alternative development paths. In keeping with the methodology, the policy cases will have in common some development objectives (e.g. increasing access to energy services, or supplying electricity demand), but they differ in the way they reach the objective.

Analysis typically starts with a base case (or 'business-as-usual' case, see chapter 6), against which different policy scenarios can be compared (for example, Nakicenovic 2000; NER 2004a; for example, Bailie et al. 2001). Note that the base case itself includes changes from present reality, but changes which are based on existing government policy. It would be possible to construct another case which simply extends current development trends. The difference, for example, would be that the base case in this thesis (see chapter 6) includes 'cleaner coal' technologies; a 'current development trends' case could examine what would happen if only conventional pulverised fuel was used for future electricity generation as in the past.

Policy cases are constructed to examine how South Africa's energy development path can be made more sustainable. Policy cases have both qualitative and quantitative aspects. The 'storyline' of a policy case captures the intuition of how a possible future might unfold. Some aspects, such as behavioural changes, are better dealt with qualitatively. Energy policy cases that seek to achieve strong sustainability, for example, would tell a story about the development path that might lead a society in that direction.

While the descriptions of policy cases are important, the key function of modeling is to translate them into quantitative terms. Policy cases make changes from the base case, for example introducing greater end-use efficiency or switching fuels for electricity generation. The implications for the energy system can be seen in the results. Modeling provides a framework in which some interactions between policies and technologies are taken into account. An advantage of the modeling framework is that double-counting can be avoided.

The policy cases are not 'energy scenarios' in the sense that that term is used in the literature (Nakicenovic 2000: 335; Flavin & Lenssen 1995; IWG 2000; Shell 2001; Mintzer et al. 2003). Energy scenarios tend to examine the future of particular policies in the context of different changes in the external environment. Scenarios might consider whether energy policy is robust to changes in global oil prices, or the introduction of future carbon constraints, for example. To distinguish, the terms 'policy case' and 'energy policies' are used, rather than scenarios. The available tools to construct such policy cases are examined in the following two sections.

5.3 Modeling tools

Various tools are available to develop policy cases quantitatively and to provide a consistent framework for their analysis. At least two broad types of energy models can be distinguished, simulation models and optimization models. The Long-Range Energy Alternative Planning (LEAP) and the MARKet ALlocation (Markal) tools have both been used for energy analysis in South Africa, and represent these two types. Optimization models use linear programming to optimize an objective function subject to specified constraints. Typically, the objective function is to minimize costs, subject to balance energy supply and demand, as well as other constraints. Optimization models are prescriptive rather than descriptive and tell the user how to make the best of a given situation in relation to a predefined goal (Alfstad 2004b). To perform this cost-effectiveness analysis, optimization models include detailed technological information and costs. A typical research question would ask what are the least-cost set of technologies to provide energy supply and meet demands in the future.

Simulation models are based on cases determined by the user, meaning that assumptions for a set of potential futures are compiled. They also contain detailed data and sometimes costs, but

rather than calculating ‘optimal’ (least-cost) solutions, cases are defined by the modeler. The simulation model is descriptive rather than prescriptive. This lends itself to ‘what if’ questions – what are the implications if a user-specified set of energy supply and demand technologies and policies are implemented.

5.3.1 Long-range Energy Alternatives Planning tool - LEAP

The Long-term Energy Alternatives Planning (LEAP) system is a simulation model and energy planning tool. LEAP is a spread-sheet based tool that allows capture of detailed data of the energy sector, rather than a model optimizing for any particular parameter (SEIB 2002). Analysis is conducted by constructing one or several future cases, one of which may be the base case to which different futures can be compared. These cases begin with the demand for useful energy services, aggregating these to total demand which needs to be supplied by various generation technologies available. The analysis therefore comes closer to modeling energy services, not just the supply of energy (Laitner et al. 2001)

The base case reflects characteristics of a future under ‘business-as-usual’, assuming the implementation of current government policy into the future. Different possible futures can also be compared to one another. LEAP incorporates an environmental and technology database, so that the environmental implications of energy futures can be readily explored – both climate change and local environmental implications. Technology costs can be incorporated, but the tool includes no explicit economic modeling of prices, industrial sectors or households. The economic analysis tools offered by MARKAL are more powerful.

5.3.2 Optimizing tools - MARKAL

Optimization models, by contrast, are prescriptive rather than descriptive and tell the user how to make the best of a given situation in relation to a predefined goal (Alfstad 2004b). The output represents the best way of accomplishing a particular goal, which is usually minimizing costs. The question is ‘how to’ achieve this goal, given a well-defined set of alternatives. Choosing between a set of technologies for electricity generation is an excellent example of using an optimizing tool, and indeed a typical application of MARKAL.

The MARKAL (MARKet ALlocation) model, developed by the International Energy Agency (IEA), has been a popular optimizing tool for analysing energy futures. Recently, MARKAL has been integrated with planning approaches in the MESAP-TIMES model.³⁴

These models are part of the category of dynamic energy optimization models (Markandya & Halsnaes 2001: 488). The analysis represents a partial equilibrium within the energy sector, minimizing the total cost of the energy markets (including end-uses). They include significant

detail on energy technologies and their costs, including investment and operation costs. They can also include assumptions about pollutant taxes (including GHGs). They are useful in analysing changes in GHG emission reduction potential and costs. Some limited economic modeling (aggregate macro-economic demand, in change in GDP) can be analysed in Markal-Macro.

The objective function driving these models is to minimize costs subject to constraints. The strength of MARKAL models lies in answering questions about the most cost-effective technology solutions for energy systems. Both fuel costs and the cost of energy technologies are considered (Howells & Solomon 2002). Constraints, which temper the drive to least cost, can include environmental factors (e.g. emissions), limits on resource availability and dissemination rates of policies and measures. Such constraints, however, are secondary to cost. As the literature review has shown, it also leads the modeling into an assumption that the economy is already operating at an efficient production possibility frontier.

MARKAL is a powerful analytical tool, but has its weaknesses and limitations. The least-cost assumption is applied to the extent where it can become a weakness, assuming rational optimization decisions are made by all actors. Multiple objectives and non-linear constraints are not easily incorporated. The linear programming model is strongly influenced by bounds, so that without careful design, the least-cost option will take over the entire energy market – something not observed in practice. Most applications of the model implicitly assume that energy demand will be met, and thus ignore energy poverty and unmet demand.

MARKAL is mostly used for analysis at the national level, with a focus on technologies. MARKAL databases are technology-rich. Other parameters, however, such as households or vehicles, can only be introduced *in terms of* their energy demand, or as units. This places some limitation on the disaggregation of the residential sector (see chapter 7).

An approach that allows balance between economic, social and environmental dimensions is more suitable for an analysis in terms of sustainable development.

5.4 Critical analysis of modeling tools for energy policies

There is great potential to gain insight by using models to create cases, but at the same time, the limitations of modeling must be clearly understood to use the results appropriately. In short, users of models and model results need to understand what models can and cannot do.

Models are useful in providing a systematic framework by which to examine different cases of complex systems. The electricity sector is one such system, and models often contain thousands

³⁴ MESAP: Modular Energy System Analysis & Planning; TIMES: The Integrated Markal Ecom System.

of data entries (Alfstad 2004b). Models combine large amounts of data and organize it systematically, enabling analysis of volumes of information that would be virtually impossible to grasp without such a tool.

At the same time, models simplify real-life problems, making them analytically tractable. The large volumes of data are combined through mathematical formulations. Computers are able to interrelate a great number of factors, e.g. that the demand and supply for electricity are matched, while a large number of other constraints are also met. While the answers generated by computers may be faulty due to human error, computers are reliable in computation and logical processes.

In making large amounts of data tractable, models abstract reality. Household fuel use patterns provide a good example of relationships that are easily over-simplified. In standard energy models, end-use devices only supply a single demand, e.g. stoves provide energy for cooking. Especially in poor households, stoves are used for cooking, water heating and space heating. Some solutions have been found to make models more flexible to allow appliances to provide multiple end uses (Howells et al. 2005), but challenges remain in replicating multiple fuel use patterns.

A related limitation in Markal is that households are represented in terms of their demands, or as units, but do not enter the model itself. Formulations are possible that make the final unit in the reference energy system a household, but this would lose resolution on the time of use.

In attempts to represent complex energy patterns, data is often lacking. Continuing the example of household energy use, energy consumption can be disaggregated by several categories: urban / rural, electrified / non-electrified, by several income groups, by fuel, by end use; by different geographical and climatic regions. Implementing all these categories makes model structure complex and increases data requirements. Furthermore, some data not measurable, even in surveys, e.g. households can provide approximate consumption (or expenditure) on paraffin per month, but not whether it is used for cooking, lighting or water heating. Modelers have to make decisions about which categories are relevant to the policy questions being researched, as well as considering what analysis the data will allow.

It should be clearly understood that models are not a panacea, with solutions to every problem. They need to be designed carefully to answer specific policy questions. In this thesis, the purpose of using models is to provide data for evaluating various cases of the future development of the electricity sector.

A key weakness of models is that they are only as good as the assumptions and data fed into them. While they might make no error in calculation, the results may be wrong if the

underlying data is inaccurate. Most modelers will readily acknowledge that the results of models are sensitive to erroneous assumptions and model configuration, but users of model results may be less sensitive to their assumptions. The line between data and key assumptions is a blurry one, and modelers often fail to make their assumptions and input data sufficiently transparent. The lack of transparency is made worse that models are commonly perceived as a 'black box' by all others than the modeler - and parts of the model are even a mystery to the modelers.³⁵ There is a trade-off between computational power and complexity on the one hand, and transparency and ease-of-use on the other.

Because models are sophisticated tools, their results are often assumed to be accurate. The results must be right 'because the model says so'. Good modeling practice can mitigate this weakness, by not only interpreting the results but also discussing the drivers of the results and the level of confidence. Since modelers and other analysts are often different people, interpretation of results is at times inadequate.

In particular, models attempting to simulate human behaviour should be aware that this is possible only in a very limited sense. Optimization models, for example, typically provide the least-cost solution given the constraints placed on the model. In reality, the cost of energy services is one factor among others, including less tangible benefits such as status, convenience and other considerations (Howells et al. 2002).

Models are typically sensitive to key parameters. In energy-economy-environment models, for example, the discount rate chosen and the learning rate assumed for different technologies are key parameters. Modelers are often pressed to give a single answer to a particular question, and may neglect to undertake sensitivity analysis to key parameters. Much skill is required in finding a good balance between showing ranges of results, without overwhelming readers with too much data.

The sensitivity to data inputs and key assumptions allows models to be 'tweaked'. Often such tweaking is undertaken in good faith, to calibrate the model against known or 'reasonable' values. However, the process means that results at least reflect the modeler's biases, and in the worst cases, models can be abused to generate pre-determined results. A particular problem with models used for future energy development is that – almost inevitably – some parameters will be assumed to grow at a fixed rate into the future. Projections of GDP growth are a classic example, as are projections of demand for electricity. The approach taken in chapter 6 is to state the key drivers of the base case clearly upfront.

³⁵ For example, the Markal model (see below, 5.3.2) runs in a linear programming language called GAMS. Reading code may be intelligible to a few, but eventually the model calls up a 'solver'. Only the most mathematically versed users will fully understand how results are generated by the solver.

5.5 Conclusion

Modeling of energy policies is an important component of the methodology for this thesis. The MARKAL modeling framework is used to develop systematic, quantified representations of energy policy cases. The aim in this thesis is not to develop new models, but as far as possible to use existing models to test new policy cases and their implications for sustainable development.

The MARKAL framework is used for a number of reasons. The database developed at the Energy Research Center has been used to directly inform planning in the National Integrated Resource Plan and Integrated Energy Plan (see chapter 6). LEAP would have provided a simulation tool perhaps more closely aligned with a durability approach, but the tool does not provide detailed cost results. With the central aim of meeting development objectives, a detailed understanding of costs is required. The approach, then, is to use MARKAL as part of the methodology. The analysis of the thesis, however, does not end with modeling results. Rather, it uses these to inform a broader evaluation of indicators of sustainable development and an analysis of the implications for energy and climate policy.

CHAPTER 6

6. Modeling energy policies

Having considered the tools available for modeling energy policy scenarios in chapter 5, the present chapter turns to the analysis of a focused set of energy policies. Energy planning in the past was often pre-occupied with supply-side solutions. As outlined in chapter 3, government energy policy since 1994 has paid much more attention to energy demand and the provision of energy services. This thesis examines particular aspects of both demand- and supply-side energy policies. On the demand-side, the focus is on the residential sector,³⁶ while electricity generation is considered on the supply side.

Previous work at the Energy Research Centre analysed energy policies against indicators of sustainable development in the context of energy modeling (Winkler et al. 2005a).³⁷ The work presented here extends this analysis, particularly in the author's own focus areas of residential demand and renewable energy in the electricity supply sector.

An adequate understanding of these two sectors requires that their interactions with other sectors are described – liquid fuels on the supply side, and demand in industry, transport, commercial and agricultural sectors. These sectors are described much more briefly, based on existing work, to provide context for the more detailed analysis of electricity and residential energy. The industrial sector, for example, clearly makes a major contribution to economic development, and offers potential for large energy savings. The broad contours of the potential benefits for sustainable development will be outlined in the base case for all sectors, but detailed policy cases are developed further for the focus areas.

The following section motivates the particular policy focus for this thesis, providing some details on policies in the residential and electricity supply sectors. Next, the key drivers for developments in the energy sector as a whole are described, and an overview of development in the base case for the broader energy sector is presented. This lays the basis for considering the base case, before considering several policy cases in the residential and electricity sector. The current chapter outlines how the policy cases were implemented in the modeling framework, while chapter 7 will present the results.

³⁶ The author's previous work on the residential sector has informed his work on the household sector (section 6.5). It was published as : Winkler, H, Spalding-Fecher, R, Tyani, L & Matibe, K 2002. Cost-benefit analysis of energy efficiency in urban low-cost housing. *Development Southern Africa* 19 (5): 593-614. December.

³⁷ The author led this project, and gratefully acknowledges work on the database by his colleagues Mark Howells and Thomas Alfstad and the valuable learning he gained on the use Markal.

6.1 Focus of policy modeling

The residential sector is critical for the assessment of the social dimension of sustainability. Its complex socio-economic patterns reflect in a variety of energy use patterns. Past analysis has tended to focus on case studies and surveys (Mehlwana 1999b; Prasad & Ranninger 2003; Thom & Afrane-Okese 2001; Thom 2000; Simmonds & Clark 1998; Davis & Ward 1995), but the diversity of the sector has not been adequately reflected in national energy modeling. The importance of this social dimension in SA is reflected in the first goal of energy policy, 'increasing access to affordable energy services' (DME 1998). The goal of managing energy-related environmental impacts has an important dimension in the health impacts associated with indoor air pollution. The residential sector allows at least a minimum of disaggregation (by income, access to electricity and geographical location, see section 6.5.1 below), enabling some analysis of the distributional impacts of policy, and hence social equity. This makes the residential energy sector important in achieving other development goals, beyond energy policy objectives.

The focus on the demand by households includes electricity, but other fuels cannot be ignored – particularly the use of LPG for cooking and its potential for productive use. Chapter 3 outlined the importance of electricity to development on the supply side. This chapter examines the major policy options for supplying electricity in the future. The major options – cleaner coal, imported hydro, renewable energy, PBMR nuclear and imported gas – have already been discussed in general in chapter 4.

One means of scoping the impact of a range of policies on major policy goals is the Action Impact Matrix (AIM, see Table 6.1) (MIND 2005). The AIM tool is designed to understand the interactions between national development goals and policy goals. This method is useful to analyse how to make development more sustainable, and to motivate the scope of the detailed work of this thesis. A later part of the AIM methodology examines the impacts of climate change on both development and energy policy, but for the present purpose we only use the first four steps of the methodology, the others being more focused on climate change (MIND 2005: 4).

Table 6.1: Action Impact Matrix scoping the impact of policy interventions on development goals

	Industrial EE	Commercial CFL, SWH, HVAC, building codes	Efficient houses, CFLs SWH, LPG	Elec: cleaner coal	Elec: imported hydro	Elec: renewables	Elec: imported LNG	Elec: PBMR nuclear	Imported petroleum products	Bio-fuels	Fuel tax, with recycled revenue
Development goals											
Job creation	+3	+3	+3	-2	-1	+3	-1	0	■	+3	0
Economic growth	+3	+2	+1	+2	0	+2	0	+2	0	+2	0
More equitable distribution of income	0	0	+3	0	0	0	0	0	0	+2	+2
Delivery of energy services for basic needs	0	0	+3	+2	+1	+2	+1	+2	+2	+2	-1
Energy policy goals											
Improving access to affordable energy services	0	0	+3	+3	+1	+2	+1	+2	+2	+2	-1
Governance	0	0	0	0	0	0	0	0	0	0	+2
Stimulate economic development	+3	+2	+1	+2	0	+2	0	+2	0	+3	+1
Manage energy-related environmental impacts	+2	+2	+3	+1	0	+3	0	-2	0	+2	+3
Securing supply through diversity	+2	+1	+1	■	-1	+3	+2	+3	■	+2	0

The row headings of the matrix represent development objectives. The more detailed discussion of development objectives in chapter 3 can be summarised, for the purposes of this thesis, in the major goals of GEAR— growth, employment, redistribution and those of the RDP – the delivery of services essential to meeting basic human needs. For the latter, we focus here on energy services.³⁸

The column headings are policy options. A broader set of energy policy interventions is taken from a study of “South African energy policies for sustainable development” (Winkler et al. 2005a). It considers, amongst other policies, the major options for electricity supply, and examines interventions in households that include CFLs, solar water heaters, geyser blankets, more efficient building shells (mainly through ceilings). These policies are similar to the ones proposed for this thesis, but the set here also includes industrial energy efficiency measures to meet a national goal of 12% reduction in final demand (DME 2004d). A similar goal could be achieved in commercial buildings with the introduction of building codes, efficient lighting and HVAC systems, and SWHs. Liquid fuels are important for transport, and the policies considered are importing petroleum products (rather than continuing with coal-to-liquids or gas-to-liquids at SASOL) and refining bio-fuels. A cross-cutting policy, a fuel tax on coal for electricity generation, is also included, with coal providing 93% of electricity generated.

For the purpose of focusing the thesis, the question of interest is the impact of the policy interventions on development. A simple scoring system ranging from -3 to +3 is used, with -3 representing a high negative (undesirable) impact/effect and +3 high positive; scores of 1 being low, 2 medium and 0 no impact / effect (MIND 2005). Typically this exercise would be conducted with stakeholders, but here the scores simply reflect the author’s judgement.

The scores in Table 6.1 may be subjective, but they provide a systematic consistent motivation for the focus taken in this thesis. Highlighting the high positive and negative scores, the residential policy interventions (efficient housing shells, CFLs, SWH and geyser blankets) are expected to have several high positive impacts on development. Amongst the electricity supply options, the initial scoping suggests that there are positive and negative aspects for several options. The one high negative score reflects the well-known problem of South Africa’s dependency on coal, in the energy sector in general and even more acutely in electricity (see chapter 4). The need for greater diversity makes it worthwhile examining all alternative options in more detail through modeling.

Mobility is an important contributor to quality of life. The transport sector aims to ‘move South Africa’ (DOT 1999). From an energy-environment perspective, the sector account for most

³⁸ The focus is not on the contribution of energy policies to other services, e.g. energy efficiency measures housing providing better comfort in low-cost housing.

energy used in local areas (Winkler et al. 2005c) and is the fastest-growing contributor to GHG emissions (Prozzi & Sperling 2002; Naude et al. 2000). The growing of bio-fuels can be decentralised to small growers with potentially significant socio-economic benefits. However, significant data problems arise in analysing this sector, with collection of transport information typically not providing energy data, and general energy analysis not disaggregating transport sufficiently. Analysing transport energy infrastructure deserves detailed future analysis, but will require a sophisticated understanding of vehicle stocks, ages, turnover rates; infrastructure and its costs; and the possibilities for behavioural changes.

The policy option of importing refined petroleum products, instead of continuing with production of synfuel from coal, might raise problems related to the volatility in the oil price.

From Table 6.1, it can be seen that securing supply through diversity faces major barriers, with the current dependence on coal (see chapter 3). The 1998 White Paper on Energy Policy clearly recognised this constraint (see the -3 for cleaner coal / diversity). Two major domestic energy resources – flows of renewable energy and large stocks of uranium – exist to potentially meet demand. From an environmental perspective, they are often considered polar opposites – yet from the point of view of GHG emissions, both radically reduce emission (zero for operation, but some in construction). These factors motivate the focus on the electricity supply.

The multiple high positive scores for efficiency and fuel switching measures confirm the motivation for focusing on the residential sector. The potential contribution to reaching the development objectives is large in this sector. The focus, then, is on residential policies on the demand side, and options for electricity generation on the supply side.

Energy policies in the residential sector can make a major contribution to South Africa's development objectives, as outlined in chapter 3. Policy since 1994 has included the national electrification programme, raising the rates of grid access from about one-third to two-thirds over the 1990s. The issue of affordability is emerging as critical, with consumption levels of newly electrified households remaining low. The poverty tariff has sought to address this issue. The energy policy goal of 'increasing access to affordable energy services' (DME 1998) has been pursued vigorously, but more needs to be done. Residential energy policies can contribute to managing environmental health impacts, another major energy policy goal. The third relevant energy policy goal is governance, with power sector reform concentrating on the distribution side (see chapter 4).

Having identified and prioritised development objectives and energy policies, the thesis turns to representing these in a modeling framework. Important drivers – including economic development, population growth, technology, fuel prices and more – shape both policy cases

and the base case. The next section discusses the key drivers of future trends and the assumptions made about how these might change in the future.

6.2 Drivers of future trends and key assumptions

Future energy needs depend on the number of people in a country, as well as the rate of economic change. Two important drivers of future energy trends include economic growth and population projections. A third important factor is technology, and the rate at which technological learning occurs. Future fuel prices, fourthly, are important particularly for fuels that are internationally traded. Fifth, the discount rate makes an enormous difference to any modeling in an economic framework, and warrants discussion in relation to the Markal model used here. Finally, the emission factors for local air pollutants and global GHGs are stated.

6.2.1 Economic growth increases energy demand

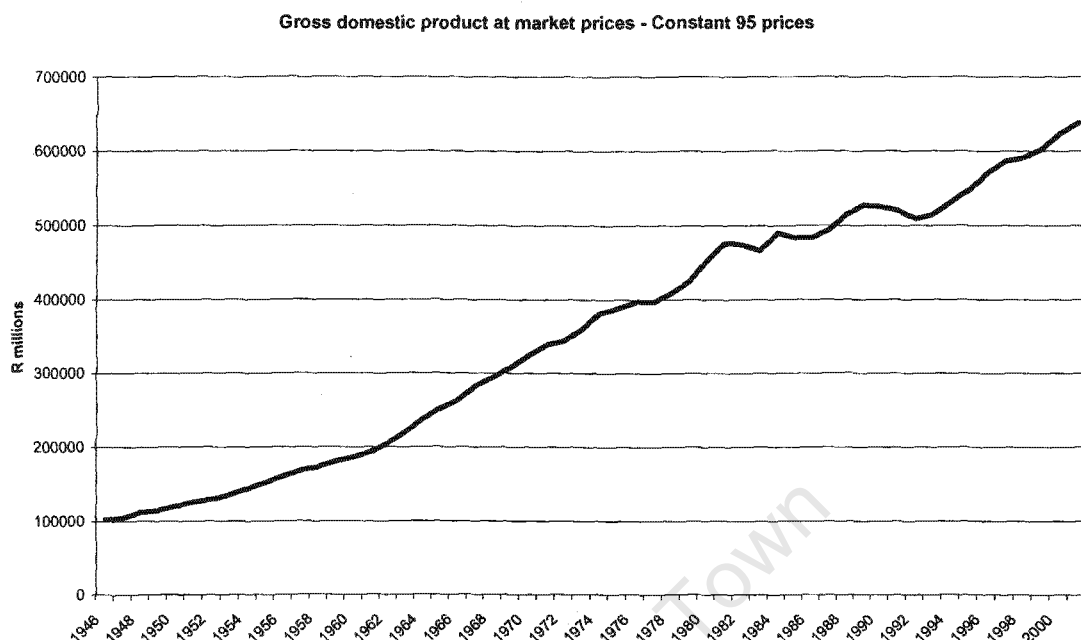
In the absence of interventions that de-couple energy demand from economic growth, projections of GDP are an important driver.

Figure 6.1 shows the historical trends, which are clearly upward in general, but with significant downturns in the 1980s and 1990s. Economic growth over the next twenty-five years is hard to predict year-on-year, but the upward trend can be assumed to continue.

GDP itself is an imperfect measure of economic growth (see inter alia Daly & Cobb 1989; Pearce et al. 1989; Munasinghe 2001; see inter alia Norgaard 1994; Blignaut & De Wit 1999). It accounts for all economic activity, even when that activity may have negative social or environmental consequences. For example, the clean-up of an oil-spill or expenditure on replacing stolen goods would add positively to GDP. GDP also accounts for the sale of natural resources as positive income, thus assigning a zero value to implied depletion of scarce natural assets (Munasinghe et al. 1999). Other indicators, such as the Human Development Index, include a broader composite of social factors, including literacy, life expectancy and GDP per capita (Atkinson et al. 1997), with the index having declined in the context of AIDS.

Figure 6.1: Trends in GDP, 1946 - 2000

Source: SA Reserve Bank (SARB various)



Despite the critique of GDP, it is widely used in international comparison and for national planning. Most SA government projections therefore assume a smooth growth rate into the future. Annual GDP growth was assumed to be 2.8% per year in the first Integrated Energy Plan (DME 2003d), while the Integrated Resource Plan also considers forecasts of 1.5% and 4% (NER 2001/2). A central GDP growth figure of 2.8% seems a reasonable approach, even though government targets higher growth in the future.

6.2.2 Population projections impact on energy consumption

The number of people in the country drives energy consumption, unless per capita consumption were reduced. For the residential sector, the *household* growth rate is important, and it turns out that this differs significantly from the growth rate for population by individuals. Urban and rural households differ in many respects, including their energy use patterns. The impact of AIDS on all population projections makes a marked difference. All the factors have implications future residential energy demand, discussed in section 6.3.3.

6.2.2.1 Urban - rural shares in future

The analysis of the residential sector will divide households into six types (see section 6.5.1), distinguished along urban / rural, high / low-income and electrified / non-electrified lines.

The first of these distinctions, the urban-rural, is relevant, since energy use patterns differ markedly. Rates of electrification are much higher in urban areas, and other fuel use patterns

differ too. Urban population growth rates for earlier periods were substantially higher, e.g. population growth from 1946 - 1970 was 3.45% per year, 3.09 % for 1970-1996 (SACN 2004). Overall, this gives a picture of a growing population, but growth slowing down to lower rates. Will South Africa's population continue to urbanise? There have been some suggestions that rural populations have peaked and will stabilise or even decline (Calitz 1996).

This question is complicated by definitions of 'urban' and 'rural', and the intermediate categories of peri-urban and dense rural settlements – the latter a legacy of Apartheid, where large numbers of people were moved to rural 'homelands' and settlements developed with high density but very little industrial or commercial base. Furthermore, the 2001 Census data no longer reports by urban / rural division (SSA 2003a). For the analysis of energy demand, it seems reasonable to assume that peri-urban and dense rural settlements are more similar to urban areas than 'deep rural'. The thesis assumes that virtually all the household growth – moderate as it is projected to be - will occur in this broadly defined urban category and that rural household numbers remain stable. Under these assumptions, 64% of the population will be urbanised by 2030.

This assumption has some support in the analysis of migration patterns between provinces, where Gauteng, Western Cape and North West had a positive net migration rate in 2004 – the former two having large urban populations – while provinces with a higher percentage of rural population, namely the Eastern Cape and Limpopo, had the highest outflow of people. The DBSA approach of assuming stable numbers of rural households is adopted for this thesis (SSA 2004a).

6.2.2.2 Households and household size

Energy use in many respects relates more directly to households, rather than to individuals. Electricity connections, for example, are made to each household. A notable trend across South African cities is that households have been growing faster than population. Most of the population growth is expected to occur in urban areas in future. Across South Africa's nine largest cities, population grew between 1996 and 2001 by 2.8% per year, but households increased at 4.9% per year (SACN 2004:179). Possible reasons include people moving out of backyard shacks and establishing new households; migration from rural areas to the cities; and increased household formation.

The average number people per *urban* household has dropped from 3.98 in 1996 to 3.58 in 2001 (SACN 2004). In the national picture, it has dropped from 4.48 to 4.0 over the same time (SSA 2003a; 1996), although these trends are probably partly the result of reconsideration of earlier Census data. Given demographic trends elsewhere in the world, it seems plausible to assume that household size will continue to decline a little further, reaching 3.8 people per household by 2030.

6.2.2.3 The impact of HIV/AIDS

Studies considering future – of energy development or other matters – have to consider the potential impact of AIDS. While the topic is strongly debated, some highly respected studies show a substantial levelling off in population during the study period. Major institutions have conducted investigations that projected trends in population, some distinguishing between scenarios with more or less impact of AIDS. However, due to the HIV/AIDS pandemic in the country, population projection might be higher than actual. The Development Bank of Southern Africa (DBSA) uses population projection, differentiating on low and high impacts of HIV/AIDS (Calitz 2000a; 2000b). The first Integrated Energy Plan also included projections of population growth (ERI 2001), which are shown together with other estimates in Table 6.2. Not all studies covered all years.

Table 6.2: SA population projections from various sources, millions

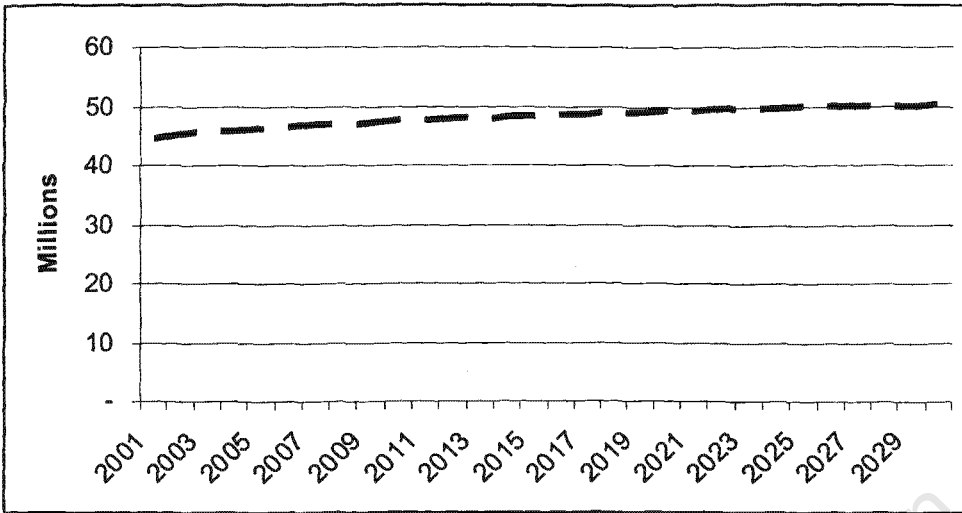
	<i>DBSA low AIDS impact</i>	<i>DBSA high AIDS impact</i>	<i>ASSA 2002 (base run)</i>	<i>IEP assumptions</i>	<i>UN world population projection</i>	<i>This study</i>
2001			45	44	43	44.8 ³⁹
			46			46.4
2011	56	49	48	50		47.6
2016	61	50	48		45	48.5
2025	70	49	50	57	44	49.7
2030			50			50.0

Academically, studies by Prof Dorrington of the University of Cape Town Commerce Faculty for the Actuarial Society of South Africa are well respected (ASSA 2002). The ASSA projections seem reasonable, still indicating population growth over the period, but at lower rates, growing 12% over the 30 year study period, with annual growth rates between 0.1 and 1.0%. For this thesis the assumption is that the past pattern of household / population growth will continue, but, based on other studies, assume lower growth rates due to the impact of AIDS.

³⁹ The 2001 Census reported 44,819,778 people in South Africa (SSA 2003b) and we use this number instead of ASSA's projection.

Figure 6.2: Population projections by ASSA model

Data source: (ASSA 2002)



6.2.2.4 The future of poverty

Perhaps one of the most difficult assumptions is about the future about poverty. The approach taken here is a middle path between assuming that no inroads are made into the shares of poorer households, and dramatic decreases of poverty. At least in absolute terms, we assume that overall income levels increase so that 70% of urban households are non-poor (Van Ryneveld et al. 2003), compared to 61% in 2001 (SSA 2002). Shares of low-income households decline to 60% in the base case by 2030, down from 69% in 2001. This overall affect does not claim to address issues of relative poverty, where households may still consider themselves poor, as high-income households have grown wealthier.

6.2.2.5 Future household numbers

In summary, population projections used for the base case in this study assume that the overall population projections from the base run of the ASSA model are reasonable, and comparable with the range in the literature. Population grows at moderate rates, reaching 50 million by 2030. Household numbers grow slightly more slowly as household size declines, increasing – with growth in urban areas – from 11.2 million in 2001 to 12.9 million in 2030. Rural household numbers stay constant. Electrification is almost complete in urban areas by the end of the period, while 10% of rural households do not have electricity services – but all high-income rural household are assumed to be electrified.

Given the data for the starting year of 2001 and the assumed changes as described above, the changes in the numbers and shares of the six different household types in this study are shown in Table 6.3.

Table 6.3: Number and share of households, estimated for 2001 and projected for 2025*Source: See text for underlying data and assumptions*

	2001		2030	
	No. of households	Share of households	No. of households	Share of households
UHE	4,074,438	36%	5,709,438	44%
ULE	1,255,728	11%	2,290,812	18%
ULN	1,349,240	12%	304,155	2%
RHE	1,181,279	11%	1,702,030	13%
RLE	1,095,449	10%	2,061,822	16%
RLN	2,249,571	20%	762,447	6%
Total	11,205,705		12,830,705	

Population projections, as described in this section, are complex. We have simplified them for the purposes of analytical tractability in the modeling to six household types – still an improvement on the usual modeling approach of treating all households as homogenous. Another complex driver of energy futures is technology and the dynamics of their costs.

6.2.3 Technological learning can reduce costs

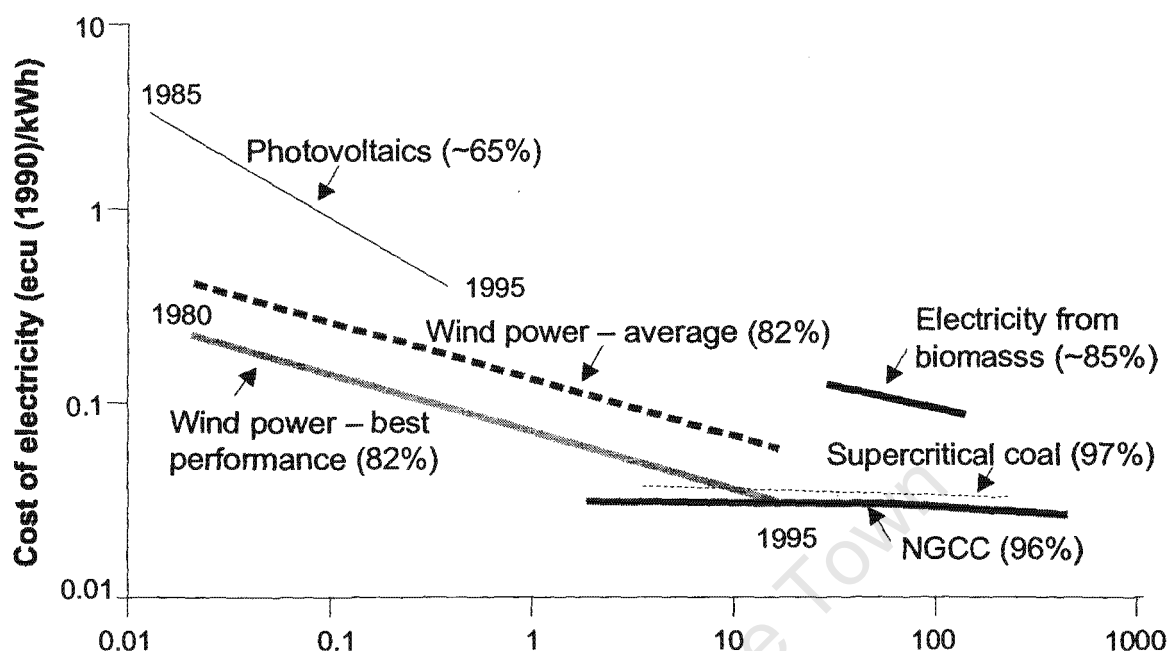
Technology is an important driver of energy development, and technology costs change over time. One of the most important factors shaping the results of energy models are the assumptions they make about technology learning (IEA & OECD 2000; Repetto & Austin 1997; Fisher & Grubb 1997; Energy Innovations 1997) – the extent to which technologies get cheaper per unit over time. New technologies tend to benefit from learning-by-doing and economies of scale.

The first proto-type is typically much more expensive than later models, which are produced in smarter, more cost-effective ways and often in larger production runs. Learning by experience reduces costs (Arrow 1962) and this general finding has been found true for energy technologies as well (IEA & OECD 2000). These can be assessed by learning ratios, measuring the reduction of cost per installed capacity for each doubling of cumulative capacity.

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

Figure 6.3: Learning curves for new and mature energy technologies

Source: (IEA & OECD 2000)



Technology costs for new energy technologies change over the period. Technology learning rates are included in some of the policy cases on both the demand and supply-sides. Such analysis should be conducted carefully, taking into account several factors:

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

6.2.4 Future fuel prices

Prices of domestic fuels are important for the residential sector. Of particular concern, though, is price volatility in imported and exported fuels. The oil price reached \$ 50 / barrel, affecting South Africa's imports, with impacts on the local petrol and diesel price felt in SA. The prices for exports of SA coal have been volatile (DME 2004e). Predicting these prices into the future is uncertain. The prices for the base year (2001) are stated in Table 6.1, as are the assumptions for the middle (2013) and end (2025) of the period.

Table 6.4: Fuel prices by fuel and for selected years*Source: (Winkler et al. 2005a); detailed sources listed at right*

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

6.2.5 Discounting costs favours the present over the future

Discount rates reflect the time preference for money. Since the modeling undertaken for this analysis operates in a least-cost optimizing energy-economy-environment model, the discount rate is an important factor. A higher discount rate implies that policy interventions that have high upfront capital costs and good returns in the future (e.g. SWHs), are favoured less than if a

lower rate is used. The current costs are counted fully, but future benefits are discounted. Conversely, the higher discount rate favours technologies and policies with low initial costs, but higher costs in the future (e.g. gas –fired power stations).

In South Africa, discount rates vary between social discount rates, reflecting public investment at 8% (Borchers et al. 2001; Davis & Horvei 1995) and private lending rates between 15% and 20% (SARB 2001). The first IEP used a rate of 11% (DME 2003d), although this may be revised for the second plan.

The general discount rate used in the study is 10%. However, we assume that poorer households have a higher discount rate than high-income households but for poorer households, we assume their time-preference for money is 30% (Spalding-Fecher et al. 2002a; Banks 1999). In other words, poorer households strongly prefer money now to money later. The implication is that they will be less likely than other sectors to invest in technologies that will lead to energy savings in the future, even though it would reduce monthly energy bills.

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

Table 6.5: Cost deflators based on Gross Value Added

Sources: (SARB 2005; SSA 2004b)

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

6.2.6 Emission factors

Emission factors are needed to convert energy consumption (in energy units, e.g. PJ or GJ) to emissions. The IPCC default emission factors (in tC / TJ, or t CO₂ / TJ) are used for emissions of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO₂) (IPCC 1996: Tables 1-2, 1-7, 1-8, 1-9, 1-10, 1-11 and 1-12 respectively). Following IPCC methodology, local emission factors or adjustments to defaults based on local conditions are made.

For CO₂ from other bituminous coal, 26.25 tC / TJ instead of the IPCC default of 25.8 tC / TJ. The adjustment is based on direct measurements at South African coal-fired power station (Lloyd & Trikam 2004). The higher emissions are consistent with the lower calorific value of SA sub-bituminous coal at 19.59MJ/kg, whereas the IPCC default value is 25.09 MJ/kg coal. Further measurements at more stations in future may lead to a submission of a SA-specific emission factor to the IPCC.

The above list already includes important local air pollutants (SO₂, NO_x, CO, NMVOC), but not particulate matter. Emission factors for particulates are highly technology-specific, and no similar set of default factors as for other pollutants was readily found. An important area for future research would be to examine the applicability of the international literature (IIASA 2005; US EPA 2000) to South Africa. Future research should review previous work in South Africa (NER 2004a; Howells 2004) and establish a list of emission factors (kg TSP / TJ) for the particular technologies.

6.2.7 Conclusions on drivers of future trends

The discussion of economic growth, population, technology learning, fuel prices, discount rates and emission factors shows that the base case implemented in the model is driven by a set of complex factors. The critical assumptions made about these factors and how they might change in the future have been outlined. The drivers are important for policy cases, but in particular in shaping the base case.

The base case (sometimes also called the 'reference scenario') represents the continuation of current development trends, including some existing policies. The base case provides a benchmark against which new policy cases can be measured – or implementation of policies which are on the books, but have not been realised. The next section presents key elements of the base case.

6.3 The base case

The base case presents a path of South Africa's energy development that can also be called 'current development trends' or a reference scenario. The base case for this analysis is similar to that of government plans, the first Integrated Energy Plan (IEP) (DME 2003d) and for electricity, the second National Integrated Resource Plan (NIRP) (NER 2004c). The technologies chosen for the NIRP were described in the chapter on electricity policy (chapter 4). Table 4.8 summarised the key characteristics of the technologies for electricity generation. The reference case for the NIRP was conducted in collaboration Eskom, the NER with the ERC's modeling group (NER 2004a), and the assumptions for the base case here are very similar.

An important difference relates to population projections. The assumptions made for this thesis are clearly stated in section 6.2.2. The population projections used in the IEP were for 50 million (here: 47.4 million) and 57 million (49.1 million). While the IEP projections are reduced from previous estimates, they are still higher. Another difference relates to confidential data used in previous studies, which was not available for this thesis.

The time-frame for the base and policy cases is from 2001, the base year, until 2025. The modeling approach was to extend the model run to 2030 to avoid sudden changes in the end year. References to the ‘end of the period’ are for 2025. Costs are reported in year 2000 Rands.

The major changes reported here are those for future demand in the energy sector as a whole. The broader analysis provides the context for the policies in the residential sector. The fuel mix for electricity generation is reported on the supply side. More detailed results of the base case will be elaborated, as the base case is used as a bench-mark for new policy cases.

6.3.1 Fuel mix on the supply side

Given the focus of the analysis, the overall energy supply is reviewed briefly, before considering electricity supply in the base case in a little more detail. The overall mix of fuels in the base case is illustrated in Table 6.6:. Clearly, coal dominates total primary energy supply (TPES), with most of it being used for electricity generation. Consumption at SASOL for coal-to-liquids provides a major share, with ‘other’ coal supply feeding industry, other domestic uses. Coal exports are deducted from indigenous production to reach the figure in ‘other’ coal production. Discard coal, as the name suggests, is not mined separately, but would have been discarded. It starts being used after 2010 for fluidised bed combustion. The amount of gas production at PetroSA remains constant.

Table 6.6: Total primary energy supply by fuel group in base case

PJ	2001	2005	2010	2015	2020	2025
Coal for electricity	1,718	1,966	2,286	2,650	2,872	3,205
Coal other	624	647	648	646	648	490
Coal SASOL	859	859	859	859	859	859
Biomass	76	41	37	33	29	25
Crude oil	966	966	1,376	1,469	1,542	1,542
Discard coal	-	-	-	962	1,080	1,169
Hydro	7	7	7	7	7	7
Gas	98	98	98	98	98	98
Total	4,347	4,583	5,311	6,723	7,134	7,395

The contribution of non-fossil, renewable fuel sources to primary energy supply declines. The contribution of hydro-electricity remains constant, with few large new sites available, while

biomass declines as other fuels are preferred. TPES in 2001 is within half a percent of the 4,370 PJ reported in the national energy balance for that year (DME 2003a).

The fuel mix for electricity generation is illustrated in two ways. Figure 6.4 shows the power plants by the output of electricity generated. The plants are grouped by fuel to make the graph more readable – for the full set of plants see Figure 10.1 in the Appendix. The most striking feature is the continued dominance of coal-fired power plants. Most of these are Eskom plants, but as generation from these levels off in the latter half of the 2020s, new coal (pulverised fuel) and FBC plants using discard coal come in (see section 6.6.6). Nuclear power from Koeberg adds some more baseload from its pressurized water reactor (PWR). Several types of plants provide peaking power – pumped storage, natural gas combined cycle, small hydro and the only renewable - bagasse co-generation.

Coal plants using pulverised fuel dominate the base case, warranting a brief summary of their key characteristics (see also Table 6.14). The stations have an investment cost just under R10 000 per installed kW. Variable operating and maintenance (O&M) costs are low reflecting the relatively low cost of coal at R 3.02 / GJ. Costs are unlikely to decrease very significantly over time and economies of scale have already been factored in. Since this is a mature technology, efficiencies of such plants have been improved in the past already, and are assumed to remain at similar levels, 35% (NER 2004c). Efficiencies assume that new stations are dry-cooled and use flue-gas desulphurisation. For South African coal characteristics, about 65% of sulphur must be removed (NER 2004a), so that the dry FGC method at 70% efficiency can be used.

Figure 6.4: Electricity generation (GWh) in the base case, grouped by fuel

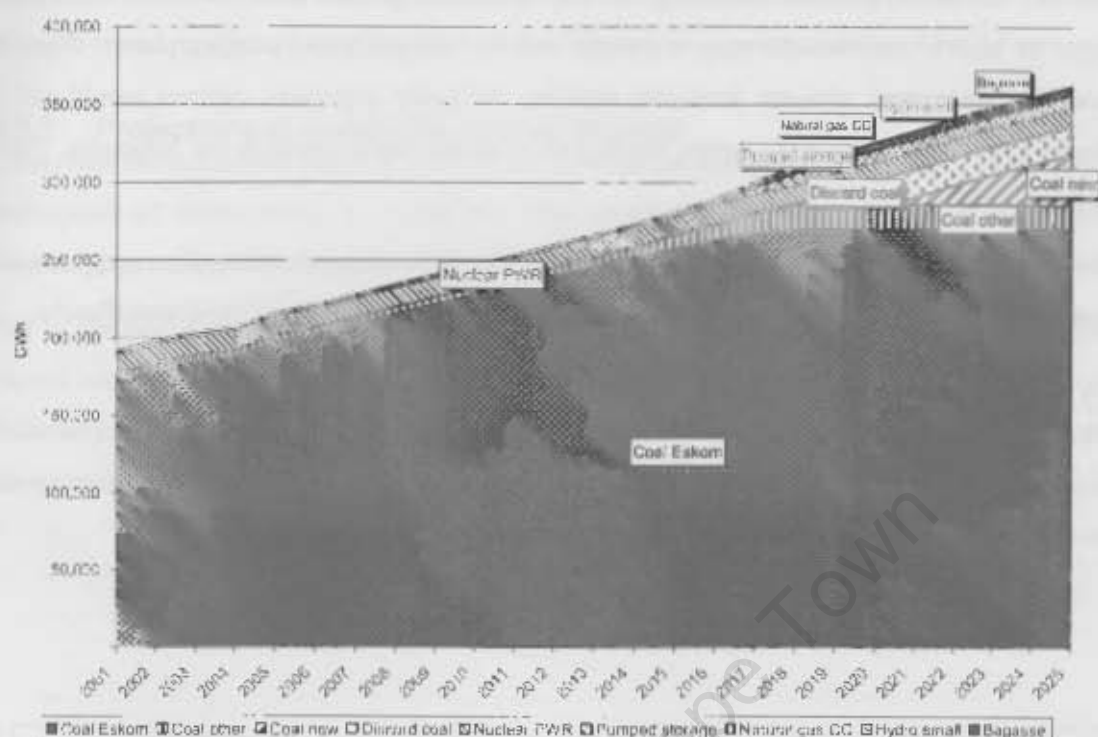


Figure 6.5: Electricity capacity (GW) in the base case

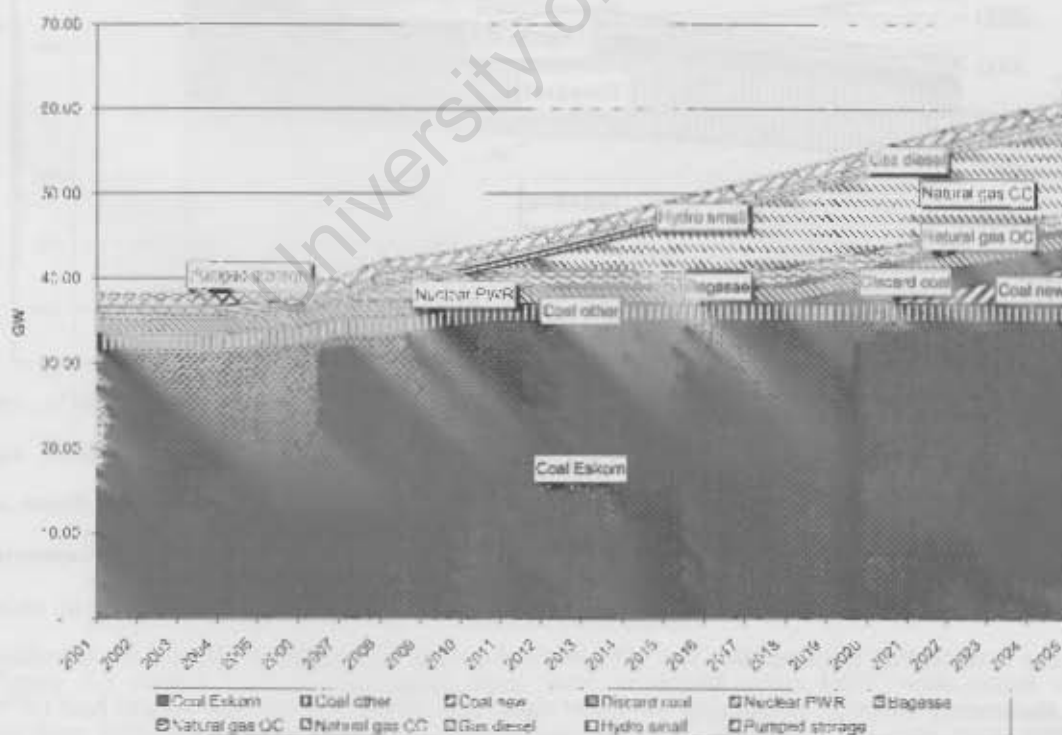


Figure 6.5 shows a similar picture, but by capacity (GW). The difference is striking – while coal is still clearly dominant, other technologies take up a much larger share than by generation (GWh). The difference reflects different load factors, i.e. the extent to which plants are used –

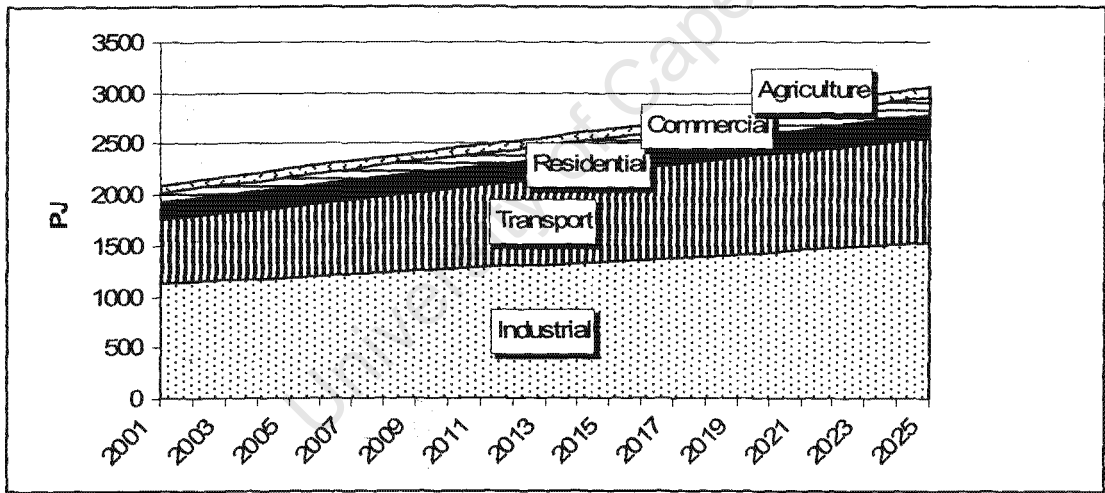
these would be high for baseload plants, and low for peaking plants. Several plant types have capacity that do not generate electricity, notably open cycle gas and diesel turbines. Such plants might be built to maintain the reserve margin and for emergency and peaking power. Since the modeling framework chooses least-cost options, relatively expensive options would not be chosen to generate electricity. Again, the full set of plants can be found in the Appendix, Figure 10.2.

The supply options exist to meet energy demand. The base case projections for energy demand from all sectors is presented first, before honing in on residential demand more specifically.

6.3.2 Demand projections

While the focus of analysis is the residential sector, the base case provides the context of the broader energy system. Figure 6.6 shows that the demand for future energy services comes predominantly from other sectors, the largest being industry and transport.

Figure 6.6: Projected energy demand by sector in the base case



Fuel consumption in the base year for the reference case is dominated by industry at 54%, with transport being the next highest at 29%. The other sectors make up smaller shares, with residential (9%), commerce (4%) and agriculture (3%). The transport and agriculture shares are similar to those reported in the national energy balance (DME 2003a). Industry is somewhat higher, and commercial fuel consumption lower. Of particular note is that the residential sector here has a share that is lower than the 16% of final energy consumption that can be calculated from the energy balance. Examining the latter data more closely shows that almost half (49%) of the residential consumption derives from 'renewables and waste', the category which includes biomass (calculated from DME 2003a). Biomass data vary significantly for year to year and are highly uncertain; on their own, they constitute 8% of final demand in the energy balance, i.e. a greater amount than the difference between the share in this thesis and the energy

balance. The approach taken here is to work with the detailed estimation of energy demand derived through bottom-up analysis. Results comparing policies *within* residential sector would be relative and unaffected; care should be taken if comparing policies *across* demand sectors.

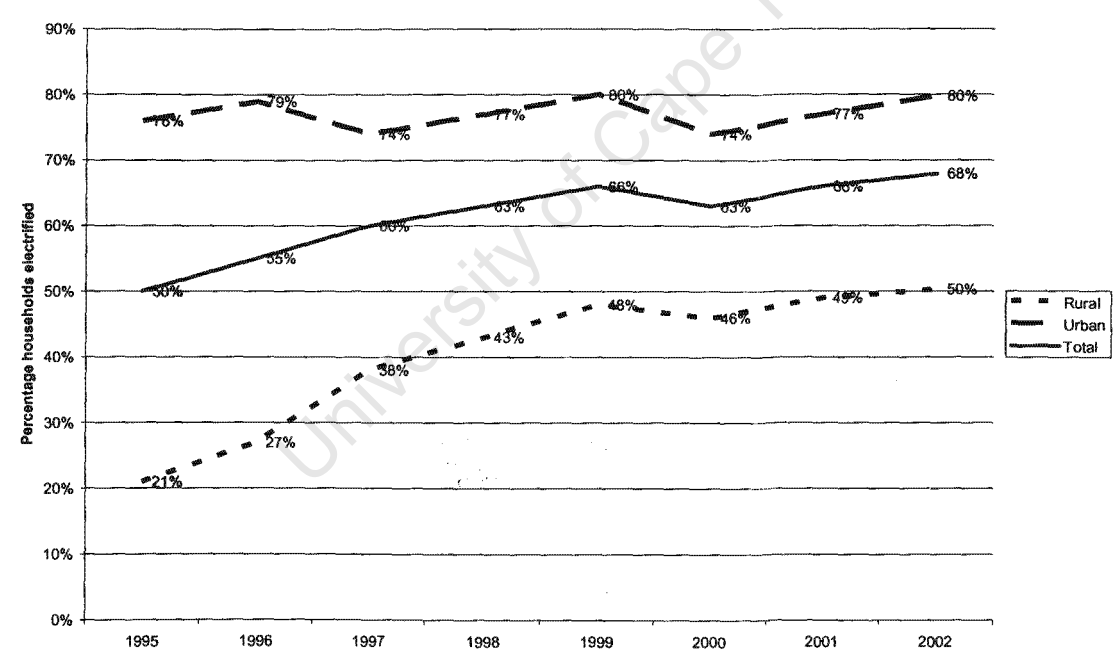
6.3.3 Projections of residential energy demand

Given that the residential sector is a major focus of the modeling for this thesis, a more detailed description of future trends is warranted. The trends in the base case, i.e. without policy intervention, are described here, followed by a section detailing the future policies.

One of the key changes since 1990 has been the electrification programme, which has gradually moved energy use patterns to a greater reliance on electricity – although affordability of using electricity remains an issue in low-income households. Many other fuels, such as kerosene, coal, fuel-wood and LPG are used as well.

Figure 6.7: Trends in electrification of households in SA, 1995-2002

Data source: NER (2002a; 2001c)



Note: The drop in urban electrification rates from 1999 to 2000 is explained by changes in the numbers of households reported in the 1996 Census to new data. As a result, the number of households for statistical purposes increased markedly from 1999 to 2000 (NER 2001c).

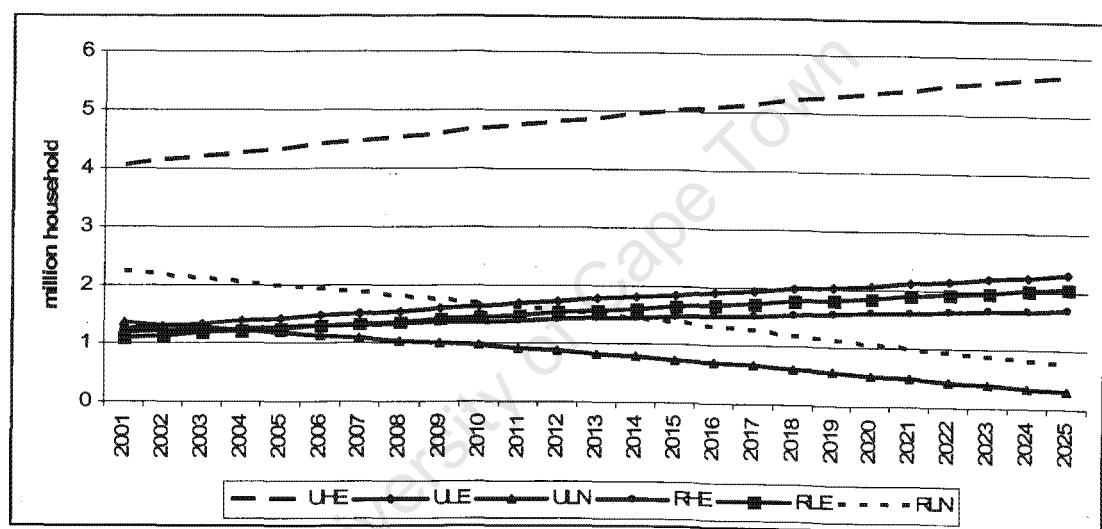
Figure 6.7 shows how electrification rates have increased since 1995, with urban centers reaching 80% by 2002 despite their populations growing. While half of rural areas remained non-electrified by 2002, this was a significant increase from 21% in 1995.

Universal access to affordable electricity will remain a corner-stone of policy for the sector and treated as a ‘given’ in considering policy choices. Government’s commitment to achieving

universal access has been reiterated in many policy speeches (Mbeki 2004a; Mlambo-Ngcuka 2003, 2002a, 2004).

The base case assumes that the current development trend of electrification continues. Having moved from roughly one-third to two-thirds with access to electricity in the 1990s, the trends continues. However, as the ‘easier’ connections were made first, the last third of households will be more marginal – both geographically and economically. Some rural households might remain distant from the grid, and their marginalisation in terms of poverty might mean that off-grid options do not reach them either. By 2030, it is assumed that almost all urban households and the 90% of rural households will have access to electricity.

Figure 6.8: Projected changes of household numbers in the base case, 2001 – 2025



Continuing electrification has implications for the household types as defined here. The two categories of non-electrified households (urban, ULN and rural, RLN) will decline, as can be seen in Figure 6.8. The growth of numbers in other household types is the result of three trends – increasing electrification, higher urbanisation and a moderate growth in total number of households. The growth in UHE households – where all three factors are positive – is the highest.

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

driver of future energy patterns beyond just the residential sector, it is discussed together with other key assumption about the future in section 6.2.2.

The base case and all the policy cases assume increased access to electricity. Disaggregated by household type, household numbers shift from non-electrified households (ULN, RLN) to electrified household types. Assuming that urban electrification rates reach 99% and rural 90% by 2025, there are some 3 million fewer poor households unelectrified by the end of the period. Much of this is made up by 2.4 million more low-income electrified households (ULE, RLE), plus a smaller shift into the higher-income category. All this occurs against a backdrop of household growth occurring mainly in urban areas, with this group growing by almost 2 million households over the period.

Changes in population have a relatively small direct impact on energy demand, since the residential sector only accounted for 16% of final energy consumption in 2001 (DMF 2003a). However, demographic changes have significant indirect consequences. The impact of reduced population growth would be felt more strongly through reduced labour, consumption of goods and other factors reflected in GDP. Understanding potential changes in future residential energy demand is also particularly important in social development and improving the quality of life of ordinary South Africans.

Energy demands for different end uses by each household type are shown in Table 6.7. Estimates of demands used in the modeling for the base, 2001 are shown together with projections for the end year 2025 and an intermediate year, 2014, for which the energy efficiency target is set.

Table 6.7: Energy demand by household type and end use for selected years

PJ		RHE	RLE	RLN	UHE	ULE	ULN
Cooking	2001	1.79	0.59	4.37	15.84	1.43	1.89
	2014	2.22	0.87	2.8	19.29	2.06	1.1
	2025	2.58	1.11	1.48	22.2	2.6	0.43
Lighting	2001	3.7	1.31	0.04	7.64	2.05	0.02
	2014	4.58	1.93	0.02	9.3	2.96	0.01
	2025	5.33	2.46	0.01	10.7	3.74	0
Other electrical	2001	3.28	0.08		12.57	0.11	
	2014	4.34	0.12		16.33	0.17	
	2025	5.33	0.16		19.86	0.22	
Space heating	2001	1.68	0.53	4.8	16.31	2.42	1.83
	2014	2.09	0.78	3.08	19.85	3.5	1.06
	2025	2.43	1	1.63	22.85	4.41	0.41
Water heating	2001	2.85	0.67	2.75	23.22	4.35	0.87
	2014	3.53	0.99	1.76	28.27	6.29	0.5
	2025	4.11	1.26	0.93	32.54	7.93	0.2

The demands are total demands for the household type, so that declines in the RLN and ULN categories should be understood against the decline in numbers of these households. Overall, energy demands are increasing over the period. Most of the increase derives from increasing incomes – more households move from the poorer to richer classification, where more energy is used per household.

Having outlined how energy patterns unfold in the base case, an overview of the policy cases is presented in the following sections – first a brief overview, before the residential energy policies and electricity supply options are each outlined in more detail.

6.4 Overview of policy cases

Sketching a policy case of sustainable development should not suggest that this is easy to achieve. The challenge of building new power stations present a major opportunity to choose cleaner technologies, but significant resources and effort are required to make such major changes. Some models that focus on sustainability assume a shift away from fossil fuels for coal-dependent countries too easily (Berk et al. 2001: 16). Such a transition involves major changes in infrastructure and the requirements should be carefully examined in policy analysis. A sustainable development policy that has low impact on the local environment, promotes access and favours an equitable allocation of wealth and resources represents a major challenge.

A short overview of the policies in the residential demand and electricity supply sector is provided in Table 6.8. The policies, described in more detail in the following two sections, are grouped under electricity and residential sectors. The electricity policies focus on supply from renewable energy, PBMR nuclear, importing hydro or gas, and also consider the impacts of cleaner coal in the base case. On the residential demand side, efficiency in lighting, water heating and space heating (houses) are complemented by a fuel switch to LPG.

Table 6.8: Summary of policy cases in residential and electricity supply sectors

Short name	Key features	MARKAL name
	HOUSEHOLDS	
SWH	Cleaner and more efficient water heating is provided through increased use of solar water heaters and geyser blankets. The costs of SWH decline over time, as new technology diffuses more widely in the SA market	RESWHGB
CFL	More efficient lighting, using compact fluorescent lights (CFLs) spreads more widely, with a slight further reduction in costs beyond that achieved already	RESCFL
Eff house	The shell of the house is improved by insulation, prioritising ceilings. Since the technology has zero fuel costs, bounds are place to ensure that no more households are built than exist	RESHOUSE
LPG switch	Households switch from electric and other cooking devices to LPG stoves and rings	RESLPG
Combined elec	The combined effect of all the above policies	RESCMB

Short name	Key features	MARKAL name
	ELECTRICITY	
Renewable energy	The share of renewable electricity increases to meet the target of 10 000 GWh by 2013. Shares of solar thermal, wind, bagasse and small hydro increase beyond the base case. New technology costs decline as global production increases	ELCRET
PBMR	Production of PBMR modules for domestic use increases capacity of nuclear up to 4,480 MW by 2020. Costs decline with national production and initial investments are written off	ELCPBMR
Hydro	Share of hydro-electricity imported from SADC region increases up to 15 GWh by 2010, from 9.2 GWh in 2001. As more hydro capacity is built in Southern Africa, the share increases.	ELCHYDRO
Gas	Sufficient gas is imported to provide 1 950 MW of combined cycle gas turbines, in units of 387 MW.	ELCGAS
Base w/out FBC	Fluidised bed combustion using discarded coal, a low-cost resource, is part of the base case already. The implications of what would have happened without this resource are explored.	EBASEFBC

The energy policies are elaborated in the following two sections. The data input for these policies is described and its implementation in the modeling framework.

6.5 Residential energy policies ⁴⁰

Having examined the broader energy sector, the thesis now turns to the first focus area, energy policies in the residential sector. The analysis disaggregates the residential sector in a way that has not been done in previous national energy modeling in South Africa. Significant previous work has been conducted in understanding household energy use in detailed surveys and analyses (Eberhard & Van Horen 1995; Mehlwana & Qase 1998; Mehlwana 1999b; Prasad & Ranninger 2003; Winkler et al. 2000; Spalding-Fecher et al. 1999; Simmonds & Clark 1998; Mehlwana & Qase 1999; Mapako & Prasad 2005; Cowan 2003), but this has generally focused at a local level and has not linked into modeling. Rural village's energy systems in SA have been modeled initially (Howells et al. 2005), but again not linked into national projections.

6.5.1 Defining six household types

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

Six household types are defined here, differentiated along urban / rural, high / low-income and electrified / non-electrified dimensions. The energy use patterns of richer and poorer households differ quite markedly from one another, as do those of rural and urban households. Given the policy drive to universal electrification since the 1990s, the distinction between

⁴⁰ This section builds on and extends work done by the author in Winkler *et al* (2005a).

electrified and non-electrified households has become significant, with lack of electricity being seen as similar to energy poverty.

For this sector, activity levels are defined by the number of households, which were 11,205,705 according to the 2001 Census (SSA 2003b). Definitions of urban and rural are technically difficult in SA, exemplified by the existence of ‘dense rural settlements’ like Bushbuckridge or Winterveld, and the Census no longer reports this distinction. Other statistical publications continue to report different patterns of urban and ‘non-urban’ (e.g. SSA 2002; e.g. SSA 2000). For the purposes of evaluating electrification, the National Electricity Regulator distinguishes between urban and rural connections (NER 2002a; 2001a), so that for the purposes of this study, we can assume a 60:40 split of urban to rural households.⁴¹

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

Table 6.9: Income and expenditure in urban and non-urban areas in 2000 market values, grouped by 1995 quintile

Source: SSA (2002)

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

It seems reasonable to define energy poverty for the purposes of this analysis by treating the bottom two quintiles as ‘poor’, i.e. the poorer are those with an *annual* per capita income less than R4033, and expenditure less than R3703 (SSA 2002: Fig 4.9).⁴² Consequently, 61% of urban households could be considered not poorer or ‘rich’ (medium to high income), while in rural areas only 31% would fall into this category. In other words, almost seven out of rural households are poorer by these assumptions.

The average *expenditure per household* of the groups is reported by Statistics SA (SSA 2002: Fig 4.9). The average income of ‘poor’ households can be taken as R7 547 (break point between bottom two quintiles) and R 41 041 (upper point of quintile 2). For analysis of the household types defined here, deductions about relative urban : rural incomes are possible, rural household

⁴¹ The percentages used in the modeling are 59.61% urban households, 40.39% rural, but reporting them with two decimals would give a false sense of accuracy.

incomes were about 41% of urban in 2000 (SSA 2002: Fig 4.9). No breakdown of incomes between electrified and non-electrified households was found at national aggregate level.

The proportion of poorer and richer households varies across urban and rural areas, with the former having a much higher share of medium and high-income households. Similarly, the share of electrified households is lower in rural areas, as shown in Table 6.10.

Table 6.10: Numbers and shares of rural and urban households, electrified and not

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

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

Taking three categories – richer / poorer, urban / rural, electrified / non-electrified would yield eight household types. However, richer urban households are all electrified, and most rural richer households are as well. Again there is no comprehensive statistical survey available, and it is furthermore clear that access to electricity still differs by population group. Almost all African (99%) and coloured (>99%) households in the highest expenditure category in urban areas had access to electricity for lighting, as against proportionately fewer households in this expenditure category in non-urban areas (79% of African and 93% of coloured households) (SSA 2000: 70). These percentages only refer to the highest income group, and weighted by population groups would give some 84% of richer rural households electrified. Further calculations reveal that 33% of the rural poor are electrified, while not quite half (48%) of the urban low-income households has access to electricity. With this information, it is possible to derive the number of households in each of six household types shown in Table 6.11.

Table 6.11: Six household types, with total numbers in 2000, shares and assumptions

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

<i>Household</i>	<i>Acronym used in thesis</i>	<i>No. of households</i>	<i>Share of all households (HH)</i>	<i>Notes</i>
Urban richer electrified	UHE	4,074,438	36.4%	Virtually 100% of richer urban HH are electrified
Urban poorer electrified	ULE	1,255,728	11.2%	remainder of urban electrified must be poorer
Urban poorer unelectrified	ULN	1,349,240	12.0%	rest of urban HH must be non-electrified

⁴² At exchange rates of R6/\$1, this works out to less than \$2 per person per day.

<i>Household</i>	<i>Acronym used in thesis</i>	<i>No. of households</i>	<i>Share of all households (HH)</i>	<i>Notes</i>
Rural richer electrified	RHE	1,181,279	10.5%	assume 84% of richer rural HH are electrified
Rural poorer unelectrified	RLE	1,095,449	9.8%	remainder of rural electrified must be poorer
Rural poorer unelectrified	RLN	2,249,571	20.1%	rest of rural HH must be non-electrified; number of HH includes the few richer rural not electrified

Of course, reducing all households in the country to six types still abstracts enormously from the rich diversity of different energy patterns. However, for purposes of national level policy cases provides some distinction of the major residential energy use patterns. Perhaps the biggest omission is the lack of geographical disaggregation – poorer urban unelectrified households in Cape Town, for example, would use paraffin extensively for cooking, heating and lighting (Mehlwana & Qase 1999); while households in the same category in Gauteng are more likely to use locally available coal (White et al. 1998). Apart from responding to different fuel availability, there are also climatic differences.

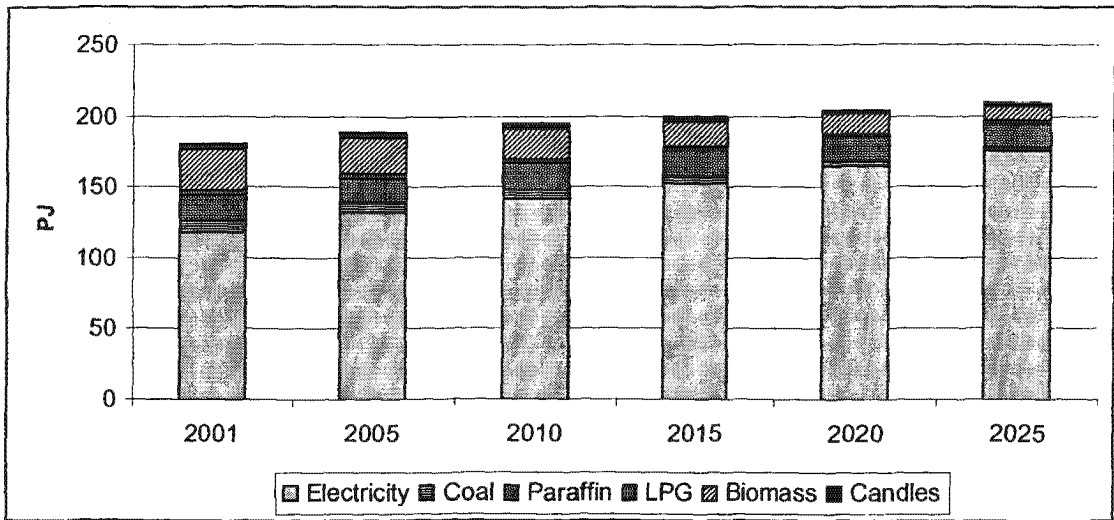
Since each additional household type requires additional data in the modeling, the number of household types needs to be limited. Further disaggregation could be achieved in future work, but is constrained by our limited knowledge of distinctive energy use patterns. For example, there is relatively little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

6.5.2 Energy use patterns in the household types

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

Multiple fuels are used in the residential sector, with electricity clearly dominating useful energy demand (see Figure 6.9). This reflects both in the increased use of energy, but also the relatively high efficiencies of electrical appliances. About 5% of the total electricity is sold to the domestic sector, so that the bar for electricity in 2001 represents 34.6 TWh of final energy (NER 2001).

Figure 6.9: Trends in fuel shares in the residential sector in the base case



Over time, electricity increases its share in overall residential demand, growing faster than other energy carriers. Patterns of household energy demand differ significantly in richer and poorer, urban and rural households (Mehlwana & Qase 1998; Simmonds & Mammon 1996; Mehlwana 1999b). Electricity contributes a larger share of household energy use in urban areas than in rural, while the inverse is true for fuelwood.

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

Energy is needed to provide key services – for lighting, electrical appliances, cooking and heating water and space. Five end uses are considered in the modeling framework. The appliances (residential end-use technologies) described in the following section convert energy into services. The mix of technologies differs by household type.

Table 6.12: Energy demand by household type for each end use

	<i>Urban high-med income electrified</i>	<i>Urban low income electrified</i>	<i>Urban low income non-electrified</i>	<i>Rural high-med income electrified</i>	<i>Rural low income electrified</i>	<i>Rural low income non-electrified</i>
<i>GJ / HH per year, 2001</i>	<i>UHE</i>	<i>ULE</i>	<i>ULN</i>	<i>RHE</i>	<i>RLE</i>	<i>RLN</i>
Cooking	3.9	1.1	1.4	1.5	0.5	1.9
Water heating	5.7	3.5	0.6	2.4	0.6	1.2
Space Heating	4.0	1.9	1.4	1.4	0.5	2.1
Lighting (in PJ)	1.9	1.6	0.01	3.1	1.2	0.02
Other electricity	3.1	0.1		2.8	0.1	

Household energy use pattern vary across the six household types. Table 6.12 shows the consumption for each end use for the base year 2001 (see Table 6.7 for aggregated demand, projected into the future). The energy services related to each end use are delivered by multiple technologies for most end uses, as can be seen from Table 6.13.

6.5.3 Characteristics of energy technologies

MARKAL is a technology-rich modeling framework. Demand for useful energy services is met by a range of technologies. The previous section indicated how these technologies provide energy services for cooking, heating, lighting and other end uses. The key characteristics of technologies included for the residential sector are shown in Table 6.13. Of course there are many more technologies that are used in reality, but some of the major energy-consuming ones have been included here. The information is organised by the services that households required – the end uses of cooking, space heating, water heating, lighting and electrical appliances.

The nominal appliance costs were collected by the author for a study in early 2005 (Winkler et al. 2005a). They were deflated from end of 2004 to provide costs in year 2000 Rands. Residual capacity refers to the capacity available in the base year, without any further investment.

Table 6.13: Key characteristics of energy technologies in the residential sector

<i>Fuel consumed</i>	<i>Device</i>	<i>Efficiency</i>	<i>Capital cost - nominal</i>	<i>Adjusted cost</i>	<i>Residual capacity</i>	<i>Lifetime</i>
		%	2005 Rand	2000 Rand	PJ	years
Cooking						
electricity	hot plate	65%	R 229	R 178	0.6559	5
	oven	65%	R 2,349	R 1,823	16.2011	9
	micro-wave	60%	R 874	R 678	0.1004	5
paraffin	wick	40%	R 107	R 83	0.1657	3
	primus	42%	R 37	R 29	2.4558	6
LPGas	ring	53%	R 249	R 193	0.7088	5
	stove	57%	R 4,995	R 3,877	1.1136	9
Wood	stove	25%	R 848	R 687	4.1593	9
Coal	stove	13%	R 5,231	R 4,060	-	11
	brazier	8%	R 0	R 0	-	1
Water heating						
electricity	geyser dummy	100%	R 2,172	R 1,686	29.1709	22
electricity	geyser no blanket	70%				22
electricity	geyser blanket	79.55%	R 150	R 116	-	22
paraffin	wick/kero/pot	35%	R 37	R 29	1.8019	3
LPGas	geyser	84%	R 4,298	R 3,479	0.2936	22
Solar	SWH (integral)	100%	R 6,500	R 5,045	0.1922	17
Coal/wood/wastes	stove(jacket/pot)	25%	R 0	R 0	2.5709	1
Space Heating						
electricity	Radiant heater	100%	R 100	R 78	11.8984	6
	Rib/fin/radiator	100%	R 968	R 751	7.3770	9
paraffin	heater	73%	R 59	R 46	3.4390	9
LPGas	heater	75%	R 993	R 771	0.3012	5
Wood	open fire/stove	40%	R 0	R 0	-	-
Coal	stove	59%	R 5,231	R 4,060	-	11
	brazier	8%	R 0	R 0	-	1
Lighting						
electricity	incandescent	100.00%	R 3	R 2	14.2820	1
	fluorescent	290.29%	R 13	R 10	-	4
	CFLs	400.00%	R 17	R 14	0.0989	10
paraffin	wick	1.71%	R 5	R 4	3.8536	4
	pressure	7.43%	R 192	R 155	-	4
LPGas	Pressure	5.71%	R 250	R 194	-	4
candles		0.05%	R 1	R 1	-	0.01
Other electrical appliances						
Electricity	Appliances	80%			16.0407	5

Lifetimes and efficiencies are taken from previous studies (DME 2003d; De Villiers & Matibe 2000), updated in some cases by expert input (Lloyd 2005; Cowan 2005). For all end uses other

than lighting, the efficiencies relate to the amount of useful energy delivered by the appliance for each unit of final energy delivered to the household. For lighting, however, relative efficiencies reflect the amount of lighting service produced, not thermal outputs.

Penetration rates for different technologies were derived from existing technology shares of useful energy demand for the base case. In the modeling framework, upper and lower bounds were set, by defining user constraints in Markal. In the base case, these remained at the same level, the existing contribution of the technology to the end use. In policy cases, as described below, different values can be set for upper and lower bounds. A lower bound will require a certain amount of investment in the technology, but the model can seek the most cost-effective solution between the lower and upper bounds. Upper bounds are useful to prevent investment beyond known limits, e.g. the number of households in SA.

6.5.4 Policy interventions in the residential sector

Having described the base case overall, and provided more background on current trends and future projections for the residential sector, the attention shifts to the policy interventions. In keeping with the methodology, the policy interventions in the residential sector modeled in this thesis should contribute further to development objectives, beyond what has already been achieved (see chapter 3 and the introduction to section 6.4). People do not want energy for its own sake, but the services that it provides. The policies considered focusing on improving access, using cleaner and more efficient fuels, to provide energy services – energy to heat water, light houses and keep them warm, and to cook food.

6.5.4.1 Cleaner and more efficient water heating

Water heating uses up to 30% of household total energy (DME 2004a) and so an energy-saving policy examines the installation of solar water heaters (SWH) in middle- and upper-income households. Establishing local production of new SWH technology would assist in bringing upfront costs down. For electrified poorer households (ULE, RLE), geyser blankets are promoted. The policy case is referred to in short-hand as ‘efficient water heating’ or ‘SWH / GB’ (solar water heaters / geyser blankets).

The development objectives of improving water heating by SWH / GB are:

- to make water heating more affordable due to reduced fuel (or electricity input);
- to enhance environmental health by avoiding the use of energy carriers other than solar energy and electricity to heat water, reducing the health impacts of indoor use of fuels such as coal and paraffin;
- to use electricity more efficiently, where regular geysers are used; and

- to reduce household energy expenditure for water heating, with savings available to be spent on other life-improving activities, or using more hot water (itself a benefit).

The broad characteristics of SWH and GB's have been described in Table 6.13. A policy promoting these technologies is implemented in the modeling framework by allowing wider ranges for the penetration rates of SWH and GB for electrified households. In the base case, energy for water heating continued in the proportions of the base year, although total energy use could increase. However, one should consider the maximum penetration rates achieved elsewhere, which was done in previous studies finding from 20% (De Villiers & Matibe 2000) to 33% (DME 2004a). Based on calculations from the White Paper on Renewable Energy, a more optimistic approach for the policy case could increase up to 60% (DME 2003c). A higher level is assumed only for urban medium- to high-income households and that only after 25 years (UHE: 50% for solar water heaters, 20% for geyser blankets). For urban low-income and richer rural households, the analysis stays within the range (ULE and RHE, 30 % SWH and 20% GBs); while poorer rural electrified households still achieve RLE still do 20% of each. A brief sensitivity analysis on widening the ranges fully showed that the model would only invest in SWH to the same extent as in the base case, providing no heuristic value. The modeled case with the ranges stated above still allows the model room to choose between the most cost-effective means for water heating, but requires a minimum level more efficient water heating technologies of 10 to 20%. The results are then compared to the base case (chapter 7).

The initial cost of SWHs is significantly greater than for electric geysers (see Table 6.13), but over time savings on electricity bills make up for the initial cost. 60% saving of electricity for SWH are reported in the literature (Karekezi & Ranja 1997; Spalding-Fecher, Thorne & Wamukonya forthcoming). Geyser blankets (GB), with lower upfront costs (~R150 (Borchers 2005)), are available to all households, including poorer ones. Currently, "virtually no SWH are encountered in low-cost housing areas" (DME 2004a). Existing homes can also insulate electric geysers, since only 1-3% currently do so (Borchers 2005), with the literature reporting 12% saving (EDRC 2003a; Mathews et al. 1998).

The policy case assumes that SWH costs decline over time, as new vacuum tube technology costs brings costs to a range of R4000 to R6000 per system (Borchers 2005). The technology already exists in South Africa, but is not yet widely dispersed (Morris 2005). Since this cost reduction relies on economies of imported components (the vacuum tube), it is likely to be a step-change and not be continued. The modeling assumes that investment costs decrease from R6500 to R5000. For the policy case, we assume that this cost reduction occurs by 2010, providing a 5-7% reduction per year. Some further learning-by-doing and economies of scale in local manufacturing are possible later, but it is assumed that this as a more moderate rate of 2-3% per year.

6.5.4.2 *Efficient lighting*

The policy case for efficient lighting examines increased penetration rates of CFLs. Development objectives include providing more affordable lighting, saving on energy bills for lighting, or using savings for increased lighting services. More lighting can contribute to education – through studying at home – and safety. Lighting is one of the smaller end use compared to water heating, cooking and space heating, but often is used extensively in newly electrified households.

From the utility's perspective, lighting demand has a high degree of co-incidence with peak demand, especially in the winter when daylight fades early and the peak occurs in the evening. CFLs can therefore reduce expensive peak demand. Efficient lighting practices include switching off lights when a room is unoccupied, fitting lower power light bulbs where possible and controlling security lighting with light or movement sensors.

Efficient lighting for UHE, ULE, RHE and RLE households occurs in the base case. The efficient lighting initiative (ELI) pursued a strategy of buying down the price of CFLs through a subsidy program with participation from major manufacturers, in the expectation that prices would stabilize at new lower levels (ELI 2005). This would lead to higher sales and market penetration. One can assume that most of the price decline in CFLs has happened by 2005, but a further drop to R10 in real terms by 2010 (Bredenkamp 2005) is included.

It is assumed in the base case, as in the second NIRP (NER 2004c) that the share of CFLs for electric lighting could increase up to 20%. Even in the policy case, it is unlikely that 100% of households will use CFLs, based on studies in the Netherlands, Germany, and Denmark where penetration might be high. In these countries, about half the households have CFLs installed (NL 56%, DE 50%, and DK 46%) (Kofod 1996). These high penetration rates are probably not matched anywhere else in the world and are the upper bound for our reference case, at 40% for poorer households and 50% for richer ones. The model still chooses the least-cost option, it is not required to meet an upper bound.

6.5.4.3 *Efficient houses*

The DME suggested in a strategy that housing could be made more sustainable if “50% of all new houses built (including RDP houses) ... incorporate climate conscious solar passive design principles in their construction (thereby eliminating the need for space heating and cooling)” (DME 2001c). Housing developments in coastal areas already qualify for an incremental subsidy of R1003 for ‘weatherisation’.

More efficient houses may make economic sense, but are they affordable? The issue of affordability is prominent in this regard. While cost-benefit analysis of efficient houses indicates that they make financial sense (Winkler et al. 2002d), the upfront costs are typically beyond the reach of poorer households. The higher discount rate (30% against the general rate for the

modeling of 10%) reflects the strong preference of these households for money in the present. A relatively small additional investment in housing for poorer communities creates more comfort, reduces household energy costs, as well as cutting emissions from the residential sector (Winkler et al. 2002d). Financing mechanisms are an important policy consideration, as are building codes to make efficiency measures in housing mandatory.

The development objectives of efficiency in housing have much in common with more efficient water heating and lighting. Again there are energy savings for households, with reduced fuel expenditure for space heating. Less indoor space heating with other fuels contributes to better environmental health. Efficient houses are more comfortable, being cooler in summer and warmer in winter, therefore improving quality of life. Background research for low-cost efficient houses in Khayelitsha confirms this experience (SSN 2004).

Implementing the policy case in the model, one should first note that a constraint is needed in the base case. Without a limit, the model would implement excessively in efficient housing, since they have no fuel cost at all. Indeed, in an optimized base case, some 14 million efficient houses would be built in the urban-richer category (UHE) alone – the projection is that there might be about 3 million households in this category by 2025. A cap is placed on households in the base case increasing from the current estimate of 0.5% of households to 5% by the end of the period. The upper limit is an intermediate value between the estimates of current (0.5%) and future (50%) levels. The policy case allows a much more generous upper limit, taking the DME estimate. However, there is a gradual escalation from the low levels of the base case and year. The full 50% is only assumed at the end of the period.

6.5.4.4 *Cooking more efficiently with LPG*

The policy cases examined thus far in the residential sector all have efficiency gains. For cooking, it is not likely that appliances using a particular fuel, e.g. electric stoves, would get very much more efficient. However, switching to other fuels can have benefits. Liquefied petroleum gas (LPG) is the policy option examined here. It has the advantage that it is possible to switch from electricity to LPG, but particularly for households not using electricity for cooking, it is attractive. The other fuels – paraffin, coal and wood – all have significant health impacts when used indoors for cooking. LPG can offer a cleaner, safer fuel which is also more efficient.

As with other policy cases on the demand side, the modeling approach is to increase the range for LPG for cooking. An increased lower bound means that some LPG must be used and the implications are examined in the results. Lower limits were established at 20%, except where the base case already indicated that LPG as a least-cost option achieved a higher rate (ULN 21%, RHE 33%). Upper bounds between 40% and 60% were set, depending on the level

already achieved in the base case. Up to this limit, the model chooses the most cost-effective mix.

Cost-effectiveness is similarly appropriate for electricity supply options. Electricity supply needs to meet growing demand, and the cost of competing options is one key criterion. The following section examines the major options and their characteristics.

6.6 Electricity supply options

The excess capacity that SA developed in the 1970s and 1980s and lasted into the 1990s has come to an end (see chapter 4). Over the next two to three decades, some 17 000 MW will need to be built at approximately 1 000 MW per year. After 2020, many large stations will near the end of their life, and although options for refurbishment will then be considered, significant portion of existing capacity will need to be replaced.

The options for electricity supply were reviewed in the chapter on electricity policy (section 4.5). The options included all available energy resources and conversion technologies – coal, nuclear, imported gas and hydro, and renewable energy. The options considered for the National Integrated Resource Plan (NIRP) were reported in Table 4.8.

The major options included:

- Base-load coal stations, with flue-gas desulphurisation (FGD);
- ‘Cleaner coal’ technologies, in particular the Fluidised Bed Combustion (FBC) technology;
- Nuclear technology in the form of the Pebble-Bed Modular Reactor;
- Imported hydro-electricity from Mozambique, Zambia or the DRC;
- Imported gas, and
- Renewable energy technologies (wind, solar thermal, biomass, small hydro).

6.6.1 Characteristics of electricity supply technologies in policy cases

Key characteristics of the electricity supply options are summarised in Table 6.14. The data served as input to the modeling and is broadly consistent with the second NIRP. Presenting the data in a consolidated table allows comparison across the various options.

Table 6.14: Characteristics of electricity supply technologies in policy cases

Source: Markal database for this model (see Winkler et al. 2005a), and NIRP database (NER 2004a) and also drawing on modeling for the first IEP (DME 2003d)

	Units of capacity	Investment cost	Lifetime	Lead Time	Efficiency	Availability factor
Type	MW	R/kW	Years	Yrs	%	%
Imported gas						
Combined cycle gas turbine	387	4,583	25	3	50%	85%
Open cycle gas turbine (diesel)	120	3,206	25	2	32%	85%
Imported hydro						
Imported hydro	9200 GWh p.a.		40	6.5		
Renewable energy						
Parabolic trough	100	18,421	30	2	100%	24%
Power tower	100	19,838	30	2	100%	60%
Wind turbine	1	6,325	20	2	100%	25, 30, 35%
Small hydro	2	10,938	25	1	100%	30%
Land fill gas (medium)	3	4,287	25	2	n/a	89%
Biomass co-gen (bagasse)	8	6,064	20	2	34%	57%
Nuclear						
PBMR initial modules	165	17,136	40	4	41%	82%
PBMR multi-modules	171	10,761	40	4	41%	82%
Coal						
New pulverized fuel plant	642	9,980	30	4	35%	72%
Fluidized bed combustion (with FGD)	233	9,321	30	4	37%	88%
Storage						
Pumped storage	333	6,064	40	7	storage	95%

The background to the energy technology characteristics and more details on their implementation in the model are presented in the following sections.

6.6.2 The green option - renewable energy technologies

6.6.2.1 Meeting the target

The Minister of Minerals and Energy re-stated in 2002 that “renewable energy plays an important role in the energy mix and increases supply security through diversification” (Mlambo-Ngcuka 2002b). Renewable electricity technologies (RETs)⁴³ can contribute not only

⁴³ Renewable electricity technologies is used as short-hand for technologies using renewable energy sources. However, it is not the electricity that is renewable, but the energy source.

to diversity of supply, but also to another major energy policy objective, managing the energy-related environmental impacts. Whether these aims can be achieved at large scale, while also meeting the socio-economic needs of the country, is a key question.

In 2005, the Renewable Energy Finance and Subsidy Office (REFSO) was established. The REFSO mandate includes the management of renewable energy subsidies and provision of advice to developers and other stakeholders on renewable energy finance and subsidies, (including size of awards, eligibility, procedural requirements, etc).. A once-off capital grant has been made available for project developers in 2005/06 – 2007/08 financial years. The subsidies for 2005/6 are R250 / kW capacity for electricity; R 273 / kl capacity / year for biodiesel and R 167 / kl capacity / year for bio-ethanol or equivalents for other RE technologies. The subsidy can not exceed 20% of the total capital cost, and minimum project size is 1 MW (for electricity), implying a subsidy amount of R250 000.⁴⁴

RETs (other than hydro) in South Africa have been largely confined to the realm of research, development and demonstration (see chapter 4). In 2003, government adopted a target of 10 000 GWh renewable energy consumption (DME 2003c). Although this is not limited to electricity but also includes solar water heating and biofuels, the policy document explicitly calculates that this would be 4% of expected *electricity* demand in 2013. The approach taken here is to examine the durability of reaching 10 000 GWh of electricity from renewable energy sources by 2013. A number of technologies could contribute to the goal, including solar thermal electricity (both the parabolic trough and ‘power tower’ options, wind turbines, small hydro facilities and biomass co-generation (already done in pulp and paper and sugar industries).

6.6.2.2 Approach to modeling renewable energy technologies

To implement the policy case with various RE technologies in Markal, a lower bound was set to meet the target, moving incrementally up to 10 000 GWh from renewable resources by 2013. After 2013, a lower limit of 10 000 GWh is maintained; that is the model can choose to generate more, as long as it does not exceed the capacity. Global capacities for renewable energy (RE) were reviewed in chapter 4; more specific factors developed for SA are shown in Table 6.15.

⁴⁴ <http://www.dme.gov.za/dme/energy/refso.htm>

Table 6.15: Technically feasible potential for renewable energy by technology*Source: DME (2004a)*

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

The capacity for wind is higher than the range suggested in previous studies – the highest estimate of *theoretical* potential in Table 4.6 was 50 PJ (13 889 GWh). One would expect technical potential to be less than theoretical. However, since both this number and the estimate above well exceed the renewable energy target, the 50 PJ limit for wind is used.

A more aggressive approach would have been to keep increasing the target linearly. The approach taken here has the advantage of meeting the target, but allowing the model to choose how to meet it with the various options.

- Solar thermal plants use various arrangements to collect sunlight on a central receiver, generating steam to drive a turbine. The ‘power tower’ uses mirrors to focus on a central receiver, with molten salt providing some temporary storage of energy. The parabolic trough concentrates sunlight on long tubes contain suitable liquid. Areas of the Northern Cape have insolation of 6,000 W / m² (DME et al. 2001).
- Installed wind capacity in South Africa is limited to two projects in the Western Cape, Eskom’s turbines at Klipheuwel and the Darling Wind Farm (DARLIPP). Eskom installed a 660 kW wind facility in August 2002. Eskom currently charges the Swartberg-Malmesbury municipality approximately 20c/kWh, while Cape Town pays 11-12 c/kWh for bulk electricity. Several areas in South Africa, especially along the coast, have a good wind sites, with estimated mean annual wind speeds of between 4 and 8 m/s at a height of 10 m above the ground (DME et al. 2001). However, wind is a site-specific resource, so that an upper bound of 50 PJ is used (Howells 1999). Availability is an important factor with the intermittency of wind. The turbine availability is considered high, even though ESKOM are experiencing lower availabilities at Klipheuwel with their three turbines reporting 73%,

90% and 75% (Smith et al. 2003). To accommodate uncertainty about the availability of the wind resource itself, wind technologies at a range of availability factors between 25% and 35% are included. The load factor given for the Darling wind farm is 34.5% (personal communication, Herman Oelsner) and that at Klipheuwel is expected to be 20-30% (Smith et al. 2003). The life of each wind turbine is expected to be 20 years (IEA 2003).

- Small hydro stations are based on existing Eskom and private stations. The potential for hydro within SA is limited, especially when compared to the scale of imported hydro-electricity from SADC (a separate policy case).
- Bagasse co-generation stations are already used in the sugar and paper & pulp industries, but new stations may also be installed.
- Hydro-electric capacity constitutes 6 facilities owned by Eskom, 3 by municipalities and 1 by a private generator, accounting for approximately 0.8% of electricity generation in South Africa (NER 2001a). The future potential in domestic sites is limited, with much larger options of importing hydro-electricity (see section 6.6.4).
- Landfill gas (LFG) derives from the organic content of municipal solid waste, and hence the energy source is renewable. Whether it is based on sustainable waste management practices is debated, in the context of initial CDM projects using LFG being proposed for South Africa (Omar & Mncwango 2003; Lumby 1996; TNI 2003). The local benefits are contested, but the benefits of reducing global GHG reductions are clear. LFG projects are included in various size options, with limits on the total capacity related to the waste sites.

The characteristics of the renewable options are summarised for comparison in Table 6.14. The data served as input to the modeling and is broadly consistent with the second NIRP. Presenting the data in a consolidated table allows comparison across the various options. Investment costs vary considerably, with solar thermal being the most expensive at present, while landfill gas and bagasse being competitive compared to alternatives. For many renewable energy technologies, O&M costs are only fixed ones, with no fuel costs. Efficiencies are typically assumed to be 100%, but availability factors are important in reflecting the intermittency of some resources. Note that the molten salt storage for the solar power tower increases its availability relative to the parabolic trough (without any storage).

6.6.2.3 Learning for renewable energy technologies

The initial capital costs of RE technologies are relatively high. Costs of new electricity technologies can be expected to decline as cumulative production increases. To understand the market and economic potential of RE sources for electricity generation, it is important to consider international trends in costs. Chapter 4 reviewed some international cost data on renewable energy technologies, as well as the theoretical potential of the resources.

Table 6.16: Current capacity, increases and progress ratios for RE technologies*Sources: (UNDP et al. 2000; Laitner 2002; NREL 1999; World Bank 1999)*

Technology for electricity generation	Operating capacity, end 1998 (GWe)	Increase in installed capacity in past five years (%/yr)	Number of years for doubling at historical rate ¹	Progress ratio ²
Biomass	40	~ 3	23	85%
Wind	10	~ 30	3	82%
Solar photovoltaic	0.5	~ 30	3	71%
Solar thermal, parabolic trough	0.4	~ 5	14	83%
Solar thermal, 'power tower'	0.4	~ 5	14	88%
Small hydro	23	~ 3	23	-
Geothermal	8	~ 4	17	-
Tidal	0.3	0	-	-

1: Years of doubling own calculation, $\ln(2) / \text{historical increase (\%/yr)}$, and rounding up for small numbers of years.

2: Progress ratios from (Laitner 2002), except parabolic trough (NREL 1999)

Table 6.16 shows estimates, again from the World Energy Assessment (WEA), of how capacity has increased from 1995 to 2000. Using the percentage growth, an estimate can be made of the time it will take for capacity to double – assuming that current trends continue. In some cases, cumulative capacity might double faster (or slower). The approach taken here is to use the estimates based on current trends, together with the progress ratios from the literature. Progress ratios are the changes in costs after doubling of cumulative capacity, as % of initial cost. Based on these assumptions, the investment costs of RE technologies are assumed to decline in future.

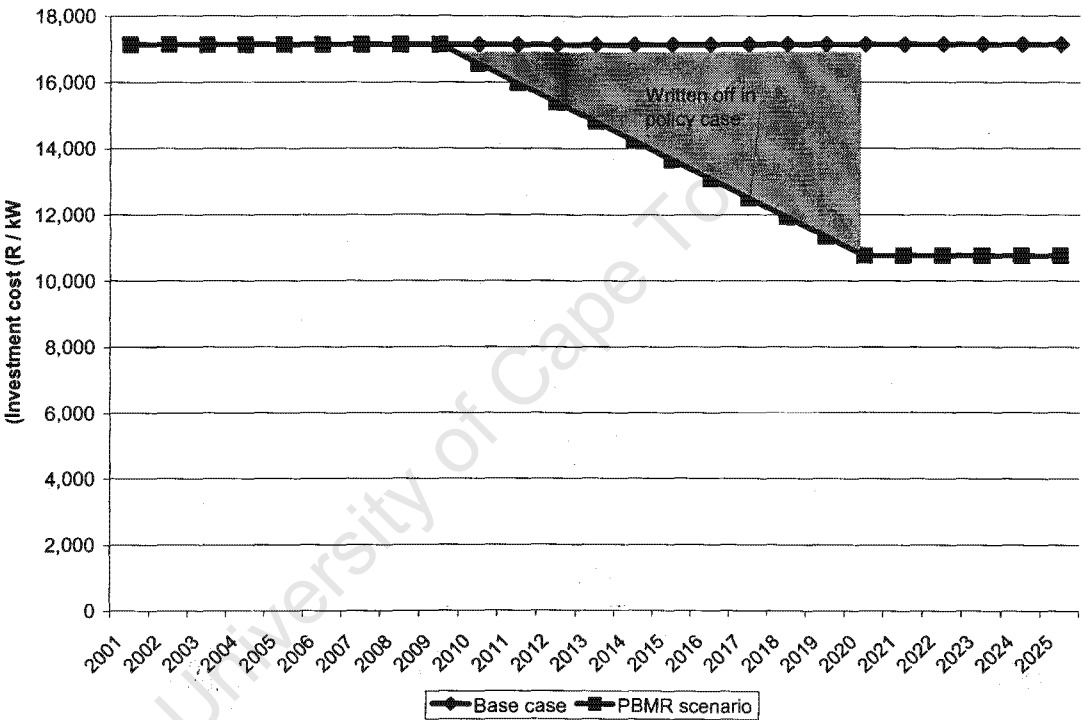
6.6.3 The PBMR option - nuclear

The Pebble Bed Modular Reactor (PBMR) was initially intended primarily for export, but plans have shifted to include it for domestic electricity use. The policy case assumes that the PBMR would be built domestically, and that the Environmental Impact Assessment would be approved.⁴⁵ The PBMR would be developed first with a demonstration module in about 2008, after which modules of eight units of 140 MW each would be developed. The model is required to build a fixed amount per year, an average of 373 MW. In practice this would be in increments of 140 MW units, i.e. 280 MW or 420 MW, etc. The capital costs exclude benefits from avoided transmission losses, if these stations are built at the coast.

⁴⁵ The EIA for the PBMR was initially approved by the Department of Environmental Affairs and Tourism in 2004. However, the NGO Earthlife Africa brought a court case with the assistance of the Legal Resources Centre. The high court required a re-consideration of the decision, taking account of the objections by Earthlife.

The capital costs of the first modules would be significantly higher than later units. In this case, there is no global learning curve, although China began development of a design also based on the original German High Temperature Reactor (HTR) (AEJ 2005). Economies of scale and learning-by-doing would operate at the national level, and by the time the assumed limit of 4 480 MW – based on 32 units – has been reached around 2020, costs are assumed to have declined by more than a third (37%) from those of the first units. The approach is to include technology learning in the policy case, not the base case, similar to the approach taken for the other new technologies based on renewable energy.

Figure 6.10: Schematic description of assumed PBMR costs in reference and policy cases



The PBMR policy case implemented in the modeling for this thesis examines the implications of four such multi-modules being built. PBMR nuclear capacity is increased gradually, reaching 4 480 MW by 2020, taking into account lead times for about four years.

Decommissioning costs of a PBMR eight pack, which have been assessed at between R1.7bn and R2.0bn (at 2003 prices), are included in the investment cost. They would actually be incurred at the time of decommissioning, which could be at any time from the end of plant operating life (40 years) to the point at which the spent fuel is transferred to the final disposal.

6.6.4 The SADC option - importing hydro

One of the major options for diversifying the fuel mix for electricity is to meet growing demand by importing hydro-electricity from Southern Africa. Importing electricity from another

country, rather than generating it domestically, has impacts on the balance of payments. Only if the imported electricity is cheap enough, will it be attractive to incur the extra expenditure and the loss of local capacity and associated jobs. The potential to augment South Africa's small hydro resources (0.8% of generation)(NER 2002a) and imports from Cahora Bassa with further imports was reviewed in chapter 4.

Given the uncertainty associated with the political situation in the Congo, the case for importing hydro-electricity is based on firm power from Mepanda Uncua as for the NIRP (NER 2004c), but assumes that additional hydro-electricity can be imported from Inga Falls (Inga 3). In total, the additional imported hydro-electricity would be 15 TWh by 2010, approximately equally derived from Mepanda Uncua and Inga 3. Imports of 9.2 TWh (NER 2001a).are set as an upper bound in the reference case. The increase in the hydro policy case represents is about two-thirds, increasing linearly thereafter.

The average cost of existing electricity imports was 2.15c/kWh, well below the cost of South African generation in 2001 (NER 2001a). The import costs are part of a long-term agreement with Mozambique for Cahora Bassa. The historical value (equivalent to R6 / GJ) is assumed for imported electricity in the future.

6.6.5 The gas option – importing natural gas

Running a gas-fired turbine requires importing gas, since South Africa's domestic resources are small. Gas is attractive because of its relatively low capital costs, and the contribution it can make to meeting peak demand, a particular concern as reserve margins in SA are reduced.

Gas is being imported by pipeline from Mozambique since 2004, but its preferred use has been for feedstock at SASOL's chemical and synfuel plants. The alternative is shipping of Liquefied Natural Gas, potentially landed at Saldanha in the Western Cape, Coega in the Eastern Cape or Richards Bay in KwaZulu Natal. Construction of a LNG terminal would add two years to the lead time of a project. Gas turbines have relatively short start-up times and play an important role in meeting peak power. Chapter 4 provided some background on switching from coal to gas.

Gas-fired turbines can be run with open cycle or a combined cycle, where the exhaust heat is used in a second loop. Efficiencies of combined cycle gas turbine (CCGT) are about 50%, significantly higher than for the open cycle (OCGT) at 32%. The capital costs of CCGT are, however, some 43% higher (see Table 6.14).

The policy case modeled for imported gas assumes that 1950 MW of electricity is generated from combined cycle gas turbines by 2020. Five units of 390 MW each are constructed with lead times of 3 years spreading them over the period.

Part of this supply could also be met by importing electricity from a gas-fired power station in Namibia. The differences in this option are not quantified here explicitly. While gas-fired electricity generation still has some emissions, these are significantly lower per GWh than for coal-fired plants.

A fuel cost of R21.5/GJ is used for LNG and R45 / GJ for diesel run in an OCGT, based on current wholesale fuel costs (see Table 6.4).

6.6.6 Cleaner coal technology (FBC) in the base case

A potentially cleaner coal technology, namely fluidised bed combustion (FBC) plants, are also taken up in the base case, see chapter 6. The major economic advantage lies in the ability to use discard coal, of which South Africa produces about 60 million tons per year (Howells 2000). The technologies are part of existing policy, with their inclusion in the National Integrated Resource Plan (NER 2004c) indicating a good likelihood of them being built. No separate 'cleaner coal' policy case is constructed, but the benefits of FBC plant being built compared to new pulverised fuel, or the continued operation of existing coal plants is examined.

The capital cost is similar to pulverised fuel plants, just under R10 000 / kW (see Table 6.14). While technical construction time is assumed to be about 4 years, lead times eight and nine years depending on political and technical considerations are reported in the international literature (Van der Riet 2003). O&M costs are still included due to the need to transport the discard coal to the power plant. Efficiencies are slightly higher than for other coal plants, although these are expected to degrade over time.

Other technologies, notably integrated gasification combined cycle power plants, are not likely to be introduced in the medium-term. Since FBC enters the base case, one could assume that it requires no particular policy intervention. However, since there are no plants in operation yet, it is worth briefly examining the impacts against a case without any FBC (i.e. only pulverised fuel plants for coal). The IRP base case envisages 466 MW of FBC by 2013 (NER 2004a; 2001/2). The modeling approach is to examine a version of the base case that explicitly excludes electricity generation from FBC, to examine the contribution made by the technology.

6.6.7 Other options

6.6.7.1 New pumped storage

Pumped storage schemes are a net user of electricity, and therefore results are not reported as one of the supply options. Nonetheless, they have an important role in meeting peak demand.

The demand for electricity is not uniform throughout the day or the year but has peaks in the morning and evening and in mid-winter. By storing energy to meet these peak demands, one can save on the capital expenditure for extra generation capacity. Electricity itself cannot be stored except in limited quantities but energy can be stored in forms that can readily be converted into

electricity. This can be done in batteries, by compressed air and by pumped storage. In pumped storage schemes, water is pumped from a lower dam to a higher in off-peak times and then allowed to flow through a turbo-generator to the lower dam in peak times to produce electricity. South Africa already has pumped storage schemes at Drakensberg (1000 MWe) and Steenbras (180 MWe), and further stations are considered in the second National Integrated Resource Plan (NER 2004c).

6.6.7.2 Off-grid electricity

Off-grid electricity deserves a mention due to its importance in rural electrification (Cowan 2003; NER 2001d). The literature indicates significant operational and institutional barriers to large-scale off-grid concession programmes (Afrane-Okese 2003; Thom & Afrane-Okese 2001; ERC 2004b), and some of the perspectives of local communities were discussed in chapter 3. The overall contribution to electricity supply – even if 350,000 households were supplied – would amount to some 0.2% of residential electricity demand.⁴⁶ This option is not modelled, but some of the existing initiatives are highlighted below.

Currently, most use of renewable energy is for off-grid electricity system using photovoltaics, as well as solar cooking and water heating. Photovoltaic (PV) systems are used as stand-alone sources of electricity in areas remote from the grid, but are expensive compared to grid-connected electricity in South Africa. A number of projects have been implemented:

- The Schools and Clinics Electrification Programme provided off-grid energy services with solar home systems (SHSs) to community facilities. By 2000, 1 852 schools had been connected, and an unspecified number of clinics (DME 2001d: 97).
- A Shell/Eskom joint venture for SHS electrification built 6 000 systems for residential use by 2000 (DME 2001a; Spalding-Fecher 2002c); in 2002, indications were that 4 700 of these systems were operational (Afrane-Okese 2003). Based on recent reports (EC et al. 2000; Stassen 2001), the size of the SHS market, outside of the major government programmes, has been estimated at R28 million in 2000 (Spalding-Fecher 2002c).
- Roll-out of the off-grid electrification programme began in 2002. The programme will target 350 000 homes for SHSs, but had been slowed down by negotiations among government, Eskom, and the concessionaires. In 2002, DME agreed to the subsidy level (Kotze 2001) and Eskom's role in the programme was clarified. Concessionaires have signed interim contracts, with NuonRAPS, EdF and Solar Vision each installing some 200 systems.

⁴⁶ Own calculation of 0.06 TWh from SHS, as share of 34.6 TWh (NER 2002a).

For residential customers who wish to use renewable energy with a grid connection, two-way metering would be a benefit. Households can sell excess electricity during times when their resource is high (e.g. the sun shines) but demand low. They obtain credit and buy electricity from the grid when conditions are reversed – low supply but high demand.

6.7 Conclusion

The chapter has motivated a focus on energy policies modeled for this thesis – the residential demand and electricity supply sectors. Key drivers for changes in the base case were identified as economic growth, population and technological change. Each of these factors is complex in its own right, as the discussion of population growth made clear. The projections made about future urban / rural dynamics, levels of poverty, household size and the impact of AIDS make an important difference, and impact on the projections of residential energy demand. An important change from previous analysis is the disaggregation of households into household types, allowing at least a basic differentiation of energy use patterns in a national model.

The base case projections for residential demand was placed in the context of other demands, with residential demand being one of the smaller sector. Supply was considered in the broader mix of primary energy supply, and more specifically the fuel mix for electricity supply. In the base case, SA will clearly remain dependent on coal for electricity generation up to 2025, particularly if analysed by generation rather than capacity.

The heart of this chapter outlined energy policies and how they were modeled. On the supply-side, the implications of increasing shares of four major options – renewable energy, PBMR nuclear, importing hydro or natural gas – form the heart of the policy cases. The impacts of cleaner coal, which is already represented through FBC in the base case, are considered as well.

Residential energy policies have a large component of efficiency, be it more efficient houses, or specific appliances such as CFLs. Solar water heaters both use a cleaner energy source, and improve the efficiency of providing energy for heating water. An option of geyser blankets was included, being more affordable. The importance of energy for cooking meant that a switch from electricity, paraffin, coal or wood to LPG is modeled.

While the focus in this chapter is on modeling, the overall development objectives that the policies are intended to meet were not forgotten. The policies add up to a substantial contribution to energy for sustainable development. In the next chapters, the results will be analysed policy by policy (chapter 7) and against indicators of sustainable development (chapter 8).

CHAPTER 7

7. Discussion and interpretation of results

The policy cases specified in chapter 6 are examined in this chapter case by case. First, the results for policy cases in the residential demand sector are reported, followed by electricity supply options. The base case serves as a benchmark for each of the policy cases. An evaluation against indicators of sustainable development in chapter 8 will allow comparison across both demand- and supply-side policies. Table 8.21 provides a consolidated table of quantitative results. The discussion here focuses on results of particular importance to the policy in question, starting with residential energy policies.

7.1 Residential energy policies

The results from the modeling of residential energy policies for social, environmental and economic dimensions are summarized in Table 7.1. The table will be combined in chapter 8 with a similar one for electricity supply. The results for each policy – i.e. column by column – are discussed in the following sections.

Table 7.1: Overview of results for residential energy policies

Indicator	Unit	Base case	Efficient houses	CFLs	Water heating - SWH / GB	LPG for cooking	Residential pol's combined
SOCIAL							
Fuel consumption in residential sector	PJ						
Electricity	2014	98.9	93.1	98.9	95.9	96.4	98.3
	2025	116.8	104.9	116.8	110.3	112.6	115.5
Liquid fuels	2014	51.9	43.0	51.9	51.9	41.3	51.9
	2025	58.9	39.3	58.9	58.9	36.1	58.9
Renewable energy	2014	1.7	7.9	1.7	1.7	9.5	1.7
	2025	3.5	16.7	3.5	3.5	20.1	3.5
Total fuel use	2014	201.1	195.3	201.1	201.5	195.2	200.5
	2025	213.5	202.3	213.5	214.4	202.1	212.3
Cost of energy services to households	c / kWh	37.8	34.2	34.8	34.8	34.8	34.2
<i>electricity in common units</i>	R / GJ	105.1	95.1	96.7	96.7	96.7	95.1
Cost of energy services to households: Shadow price of non-electric fuels, residential							
Coal for HHs	R / GJ	3.5	3.5	3.5	3.5	3.5	3.5
Biomass		30.0	30.0	30.0	30.0	30.0	30.0
LPG		149.4	149.4	149.4	149.4	149.4	149.4
Paraffin		96.9	96.9	96.9	96.9	96.9	96.9
Candle wax		70.3	70.3	70.3	70.3	70.3	70.3

Despite a much greater investment in residential energy technologies compared to the base case – annualised investment in 2025 is 2.9% higher in 2025, compared to the base case, an amount of R 0.87 billion).

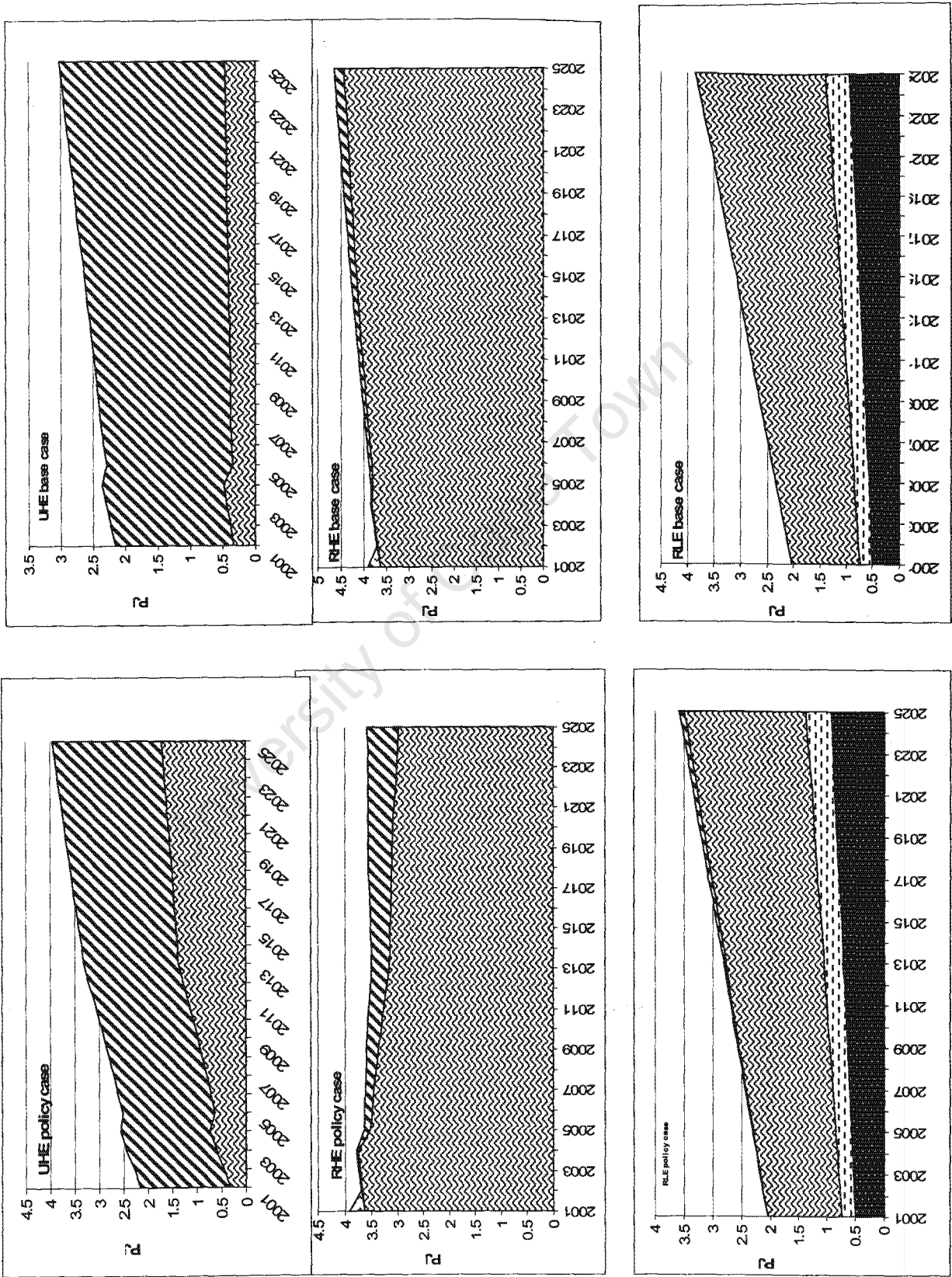
Efficient houses reduce local and global air pollutants, as shown in the environmental section of Table 7.1. Local air pollutants are reduced between 1 -2 % against the base case, amounting to 46 000 tons of SO₂ and 23 000 tons of NO_x reduced. Reduction in GHG emissions of 7.5 Mt CO₂-equivalent are achieved by the policy in 2025, which derive mostly (97%) from CO₂ from electricity generation. A simple estimate of abatement cost divides the total emissions reductions (policy – base case) by the incremental costs of investments in technologies.

The results of the policy case have demonstrated higher investment in efficient technologies, reduced local and global pollution, energy savings and reduced energy bills for households, and a benefit for the total energy system. A key policy question (see chapter 9) is whether efficient houses are affordable, even if they make economic sense at a national and household level.

7.1.2 Efficient lighting for improved services

The lighting policy case considered the further spread of CFLs and a continued, albeit slight reduction in costs. The changes seen in three household types illustrate the effects of the policy intervention, (Figure 7.2, policy shown on the left, compared to the base case at right). A striking result is that the share of CFLs for richer urban electrified (UHE) households looks bigger in the base case. This is indeed the case, although one should note that total demand for lighting services is higher in the policy case (4 PJ versus 3 in the base case).

Figure 7.2: Changes in lighting technologies in the CFL policy case



The explanation for the finding, then, is partly that CFLs indeed are an intervention that should work well in the market. Particularly more affluent households should be able to purchase CFL as a least-cost strategy, given the price reductions that have already occurred (see chapter 6). The second factor is that some of the energy savings are 'taken back' by UHE households consuming more energy.

For RHE households, the pattern is more as expected, with CFLs displacing incandescent lights. Population growth is projected to occur mainly in urban areas, so unlike the urban counterpart, growth in household numbers is not a major factor. For poor rural households, consumption levels are low and CFLs show up only as a small band at the top. ULE households (not shown) have a greater share of CFLs displacing paraffin and candles.

What implications do the changes in CFL penetration rates for the overall system (see Table 7.1). Overall system costs are affected less than 0.1%, with lighting being a smaller end use than space heating, in the case of efficient houses above. The annualised investment cost in residential technologies actually *declines*, only by 0.7%, by 2025. The reasons are that the longer life of the CFLs, together with their declining costs, make them more competitive.

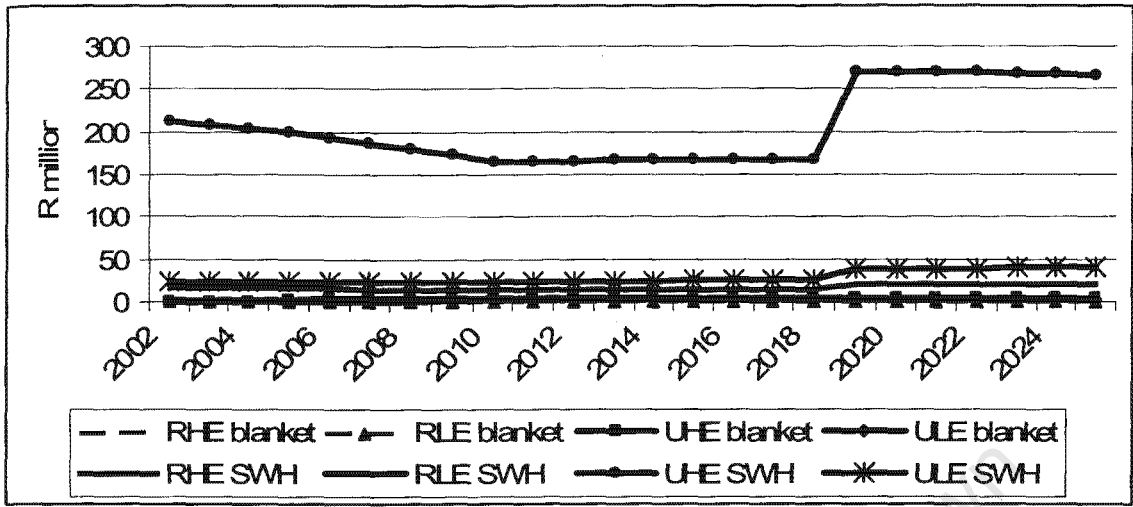
Households certainly can make energy savings, with total fuel use, in the form of electricity, declining by 1.23 PJ against the base case (or 342 GWh in electricity units). The more efficient use of electricity reduces the opportunity cost of electricity, the shadow price drops by 3 c / kWh. Reductions in household expenditure are highest for UHE at R 13 per household per month. Consumption of lighting services in this group is highest, hence the largest savings can be made. Arguably as significant is the almost R5 each poor urban electrified household can save from more efficient lighting alone.

The implications for local air pollution are not large compared to other residential policy cases. Reductions in local pollutants are small - CFLs mainly avoid incandescent electric lighting, with no local emissions. Even the limited use of other fuels is contained, unlike for cooking. The absolute value of reduction of GHG emissions is moderate at 336 kt CO₂ avoided through CFLs in 2025.

7.1.3 Providing hot water with solar energy or insulation

The solar water heater / geyser blanket (SWH/GB) policy case increased the range of cleaner and more efficient water heating. Investments in SWH and geyser blankets total R 339 million in 2025 in the policy case. All but R 7.6 million (2%) is invested in SWH. Figure 7.3 shows that the required investments for the policy case are mostly spent in UHE households.

Figure 7.3: Invest costs for SWH and geyser blankets by household type



The aggregate figure only tells part of the story, however, as Table 7.3 shows.

Table 7.3: Energy saved and costs for cleaner water heating

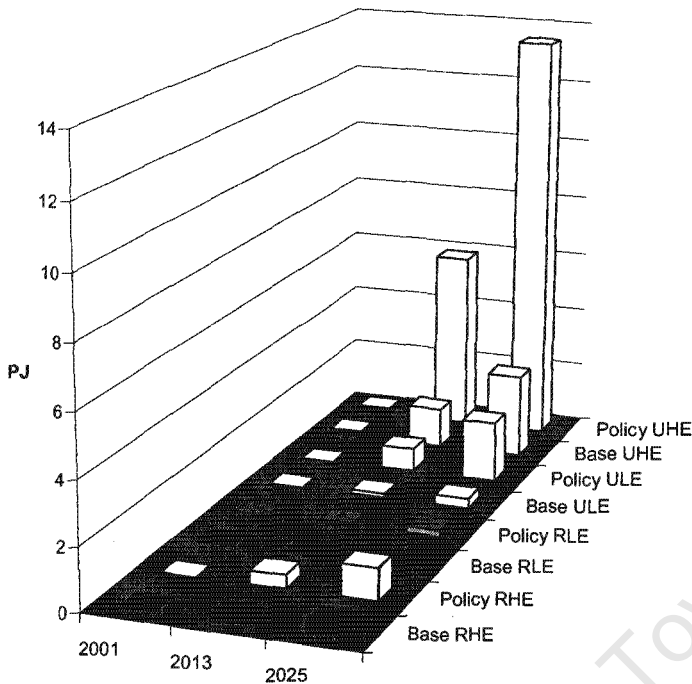
	Saved energy (policy – base case)	Total investment in policy case	Cost of saved energy	
	PJ	R million	R / GJ	c / kWh
Geyser blanket	4.9	7.6	1.5	0.6
Solar water heater	13.3	331	25.0	9.0

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

The policy results in a three-fold increase in the use of solar energy in the residential sector; while the use of other fuels, notably liquid fuels like paraffin, for water heating decline. Total fuel use is 3% lower with SWH and geyser blankets than in the base case. Figure 7.4 shows the savings by representing the equivalent of fossil fuel use that would have been consumed in the place of solar energy. The Markal model assigns a ‘fossil-equivalent’ to renewable energy consumption, taking into account the relative efficiencies.⁴⁷

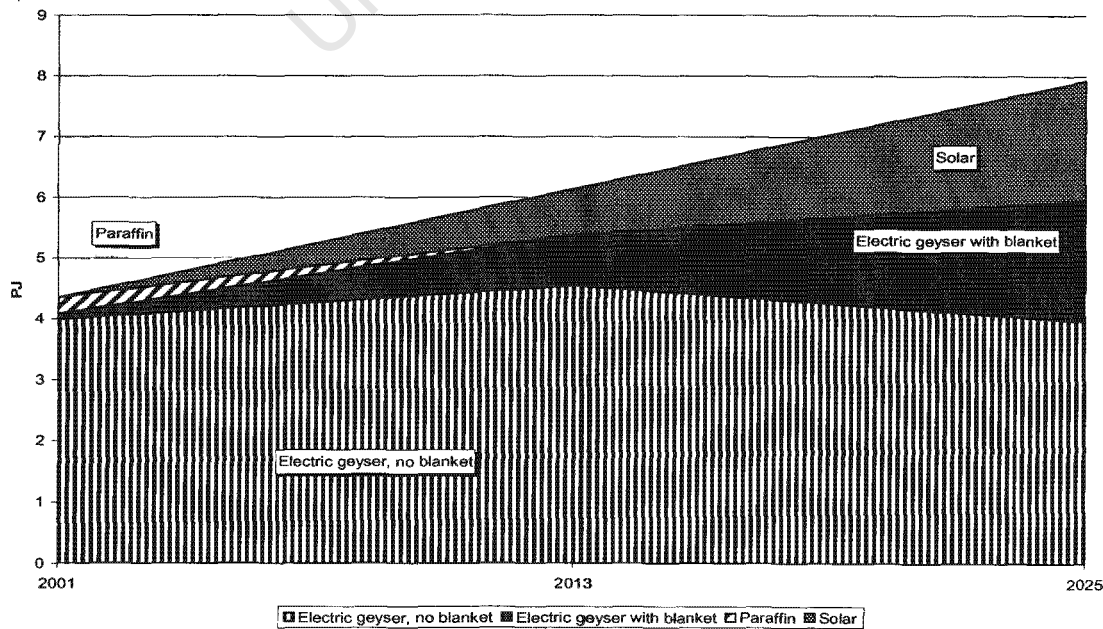
⁴⁷ The value of the parameter is a unitless 3.125 of fossil-fuel energy per unit of solar energy; the same value is used throughout the model.

Figure 7.4: Equivalent of fossil fuel use for solar water heating, by household type (PJ)



For all household types, the energy savings increase over the time – three years are selected here. Clearly, the greatest savings are made in the UHE household type. And the policy case shows clear gains over the base case for the respective household. To illustrate how the fuels used for water heating change over time, the example of ULE households is shown in Figure 7.5.

Figure 7.5: Energy used for water heating by urban low-income electrified households



The figure shows how solar water heaters increase their share over the period, completely displacing paraffin use at the end. The reduction of paraffin use is important from the social perspective, given the problems associated with its use in South Africa's poor communities (Mehlwana 1999a; Lloyd 2002). Electric geysers provide most of the water heating services, but an increasing portion are insulated with blankets.

The saving on energy bills for households is about 8% on the water heating bill. Continuing with the ULE household example, this translates into R 5 less spent on water heating per household per month.

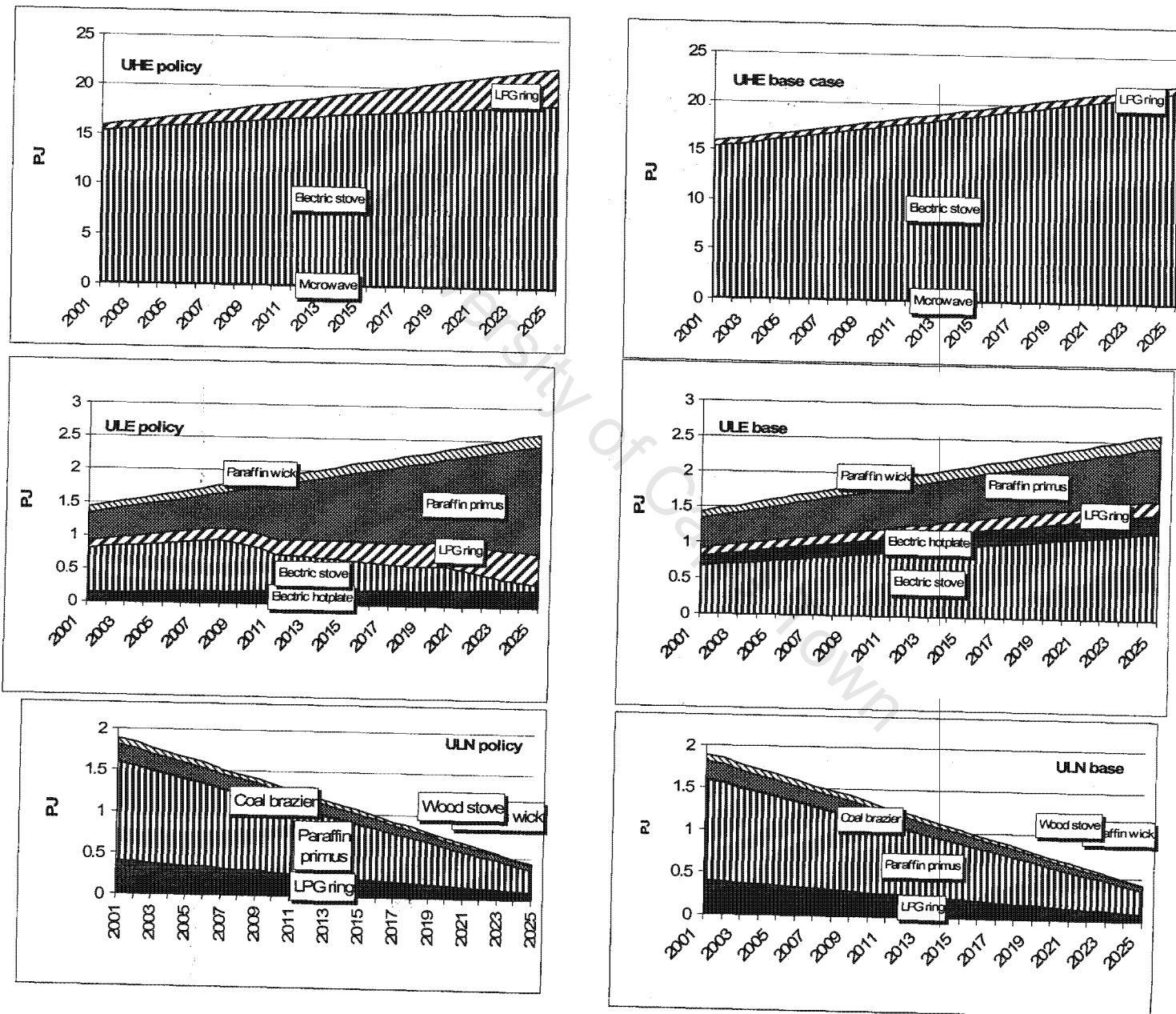
In terms of reducing local air pollution, reductions of 18 800 tons of NO_x is notable, and SO_2 emissions are 40 000 tons less than in the base case. From a climate change perspective, a reduction of 5.9 Mt CO_2 can be achieved in 2025 at a cost of R 21 / t CO_2 –equivalent.

7.1.4 Switching to LPG for cooking

Cooking is one of the socially most important uses of energy. The LPG policy case requires households to switch from electric and other cooking devices to LPG stoves and rings. Other cooking fuels commonly used by poor households for cooking, such as paraffin, coal and wood, have health impacts when used indoors. Figure 7.6 shows the changes resulting from wider ranges for LPG for three household types (policy shown at left compared to the base case at right). For UHE households, the wider range that the model is allowed has the expected effect. LPG stoves replace electric stoves for cooking needs. For the poorer urban electrified households (ULE), however, the fuel switch to LPG does take place, but another switch happens at the same time. The use of paraffin primus stove increases even more dramatically than for LPG.

The changes are the result of the model choosing least-cost options. The switches in fuels change relative prices of fuel costs. Electric stoves have become too expensive, and are partly replaced by hotplates as well. In addition, the investment costs of LPG cookers are slightly higher (R250) than for hotplates (R 230), and about double those for paraffin primus (R107) and much higher than wick stoves (R37) (see Table 6.13 for the full range).

Figure 7.6: Fuel switch to LPG for three household types



For non-electrified urban households (ULN), the effect of the policy case is negligible. The declining overall use due to electrification far outweighs the impact of the fuel switch.

Considering all household types, the LPG policy case has a relatively small impact on total energy system costs (see Table 7.1). The investments made are relatively modest. Investments required in LPG cooking appliances are R 176 million in 2025, the lowest for all the residential policies.

Despite this modest investment, 11 000 tons of SO₂ can be avoided, as well as 5 000 tons of NO_x. While substantial in absolute amounts of local air pollutants avoided, these reductions are below 1% compared to the cooking fuel mix in the base case. In addition, some 1.4 MtCO₂ can be avoided through the cooking with LPG, at a cost of only R 7.7 per ton of CO₂.

Total fuel use (in energy units) *increases* by 0.9 PJ over the base case in 2025, but this amounts to only 0.4% of total fuel use. Looking more closely at the fuels used, electricity consumption is reduced by 6.5 PJ. For RHE households, associated expenditure on electricity for cooking is reduced from R 87 / HH * month in the base case to R 80. However, given the patterns shown in Figure 7.6, some subsidy for LPG may be required if higher penetration rates of a cleaner fuel are desired (beyond UHE households). Such a 'subsidy' need not be directed at the fuel cost, but at making the fuel more readily accessible.

7.1.5 Conclusions on residential policies

Each of the residential policy cases modeled in Markal has been discussed separately above. Table 7.1 provided an overview of results. In conclusion, the effects of combined policies are considered. Given the importance of the analysis of residential energy by household type, some concluding comments draw together the results from individual policies in this respect.

A policy case combining all four individual residential policies was included in the Markal model. The combined policy case includes solar water heaters, geyser blankets, efficient houses, CFLs and allows fuel switching to LPG. The results are reported in the last column of Table 7.1.

Fuel consumption in the combined case decreases against the base case. The rows showing total fuel use in Table 7.4 indicate that the highest reduction comes from the efficient house case. The effect is particularly due to the reduction in liquid fuels, mostly paraffin. Note also the declining trend in paraffin for water heating, from the mid-term year 2014 to the end year 2025. The reduction makes the SWH / GB policy case the second-lowest in total fuel use of the individual policies.

Table 7.4: Fuel consumption in the residential sector across policy cases, 2014 and 2025

	PJ	Base case	CFL	Efficient houses	LPG for cooking	Water heating - SWH /GB	Residential policies combined
Electricity	2014	98.9	98.3	96.4	95.9	98.9	93.1
	2025	116.8	115.5	112.6	110.3	116.8	104.9
Liquid fuels	2014	51.9	51.9	41.3	51.9	43.0	43.0
	2025	58.9	58.9	36.1	58.9	39.3	39.3
Renewable energy	2014	1.7	1.7	9.5	1.7	7.9	7.9
	2025	3.5	3.5	20.1	3.5	16.7	16.7
Total fuel use	2014	201.1	200.5	195.2	201.5	197.8	195.3
	2025	213.5	212.3	202.1	214.4	206.8	202.3

An important dimension of this thesis is the analysis of the residential sector across household types. In the discussion of the results of individual policy cases, several examples of the differential impact across household types were noted.

A consistent finding was that the greatest energy savings from efficiency were to be made in UHE households. The reduction in fuel use for this household type was greater in absolute terms. Beyond that, the expenditure on energy *per household* also decreased the most. Energy savings translate directly into expenditure when measured in terms of Rand spent monthly on energy per household. The case of efficient housing showed reductions in monthly energy expenditure, where highest in Rands per month for UHE, but similar in the percentage saved.

Given the higher consumption, the higher savings for UHE households are trivial in one respect – the same percentage saving applied to higher consumption (more kWh or GJ) would automatically yield a greater saving. The policy question that arises, however, is how much the savings affect affordability – what difference do the monetised savings make to household income. Put another way, further analysis is needed to indicate to what extent the saving might relieve the energy burden of the household.

A starting point is to consider energy consumption across housing types. Cutting across the policies, Table 7.5 shows the variation of energy consumption for different household types by 2025. Policy cases are associated with particular end uses – CFLs with efficient lighting, SWH / GB providing cleaner and more efficient water heating, better insulated housing shells reducing the energy needed to heat space, and LPG use focusing on cooking.

Table 7.5: Energy consumption by end use for household types, 2025

MJ / (HH * mth)	RHE	RLE	RLN	UHE	ULE	ULN
Cooking	126	45	162	324	95	118
Lighting	261	99	1	156	136	-
Other electric	261	6	-	290	8	-
Space heating	119	40	178	334	160	112
Water heating	201	51	102	475	288	55

Table 7.5 illustrates the significant variation across household types in monthly energy consumption. Taking the highest consumption type, UHE, as 100%, ULN only consume in aggregate 18% as much energy per month, and RLE 15%. The shares for RLN households are increased beyond expected levels, since relatively large portions of their energy requirements are met from wood or coal in inefficient appliances. As noted in individual policies, however, the number of households in the RLN and ULN categories are small by 2025. The comparison here is per household, and the implications for household income will be explored further in the following chapters.

Not all measures achieved energy savings greater than the base case for in all households. The LPG case showed the expected fuel switch only in some households, e.g. ULE. However, other changes took place at the same time, with more paraffin being consumed, reflecting different investment costs of the appliances as well as relative prices changes. UHE households already had shifted to LPG in the base case as an optimal strategy, while for ULN, the shift hardly showed up, since household numbers in this group declined with electrification.

Put differently, some policy interventions are already ‘optimal’ in a least-cost framework. Efficient lighting was found to be a policy intervention that should work in markets for higher-income households. Penetration rates in the least-cost framework were high. In a case such as CFLs for richer households, market mechanisms are clearly appropriate as policy instruments.

Other policy cases may need more intervention for benefits other than economic ones. Water heating, for example, was shown to change the fuels used for water heating in ULE households. The social benefits from savings for poorer households and improved indoor air quality would motivate this policy, rather than least-cost optimality.

Having examined the results of residential policy intervention, the next section provides an insight to the implication of different electricity supply options.

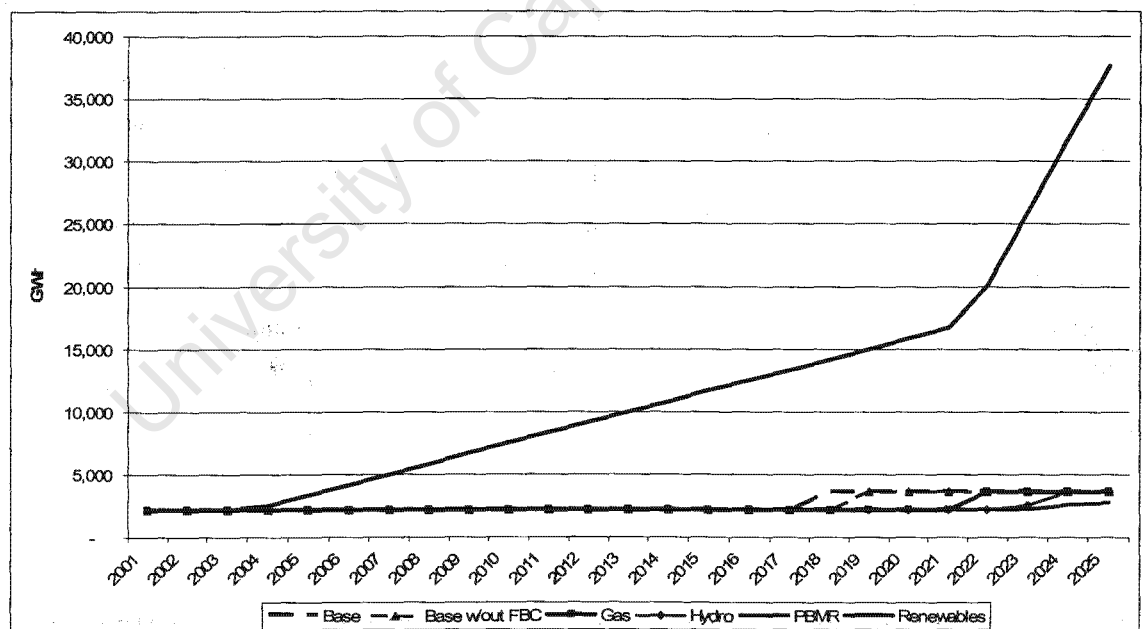
7.2 Electricity supply options

The various options for electricity supply options are best compared across the major dimensions of sustainable development – economic, social and environmental. Since the focus of chapter 8 is such an evaluation, most of the comparison is reported in that chapter. Note also that chapter 6 already reported important *input* parameters (see Table 6.14). In this chapter, key results for each option are highlighted briefly, reporting policy by policy.

7.2.1 Renewable energy

The renewable energy policy case was designed to meet the target of 10 000 GWh by 2013, with a combination of technologies – biomass (bagasse and pulp & paper co-generation), wind, solar thermal (trough and power tower), small hydro and landfill gas. Costs of renewable energy technologies were assumed to decrease as global markets grow. The increase in electricity generation from renewable resources is clearly apparent in Figure 7.7, which shows the renewables case increase well above all other policy cases and the base case. Note that the increase occurs gradually up to the 2013, the year the target is set, and beyond. The sharp turn-up after 2020 reflects the fact that renewables have become competitive with other technologies.

Figure 7.7: Renewable energy for electricity generation by policy case

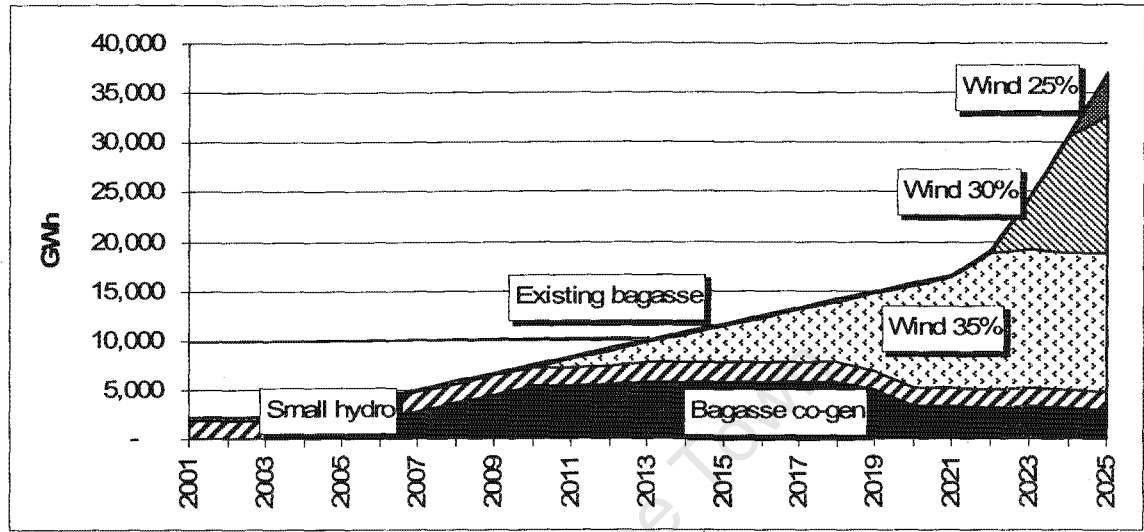


Consequently, diversity in the fuel mix is increased. By 2025, the share of electricity generated from renewable sources increases to 11%, while other, mainly generation decreases, notably coal from 88% to 78%. Even in this policy case, however, three-quarters of electricity still comes from coal over a 25-year period.

The renewable energy technologies chosen in the policy case include existing bagasse and small hydro facilities (see Figure 7.8). New bagasse co-generation and wind are the two new

technologies that are chosen by the model. For wind, the technology assuming the highest availability factor (35%) is chosen first, up the available capacity. Some wind at the lower capacities is added in later years. The solar thermal and landfill gas technologies are not chosen.

Figure 7.8: Contribution of renewable energy technologies to meeting the target by 2013



One measure of the choice of technology is the marginal investment. The ‘investment marginal’ result parameter in Markal is not the same as the investment cost. Rather, it is the additional cost to the energy system of adding *another unit* of the particular technology. The model seeks an optimal, least-cost solution, the marginal investment if the *difference* between the cost of the technology considered and the cost of the one it displaces in the optimal run. In the renewables policy case, the investment marginals for solar thermal electricity have reduced from R10 803 to R 9 408 per kW for the parabolic trough by 2025, and similarly from R 11 754 to R 7 731 / kW for the ‘power tower’. However, the costs difference between other renewable energy and the least-cost technology is even smaller at this point. Therefore, despite the reductions in the costs of solar thermal electricity, the technology does not compete on a least-cost basis within the 25-year period.

Overall, additional investment in electricity supply technologies is needed. Focusing only on the investment in supply technology shows an increase of R 6 billion, but in the balance of the energy model the increase in total system costs is significantly lower at R 1.9 billion. While this is a large amount, it is 0.03% of the total system cost in the base case. For all policy cases, it should be remembered that the total system cost is large and absolute Rand amounts should be understood in this context.

Local air pollution is reduced in the renewables policy case, in particular for sulphur dioxide and nitrogen oxides. SO₂ emissions are 6% lower than in the base case (197 kt), while 96 kt NO_x can be avoided (4%).

Reduction of global greenhouse gases (GHGs) contributing to climate change are achieved with renewables policy. GHG emissions in 2025 are 32 Mt CO₂ or 5% lower than in the base case. Looking at the individual GHGs, the change is mostly in the form of a reduction of CO₂ (5%). Nitrous oxide declines by 4% as well, but despite its higher global warming potential contributes less to the total GHG reduction. The reduction in the two gases outweigh a 2% increase in methane, which results from the increase in biomass used in some of the renewable energy technologies.

Considering the social dimension, all the policy cases assume that electrification rates increase as described in the base case. Urban households achieve higher rates of electrification by 2025, as shown in Table 7.6.

Table 7.6: Share of households with access to electricity in 2025 for all policy cases

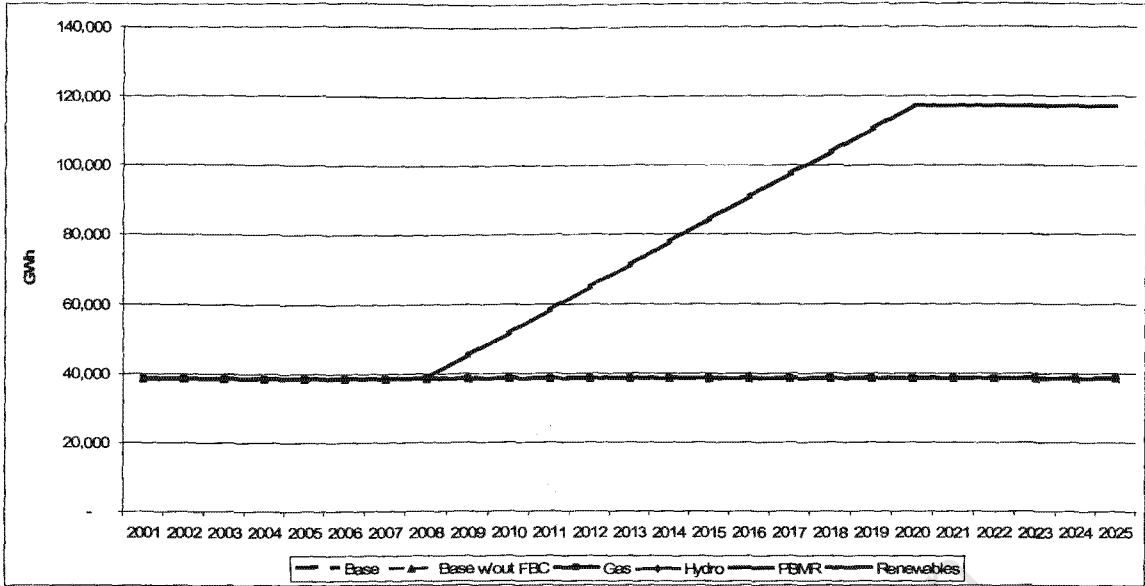
Electrified total	92%
Electrified urban	96%
Electrified rural	83%

The social dimensions of sustainability – often with important qualitative dimensions - will be discussed more fully in chapter 8. The indirect effect of electricity supply options, via the price of electricity, will be part of that discussion.

7.2.2 PBMR nuclear

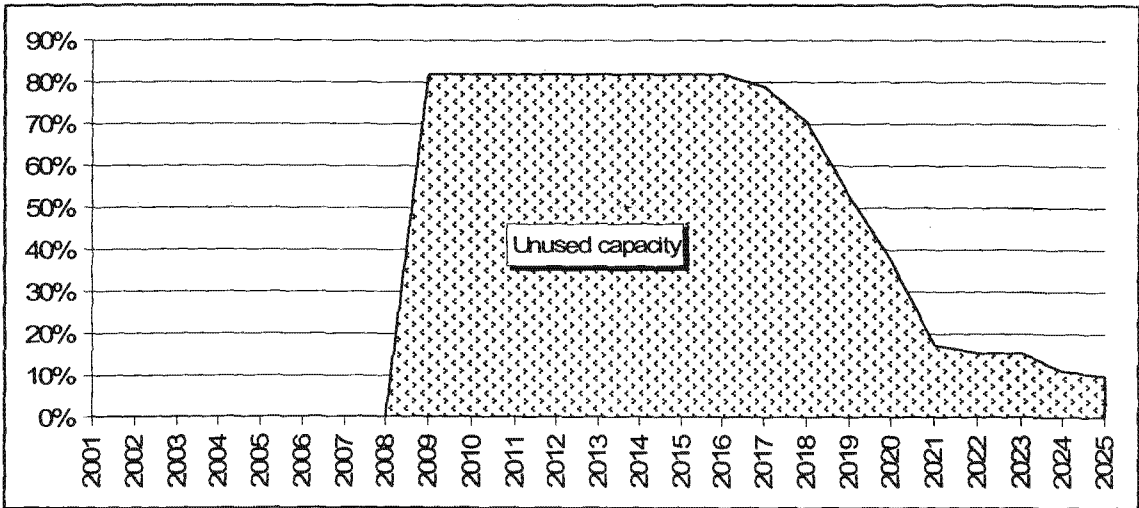
The PBMR policy case required 4 480 MW of nuclear electricity generation capacity to be built by 2020, with costs declining as more units are built. As expected, such a requirement would shift the fuel mix for electricity generation dramatically to nuclear energy, comprising a third of the total (34%) by 2025. Figure 7.9 shows the increase of electricity generation in the PBMR case, with all other policy cases following the base case. Virtually all the displaced generation is coal-based for the PBMR policy case, with the share of renewable energy technologies decline slightly from 1.0 to 0.8%. Note that when the requirement is relaxed after 2020, nuclear generation capacity remains constant at the 2020 level.

Figure 7.9: Nuclear energy (PBMR) for electricity generation by policy case



Greater diversity comes at a price. Annualising the investment costs for all electricity generation technologies, and adding them up over the 25 years, indicates that 50% *extra* would be invested in electricity supply technologies. For all electricity supply technologies, the cumulative investment cost would be R 141 billion in the policy case, rather than R 93 billion in the base case. However, again the balance of the electricity system means that investment costs are partly off-set. The balance can only be struck partially, however, in the aggressive policy requirement for building nuclear capacity, and is forced initially to leave much of the PBMR capacity unused.

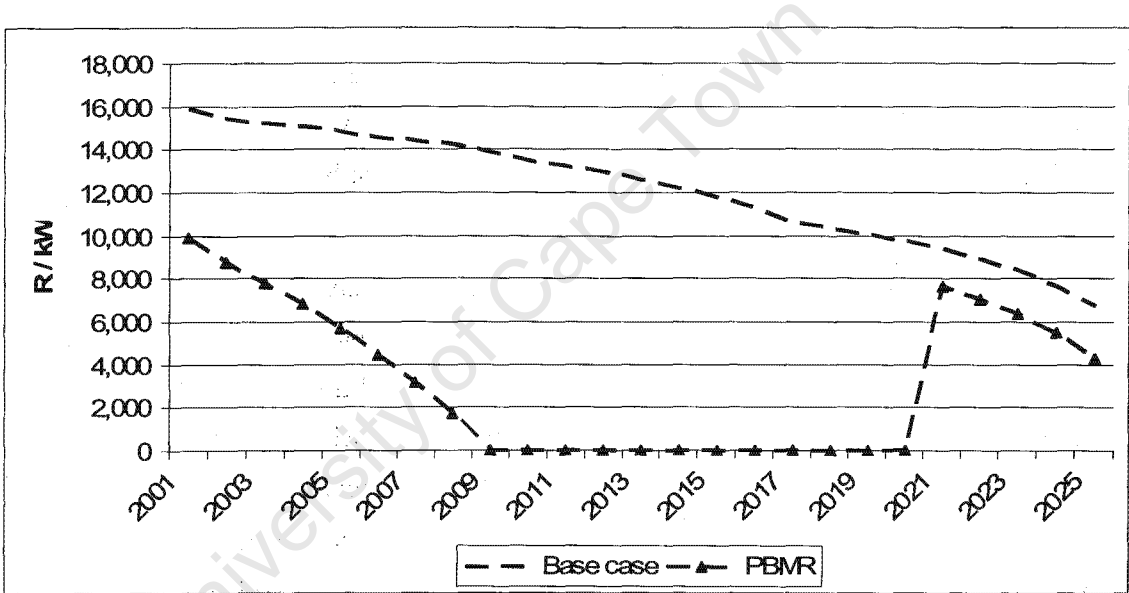
Figure 7.10: Unused capacity of the PBMR in the policy case



Only as costs decline from 2015 onwards, is the capacity utilised more effectively. The total cost of the energy system increases by R 12 billion over the period, compared to the base case. The unused capacity suggests that the policy case may be too ambitious. At least, nuclear capacity should be phased in more gradually if it is built domestically at this scale.

Figure 7.11 shows the marginal investment required in both the base and PBMR cases. In the base case, it declines gradually, but in the policy case more sharply. It reaches zero in years in the policy case where actual investment takes place, but then rises again after 2020. However, the investment marginal remains below the base case throughout, given the favourable assumptions about decline in costs with domestic production.

Figure 7.11: Marginal investment required for more PBMR capacity



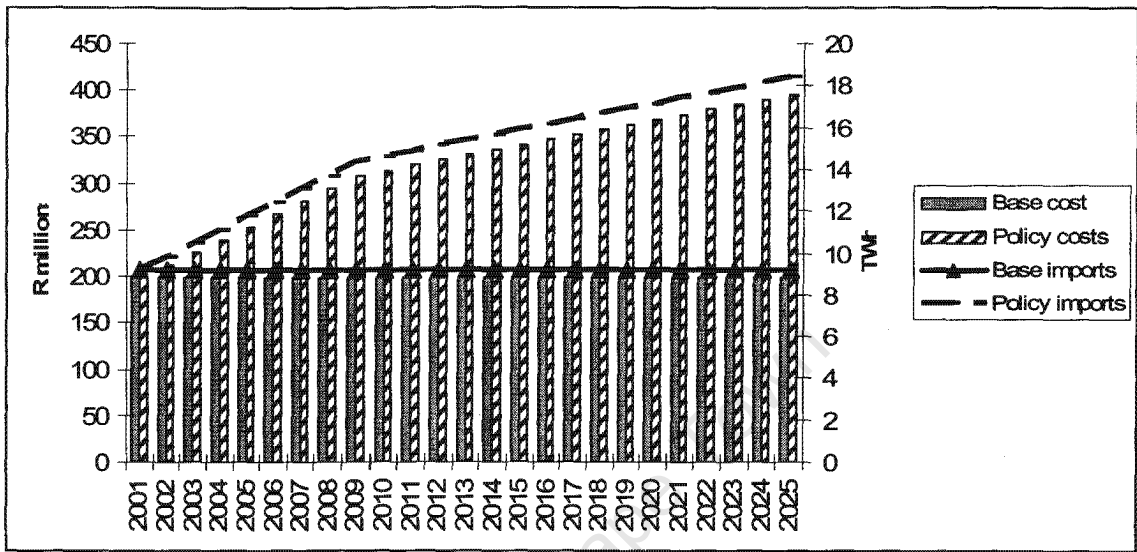
The PBMR case avoids significant amounts of local air pollutants, notably 210 ktSO₂ (6% less sulphur dioxide than in the base case), and 5% NO_x (102 kt) in 2025. 33 MtCO₂-equivalent of global GHGs are reduced in that year, mostly in the form of CO₂ with a small reduction in nitrous oxides. As discussed above, the PBMR policy case meets the same goals of increasing access to electricity as for all policy cases.

7.2.3 Importing hydro-electricity from SADC

The policy case of importing hydro-electricity increases the amount of hydro-electricity, almost doubling from current levels of 9.2 TWh to over 18 TWh by 2025. The imports incur a resource cost, as shown in Figure 7.12 by the bars measured on the left-hand axis, reaching R 395 million by 2025. Analysis of the direct costs, however, only tells part of the story, with the reduction in investment in other supply side options being the other side. The modeling

framework shows that, over the period, cumulative investments in electricity supply technology are reduced by R 11 billion. The reduction in total energy system costs, however, is much lower at R 3 billion, off-setting the gains against import costs shown in the figure.

Figure 7.12: Imports of hydro-electricity and import costs in policy and base case



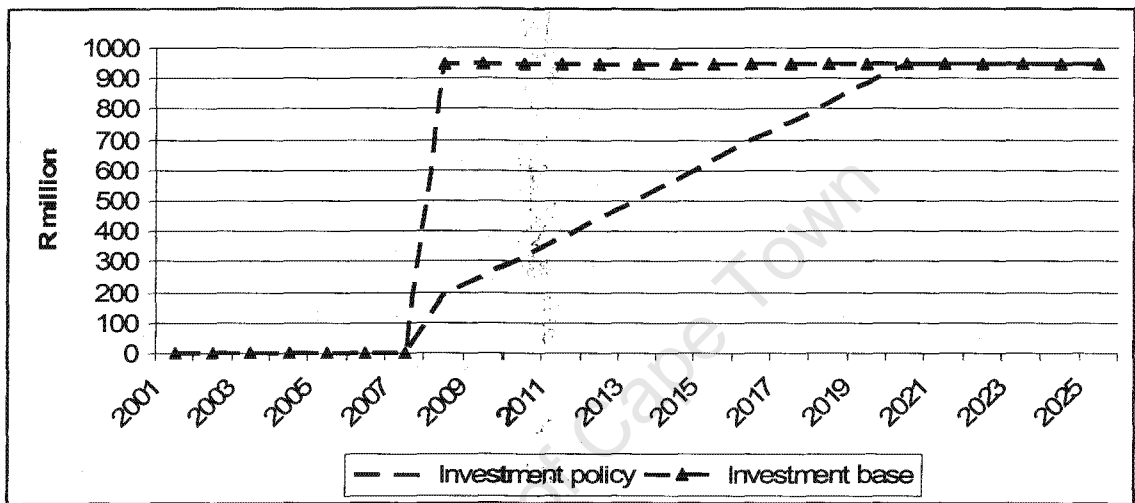
Extra imported hydro-electricity increases the share of renewables by one-tenth of a percentage point, but system changes reduce the share of coal-fired electricity from 88% to 87%. Reductions in local air pollutants amount to 142 kt SO₂ (4% less than base case) and 70 kt NO_x (3%). Total GHG emissions are reduced by 4% or 22 Mt CO₂-equivalent. However, it should be noted that part of this is a reduction in methane emissions. The emissions of methane from large dams are subject to on-going research (IPCC 2001b; Dos Santos et al. 2006), and the assumption that hydro-electricity is zero-emissions may change as more information becomes available.

7.2.4 Importing gas for electricity generation

The imported gas policy case reduces the overall system cost by R 0.8 billion over the 25 year time horizon, compared to the base case. As with hydro, the costs of the imported fuel need to be taken into account. The shadow price of electricity is reduced to by 0.5 c/ kWh, completing a picture where the reduced domestic investment costs outweigh the increase in expenditure on importing gas. These results are sensitive to the assumptions made about future fuel prices in chapter 6. The natural gas price was assumed to be R 21.5 / GJ (Table 6.4). The gas price was significantly higher in Rand terms when the currency weakened against the dollar, apart from fluctuations in the dollar-denominated prices of oil and gas in international markets.

The base case as reported in chapter 6 reflected the plans of the National Integrated Resource Plan (NIRP) and reflected some capacity invested in gas. The policy to import a fixed quantity of gas changes relatively little, but does optimize more effectively the use of the gas-fired capacity which is built. The NIRP brought in the full capacity in 2008, whereas in the policy case, a more gradual introduction allows better adjustment (see Figure 7.13). In both cases, a lead time is required before the investment begins in 2008.

Figure 7.13: Annualised investment in combined cycle gas in the policy and base case



Importing gas makes no difference to the domestic fuel mix – the shares of electricity from coal (88%), renewable energy (1.1%) and nuclear (11%) energy sources remains the same in percentage terms as in the base case. The share of natural gas used is does not changed significantly (less than 1%).

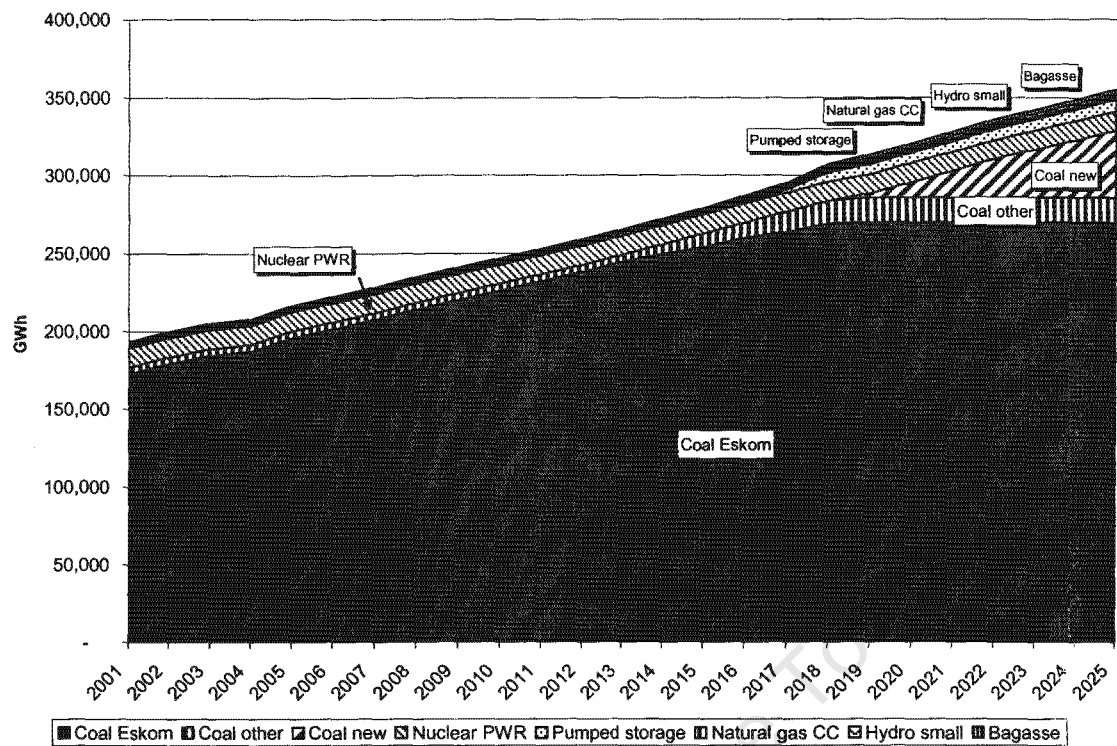
Despite the small changes, gas is a cleaner-burning fuel than coal, and some reductions in local and global air pollutants are observed. Relative to the base case, the reduction for sulphur dioxide, nitrogen oxides and greenhouse gases are all 2% lower for the policy case. The reductions amount to 83 ktSO₂, 42 kt NO_x and 14 Mt CO₂-equivalent.

7.2.5 Cleaner coal technology in the base case

Chapter 6 outlined that fluidised bed combustion (FBC), a technology using discard coal for electricity generation, is included in the base case and no separate policy case was constructed. Here, the contribution made by the technology is examined by briefly presenting results for a version of the base case that explicitly excludes electricity generation from FBC.

Figure 7.14 shows electricity generation grouped by fuel, comparable to Figure 6.4 for the base case. By design, there is no discard coal, with the slack being taken up mostly by additional new coal-fired plants (10,650 GWh in 2025), with a small increase in bagasse (811 GWh).

Figure 7.14: Electricity generation without Fluidised Bed Combustion



The total system costs *with* FBC are R 11 billion higher over the period, in other words the removal of FBC electricity generation from the optimized case decreases costs. The higher cost of the alternative technology (pulverised coal) outweighs the reduction in fuel costs, since a discarded product is used for fuel. The fuel mix remains unchanged, as discard coal is replaced by new coal. While FBC contributes to removing stockpiles of discard coal, there are small increases in air pollutants. One factor contributing to this increase is the lower heating value in the poorer quality coal; the other is that the modified base case is not fully optimized. SO₂ emissions with FBC increase by 62 kt, i.e. the optimized base case has 2% less sulphur dioxide emitted in 2025 than the case with FBC removed. Similarly, there is an increase of NO_x with FBC of 30 kt (1.4 %). Total GHG emissions, primarily in the form of carbon dioxide, increase by 9.4 MtCO₂ or 1.5% in 2025. A fuller investigation of ‘cleaner coal’ technologies as a policy case would be a useful future piece of work; the approach here is to consider the take-up of FBC as part of the base case.

7.2.6 Conclusions on electricity supply options

The quantitative results of modeling electricity policy cases have been presented in this section. Before turning to an evaluation of both residential and electricity policy cases against indicators of sustainable development, some findings from the results are summarized.

The renewables case demonstrated that a mix of renewable energy technologies can supply ‘real’ electricity. The 2013 targets was met, and continued beyond that year, driven by

decreasing costs. Certainly the policy intervention incurred an increase in costs, but of the same order of magnitude as other policy cases. The mix of renewable energy included existing small hydro and bagasse, and brought in new bagasse co-generation and wind at various capacity factors. Despite declining costs, solar thermal electricity technologies did not enter the system over the 25-year period.

The PBMR policy case showed the increasing the share of nuclear energy to a third of total electricity generation reduces air pollution, but incurs large increases in cost above the base case. Building 32 modules (4 480 MW) into the system by 2020 is ambitious. Not only did investment level off after 2020, but the new capacity was underutilized. If built, the technology would better be phased in more gradually.

Imports of gas should also be phased in, as shown in the gas policy case's more gradual approach compared to the base case. Being an internationally traded commodity, the introduction of gas depends on fluctuations in market prices, and is also sensitive to exchange rates variations. The other import, hydro-electricity, was successfully increased in the policy case. Its global environmental benefits assume that there are no methane emission from large dams, which might change in future. The local impacts of large dams will be further discussed in chapter 8. Brief consideration of FBC confirmed that it should be considered in the base case.

So far this section has considered the findings for individual policy cases, now it turns to the combined effect. As for residential policies, a combined case including four electricity policy options was developed. The combined electricity case includes renewable energy, PBMR nuclear, imported hydro and gas. In contrast to the residential policies, which were aimed at different end uses and complementary to some extent, each of the electricity cases has the same aim, of supplying electricity to meet demand and increase access.

The share of renewable energy increases to 6%, about half of the level in the renewables case. The share of nuclear is only slightly higher than in the base case, given the other requirements to meet targets for renewable energy and to import hydro and gas. Coal remains dominant by 2025, reduced by five percentage points from 88% to 83%.

Unsurprisingly, the combination of requiring several switches from the least-cost base case increases the avoided cost of electricity. The shadow price of electricity increases by 3 c / kWh, more than in any electricity policy case on its own. In terms of investment costs, combining all the policies increases the total cost to the energy system by R 11 billion. Most of the investment costs are for the PBMR, which itself had a slightly higher increase.

From an environmental point of view, the combined case does yield the most reductions of local and global emissions. The sum of the parts, however, is greater than the combined whole, i.e. one cannot simply add up the emission reductions in the combined case, as different supply

options compete. Nonetheless, the reductions of 245 kt SO₂ are a higher at 7% than in any single policy case; as are the 120 kt NO_x less than the base case in 2025 (6%). GHG emission reductions add up to 40 Mt CO₂-equivalent in 2025 (6%). 39.6 of these Mt are in the form of carbon dioxide.

7.3 Conclusion

The results of modeling energy policies – both residential demand and electricity supply options – yield useful quantitative information. They provide important input to the analysis of indicators of sustainable development, examined in chapter 8. Further policy analysis of some issues that are not easily quantified will receive attention in chapter 9.

A notable feature of the modeling results has been that they tended to focus on the energy system and its economic and environmental dimensions. The social indicator of increased access to electricity was constant across the policy cases. The social implications of electricity supply options are less direct than those in the residential sector, where household energy use and expenditure is affected directly. Of course, the choices about electricity supply affect households not only through access to electricity, but also through the price. Hence the differences in the costs to the energy system reported in this section have implications for the burden that expenditure on electricity places on household budgets. Modeling can provide some useful inputs, but more detailed policy analysis is required to compare the effects to total household income (see chapter 8). The next chapter considers both residential and electricity policies against indicators of sustainable development.

Part IV: Sustainable development, energy and climate change policies

CHAPTER 8

8. Evaluating energy policies against indicators of sustainable development

Chapter 8 evaluates the policies in the residential and electricity sectors against indicators of sustainable development. A working definition of sustainable development was outlined in chapter 2. There is broad agreement that sustainable development has social, economic and environmental dimensions, and it is in these three categories that the evaluation is structured. The evaluation does not seek to define thresholds for each indicator that would be considered sustainable. Any particular definition of a level representing an end-state of sustainable development could be contentious. In keeping with the methodology, the focus is on making development more sustainable. Hence the comparison is relative, using the base case as a benchmark to evaluate the sustainability of each policy case.

The modeling results presented in chapter 7 are an important input to this evaluation. The analysis will show, however, that there are limits to the information obtained from the modeling. The discussion of indicators therefore includes aspects that are more difficult to quantify. The difficulty in describing the social implications of supply-side options is one example. Some of the more qualitative aspects are important in the policy analysis in chapter 9.

8.1 Indicators of sustainable development

The working definition of sustainable development in the energy context (chapter 2) emphasised that energy consumption per capita is increasing over time *and* the increase is not threatened by 'feedback' from either biophysical impacts (local air pollution, greenhouse gas emissions), economic disincentives (high costs) or from social impacts (social disruption, lack of affordability).

A wide range of energy indicators has been developed by various institutions and some have been applied in South Africa (Spalding-Fecher 2003; IAEA; UNDESA; IEA; Eurostat; EEA 2005; UN DSD 1996; CSD 1995; Bossel 1998; Villavicencio forthcoming; Helio International 2000). It is worth reflecting on the purpose of choosing a set of indicators.

Indicators should be accurate in assessing sustainability in the energy sector, representing the key dimensions of sustainable development (Spalding-Fecher 2002d). Each indicator is a single figure that expresses an aspect of a country's production and use of energy (IAEA; UNDESA; IEA; Eurostat; EEA 2005). Taken together and assessing changes over time, the set of

indicators can assist policy-makers in assessing progress (or lack thereof) in making development more sustainable.

Indicators should be representative of the major dimensions of sustainable development (Spalding-Fecher 2003). Some indicators focus on socio-economic aspects, e.g. the delivery of essential services for reducing poverty, while other indicators focus on environmental effects. The skill of the policy maker will be to select and weight indicators as appropriate for the country situation so as to develop in a sustainable manner (IAEA; UNDESA; IEA; Eurostat; EEA 2005).

However, more indicators are not necessarily better, since indicators need to be intelligible to a range of stakeholders. Too many indicators can cause confusion - for example, the Commission on Sustainable Development (CSD) has compiled a working list of more than 130 indicators, including social, economic, environmental and institutional aspects of sustainable development (CSD 1995). Such a broad list may be useful to enable countries to choose across all sectors, but seems too broad for application to a single sector and country. A smaller set of indicators can give a more concise message – but clearly the indicators need to be chosen with care. If indicators are to be tracked over time, the data should be relatively easy to gather (Spalding-Fecher 2002d).

The pragmatic approach taken in this thesis is to identify a small number of indicators for each of the economic, social and environmental dimensions. The indicators should address both parts of sustainable development – the sustainability of the dimension, and be relevant to development.

The motivation for particular energy indicators for sustainable development in South Africa is largely contained in chapter 3. The indicators should reflect the country's development objectives, be consistent with the energy policy goals spelled out there, and mark progress towards sustainability in its economic, social and environmental dimensions. Given this broad motivation, the specific indicators shown in Table 8.1 are motivated in the following way.

For the development of the South Africa energy sector, access to energy services in general and electricity in particular is a major goal. One indicator is the share of households connected to the grid. Development could be made more sustainable if the services become more affordable. An indicator giving relevant information is the cost of energy services, for both electricity and other fuels. A more complete understanding of the burden on household incomes, however, will require further policy analysis.

Greater access to energy services can indirectly contribute to social sustainability. Better lighting, for example, assists with education, giving household members the ability to study at night with lighting. The initial cost of the options considered in policy cases needs to be

affordable. Improved indoor air quality contributes to health effects – but only the former is quantified here, not the health impacts themselves.

Increasing diversity of supply is a major energy policy goal, seeking to reduce South Africa's dependence on a single fossil fuel, coal. Increased diversity can contribute to energy security, at least in one interpretation of the concept. In so far as these diversified sources are also domestic, as is the case with renewables and can be done with uranium, they avoid the imports of energy, with possible foreign exchange impacts. With the focus on electricity supply options, the fuel mix for electricity generation is an important indicator.

Greater shares of cleaner fuels contribute to an environmental indicator, managing the energy-related impacts on air quality. Energy supply and use contributes to both local and global air pollutants. Locally, reductions of indoor air pollution assists in lessening health impacts. Reducing greenhouse gas emissions contributes to mitigating climate change.

The policies are evaluated against the indicators of sustainable development shown in Table 8.1.

Table 8.1: Indicators of sustainable development for energy policies

<i>Indicator</i>	<i>Units</i>	<i>Comments</i>
ECONOMIC		
Total cost of energy system	R billions	Cumulative over the 25-year period
Marginal cost of electricity supply	c / kWh	Shadow price of electricity supply, 2025
Diversity of electricity fuel mix from domestic sources	%	Share of renewable energy, nuclear and coal, 2025
ENVIRONMENTAL		
Local air pollutants in 2025		2025
sulphur dioxide	kt SO ₂	
nitrogen oxides	t NO _x	
carbon monoxide	t CO	
Global greenhouse gases,	Mt CO ₂ -equiv	Some disaggregation by gas in the text, 2025
SOCIAL		
Fuel consumption in residential sector	PJ	by fuel type
Cost of energy services to households		
Shadow price of residential electricity	c / kWh	Not tariff, but opportunity cost
Shadow price of non-electric fuels	R / GJ	coal, biomass, LPG, paraffin, candle wax
Initial investment for households	R / HH	'First cost' of investment required
Monthly expenditure on electricity	R / (HH * month),	Disaggregated by household type - RHE, RLE, UHE, ULE

There are important social dimensions in particular which are more difficult to measure with a single number from the model results of chapter 7. Such issues include the burden that

electricity places on household income, which is analysed a little further in chapter 9. The impacts of economic measures on job creation would require either a detailed bottom-up study, and / or the generation of employment multipliers through a social accounting matrix.

The partial ways in which health and education are addressed has been described above. Other dimensions, such as the impacts on empowerment and participation of civil society, are not usefully quantified.

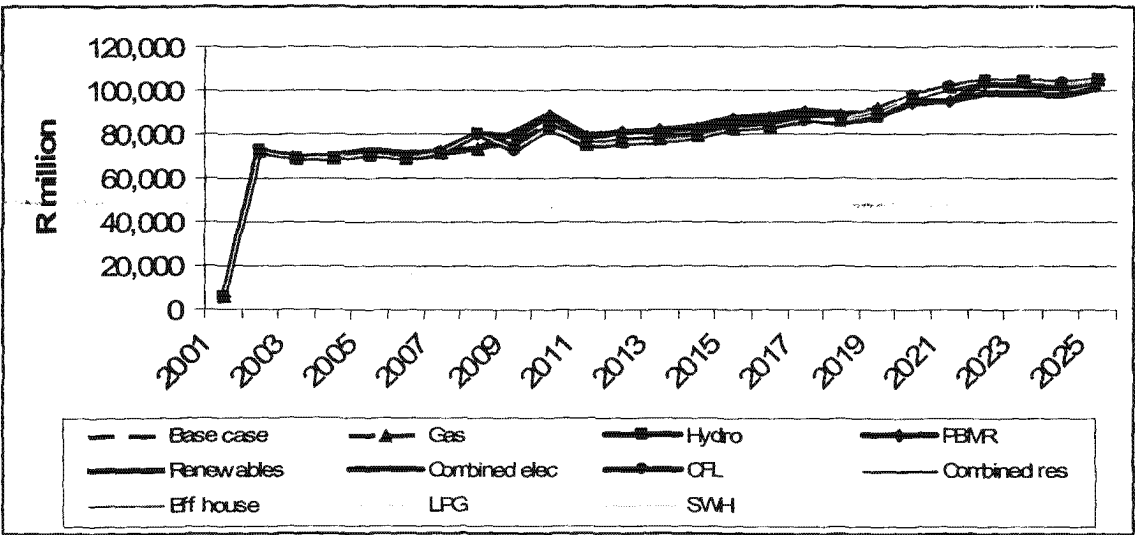
The chapter proceeds by evaluating the economic, environmental and social dimension in turn, using indicators outlined in Table 8.1. The policy cases described in chapters 6 and 7 are evaluated, excluding the FBC case for electricity supply, since this was found to be better represented in the base case (see 7.2.5). The overall comparison across all three dimensions and supply- and demand-side policies is summarized in Table 8.21 at the end of the chapter.

8.2 Economic

8.2.1 Overall investment levels

The levels of investment in supply and demand technologies in nominal terms rise sharply from the base year, and then increase gradually over the period (Figure 8.1). The difference between the various policy cases is relatively small, in the context of large absolute amounts of investment. Whether SA chooses a least-cost path as represented in the base case, or particular policy interventions, a large amount of total investment in the energy system will be needed. The incremental costs of investment are not that large in relative terms, and the costs reported in Figure 8.1 are undiscounted. Much of the further analysis will consider the costs to the entire energy system, which are discounted. As context, it is useful to have an impression of the scale of capital requirements.

Figure 8.1: Undiscounted total investment in technologies, supply and demand



8.2.2 Residential policies and savings in energy system cost

Residential policies have relatively little impact on overall energy system costs. The residential sector is a fairly small part of total demand. In the base case, residential demand accounted for 9% of total fuel consumption (see base case in chapter 6). It is not surprising, therefore, to see in Table 8.2 that the cost implications of policy cases in the tenths or hundredths of a percent. Costs are dominated by supply and larger demand sectors.

Table 8.2: Total energy system costs across residential policies

	<i>Unit</i>	<i>Base case</i>	CFLs	Efficient houses	LPG for cooking	Water heating - SWH /GB	Residential policies combined
Total cost of energy system, cumulative over the period	R billions	6,120	6,119	6,119	6,121	6,115	6,115
<i>Change policy - base case</i>	R billions		-0.9	-0.9	0.6	-4.6	-5.0
<i>Difference to base case</i>	%		-0.01%	-0.02%	0.01%	-0.08%	-0.08%

Since total costs are large, and the costs are considered over the 25-year period, the absolute changes amount to billions of Rands. There are cost reductions for all policy cases, except for LPG for cooking. The analysis in chapter 7 indicated that the policy case increased fuel consumption, that other fuel switches (e.g. to paraffin) also took place and changed relative prices.

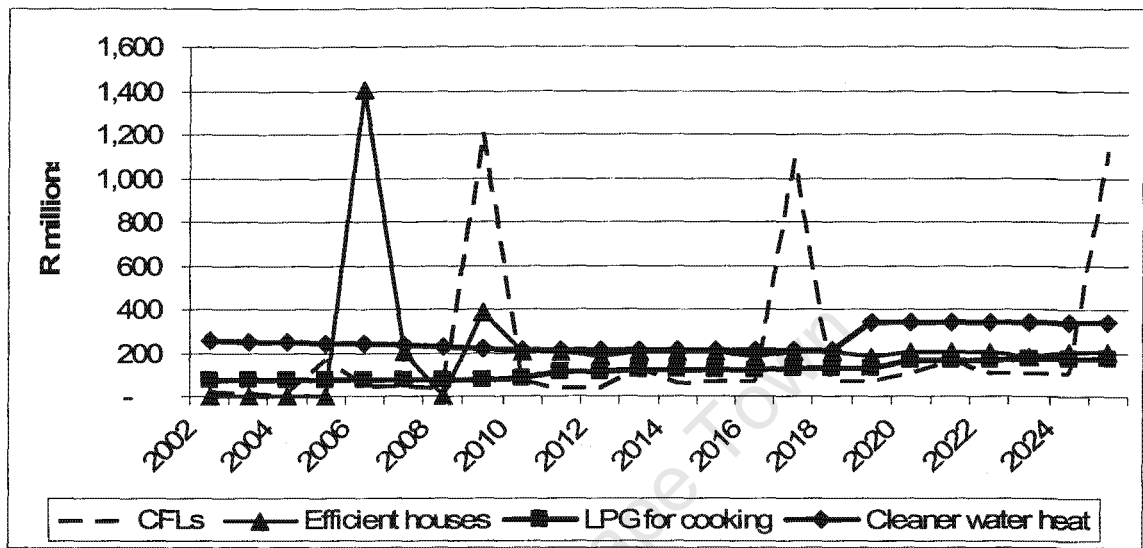
Savings in the other policy cases range from R 900 million to R 5 billion. The largest reduction in costs for the energy system for a single policy comes from water heating, with the introduction of solar water heaters (SWH) and geyser blankets. The higher reduction reflects the high proportion of energy used for water heating, the large savings from SWH and the low cost of geyser blankets. The combined case does not simply add up these savings (and the higher cost of the LPG case), but considers the combined effects without double counting.

8.2.3 Investment requirements for residential policies

The investment costs of the four policy cases can be seen in Figure 8.2 for each year. Note that the order of magnitude here is Rand millions, since only the direct monetary requirements are reported here, not the discounted total system costs as above. The pattern of investments also differs markedly. Investment of efficient housing occurs early on, and then declines. CFLs also

show spikes, but investment is repeated as the life-time of the bulbs is shorter than 25 years (unlike houses). Investment in water heating and cooking appliances and fuels is more evenly spread over time.

Figure 8.2: Investment required for residential policies in the respective policy case



8.2.4 Financing residential policies

The residential efficiency measures are economically attractive, with solar water heating / geyser blankets standing out in particular. SWH and CFLs have been identified as policy priorities already (see chapter 4), with efficient housing receiving less attention. The investments required have to come from households, either those who can afford them or with government support. The key policy question is how to assist households to invest in the upfront costs.

Taking SWH with the biggest reduction as an example, the question is what policies would promote greater uptake of the technology. In part, the design of the policy took these concerns into account, by combining SWH with a low-cost option, geyser blankets. The analysis in chapter 7 showed that SWH were taken up primarily in higher-income urban households, who can afford the upfront costs. Chapter 9 will examine options for financing investments in residential policies, using examples of subsidies for efficient housing and financing for solar water heaters.

8.2.5 Investments in electricity generation technologies

The cost implications of different electricity supply options are an important indicator of economic sustainability. Given the end of excess capacity (see Table 3.2 above), investment will be required in new capacity. Some 20 GW of new capacity will be needed over the next 20 years. Eskom has announced investment plans of over R 100 billion for initial additions, but now that it is no longer a para-statal, investment decisions will be even more closely scrutinized (see section 3.4).

Table 8.3 shows the total cost of the energy system in all cases, in absolute terms as well as the difference between base and policy cases. The changes expressed in percentages are small, relative to the large absolute sums.

Total energy system cost increases for PBMR and renewable energy, and only introducing all options at once has a higher cost. By contrast, importing gas or hydro reduces system costs. Domestic investment is reduced, and the reduced expenditure is not made up by increased imports. However, the increased expenditure on imports may have foreign exchange implications. This issue also arises with the PBMR, for which processed fuel is expected to be imported despite the local uranium resource. As noted in chapter 7 in the gas and hydro cases, the results are sensitive to the assumed costs of the imported fuels. The combined case is the second most expensive, as supply side options compete to provide supply (unlike residential efficiency, where savings are highest in combination).

Table 8.3: Total cost of energy system for electricity supply options

	Unit	Base case	Imported gas	Imported hydro	PBMR nuclear	Renewable electricity	Combined electricity
Total energy system costs, cumulative over 25 years	R billions	6,120	6,119	6,117	6,132	6,122	6,131
Change policy - base	R billions		-0.8	-3.1	11.7	1.9	10.9
Difference to base case	%		0.0%	-0.1%	0.2%	0.0%	0.2%

Note: Combined electricity includes the imported gas, hydro, nuclear and renewables cases.

Beyond changes in sign, one can note that importing hydro-electricity under the given assumptions would have the greatest reduction of energy system costs, larger than for gas. Similarly, the increase for the PBMR is significantly greater than for the renewables case. However, the changes in total costs should be understood in the context of different goals being set in each case. The electricity policy cases were designed as ambitious targets for the particular technology, within reasonable bounds.

Investment levels in the policy cases vary significantly. Smaller investments are required to meet lower targets, and are associated with less installed capacity. Renewable energy, for example, in the policy case reaches the target of 10 000 GWh in 2013 and increases to 37 000 GWh in 2025. The additional cost to the energy system is R 1.9 billion over 25 years. The PBMR case installs 4 480 MW, adding R 11.7 billion to total system costs, but also generates 28 300 GWh in 2025. Despite the different objectives, the PBMR is therefore more expensive in this comparison, as the ratio of additional costs is much greater than electricity generated. An important reason is the unutilized PBMR capacity noted in chapter 7.

Table 8.4: GWh electricity generated by technology in its policy case

GWh	Renewables	PBMR	Imported hydro	Imported gas
In 2025	37,058	28,303	18,400	1,367
Over 25 years	290,719	166,681	370,067	11,567

Two other means of direct comparison are available. The assumed costs per kW as *input* parameters (rather than results) are shown in Table 6.14 (repeated from chapter 6), together with the fixed and variable operation and maintenance costs. The input parameter, however, does not take into account the opportunity cost – the electricity generated from renewable or nuclear energy displaces other, predominantly coal-fired electricity. The marginal investment is a better reflection of the opportunity cost (see 0), but this measure is specific to each electricity generation technology.

Table 8.5: Costs of electricity supply technologies per capacity and unit of generation

Sources: Markal database for this model (Winkler et al. 2005a), and NIRP database (NER 2004a) and also drawing on modeling for the first IEP (DME 2003d)

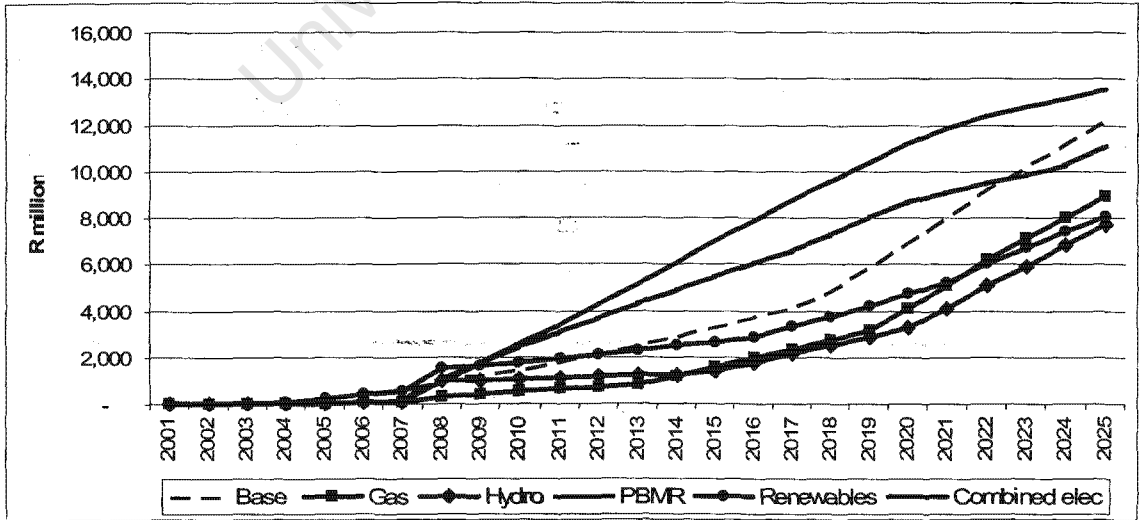
	Investment cost	Fixed O&M cost	Variable O&M cost
Type	R/kW	R / kW	c / kWh
Imported gas			
Combined cycle gas turbine	4,583	142	0.7
Open cycle gas turbine (diesel)	3,206	142	5.4
Imported hydro			
Imported hydro			2.1
Renewable energy			
Parabolic trough	18,421	121	0
Power tower	19,838	356	0
Wind turbine	6,325	289	0

	Investment cost	Fixed O&M cost	Variable O&M cost
Type	R/kW	R / kW	c / kWh
Small hydro	10,938	202	0
Land fill gas (medium)	4,287	156	24.2
Biomass co-gen (bagasse)	6,064	154	9.5
Nuclear			
PBMR initial modules	17,136	317	0.7
PBMR multi-modules	10,761	317	0.7
Coal			
New pulverized fuel plant	9,980	101	0.7
Fluidized bed combustion (with FGD)	9,321	186	2.9
Storage			
Pumped storage	6,064	154	9.5

Note: The costs are input parameters, rather than results, and are included here to show differences in cost per unit of capacity (R/kW) and electricity generation (c / kWh).

The pattern of investments over time is shown in Figure 8.3, where investments in new capacity have been annualised over the life-time of the technology. All electricity technologies have a lead-time, so investment picks up from 2005 onwards. The combined case has the highest costs for most of the period, with the PBMR next. The same caveats apply that the investment costs are achieving different objectives for each policy.

Figure 8.3: Annualised investments in electricity supply technologies by policy case



There are no clear winners among the options and the trade-offs required are further considered in the policy analysis in section 9.1.2.

8.2.6 Price of electricity

8.2.6.1 Shadow prices and market prices

While data inputs to Markal are usually market prices, the model results are shadow prices. Least-cost optimization draws on an economic theory that assumes perfect competition. It also assumes that actors have perfect foresight, minimizing their costs over the entire time horizon of the model. In such a situation, market prices would reflect true economic costs. In reality these conditions seldom hold. Market prices are distorted by monopolies, external costs not internalised by markets, taxes, subsidies and other factors (Munasinghe 1992). With such distortions, market prices diverge from the shadow price, the future economic opportunity cost. Shadow prices represent the cost of the foregone alternative, if an additional unit of a technology is brought into the system.

For example, if the market price of electricity is subsidised for poor consumers, as in the poverty tariff, then the shadow price reflecting the opportunity cost would reflect the economic cost without the subsidy. In the SA electricity sector, prices are regulated – hence called tariffs – rather than being set by a competitive market. Even in situations of power sector reform, tariffs are likely to remain regulated, although possibly rationalised. Future tariffs might be adjusted more closely to the Long Run Marginal Cost (LRMC), which can be defined as the “incremental cost of optimal adjustments in the system expansion plan and system operations attributable to a small increment of demand which is sustained into the future” (Munasinghe 1992: 109).

8.2.6.2 Shadow price of electricity

The shadow prices for electricity are shown in Table 8.6 for the electricity policy cases for the end of the period, 2025. The shadow prices of electricity are broadly comparable, except for the combined scenario which is higher. By requiring diversification in several directions, it has the highest shadow price – when averaged across all times of the day. Importing gas or hydro-electricity reduces the marginal cost of electricity supply. Importing gas or hydro-electricity reduces the shadow price by 0.5 c / kWh. These options would therefore provide the most favourable context for ensuring the financial viability of municipal or regional distributors.

Table 8.6: Shadow price of electricity for policy cases

	Base case	Imported gas	Imported hydro	PBMR nuclear	Renewable electricity	Base w/out FBC	Combined electricity
2025	19.3	18.8	18.8	19.3	19.3	19.3	22.3

Comparing policy cases in 2025, the prices in the PBMR and renewables cases are the same as in the base case. This is possible despite the large changes in energy system costs, since these were small in relative terms (see Table 8.3). Also, the shadow prices in this analysis are averaged across six time slices (day / night for three seasons - summer, winter and intermediate). The results indicate that the respective advantages of the different technologies balance out. Although significant investment are required, shift to technologies other than coal are possible without large impacts on the shadow price of electricity. The combined case would increase the shadow price of electricity by 3 c / kWh compared to the base case, an increase which would further exacerbate financial difficulties of distributors.

8.2.7 Diversity of electricity supply

The diversity of the fuel mix for electricity generation is shown in Table 8.7. There is little variation across the first three cases shown, with fuels grouped into renewable energy, nuclear and other, predominantly coal-based electricity. Imported fuels do not change the domestic fuel mix. They do, however, contribute to reductions of local air pollutants (see environmental section). Greater diversity of supply is achieved primarily through renewables or PBMR nuclear, in two different ways.

Table 8.7: Diversity of fuel mix from domestic sources for electricity supply options by 2025

Indicator	Base case	Imported gas	Imported hydro	PBMR nuclear	Renewable electricity	Combined electricity (gas, hydro, nuclear, RE)
Share of renewable energy	1.0%	1.1%	1.1%	0.8%	11%	6%
Share of nuclear	11%	11%	11%	34%	11%	11%
Share of other (mainly coal)	88%	88%	88%	66%	78%	83%

Table 8.7 shows the fuel mix by grouped fuels, are based on electricity output, not installed capacity. The PBMR case, with a larger investment in greater capacity, achieves the largest move away from coal. However, it is a shift to single other fuel, with only renewable energy reduced to the lowest of all cases at 0.8%. The renewables case achieves the best diversity across the three grouped fuel types. The renewables policy case has a lower investment requirement than PBMR and lower installed capacity. The combined policy case does not achieve greater diversity – either in terms of coal displaced, or variety of fuel type.

The focus so far has been on the economic dimension of sustainable development. Markal is a least-cost optimizing tool, and hence the results shown above indicate the least-cost options.

Even with constraints in the policy cases, the target set will be met with the least-cost resource available.

Considerations other than cost, however, play an important role in shaping policy. The following sections turn to the social and environmental dimensions of sustainable development in the energy sector.

8.3 Environmental

8.3.1 Local air pollutants reduced by residential policies

Increasing efficiency and using cleaner fuels in the residential policy cases contributes to reducing local air pollutants. The largest changes were seen for sulphur dioxide and nitrous oxide; changes in carbon monoxide and non-methane volatile organic compounds were less than a tenth of a percent below the base case. Efficient houses and water heating achieve a reduction of slightly over 1% from the base case, for both SO₂ and NO_x emissions (see Table 8.8). Efficient housing reduces 47 kt SO₂ and 24 kt NO_x in 2025; while SWH and geyser blankets can reduce 40 kt SO₂ and 19 kt NO_x in that year.

Table 8.8: Local air pollutants in residential policy cases, 2025

	Unit	Base case	CFLs	Efficient houses	LPG for cooking	Water heating - SWH and geyser blankets	Residential policies combined
Sulphur dioxide	kt SO ₂	3,571	3,568	3,524	3,559	3,531	3,517
Difference to base case	%		-0.1%	-1.3%	-0.3%	-1.1%	-1.5%
Nitrogen oxides	t NO _x	2,156,438	2,155,275	2,132,925	2,151,339	2,137,627	2,129,828
Difference to base case	%		-0.1%	-1.1%	-0.2%	-0.9%	-1.2%

The combined case considers only the *net* effect on emissions. The reductions of sulphur dioxide emission in the combined policy case have significant amounts. Adding up the percentage reductions would have yielded -2.8% from the base case, but the combined case only reports 1.5%. An advantage of an modeling framework for such analysis is that the combined effects are not exaggerated. For both SO₂ and NO_x, the combined case does slightly better than the best individual policy (efficient houses), but by a small share.

GHG co-benefits in the residential sector. Table 8.9 shows total GHG emission in the base case and residential policy cases. The emission reductions are shown both as tons reduced from the base case and also as a percentage. The highest reductions of GHGs among residential policies are achieved by efficient houses, followed by SWH and geyser blankets. The reductions reflect

the large share of household energy consumption for space and water heating. Lighting accounts for a much smaller share, and the emission reductions is the lowest.

Table 8.9: GHG emissions in residential policies cases

	Unit	Base case	CFLs	Efficient houses	LPG for cooking	Water heating - SWH and geyser blankets	Residential policies combined
Total GHG emissions, 2025	Mt CO ₂ -equiv	634	633	626	632	628	625
<i>Reduction from base case</i>	Mt CO ₂ -equiv		-0.4	-7.5	-1.4	-6.0	-8.3
<i>Difference to base case</i>	%		0%	-1%	0%	-1%	-1%
GHG emissions by gas							
<i>Carbon dioxide</i>	kt CO ₂	630	630	623	629	624	622
<i>Methane</i>	t CH ₄	50,325	50,323	50,234	50,380	50,261	50,301
<i>Nitrous oxide</i>	t N ₂ O	8,171	8,165	8,065	8,149	8,082	8,052

The last three rows breaks down the total GHG emissions by gas. Most of the emissions in the residential sector are in the form of carbon dioxide. Greater efficiency in end-uses avoids emissions upstream at the power stations. Methane and nitrous oxide emissions are associated in the model with residential use of other residential fuels, but they make up a small portion as electrification continues.

For avoided upstream emissions, it is important to avoid double-counting when combining policies. If electricity has already been reduced through efficient housing shells, not the full amount would be reduced by also introducing efficient lighting. Adding up the emission reductions for GHGs would have given 15.3 Mt CO₂-equiv, but the combined policy case only shows 8.3 Mt CO₂-equiv – only 54% of the sum. The combined effect of residential policy is significant, but not overstated. The combined case does not increase emission reductions much beyond those of efficient houses.

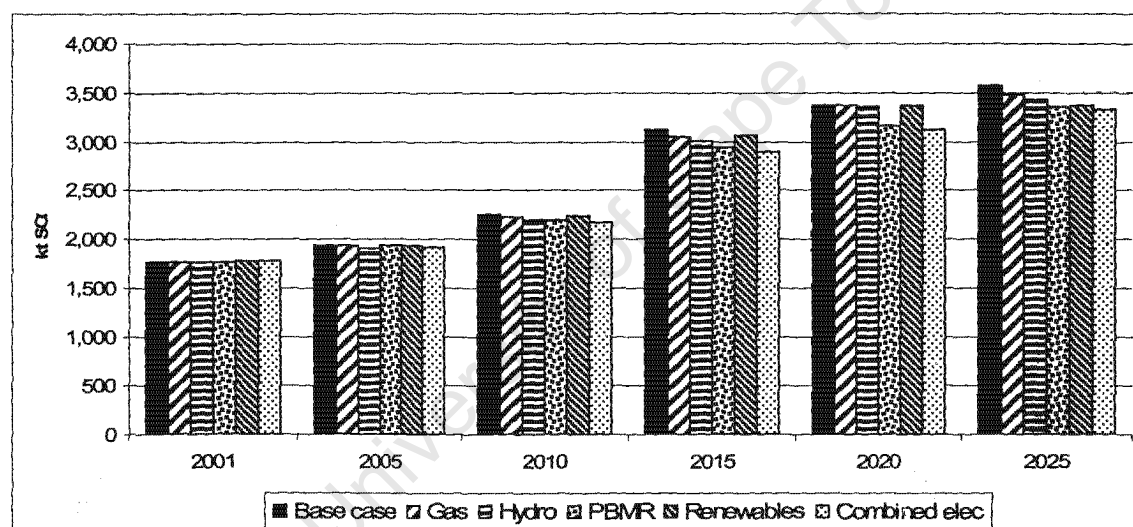
8.3.2 Local air pollutants reduced by electricity policy

The reductions in local air pollutants from electricity policy cases are larger than for residential policies. Electricity supply is a much larger contributor to total air pollution, while households are one of the smaller demand sectors. Table 8.10 shows that both the PBMR and renewables policy cases achieve high levels of reductions for local pollutants, notably SO₂ and NO_x – between 4 and 6% below the base case.

Table 8.10: Local air pollutants in electricity policy cases, 2025

	Unit	Base case	Imported gas	Imported hydro	PBMR nuclear	Renewable electricity	Combined electricity (gas, hydro, nuclear, RE)
Sulphur dioxide	kt SO ₂	3,571	3,487	3,429	3,361	3,374	3,326
Difference to base case	%		-2%	-4%	-6%	-6%	-7%
Nitrogen oxides	t NO _x	2,156,438	2,114,198	2,086,086	2,053,462	2,060,563	2,035,692
Difference to base case	%		-2%	-3%	-5%	-4%	-6%
Carbon monoxide	t CO	4,923,479	4,918,409	4,916,535	4,913,639	4,962,143	4,960,353
Difference to base case	%		0%	0%	0%	1%	1%

The trends in SO₂ emissions are illustrated in Figure 8.4. In the base year, emissions are close to 1 760 kt SO₂ in all cases, so that the variation in the policy cases appear small.

Figure 8.4: SO₂ emissions in electricity policy cases over time

Some of the reductions in absolute terms were reported in chapter 7, with the PBMR case reducing 210 kt SO₂, renewables 197 kt and the combined case 245 kt SO₂ in 2025. NO_x emissions were lowered from the base case by 103, 96 and 121 kt NO_x for the respective cases.

8.3.3 Other local environmental impacts

The focus on air pollution, both global and local emissions, should not lead one to ignore the other environmental impacts of energy supply options.

Renewable energy is generally considered environmentally friendly, but should deal with its impacts like any other energy technology – even if they are at a smaller scale. Biomass should be sustainably harvested and not use up indigenous forest. The viability of growing fuel crops will depend on scarce resources of arable land and water. Using biomass for energy will compete with using it for food. Wind turbines face three main environmental concerns – sight

pollution, bird strikes and turbine noise. For photovoltaics, it is the balance of system, such as light fixtures, batteries and the solar panels, that require careful disposal (ERC 2004a).

The environmental impacts of large dams, including flooding sensitive areas, displacement of people, possible seismic effects – have been outlined by the World Commission on Dams (WCD 2000). The largest of South Africa's hydro-electric facilities are Gariep (360 MW), Vanderkloof (240 MW) – both on the Orange River – and Collywobbles (42 MW) on the Mbashe River. None of these are very large by international comparison, and others are 11 MW or smaller. Few sites exist for the development of large hydro facilities domestically; the potential lies in the Southern African region. Nonetheless, the country has a unique biodiversity endowment and ecological sensitivity that necessitates stringent environmental measures even in the case of small hydro projects (ERC 2004a). The ecological reserve prescribed by the new Water Act (DWAF 1998) requires the sufficient water be left to maintain river ecosystems.

The higher efficiency of combined cycle gas turbines can reduce GHG emissions and local pollutants, such as NO_x . However, the production, processing and transportation of gas by pipeline can also be a major contributor to GHGs in terms of fugitive emissions. With a high global warming potential, every ton of methane leaked has the equivalent effect of 23 tons of CO_2 . The social impacts of gas pipelines on communities over whose land they pass should also be taken into account.

The social and environmental impacts of nuclear energy technologies - waste disposal, security, and public acceptance – are discussed in chapter 9.

Coal-fired power stations, which dominate the base case, have important local implications for water. Three main concerns are the effect of coal mining on water quality; that Eskom pays a price for water that is probably below the opportunity cost; and the quantity of water used by power stations (Spalding-Fecher et al. 2000a). Most of the coal stations dump their heat from the condensers in conventional cooling towers, which use between 1.8 and 2.0 litres of water for every kilowatt-hour of electricity generated. However, fresh water is South Africa's most critical resource, and so two stations, Kendal and Matimba, have dry cooling, and use only 0.1 litres of water for every kilowatt-hour (ERC 2004a).

While each energy technology should deal with its problems, the policy options examined here have important positive benefits. A large 'co-benefit' of developing these energy technologies lies in reduced GHG emissions.

8.3.4 GHG co-benefits for electricity supply options

The electricity supply options were designed to meet development objectives – achieving universal access in all cases, meeting a renewable energy target, investing in the PBMR or importing energy. The co-benefits of electricity policy options in terms of reduced GHG

emissions are summarized in Table 8.11. As would be expected, the emission reductions from the base case are larger than for the residential sector.

In terms of GHG emission reductions, both the renewables and PBMR cases result in approximately 5% reductions from the base case in 2025. The PBMR achieves 1 Mt CO₂ more reduction in 2025 than renewables, but this must be considered against the larger capacity and investment of the PBMR policy case. Section 8.3.5 below will show that the abatement costs are correspondingly lower for renewables. The combined case does have the highest emission reduction, but at a unit cost almost double that of renewables. Gas is a cleaner fossil fuel than coal, and so still reduces emissions, but the least amongst the policy options.

Table 8.11: GHG emissions for electricity supply options

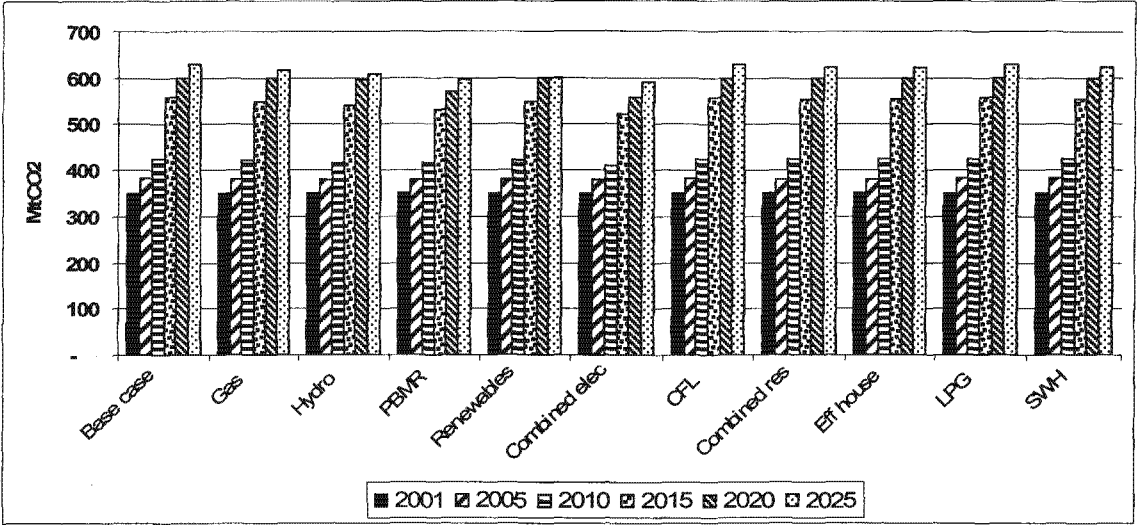
	Unit	Base case	Imported gas	Imported hydro	PBMR nuclear	Renewable electricity	Combined electricity (gas, hydro, nuclear, RE)
Total GHG emissions, 2025	Mt CO ₂ -equiv	634	620	611	601	602	594
Reduction from base case			-14	-22	-33	-32	-40
Difference to base case			-2%	-4%	-5%	-5%	-6%
GHG emissions by gas							
Carbon dioxide	Mt CO ₂	630	617	608	597	598	590
Difference to base case	%		-2%	-4%	-5%	-5%	-6%
Methane	t CH ₄	50,325	50,035	49,941	49,811	51,352	51,262
Difference to base case	%		-1%	-1%	-1%	2%	2%
Nitrous oxide	t N ₂ O	8,171	7,981	7,849	7,695	7,884	7,776
Difference to base case	%		-2%	-4%	-6%	-4%	-5%

Renewables show an increase in methane, since biomass-based renewable energy technologies contribute substantially to meeting the target. Counting the three major GHGs, however, the small increase in methane is more than outweighed by the reduction in CO₂.

8.3.5 Emission trends and abatement costs

The upward trends in CO₂ emissions can be seen in all policy cases (Figure 8.5). The upward trend of emissions in all cases is readily apparent. The relative reductions of policy cases can be seen, as the level of the bars in later years is reduced for renewables, PBMR and combined electricity cases. The cost of reducing emissions from the base case is an important factor.

Figure 8.5: CO₂ emissions for all cases over time



Detailed analysis of the costs of reducing emissions would require a separate study, drawing on the literature for detailed abatement costing (Markandya & Halsnaes 2001; Halsnaes et al. 1998; Fankhauser & Tol 1996; OECD 2000; IPCC 2001c; World Bank 1998; Krause et al. 2002). This is not the focus of the thesis, and only a simple estimate of abatement costs is derived for comparison across policies. Table 8.12 shows the incremental investment costs in technologies in 2025. Only the investments required for technologies (supply and demand) are considered, not total system costs. Costs are discounted to present value, and the increment is the difference between each policy and the base case. Similarly, emission reductions are relative to the base case. The simple measure of abatement cost is the emission reductions divided by the incremental cost.

Table 8.12: Estimate of abatement cost in policy cases

Electricity supply options		Imported gas	Imported hydro	PBMR nuclear	Renewable electricity	Combined (gas, hydro, nuclear, RE)
Abatement cost	R / ton CO ₂ -eq	5.61	3.94	2.89	2.52	4.84
Rank (1 high, 10 low)		3	5	8	9	4
Emission reductions (policy - base case), 2025	Mt CO ₂ -equiv	-14	-22	-33	-32	-40
Incremental costs of investment in technologies, 2025, discounted	R millions	-76	-89	-95	-80	-192
Residential policies		<i>CFLs</i>	<i>Efficient houses</i>	<i>LPG for cooking</i>	<i>Water heating - SWH and geyser blankets</i>	<i>Residential policies combined</i>
Emission reductions / incremental cost	R / ton CO ₂ -eq	167.37	0.12	7.72	3.50	3.07
Rank (1 high, 10 low)		1	10	2	6	7
Emission reductions (policy - base case), 2025	Mt CO ₂ -equiv	-0.4	-8	-1	-6	-8
Incremental costs of investment in technologies, 2025, discounted	R millions	-62	-1	-11	-21	-25

The range of costs is low, relative to a market price of carbon already reaching € 10 / t CO₂ (R 80 / tCO₂), and such prices are expected to be higher by 2025. Only the CFL case is above this range, given the small emission reductions.

The most cost-effective policy for abatement comes from the residential sector as well, namely in efficient housing. Renewable energy and the PBMR also have simple abatement cost estimates below R 3/ t CO₂. Solar water heating and geyser blankets cost about a Rand more per ton. Imported gas and LPG become slightly more expensive. The overall implication, however, is that the residential and electricity policies examined have an incremental abatement costs that are within the range of carbon prices.

8.4 Social

The social dimension of sustainable energy development can be assessed most directly in the residential sector. Earlier chapters have motivated that analysis needs to be conducted at the level of the household, where many of the social interactions relating to energy occur. Following the indicators outlined above, the fuel consumption patterns for households are examined, changes in fuel prices and the implications for affordability evaluated.

The approach taking in this thesis is that meeting development objectives is the starting point. With the particular focus on electricity in the residential sector, increased access to electricity reflects this as a first approximation (see chapter 6 for how this changes by household type). Access is primarily provided through the grid, but there are significant off-grid programmes in South Africa, which are not captured by this approach. Even if 350 000 solar home systems were installed, however, they would provide some 0.2% of electricity supplied by the grid to domestic customers (NER 2002a). Affordability of using electricity is important as well; hence physical connection to grid electricity is a necessary, but not sufficient condition for development.

The implications of electricity supply for social sustainability are less direct than in the residential sector. Electricity supply, however, has important implications for the price of electricity in the residential sector. Decisions about energy supply are made implicitly by governments, utilities and investors, with less discussion of their social consequences than the indirect effects might merit. Electricity prices, expenditure and the burden it places on households are discussed in sections 8.4.3 and 8.4.4. First, however, the more direct social impacts of the consumption of household fuels and their prices are examined in the following two sections.

8.4.1 Fuel consumption by households

Chapter 7 showed how monthly fuel consumption varies substantially across household types (Table 7.5). Poorer, rural and non-electrified (RLN, ULN) households were found to consume only a fraction of the energy that richer urban and rural electrified (UHE, RHE) households use each month. For the evaluation in this chapter, the variation across policy cases is examined (see Table 8.13). When considering energy prices and affordability, the analysis returns to a consideration of household types.

Table 8.13 shows the fuel consumption for electricity, liquid fuels (such as paraffin and LPG), solid fuels (coal, candle wax), renewable energy and total fuel consumption. Electricity is the largest portion of total fuel supply across time and all policy cases, consistent with the assumptions about increasing electrification.

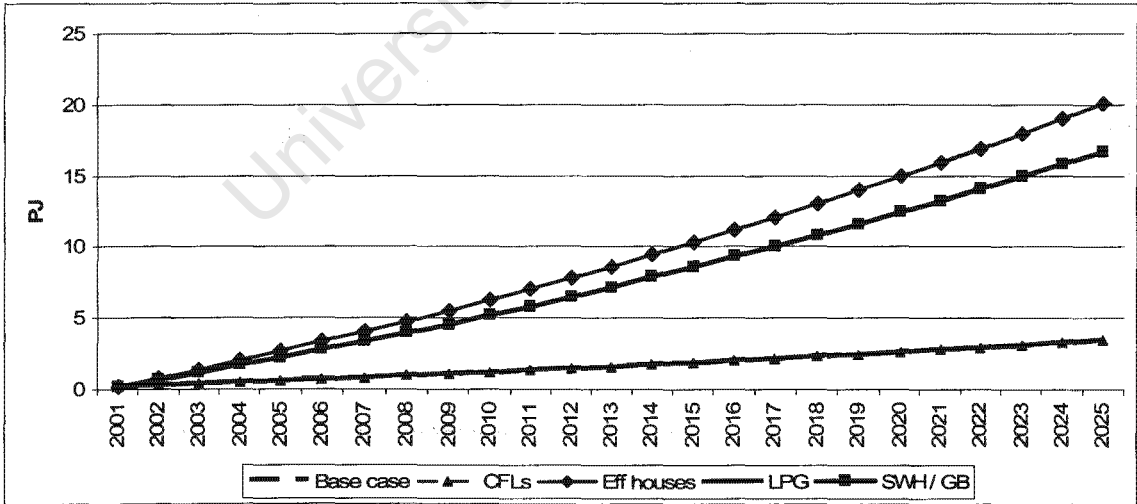
Table 8.13: Residential fuel consumption by policy case

		Base case	CFL	Eff house	LPG	Water heat	Combined res
Electricity	2014	99	98	96	96	99	93
	2025	117	116	113	110	117	105
Liquid fuels	2014	52	52	41	52	43	43
	2025	59	59	36	59	39	39
Renewable energy	2014	1.7	1.7	9.5	1.7	7.9	7.9
	2025	3.5	3.5	20.1	3.5	16.7	16.7
Solid fuels	2014	49	49	49	52	48	51
	2025	34	34	34	42	34	41
Total fuel use	2014	201	201	195	201	198	195
	2025	213	212	202	214	207	202

Relative to the base case, reductions in electricity consumption can be seen in the policy cases. The largest reduction in total fuel use by 2025 is achieved through efficient houses, consuming 11 PJ or 5% less than in the base case.

Renewable energy increases in the case of SWH and efficient housing, as well as the combined case. Rather than avoiding electricity use, SWH and geyser blankets displace the consumption of liquid fuels for water heating, since the model avoids the most costly alternative.

Figure 8.6: Renewable energy use in residential policy cases



In Figure 8.6, the two cases can be clearly seen above the others - LPG, CFLs show the same use of renewables as the base case. Efficient houses do not actively use any renewable energy source, but are considered a renewable energy technology in the sense of ‘passive solar design’. Certainly the installation of ceilings and better design reduce other fuel use.

The type of fuel used has social implications in its own right. Electricity, while generating emissions upstream, is clean at the point of use. Renewable energy is clean both in its generation and use, with environmental issues confined to balance of system issues. Household uses of paraffin and coal have significant impacts, such as indoor air pollution, paraffin poisoning and fires. Efficient houses and SWH / geyser blankets are found to be most effective in promoting cleaner fuel use.

8.4.2 Residential fuel prices

Access to cleaner fuels is one matter, being able to afford the use of such fuels another. The prices of cleaner fuels have to be brought down if households are to use them. Fuel prices are important socio-economic indicators with implications for households. The measure used for this indicator is the shadow prices of residential electricity (see Table 8.14). For electricity above, we considered the shadow price of *supplying* electricity, here the indicator is the opportunity cost of the energy carrier used in the household (see chapter 8).

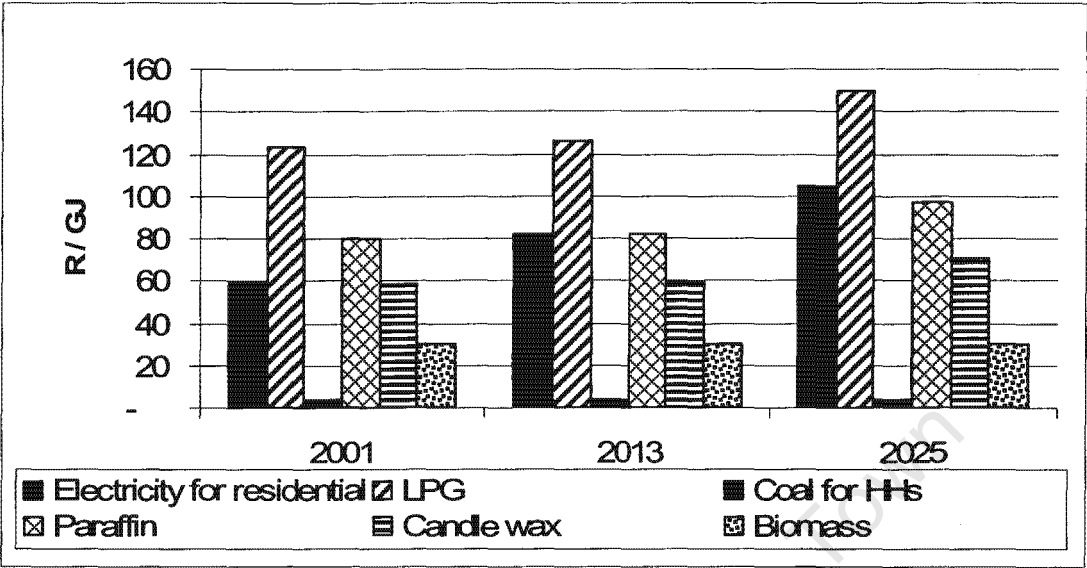
Table 8.14: Shadow prices of electricity and other fuels across policy cases

		Base case	CFLs	Efficient houses	LPG for cooking	Water heating - SWH and geyser blankets	Residential policies combined
Cost of energy services to households							
Shadow price of electricity in the residential sector	c / kWh	37.8	34.8	34.2	34.8	34.8	34.2
Electricity in common units	R / GJ	105.1	96.7	95.1	96.7	96.7	95.1
Shadow price of non-electric fuels in the residential sector							
Coal for HHs	R / GJ	3.5	3.5	3.5	3.5	3.5	3.5
Biomass		30.0	30.0	30.0	30.0	30.0	30.0
LPG		149.4	149.4	149.4	149.4	149.4	149.4
Paraffin		96.9	96.9	96.9	96.9	96.9	96.9
Candle wax		70.3	70.3	70.3	70.3	70.3	70.3

The prices on non-electric fuels do not vary across residential policies. CFLs use electricity and geyser blankets reduce the electricity required to heat water; the efficiency of houses and water heating reduces the quantity of fuels used, but not their price; the LPG policy case allowed switching to the fuel, but did not alter the price. Figure 8.7 shows that the shadow prices for

some of the non-electric fuels change over *time*. The opportunity costs of LPG, paraffin and candles increase over time; while biomass and coal remain constant.

Figure 8.7: Shadow prices of energy carriers over time



These trends are of some interest in themselves, but for comparison of policy cases the fuel of interest is electricity, which does have a different opportunity costs depending on the policy case. The shadow price of electricity in Table 8.13 is lowest for efficient houses at 3.6 c / kWh less than the base case, a reduction of 9%. The other residential policies (for CFLs, LPG and SWH / geyser blankets) achieve a slightly lower reduction, but still 3 c/ kWh. Overall, more efficient use of resources means that the opportunity cost of using electricity is reduced. Lower expenditure for the same amount of useful energy means that the cost of the more efficient service is lower. Therefore, the difference between that cost and the least-cost alternative is also reduced.

Table 8.15: Initial investment in technology in its policy case

	Total investment over 25 years, R millions	Per household (2025 estimate)
Investment in efficient houses	5,159	398
Investment in LPG cooking	2,793	216
Investment in cleaner water heating	6,193	478
Investment in CFLs	8,891	686

More important than ‘shadow prices’ for poor households are the ‘first costs’. Table 8.15 shows the total investment required in the appliances relevant to the policy case (e.g. LPG in the LPG for cooking case). The values are summed for all households over the period in the first column and an indication of the cost per household taken in relation to the estimated 12.95 million

households in 2025. For the poorest households, some assistance with initial costs might be required, but for middle- and upper-income households, costs in the hundreds of Rands would be affordable.

8.4.3 Expenditure on residential electricity

What implications does a lower cost of electricity service have for household income? An indication would be the share of household expenditure that a household devotes to energy. The answer to this question cannot be addressed within the modeling framework. Markal does not include household income; indeed households themselves occur only as units of flows of energy and money. Some further analysis of the electricity burden is presented in the following tables. The focus is on electricity, since its shadow price varies over time, and it relates to the other focal supply sector of this thesis.

Electricity expenditure is the product of consumption and price. Table 8.16 shows the monthly consumption of electricity for each household type. The initial rows show the consumption for each end use, which is added up in units of MJ per household per month. The ‘intensity’ of energy consumed per household per month does not change significantly from the base year in the model, except for a small change in electricity.⁴⁸ Electricity prices in 2001 do not diverge by policy case, so the analysis here focuses on the end year.

Table 8.16: Electricity consumption by household type

Units: MJ / (HH*mth)	<i>RHE</i>	<i>RLE</i>	<i>UHE</i>	<i>ULE</i>
Cooking	49	11	313	54
Lighting	261	99	156	136
Other electric	261	6	290	8
Space heating	84	7	330	123
Water heating	169	32	469	271
Total electricity (in MJ)	824	156	1559	591
In kWh	229	43	433	164

The shadow prices for residential electricity are different to those of electricity in general. In the same units as Table 8.14, they are R105 / GJ for the base case, R 95.1 for efficient housing and the combined case, and R 96.7 for the other policy cases. The data shown is for 2025; the corresponding table for the base year is shown in the appendix (Table 10.1) for comparison. They are shown in units of R / MJ across the second row of Table 8.17. Consumption is shown

⁴⁸ A useful future extension of the work would be to examine possible changes, although this will require assumptions about changes in consumer demand for energy services, as well as residential appliance efficiency.

in the second column, and the monthly expenditure per household on electricity in the body of the table.

Table 8.17: Monthly expenditure on electricity by household type and policy case

Units of expenditure: R / (HH*mth) 2025	Price (R / MJ)	Base case	CFLs	Efficient houses	LPG for cooking	Water heating - SWH / GB	Residential policies combined
Consumption (MJ /(HH*mth))	x	0.1051	0.0967	0.0951	0.0967	0.0967	0.0951
RHE	824	87	80	78	80	80	78
RLE	156	16	15	15	15	15	15
UHE	1,559	164	151	148	151	151	148
ULE	591	62	57	56	57	57	56

Table 8.17 demonstrates that all the residential policies reduce expenditure compared to the base case. Since shadow prices of electricity vary by policy case, the expenditure patterns vary across policy cases as well. However, the Rand amounts are not large, with the largest reduction (efficient houses for UHE) amounts to R 16 per month. For RLE households, off a low base of consumption, the savings are one or two Rand per month. The larger energy savings in efficient housing and water heating carry through to the household level. The savings amount to a 9.5% reduction from the base case, whereas other individual policies achieve 8%.

8.4.4 Assessing affordability: Electricity burden

The electricity burden is defined for this analysis as expenditure on electricity divided by the total average household expenditure. Electricity expenditure has been derived above from model results for each household type. To understand the social implications of electricity expenditure, it needs to be placed in the context of household income. Here the analysis goes beyond the modeling framework. Markal does not include household income; indeed households themselves occur only as units of flows of energy and money.

Statistics SA provides data on household expenditure for 2000 (SSA 2002).⁴⁹ The data shown in Table 8.18 were used in chapter 6 to define poorer and richer households, with the bottom two quintiles taken as poorer.

⁴⁹ The electricity expenditure is for 2025, while expenditure is for 2000, one year before the base year. No equivalent reports for 2001 were found. The approach taken is rather to report the burden in relative, percentage terms, not Rand amounts. The alternative to removing the inconsistency would have been to assume an increase in average household expenditure by 2025, or to adjust it by the ratio of electricity prices (2025 / 2001).

Table 8.18: Average annual expenditure per household by quintile group, place of residence and type of dwelling*Source: SSA (2002: Tables 3.1 and 4.2)*

Quintile	Expenditure in 2000 Rand / (HH* year)	By place of residence	Rand / (HH * year)	By type of dwelling	Rand / (HH * year)
5	< 7 547	Urban	66,000	House	66,000
4	7 547 – 12 295	Non-urban	29,000	Informal dwelling	20,000
3	12 296 – 20 450			Traditional dwelling	18,000
2	20 451 – 41 040				
1	41 041 +				

For rural households, the average annual income of ‘poorer’ households can be taken as R7 547 (break point between bottom two quintiles) and R 41 041 (upper point of quintile 2). Urban lower-income households will tend to have incomes at the high end of the range of poorer households, confirmed by the much higher expenditure shown for urban than non-urban households in the table. ULE households are likely to have a higher share of informal dwellings, with much lower expenditure (R 20 000) than the urban average. The higher income of R66 000 is influenced by the higher proportion of richer households in urban areas. The approach is to assume an average income for ULE households at the top of the fourth quintile, and to adjust the UHE income to reflect the greater share of higher-income households. The monthly and annual household expenditures used in the analysis are shown in Table 8.19.

Table 8.19: Derived average annual and monthly expenditure by household type

	R / (HH *month)	R / (HH * year)
RHE	3,420	41,040
RLE	629	7,550
UHE	7,642	91,705
ULE	1,025	12,295

The electricity burden has been calculated as a share of monthly electricity expenditure (Table 8.17) over total monthly household expenditure (Table 8.19). The results are shown in Table 8.20 below, for each household type and policy case.

Table 8.20: Electricity burden: Share of monthly household expenditure spent on electricity

	Base case	CFLs	Efficient houses	LPG for cooking	Water heating - SWH / GB	Residential policies combined
RHE	2.5%	2.3%	2.3%	2.3%	2.3%	2.3%
RLE	2.6%	2.4%	2.4%	2.4%	2.4%	2.4%
UHE	2.1%	2.0%	1.9%	2.0%	2.0%	1.9%
ULE	6.1%	5.6%	5.5%	5.6%	5.6%	5.5%

The electricity burden varies by household type, being relatively higher for ULE households. The burden reflects the lower assumed income of this household group, but increasing levels of consumption of electricity. Given that these are poorer households, residential policies could contribute to socially sustainable development if focused on this group. Comparing ULE to RLE households, the low consumption levels of the rural households keep the electricity burden lower. UHE households consume more electricity per month, but household incomes are higher by a larger ratio.

Comparing the impact of policy cases on the electricity burden, it can be seen that in *all* policy cases, the electricity burden of households is reduced. The reduction in the burden is highest among the individual policy cases for efficient houses. The burden in this case is 9.5% lower than in the base case. Only the combined case, which includes efficient housing, matches this reduction. Other individual cases still achieve an 8% reduction compared to the base case.

8.5 Comparisons and conclusions

In least-cost energy models, the assumption is typically that increases in average per capita consumption will improve the lives of most or all individuals. Efficiency implies maximization of output (or minimization of cost) subject to resource constraints. But if the distribution of consumption worsens, total welfare might be declining (Munasinghe & Swart 2005). The methodology adopted in this thesis combines least-cost energy-economic modeling with indicators of sustainable development and policy analysis. The interactions between social equity and economic efficiency deserve particular attention, since conflicts arise between them.

Hence this chapter has attempted to examine issues of social equity more closely, focusing on the residential sector. The quantifiable indicator for increasing access to *affordable* energy services was a reduced electricity burden for households. The analysis proceeded on a household basis, drawing fuel consumption and electricity price information from the modeling framework. Outside of the model, the expenditure on electricity was expressed as a share of average household expenditure. Even this analysis remains partial and represents a narrow

The analysis of the electricity burden gives only one indication of the contribution that residential policies can make to social sustainability. Other dimensions of social sustainable would include job creation and empowerment through participation, which are more difficult to quantify. In addition, access to cleaner and more efficient energy services can contribute to respiratory health and promote literacy through enhancing educational opportunities. Reducing the pressure on household budgets is important, particularly for poorer households, and hence is the one analysed here.

The key indicators are tables and figures of the economic, social and indicators. Some of the less

Table 8.21: Evaluation of all policies across three dimensions of sustainable development

[illegible]

The electricity supply options fall into three broad categories. Coal dominates the base case and remains the largest fuel over the 25 years in all policy cases. Importing either gas or hydro-electricity can be achieved at a reduction in the costs to the energy system, compared to the base case. The third category comprises two domestic options, the PBMR nuclear and renewable energy technologies.

Table 8.21 shows that both domestic options increase the total energy system cost. For the PBMR, the cumulative discounted energy system costs rise by R 11.7 billion for the period for renewables by R 1.9 billion. Only the combined case, requiring diversification in several directions at once, requiring significant investments.

For the PBMR and renewables, the different levels of investment and capacity of each policy case must be borne in mind. Even after adjusting for the greater capacity of the PBMR, however (see discussion in section 8.2.5), the PBMR is more expensive than the renewables case. The investment costs per unit of installed capacity differ for the various technologies used in policy cases (see Table 6.14). The ambitious introduction of 32 modules within this time period results in unutilized PBMR capacity. In the case of renewables, recall from chapter 7 that investment went to existing technologies plus new wind and bagasse co-generation, but the more expensive solar thermal options did not enter the policy case.

The indicators for diversity of energy supply yielded results with two aspects. Clearly, the larger investment and capacity in the PBMR case achieved the greatest share (a third) of electricity generation from non-coal technologies. The rapid transition to one other fuel meant that the resulting system was dominated by two fuels. The renewables case achieved a better mix of three fuel groups. The renewable case, with lower capacity and investment than the PBMR, still had greater dependency on coal.

From an environmental perspective, the two domestic policy cases show significant reductions for both local and global air pollutants. The largest reductions are achieved by the renewables and PBMR cases, with 6% less SO₂ than in the base case, and 4% and 5% respectively for NO_x.

Both domestic electricity cases also achieve significant reductions of GHG emissions against the base case. By 2025, the renewables policy case emits 32 Mt CO₂-equivalent less than the base case, and the PBMR 33 Mt. While this is a 5% reduction from emissions in the base case, it is 10% of the 345 Mt CO₂ emissions in 2000 (WRI 2003). It is a case not so much of emission reductions, but of avoiding future emissions. Renewables achieve a similar reduction in GHG emissions with lower capacity and investment. A simple estimate of abatement costs suggest that the incremental costs of emission reductions are correspondingly lower for renewables than PBMR.

The social dimensions of sustainability are reflected in indicators for the residential sector. Two residential policies stand out across economic, social and environmental criteria – efficient houses and cleaner and more efficient water heating.

The two policies make the greatest fuel savings in 2025, with efficient housing saving 11 PJ more than in the base case and SWH / GB saving 7 PJ.

It can be seen in Table 8.21 that the reduction of energy use translates into cost savings. In aggregate terms, water heating reduces total system costs, being a large residential end use. Introducing solar water heaters and geyser blankets can reduce system costs by R 4.6 billion over 25 years. However, Table 8.17 records reduced energy expenditure in all policy cases, even though the others are smaller in Rand terms. Comparing the economic impact in terms of shadow prices of residential electricity, the reduction for efficient houses at 3.6 c / kWh is again the highest.

Some additional analysis was conducted to quantify the contribution of policies to reducing the electricity burden. In *all* policy cases, the share of household expenditure devoted to the electricity burden of households is reduced. The efficient housing policy case reduced the burden by the largest relative amount. More significant than variation across policies were the results for different household types. The electricity burden for urban lower-income electrified households was the most encouraging, being a household type with increasing electricity use and low income. If poverty alleviation is a key policy consideration, this household type would be a priority target group for residential policies.

Efficient houses and SWH / geyser blankets contribute the most to cleaner fuel use. Contributing to diversity on the demand side, the two cases are the ones among residential policies which increase the use of renewable energy –water heating in the active sense of using solar energy and efficient housing through passive solar design.

Efficient houses and water heating achieved a similar percentage reduction for local air pollutants in the form of SO₂ and NO_x emissions. Combining all policies increases the reductions only a little. Efficient housing would be the best option, if the primary concern were local air pollution. The same pattern is followed for emissions of GHGs, most of which are in the form of CO₂.

The combined case served in a number of cases to illustrate the value of considering individual policies in the context of the whole energy system. Often policies are considered in isolation. If several policies are implemented at the same time or in sequence, the combined effect is not simply the sum of the individual policies. The combined case showed higher levels of avoided emissions, for example, but not the amount if emission reductions from individual policies were

added up. The lesson for policy-makers is that the cumulative effects of energy policies require attention through integrated assessments.

The evaluation of residential policies has revealed more insights into social dimensions of sustainability, while the larger investments in electricity supply options have a bigger impact on economic factors. Changes to the costs of the energy system are generally larger from the electricity policies (ignoring combined policies). However since two of the electricity policies involve imports and therefore less capital expenditure domestically, they have cost reductions. The large increases in system costs are associated with the PBMR and renewables cases, whereas the largest reduction is through SWH / geyser blankets.

Both electricity supply and residential demand policies can assist in reducing environmental impacts. Reductions of emissions are consistently larger for electricity policy cases. The pattern holds true for both reductions of local air pollutants (SO_2 and NO_x) and avoided GHG emissions (CO_2 , CH_4 and N_2O).

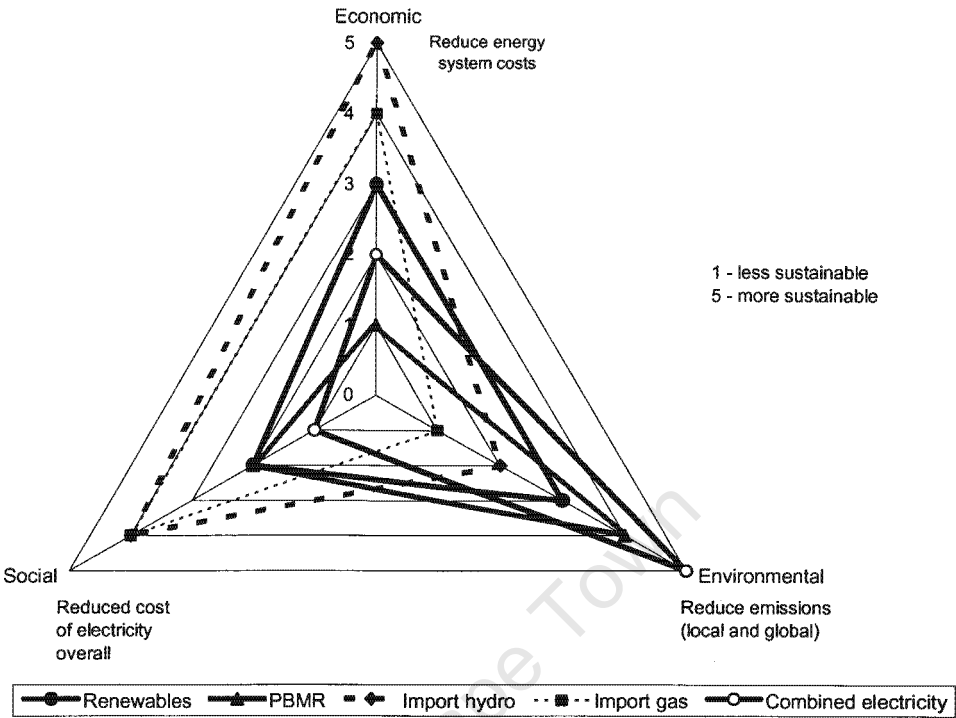
8.5.1 Comparing policies across all three dimensions of sustainable development

Do any of the policies satisfy the definition of sustainable energy development from chapter 2? The working definition was that a set of 'development indicators' is increasing over time. The increase in electricity consumption is not threatened by 'feedback' from either biophysical impacts (local air pollution, greenhouse gas emissions) or from social impacts (social disruption, e.g. if services are unaffordable). Indicators would be drawn from social, economic and environment dimensions, but different stakeholders might emphasise various criteria.

For the electricity supply options, there are no clear 'winners'. Figure 8.8 draws together the evaluation of social, economic and environmental indicators. The policies are ranked for a single indicator in each of dimension – socially for reducing electricity costs; economically for reducing system costs and environmentally for reducing emissions (local and global are same rank order). Only rank orders are shown, with 1 representing low *reductions* of emissions, and 5 high. In other words, policy cases at the outside of the triangle are ranked higher in that dimension. There is no attempt to define sustainability, merely an indication that one policy case makes residential energy development more sustainable than the others. Where one triangle completely contains another, it would higher-ranked in all three dimensions. In Figure 8.8, the triangles overlap, so there are trade-offs.⁵⁰

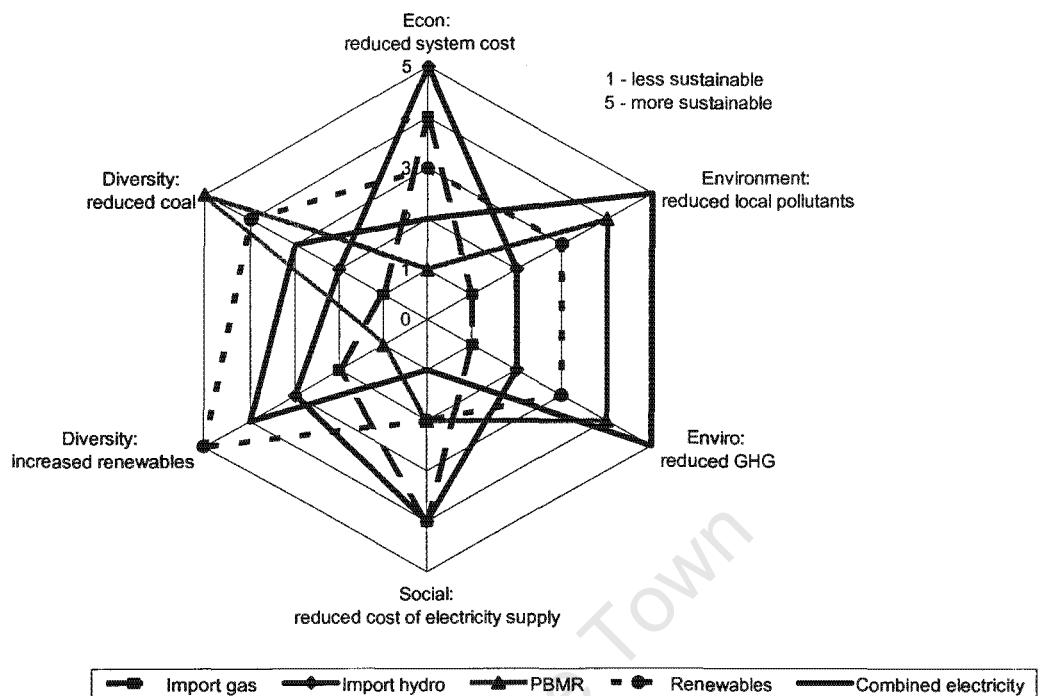
⁵⁰ See Munasinghe (2002: 174). for a discussion on 'win-win' cases and trade-offs in multi-criteria analysis of energy policies against indicators of sustainable development.

Figure 8.8: Electricity supply options ranked by economic, social and environmental indicator



If the priority were to reduce energy system costs, the importing of gas or hydro-electricity should be favoured, as that dimension is at the outer edge of the triangle for them, representing a relatively more sustainable policy. Both imports reduce domestic capital expenditure and overall system costs. Priorities of reducing emissions in South Africa would favour the two domestic options, even though these show increases of costs. Of the two domestic options, the PBMR is more expensive than renewables. The combined case might look attractive, except that it scores poorly on costs, making emission reductions expensive. Diversity of supply is shown in the figure only by the increased share of renewables. The renewables case still achieves a better mix among the other fuels, but one would need another indicator (e.g. reduction in coal) to show that the PBMR achieves the greatest diversity of supply in moving away from coal dependency. Both domestic options achieve reduce local air pollutants and GHGs by similar percentages from the base case, the simple ranking here puts the PBMR's 33 Mt CO₂ above renewables' 32 Mt. Figure 8.8 cannot show all dimensions shown in Table 8.21, for example, the lower abatement costs of renewables are relevant. More indicators for each of the three dimensions of sustainable development are shown in Figure 8.9 for the same set of options. The figure does not have clear social, environmental and economic 'corners', but ranks the same options in more ways.

Figure 8.9: Electricity options ranked against more indicators



A clearer picture emerges for residential policies. For all policy cases, access to electricity is increasing. Within the context of meeting this basic energy development objective, two residential policies go furthest in making development more sustainable in all dimensions. Visually, the triangles for efficient houses and SWH / GB completely contain those for CFLs and LPG for cooking, i.e. they are ranked on each of the dimensions shown. Efficient houses and SWH / GB make the greatest fuel savings and thus save the most energy costs for households. The policies reduce the electricity burden for households, particularly for poorer urban electrified ones. Increased affordability makes social disruption (e.g. through protests against electricity cut-offs) less likely. They also contribute the most to cleaner fuel use and improve environmental quality.

Figure 8.10: Residential policies ranked by economic, social and environmental indicator

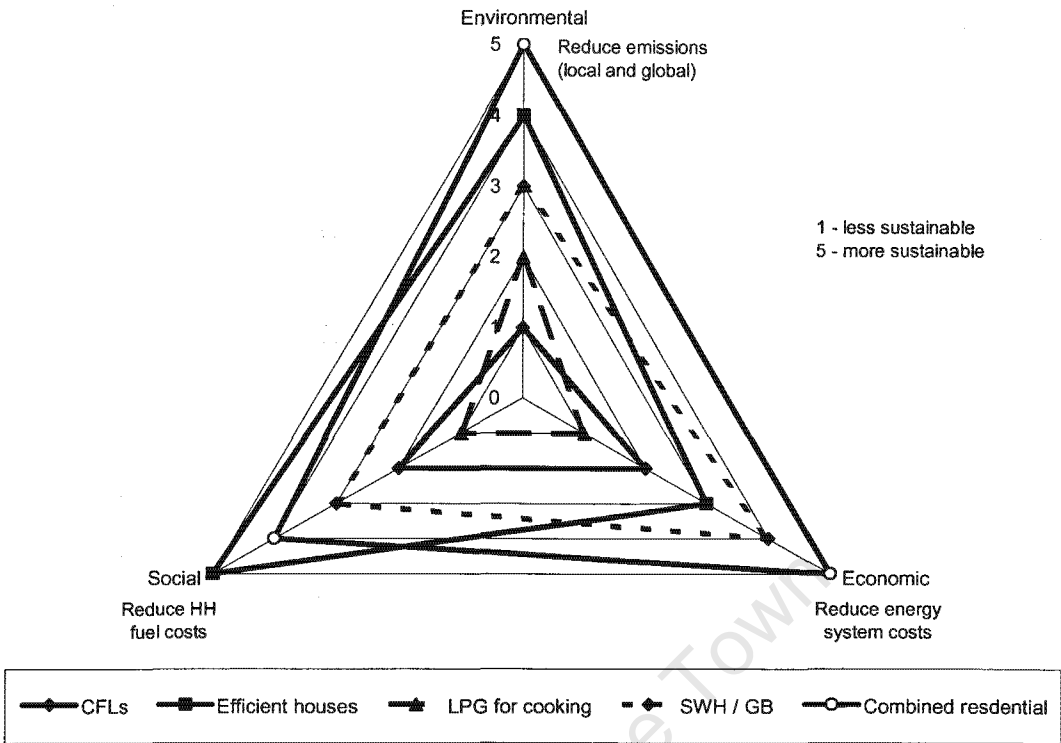


Figure 8.10 appears skewed towards efficient houses, showing that this policy case scores high in all respects. Solar water heaters rank next highest among, individual cases. For residential policies, combining works well as shown by the bulge towards that end. LPG and CFLs look flat.

Having compared both residential and electricity policies against each of the dimensions of sustainable development in turn, Figure 8.8 and Figure 8.10 have given a some representation of the synergies and trade-offs (without being able to show all the indicators at once). The analysis against multiple criteria shows that there are clear win-win cases for residential policies, but more trade-offs in electricity supply between the indicators of sustainable development. In either case, however, policies developed theoretically by modeling or indicators need to be implemented in reality. Some of the factors required to implement energy policy cases are considered in chapter 9.

Part IV: Energy for sustainable development and climate change

CHAPTER 9

9. Policy analysis

To answer the overall research question whether there energy policies to make the development in South Africa's residential and electricity sectors more sustainable, policies need to be formulated, and consideration given to what is required to implement them. The present chapter focuses on policy analysis. Results of modeling and indicators provide useful, policy-relevant information, but further policy analysis is required. It is important to recognize that decision-makers modify the results of economically 'optimal' model results before implementing them (Munasinghe & Swart 2005). A good example was the Integrated Energy Plan, which was based on least-cost modeling conducted by the Energy Research Institute. The final plan was written by officials in the Department of Minerals and Energy. Which policies are finally implemented will depend on investment decisions in which the boards of major energy companies, such as Eskom or Shell, will have a determining voice.

The chapter addresses the implementation of those policies identified in chapter 8 as having greater potential for making energy development more sustainable. Efficient houses and cleaner, more efficient water heating stood out in the evaluation of residential policies against indicators of sustainable development. Renewable energy had multiple benefits among electricity supply options, but the trade-offs with the lower costs of imports require consideration. The chapter discusses factors that promote the implementation of these energy policies, including institutional capacity, access to finance, and demonstration of innovative technologies.

The second part of the research question related to whether sustainable energy policies also reduce GHG emissions. Chapters 7 and 8 have provided information on the GHG co-benefits of energy policies. The chapter considers the implications for national climate change policy. It concludes by proposing ways in which sustainable development policies and measures – of the kind analysed in this thesis – could be included in the international climate negotiations.

9.1 Energy policies to make development more sustainable

The analysis in chapter 8 showed policies in the residential and electricity sectors that contribute to sustainable development. What factors are needed to implement policies that make development more sustainable? In general terms, one could say that policy implementation requires enough money, good people / effective institutions and inspiring demonstrations (GEF 2004).

Policies in the sense of regulation may include legislation, standards and certificates. Effective institutions are needed to implement policy, both organs of government and good business infrastructure. Access to adequate financing is a factor that is necessary for all successful policies. In many cases, financial instruments and mechanisms need to be designed to increase access to finance. Practical demonstration of innovative technologies and successful projects can provide inspiration for higher levels of implementation.

The present chapter explores concrete examples of what is needed to implement the residential and electricity policies identified in the previous chapters. How could more efficient housing be financed? What can government do to promote the uptake of renewable energy technologies?

9.1.1 Implementing sustainable residential energy policies

The evaluation of residential energy policies in chapter 8 concluded that efficient housing and cleaner and more efficient water heating through solar water heaters and geyser blankets (SWH / GB) ranked highly in all dimensions of sustainable development. The finding does not suggest CFLs and LPG should be ignored, but perhaps that efficient housing and SWH / GB have priority for *policy* interventions.

CFLs certainly have important benefits, but not only is the consumption of energy for lighting smaller than for water heating and cooking, but substantial progress has already been made in disseminating CFLs. Increased penetration rates were seen in the base case, i.e. under least-cost optimization, particularly in higher-income households. Further dissemination can be expected to occur through the market. Other policy cases may need more intervention for social and environmental benefits. Policies to promote LPG for cooking require a more detailed study of relative price changes, and possibly some form of subsidy or means of making the fuel more accessible.

Among a good set of residential policies, efficient housing and SWH / GB stand out with highest energy savings, greatest reduction of the electricity burden, uptake of cleaner fuels and improvement in local environmental quality. Policy-makers should give priority to these policies, or a set of combined residential policies.

9.1.1.1 Inspiring demonstrations for residential policies

Demonstration projects exist for residential policies for efficient housing, SWH and lighting. The efficient lighting initiative (ELI) aimed to install some 18 million CFLs and bought down the price through a subsidy programme (see chapters 4 and 6; and Bredenkamp (2005)). An LPG challenge has given initial consideration to means of making the fuel more accessible (IES & AGAMA 2004). A number of housing projects have sought to include energy-efficiency measures, particularly in low-cost housing (SEED 2002). There have been a several successful projects, such as the Lwandle hostels-to-homes, the Shayamoya social housing scheme in Cato

Manor, the Midrand Eco-City project in Ivory Park, the Missionvale project in Nelson Mandela City, the Moshoeshoe ecovillage and Eco-Homes project in Kimberley and the All Africa Games village in Alexandra (Spalding-Fecher et al. 2000b; SEED 2002; eg PEER Africa 1997; van Gass 1999) but there are very few large-scale efforts at improving housing. South Africa's first registered CDM project at Kuyasa in Khayelitsha has combined efficient design, SWH and CFLs (SSN 2004). Some 2,300 low-cost houses are to be built more efficiently, increasing the scale of implementation to some extent. Yet the challenge remains to scale up good demonstration projects through implementation of a broader policy – one that could apply to the two or three million new houses that need to be built.

The results in chapter 7 demonstrated energy cost savings for households as well as the energy system as a whole, accompanied by reduced local and global pollution. The policy question is how to turn the economic theory in practical adoption. A first step is to set standards.

9.1.1.2 Set mandatory standards for efficient housing

Political will is required to increase the share of housing that is built efficiently. The general subsidy to build low-cost ('RDP') housing is subject to detailed and intense negotiations. Money for efficiency measures in this context is not easily obtained from the general housing subsidy of R 17,500 per household (EDRC 2003b). An important signal from government would be to make housing guidelines mandatory.

Voluntary guidelines for efficient housing have existed for some time, in the form of the South African Energy and Demand Efficiency Guidelines (DME 1999). Guidelines could be made mandatory for new housing, in particular some measures that require no expenditure, but simply better planning and design. These include orientation of the house with the longer axis orientated east/west; positioning windows on the North to allow solar heat to penetrate the glazing during the winter months; and designing roof overhang for shade in summer. A further set of measures has a modest upfront cost, such as ceilings installed in the house of long-lasting material (e.g. gypsum board), a layer of low-cost insulation above the ceiling and on the walls (see Winkler et al. 2000, 2002d; see Holm 2000).

Both zero- and low-cost measures could be made mandatory for all new subsidy-supported housing, based on the results in section 7.1.1. In addition, separate codes would be needed for middle-upper income housing. The latter could be expected to pay for these measures themselves upfront, and reap the benefits of energy savings in future years. For poorer households, financing will be required and the upfront costs need to be made affordable for households

9.1.1.3 Subsidies for efficient houses

While energy efficiency makes sense from a societal perspective for low-cost housing, poor households cannot afford the upfront costs of better thermal design or more efficient lighting and water heating (Winkler et al. 2002d). To simulate the impact of a subsidy that would make efficient houses more affordable, the higher discount rate of poorer households was reduced from 30% (no subsidy) to 10% ('subsidised'), the general discount rate for the model. In other words, the case examines what would happen to investment in efficient housing if poor households were more willing to invest now for future savings.

The lower discount rate approximates a subsidy, in the sense that the energy savings (which happen in the future) are now valued more highly, and the upfront costs are valued correspondingly less. The change was made only for efficient houses. The results are shown below only for the poorer household types, since UHE and RHE households already had the 10% discount rate.

Figure 9.1: Marginal investments required for efficient houses at 30% and 10% discount rates

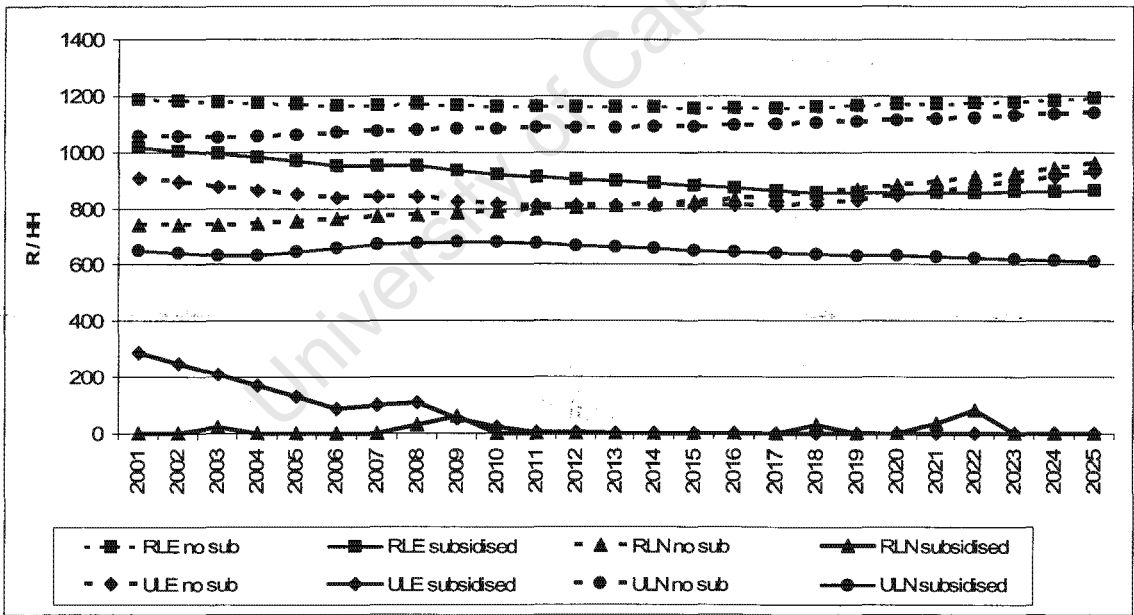


Figure 9.1 shows that for each household type, the marginal investment required (Rand per household) is lower for the subsidised case than without the subsidy. In two cases, ULE and RLN, the marginal investment reaches zero in the subsidised case. In other words, no additional investment is required and efficient houses would be built for these household types. For RLE and ULN households, the marginal investment needed to build efficient houses is reduced, but not sufficiently to lead to investment.

The level of the subsidy can be approximated by comparing the marginal investment with the higher and lower discount rates – with and without the ‘subsidy’. It should be remembered, though, that the marginal investments in Markal represent shadow prices or opportunity costs, not the prices of a real, imperfect market.⁵¹

Table 9.1: Subsidy required for making efficient housing as affordable for poorer as for richer households

<i>Unit: Rand / household</i>	<i>2001</i>	<i>2014</i>	<i>2025</i>
RLE	-169	-267	-326
RLN	-739	-818	-958
ULE	-618	-811	-930
ULN	-407	-432	-531

Note: The values in technical terms show the reduction in marginal investment as a result of lowering the discount rate for poor households from 30% to 10%. Values are shown as negative values, the difference between the marginal investment with a low discount rate (‘subsidy’) and a high discount rate (‘no subsidy’).

The reduction in investment needed is larger for the RLN and ULE, the two household types which showed investment in efficient housing in Figure 9.1. The order of magnitude of the subsidy required to make efficient housing as affordable for poorer households as for richer ones is in the hundreds of Rands; less than a thousand Rand. A relatively small additional investment in housing for poor communities creates more comfort, reduces household energy costs, as well as cutting emissions from the residential sector. An extension of this policy could improve the energy efficiency and save households money. Energy efficiency in RDP housing is an area where a policy of direct state financial support to promote energy efficiency seems warranted.

In practice, instead of changing the discount rate itself, a financial mechanism would be used to make available the necessary upfront capital to poorer households. Municipal government could play an important role in administering a subsidy scheme.

9.1.1.4 Affordability and household types

The question of where subsidies might be targeted can be further illuminated in relation to SWH and geyser blankets. The context for the example is the finding throughout chapter 7 that energy savings are largest for UHE households. The water heating policy was a clear example, where SWH and GB reduced other fuels overwhelmingly in the UHE household category.

⁵¹ The subsidy levels found here are consistent with earlier studies that used market prices (Spalding-Fecher et al. 2002a; Holm 2000; Winkler et al. 2002e; Spalding-Fecher et al. 2001; Irurah 2000). However, none of the previous work disaggregated results by household type nor considered the feed-back effects in the context of a national energy models.

The largest savings are made by those who least need to spend less; while the poorest households consume little energy, and cannot save large amounts. A quandary for policy-makers arises – should the policy focus be on the households where the greatest energy saving can be made, or those who have the greatest need?

The inclusion of geyser blankets was intended as an option that might work better in lower-income electrified households. The much lower investment cost of geyser blankets means that total investment is smaller than for SWH (see Table 9.2), geyser blankets account for a good part of the energy savings.

Table 9.2: Cost of saved energy for SWH and geyser blankets

	<i>Saved energy (policy – base case)</i>	<i>Total investment in policy case</i>	<i>Cost of saved energy</i>	
	<i>PJ</i>	<i>R million</i>	<i>R / GJ</i>	<i>c / kWh</i>
Geyser blanket	4.9	7.6	1.5	0.6
Solar water heater	13.3	331	25.0	9.0

The cost of saved energy for GB is below 1 c / kWh, while it is 9 c / kWh for SWH. The lower cost – both upfront and per unit of energy saved – suggests that geyser blankets are more affordable for poorer electrified households.

The greater energy and cost savings in UHE households only reflect one perspective. The analysis of the electricity burden in chapter 8 showed that, in relative terms, ULE households benefit the most from SWH / GB (at 5.6% reduction below base case, compared to 2.0 – 2.3 % for other household types). Policies that seek to address affordability have a major aim of alleviating poverty. From this perspective, it would be most beneficial to priorities poorer urban households.

Some limitations of the analysis of energy burden by household type should be noted at this point. The innovation of including six household types extended the boundaries of previous national energy modeling, but still simplifies the complexity of residential energy use enormously. Not only would a large research effort be needed to model 60 household types (e.g. with geographic disaggregation, or more income groups), but some of the data is not available. Energy use patterns for rich rural households, for example, are poorly understood. Even if these can be surveyed, some data will remain unknown e.g. the split of fuels used for different end uses. Markal as a tool is limited in its representation of households, which can only be represented directly (rather than as energy demands or units) with loss of resolution on

the time of use. Yet affordability is a critical policy issue. Hence the quantitative results from modeling, and the analysis against indicators in chapter 8 must be supplemented by policy analysis.

Of course, the discussion assumes that the policy needs to be targeted. If sufficient funds were available, *all* households should be targeted. With government budgets limited, different financing mechanisms could be considered. Donor funding for subsidies for SWH / GB in poorer households would be an option, at least in the process of establishing a viable local SWH manufacturing sector (see section 9.1.1.4). For higher-income households, SWH could be made mandatory, but the financing be spread out through green bonds (EEU 2000). Effectively, policy could provide direct financial support for poorer households, but only offer bridging finance for those who can afford to invest upfront for future energy savings.

9.1.1.5 Making LPG more accessible

Affordability is an issue that applies to LPG as well as electricity. LPG is a desirable thermal fuel, yet little switching from other fuels to LPG has been observed in South Africa (IES & AGAMA 2004). Several barriers exist to the greater use of LPGas. Government is still in the process of formulating a clear enabling policy and regulatory environment promoting LPG for the poor. Promotion of LPG is a 'poor cousin' to the intense focus on electrification. For customers, the affordability of LPG is a key issue, with the overall costs for boiling two litres of water being 25c, compared to 20 cents for electricity and only 13c for paraffin (IES & AGAMA 2004). For rural areas, comparative energy costs for cooking were estimated at 48 c/kWh-equivalent for LPG, compared to 30-40c for electricity (lower with the poverty tariff) and 28c for paraffin (EDRC 2003b). Fuel costs make part of the difference, but the deposit on cylinders and higher appliance cost (compared to paraffin) compounds the lack of affordability.

From the industry side, distribution systems are needed to increase retailer networks and bringing these closer to end-users. Currently, most customers have to manage the final delivery themselves, incurring transport costs and physically having to carry cylinders. LPG customers have little choice of retailers, in contrast to paraffin which is sold at many outlets. Finally negative perceptions of LPG, e.g. the feeling that gas is dangerous and can explode, need to be addressed through raising awareness of the safe use of LPG.

One important intervention is raising awareness – of the comparative costs of energy choices, health and safety issues, and practical information (EDRC 2003b). The issue of affordability can be addressed through removal of VAT on LPG, increased competition, incentives to switch fuels, and reducing costs of appliances (IES & AGAMA 2004). Reducing costs needs to be accompanied by measures that facilitate access to LPG – establishing better delivery network and encouraging more retailers by reducing barriers to entry.

Energy centres can play an important role in facilitating access to LPG and reducing costs. Existing rural energy centres have demonstrated that it is possible to sell LPG at lower prices than current ones, due to bulk buying and modest profit margins (EDRC 2003b). Energy centres also make physical access easier, and have worked on supplying cylinder in smaller sizes. Smaller cylinders are easy to carry physically and allow purchase of smaller quantities for poorer households. Energy centers may also be able to buy appliances in bulk. Together, measures that increase access and promote affordability can help reduce energy poverty.

9.1.1.6 Poverty tariff: making the use of electricity more affordable

Policy to directly address the affordability of electricity has begun to be implemented through the poverty tariff. From 2004, government committed itself to implementing a free supply of electricity for basic needs (DME 2004b) (see details of the policy in chapter 4).

The affordability of using electricity is a problem of poverty. Policy solutions limited to the electricity sector – for example the poverty tariff and weak grid – can only address the problem partially. An overall solution must be part of a broader, cross-sectoral approach to poverty eradication. Changes in the economy at large, such as job creation and higher incomes, will be important in addressing affordability in its wider sense. President Mbeki in 2004 re-emphasised the “central importance of the state as a social agent to effect the necessary resource transfers, and ensure their productive utilisation” (Mbeki 2004b). A year later, he more concretely indicated that government would “complete discussions with Eskom, the provincial governments and local municipalities to ensure that free basic electricity is provided to all with the minimum delay” (Mbeki 2005).

The analysis in chapter 8 found that policies could reduce the electricity burden between 2% and 6%, depending on policy and household type. This is similar to the relative reduction found by analysis of the impact of the poverty tariff for poor households, considering all households, which saw a reduction of 6 percentage points (Prasad & Ranninger 2003). A recent study in the poor areas of Cape Town showed that monthly electricity consumption has risen by 30 – 35 kWh/month per customer since the introduction of poverty tariff, a substantial rise against an average consumption ranging from 100 to 150 kWh per month (Borchers et al. 2001). This rise is less than the full 50 kWh/month, suggesting that households both make greater use of electricity, but also value some saving on their energy bills (Cowan & Mohlakoana 2005).

A combination of the poverty tariff (aimed at social sustainability) and the residential policies outlined in this thesis could improve affordability for poor households in two ways. The residential policies reduce the consumption of energy needed to deliver the same service, while the poverty tariff makes the price of electricity cheaper. Together, the policies have potential to address the difficult issue of affordability. Instruments and mechanisms to finance such policies will be needed.

9.1.1.7 *Develop financial instruments and mechanisms to support residential policies*

Addressing the affordability of energy services requires setting up financial instruments and mechanisms. Support for individual policies can be differentiated, as suggested with bridging finance for SWH in richer households, but direct subsidies for poorer ones. Financing can help to promote efficiency in two major ways: firstly by funding the costs of efficiency programmes, and secondly by helping to finance the upfront costs for those who cannot afford them.

Specific funding for end-use energy efficiency could be drawn from the general fiscus, or raised through a charge. To sustain investment in socially beneficial efficiency programmes – even under power sector reform – the regulator could introduce a charge on all electricity sales. This non-bypassable charge, sometimes called a ‘wires charge’, would be dedicated to funding public benefits including energy efficiency (Winkler & Mavhungu 2001; Clark & Mavhungu 2000; Winkler & Mavhungu 2002).

Financing is an essential element of promoting greater efficiency in the use of electricity. Direct financial support – e.g. subsidies of efficient housing – is one means of contributing to efficiency. As earlier parts of this section have shown, tariff structures that appropriately reflect costs in the price of electricity are equally important.

9.1.1.8 *Business capacity to manufacture locally*

Institutional capacity to implement policies is required in both the public and private sectors. The need for government to set mandatory standards has been outlined in section 9.1.1.2, but government can also assist with setting up financing mechanisms for residential policies more broadly (9.1.1.7 above). Institutional capacity is also needed in the business sector, however, as the example of solar water heaters illustrates.

Adequate business infrastructure is needed for introducing vacuum tube technology, which should reduce costs of SWH systems almost by half. Chapter 6 assumed some cost reductions will occur, but in practice a step-change is needed to import technologies. Import of vacuum tubes becomes economic at a certain scale. Aggregation among suppliers of SWH systems would help, as might assistance from government with establishing trade.

The local component of SWH would benefit from the development of a local manufacturing industry. If using imported vacuum tubes, locally manufactured components could be combined in assembly with import vacuum tubes. The policy case of SWH / GB requires a public-private partnership. Much as business capacity needs to be built to grow markets, institutional capacity is needed in government for residential policies.

9.1.1.9 Government capacity to administer residential policies

Residential policies form part of the energy efficiency strategy (DME 2005a), have a basis in broader energy policy (DME 1998) and may soon be covered a new National Energy Act (Surridge 2005). Policy and strategy, however, requires people and institutions to implement them.

Institutional capacity could be established to benefit all residential policies. Capacity is needed to not only to develop and enforce codes and standards, but also to promote policies. A National Energy Efficiency Agency has been researched in a feasibility study, but has not been established. Cooperation between agencies (DME, NER, Eskom) has many advantages. A dedicated agency might provide clearer leadership if it had sufficient authority and adequate, consistent streams of funding. In short, an institutional home for public-benefit energy efficiency needs to be found.

The CABEERE (Capacity building in energy efficiency and renewable energy) initiative within DME has provided some focus for energy efficiency research and projects, but a secure institutional home has not been established. The organisational structures of the authorities, notably the DME and NER, are important for public benefits, particularly in the context of power sector reform. With the electricity distribution industry undergoing restructuring, the pressures to compete are likely to increase. Energy efficiency measures reduce sales revenues, and therefore the protection of public benefits is needed (Winkler & Mavhungu 2001; Clark & Mavhungu 2000; Philpott & Clark 2002).

9.1.1.10 Conclusions

An approach to sustainable development that emphasizes durability would require growth (e.g. in terms of access). Rather than insisting on strict economic optimality, however, more flexibility can be shown in making some trade-offs. In the residential sector, this approach has been implemented by building the key development objective of increased access into all cases. The optimizing framework ensures that goals are reached cost-effectively.

Considering a durability approach, some trade-off of economic optimality might provide greater social benefits. An equitable *distribution* of energy services is important for social sustainability, adding a further dimension to the priority often given to economically efficient delivery. The residential policy cases illustrate that there is potential for policy-makers to achieve benefits in all dimensions. More could be achieved if some measure of economic optimality is traded off for other benefits, e.g. in the case of LPG for cooking.

The largest absolute energy savings (and associated emission reductions) will not occur in the residential sector. Levels of energy consumption are relatively low, not only in unelectrified households, but also in newly electrified households. However, the residential sector is critical

for social development. Changing development paths in this sector will need to focus on multiple issues, including more efficient use of electricity, but also switching to other fuels.

Increasing access to finance is critical for implementing policies. Several supportive policies are needed. Subsidies of less than a thousand Rand / household should be sufficient to promote an individual policy such as efficiency in the housing shell. Judging from a case with reduced interest rates, it appears that such subsidies would make efficient housing attractive to ULE and RLN households (in addition to UHE, who take up this intervention in the base case).

The household type with the largest savings need not always be the target group for policy intervention. Policy analysis of water heating showed that while UHE have larger absolute energy savings, the reduction in the electricity burden is proportionately greater for ULE. Low-cost measures, such as geyser blankets, can be aimed at poorer household types – and have a lower cost of saved energy than SWH.

A combination of the poverty tariff and residential policies could work together to reduce the consumption of energy needed to deliver the same service, while at the same time making the price of electricity cheaper. Financing instruments from the general fiscus, to funding for residential policies from systems charges, should be examined.

Institutional capacity is needed in business to develop local manufacturing and reduce costs. Capacity in government is needed to enforce policy, and a dedicated energy agency might provide an important focal point.

9.1.2 Choosing electricity supply options for sustainability

The policy challenge for electricity supply includes the need to:

- increase diversity of supply and lessen dependency on coal;
- reduce emissions of local and global air pollutants; while
- increasing access to affordable energy services (DME 1998).

The comparative analysis of electricity policies against sustainable development indicators in chapter 8 (Figure 8.8) did not show clear ‘winners’ in economic, social and environment terms, unlike the residential sector. The policy questions for electricity options relate to trade-offs of different aspects, as well as specific requirements for implementation.

This section briefly reviews the policy choices that need to be made in comparative perspective. Each electricity supply options faces specific issues, which are outlined next. The longer-term perspective of durability, introduced in chapter 2, is revisited. On this basis, the challenge of making near-term changes to meet long-term goals is outlined.

9.1.2.1 Policy choices

Policy statements on future electricity supply have tended to emphasise that all energy sources would be used (Mlambo-Ngcuka 2003, 2005). In practice, choices are being made about investments in capacity, initially to meet peaking demand (NER 2004a). The analysis in chapter 8 has suggested that choices of electricity supply options have advantages in different dimensions – there are trade-offs to be made.

On cost, imported options (gas or hydro) look attractive. Similarly, considerations of security of supply might lead SA to look to domestic options. Coal will continue to provide a large share for the next 20 years, as the base case and all policy cases illustrate. Of the other two domestic options, the PBMR performed poorly in terms of cost, even more expensive than a combined case. A mix of renewable energy options was more attractive.

With the assumption in all cases that electrification would increase, the social implications of electricity supply are mainly through the price. Measured by the shadow price, the combined case was clearly most expensive, followed by the PBMR and renewables in joint second rank. Imports provided the lowest opportunity cost.

Environmental concerns of reducing local and global air pollutants would favour the two domestic options (apart from coal), renewables and the PBMR. While the PBMR had high reductions, renewables achieved similar reductions at lower cost. In this dimension, imports of gas or hydro-electricity did not compare favourably, with the lowest reductions of both local and global emissions.

9.1.2.2 Specific policy issues

9.1.2.2.1 Markets to scale up renewables

In chapter 7, the results for the renewables case showed that the target could be met. Electricity generation from renewable energy sources increased beyond 2013, as technology costs declined. The mix of renewables was primarily supplemented by bagasse co-generation and wind, in addition to existing small hydro and bagasse. The environmental performance in reducing local and global air pollution was good, second only to the PBMR, and at lower cost.

The policy challenge for renewables is to achieve the voluntary target. Institutional capacity, as for residential policies, will be needed in both the public and private sectors. Government needs to engage key stakeholders, including Eskom, in the challenge to meet the target. Setting up a well-regulated market is important for business and for scaling up the capacity of renewables. Key policy issues to achieve this are financing (subsidies and appropriate tariffs), ensuring markets that include independent power producers (IPPs), power purchase agreements and tradable permits.

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

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

While investment subsidies have the advantage of reducing the high up-front investment costs of RETs, the major drawback is that facilities may be built to get the subsidy, but not maintained to generate any electricity. Production subsidies more directly reward the on-going production of electricity from RETs (EDRC 2003a). The DME during 2005 set up an office for subsidies to renewables (see section 6.6.2.1).

The *tariffs* that producers of renewable electricity receive will be critical to their financial viability. The National Electricity Regulator (NER) would play a key role in overseeing the process of setting tariffs. Standard contracts or power purchase agreements would set tariffs and guarantee a market for renewable IPPs. Some observers suggest that establishing long-term power purchase agreements for IPPs could tie government and consumers into non-competitive prices for years to come (Eberhard 2000; Clark 2001a). They are, however, essential if renewable IPPs are to have security that they will be able to recoup their high initial investment costs.

Indeed, power purchase agreements need to be specifically structured to reflect the cost structure of renewables. To avoid the lock-in to fixed prices, it might be desirable to limit the agreements to small-scale projects, such as renewable energy projects smaller than 50 MW (and energy efficiency equivalent to less than 10 MW). The assumption would be that, as renewable IPPs become commercialised and grow, they are able to compete with other technologies, but that while the technologies are still going through learning curves and reducing costs, they need the security of fixed contracts.

The Darling wind farm has negotiated a preferential tariff of 50 c / kWh with the City of Cape Town (CCT 2004; CCT & SEA 2003). Once the facility comes on-stream, the city would offer customers the option of buying electricity from a renewable source, at a premium. Available electricity would be 3 GWh per year, a small contribution to the 9 000 GWh consumed by the city (CCT 2004). There would be some marketing of green power. More generally, IPPs reportedly state that they require a tariff of 31 c / kWh to be financially viable (Blignaut 2004).

The NER has policy on IPPs that aims to encourage multiple players to enter the market (NER 2003b). With Eskom having operated as a virtual monopoly, and continuing to exercise market power, access to the single transmission system (often termed a natural monopoly) must be

made available on fair terms. IPPs should enjoy non-discriminatory access to the grid, paying a system charge rather than the full-avoided cost of electricity otherwise generated.

Subsidies, tariffs, and power purchase agreements contribute to setting up a market for renewable electricity governed by clear rules. Market rules for independent power producers using renewable energy sources are being developed for government. Such rules – including grid access, power purchase agreements and certification procedures – in the long term need to form part of a larger electricity market (Sad-elec 2003). Such business infrastructure will be critical if renewables policy is to be implemented.

9.1.2.2.2 *Addressing the issues of nuclear energy*

The PBMR faces a different set of issues to renewables. The results of the policy case in chapter 7 showed a substantial diversification was possible, with reduced local and global air pollution. However, this came at a high cost and with underutilized capacity.

The key policy questions that will need to be addressed for nuclear technology are waste disposal, security, public acceptance and the economic viability of the technology.

The economics of the PBMR have been debated in the literature, with proponents claiming low costs (PBMR Ltd 2002), but others claiming that these are severely understated (Auf der Heyde & Thomas 2002). The debate will likely only be settled in practice. However, before the first module can be constructed domestically, the EIA approval is required (see chapter 4). Initial plans for the PBMR appeared to rely on export of PBMR modules, but with the entry of China into PBMR production (AEJ 2005), the possibility for competition for exports of the technology has increased. Beyond the cost of the initial units, the decline in costs assumed in the policy case is only related to *domestic* production (unlike the renewables case, where it is a function of doubling of *global* capacity).

Security of PBMR installations appears to be an issue which has received less attention than it deserves. One of the attractions of the relatively small modules is the potential to spread them across several sites.⁵² While providing benefits of avoiding transmission losses, each new site and transport route would have to be secured, in turn adding to costs.

While costs of decommissioning have been included in the cost estimates for the policy case, the issue of waste disposal remains to be addressed. A requirement of the EIA approval was that the DME promulgate a policy on radioactive waste, and such a policy was approved by Cabinet in 2005. The first national principle adopted in that policy is the “polluter pays

⁵² Another attraction of the modular design is that units can be built to more closely match supply – investment is not as ‘lumpy’ as for a Pressurised Water Reactor such as Koeberg (which has a capacity of some 15 PBMRs). The same applies to any smaller electricity generation options.

principle”, stating that generators shall bear the financial burden for management of radioactive waste (DME 2005b).

The PBMR, like nuclear technologies in general, face difficulties with public acceptance. Nuclear power and its high-level radioactive waste have attracted the attention of academics, NGOs and the press (Law & McDaid 2001; Gosling 1999; Auf der Heyde 2000; SECCP 2002). Whether the initial costs of developing the PBMR should be written off, as implicitly assumed in the policy case, would be a major policy decision. Critics of the PBMR have suggested that funding of a particular technology at a larger scale than others, notably renewables, is inequitable.

9.1.2.2.3 *Imported gas and hydro-electricity*

The policy issues for imports related primarily to prices and the security of receiving the imports consistently. Chapter 7 suggested that imports of gas should be phased in more gradually, while imports of hydro-electricity can be expanded as in the policy case.

Policy interventions to promote gas-fired power plants are mostly not in the electricity sector itself. Apart from the regulation of gas pipelines, gas prices are a critical factor determining viability. Fuel prices are set in international markets, beyond the control of national policy. The anchor customers for gas from Mozambique is SASOL and industrial users in Gauteng, so that policy on liquid fuels and industrial development influences the availability of gas. Another option is importing liquefied natural gas (LNG) imported by tanker, which requires significant investment in re-gasification plant.

Hydro-electricity is already imported from Mozambique on a contract highly favourable to SA, and this option can be expanded with Mepanda Uncua. The large future potential, however, lies at Inga Falls (see chapter 4). If the large potential in the DRC is to be tapped, the interconnections between the national grids within SAPP would need to be strengthened. A Western Corridor project plans to connect South Africa, Namibia, Botswana, Angola, and the DRC with transmission lines. Several of the initiatives under NEPAD are interconnectors (NEPAD 2002).

The prospect of increased interconnection and trade of electricity across borders requires regulation. Different operating systems, markets, tariffs and policies need to be harmonised sufficiently to allow trade. A Regional Electricity Regulators' Association (RERA) was formally approved by SADC Energy Ministers in July 2002. Members are Malawi, Namibia, South Africa and Zambia, with observers from the regulatory authorities of Angola, Lesotho, Mozambique, Tanzania and Zimbabwe and support from the SADC energy technical support unit (NER 2002e).

Political stability in the DRC is an important – but highly uncertain – pre-requisite for using this option. In the Zambezi river basin, closer to South Africa, there is the potential for an additional 6000 MWe. Technical problems would be sufficient transmission capacity and line losses over long distances, but these could be overcome (Kenny & Howells 2001). More important are political uncertainties, and reaching agreement on contracts that promote the interests and development of all countries involved.

With no single policy emerging as a ‘win-win’ option in a least-cost framework, the policy approach should consider durability over a longer-time frame.

9.1.2.3 Durability: considering challenges over longer time-frames

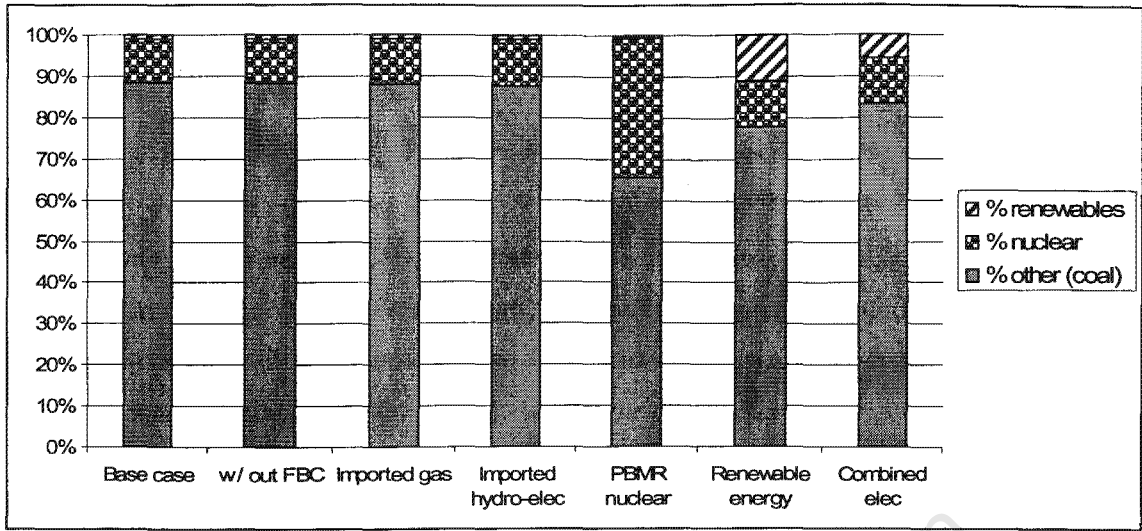
The methodology of the thesis (see chapter 1) made a distinction between optimality and durability. The Markal modeling tool is fundamentally an optimizing one, although social and environmental dimensions can be included, as demonstrated in chapters 7 and 8. However, they remain side constraints to the objective function of minimizing costs.

Durability favours development paths that permit growth, but does not insist on economic optimality. There is more willingness to trade off some economic optimality for greater safety, or for a system that has higher resilience to external shocks. The difference, however, is one of emphasis and perspective - optimality and durability have different emphases, but can complement one another (Munasinghe & Swart 2005).

An example in the South African energy system is diversity of supply. The base case showed that coal will remain the least-cost option over the 25 year period. ‘Cleaner coal’ technologies were included in the base case. Policy considerations would be to ensure that all FBC complies with emissions standards. Such standards can be set under the new Air Quality Act, with mandatory and public reporting. Yet a key challenge remains to reduce the dependency on a single fuel. The energy policy of objective of ensuring security of supply through diversity is critical.

The analysis of diversity of supply (see chapter 8) showed two distinct dimensions. The move away from coal (dominating ‘other fuels’ in Figure 9.2) is clearest for the PBMR, albeit at a higher investment cost. The balance of different fuel types, however, is more diverse in the case of renewables. The bar for renewables in Figure 9.2 below shows three distinct components, while the first four cases have a barely visible sliver of renewable energy.

Figure 9.2: Diversity of fuel mix from domestic sources for electricity supply options by 2025



Note: The data underlying Figure 9.2 is shown under the indicator ‘diversity of electricity fuel mix’ in Table 8.21. Shares are based on electricity output, not installed capacity.

Greater diversity supply has other advantages – improving energy security and reducing environmental pollution. More diverse systems are more resilient to external shocks. In the case of electricity supply, reliance on a single fuel increases vulnerability to shocks to that single resource. Possible shocks might include factors such as volatility in the politics of Southern Africa for hydro imports, or future carbon constraints for coal. A more diverse mix of fuels for electricity supply provides a greater chance that difficulties in one sector can be balanced by other ones. An approach focusing on durability should *both* lessen dependency of coal and maximize the number of other fuels used. Such changes in energy-infrastructure require a longer-term perspective.

9.1.2.4 Short-term changes for a long-term transition

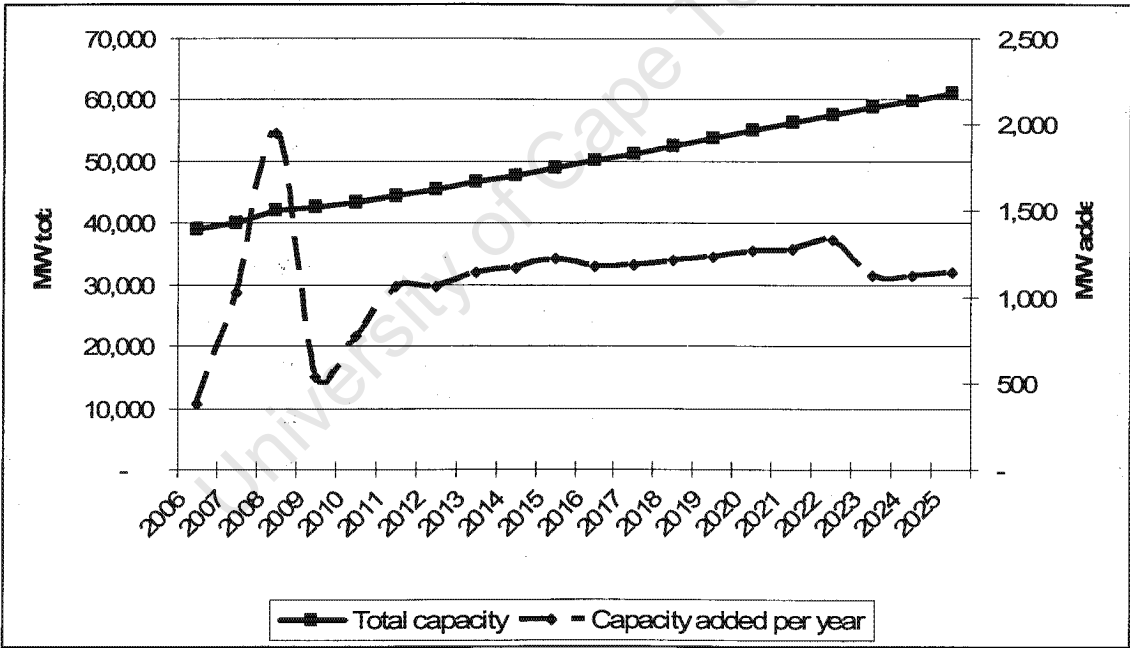
The time-frame for the analysis has been 25 years, typical for energy and electricity planning. There are two major reasons to look at longer time-frames. Increasing diversity of electricity supply involves replacement of infrastructure with long life-times. Secondly, challenges such climate change involve long-term changes. While impacts of present policies at times seem far away, critical choices for the rest of the 21st century need to be made over next 10-30 years (Nakicenovic 2000: 334). Capital turnover of power plants, refineries and other energy-related infrastructure is slow.

The power plants included in the National Integrated Resource Plan have life-times between two and four decades - 20 years for wind, 25 years for gas turbines, 30 years for solar thermal electricity and new FBC coal, and 40 years for PBMR nuclear plants (NER 2004a). Electricity generation plants coming on-line in 2007 can be expected to still be emitting local pollutants and greenhouse gases in 2037, if they are fired by fossil fuels. An efficient house, on the other

hand, constructed today will still be saving energy in 30 years, when SA may face restrictions on carbon emissions. These considerations emphasise the importance of ‘lock-in’ to chosen technologies (Kartha et al. 1998). Changes to existing coal-based energy economy and electricity sector require planning for a hundred-year time-frame, but inform critical choices in the next few years. To change the direction of large systems requires smaller changes in the short-term, to enable larger future changes.

For the electricity sector, the need to replace electricity generation capacity is a challenge that presents the opportunity of changing course. Not only is new capacity needed urgently in the next few years, but replacement of existing stock will continue into the mid-term, as power stations come to the end of their life. The additional capacity required in the 20 years from 2005⁵³ to 2025 amount to 22 750 MW of added capacity, as shown in Figure 9.3.

Figure 9.3: Total capacity for electricity generation and additions per year



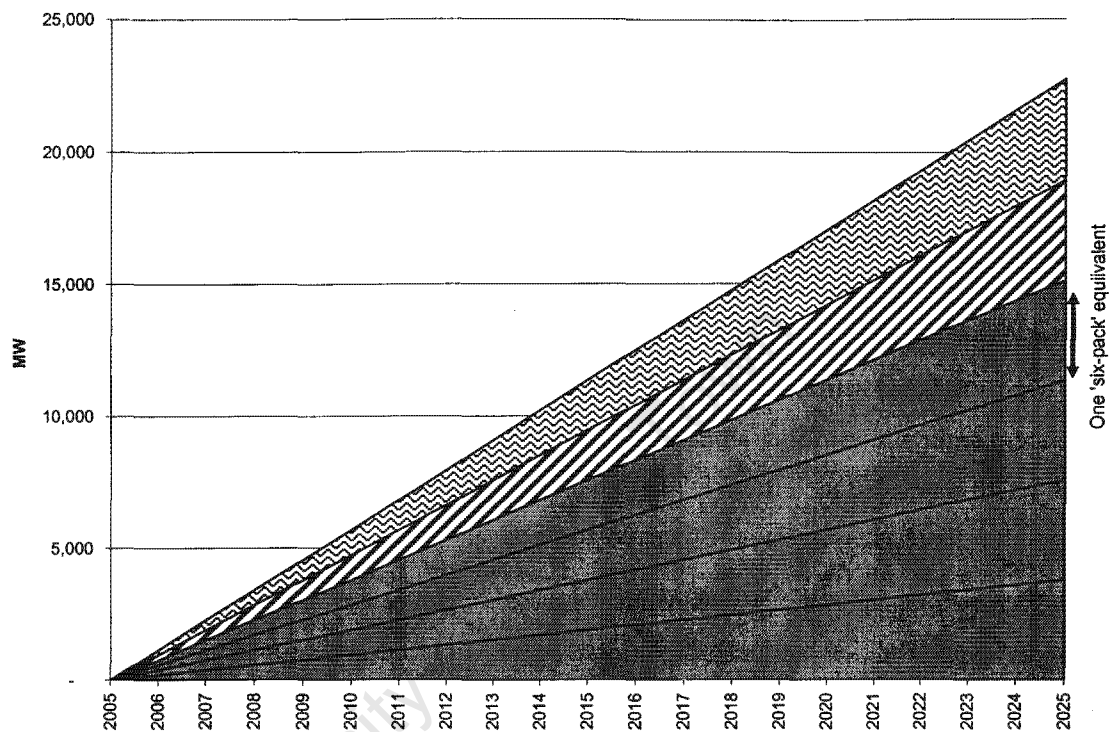
The total capacity (measured on the left-hand y-axis) increases from 40 to 60 GW over the 20 years. The added capacity (measured on the right-hand y-axis) is somewhat lumpy, with the peak of 1950 MW representing the investment in a combined cycle gas turbine. On average, just over 1 000 MW are needed per year.

The replacement of major infrastructure offers the opportunity to change direction. The new capacity could be met by six new coal-fired power stations. These pulverized fuel stations, known as ‘six-packs’, have capacity of around 3 600 MW each. If only two of the six were

⁵³ There are no investments in the first years of the model run - which starts from 2001 - due to lead times.

replaced by other options in the next two decades, this would represent a major shift in South Africa’s energy development path. In fact, as shown conceptually in Figure 9.4, capacity in each part could build up gradually over the initial 20 years.

Figure 9.4: Wedges of electricity capacity equivalent to one ‘six-pack’ each over 20 years⁵⁴



If, for example, one ‘six-pack-equivalent’ were to be from renewables, and another from PBMR or imported electricity, significant institutional capacity would have been developed in the local electricity supply industry. Longer-term goals of three six-packs over 30 years, and five over 50 years, might seem achievable. Changes in the next two decades will be critical in shaping not only energy policy, but also South Africa’s response to climate change mitigation.

9.2 Implications of sustainable energy development paths for climate change mitigation policy

The research question in its last clause asked whether making energy policies more sustainable could also reduce GHG emissions. From the preceding chapters, it is clear that there are a number of policies that promote local sustainable development objectives. In the residential

⁵⁴ The diagram draws on the concept of wedges for stabilising CO₂ emissions using existing technologies (Pacala & Socolow 2004).

sector, there were ‘win-win’ options with efficient housing and water heating. The electricity supply options require more trade-offs between environmental, social and economic dimensions, but offer opportunities to change each dimension at larger scale in the longer-term.

9.2.1 Options for SA mitigation policy

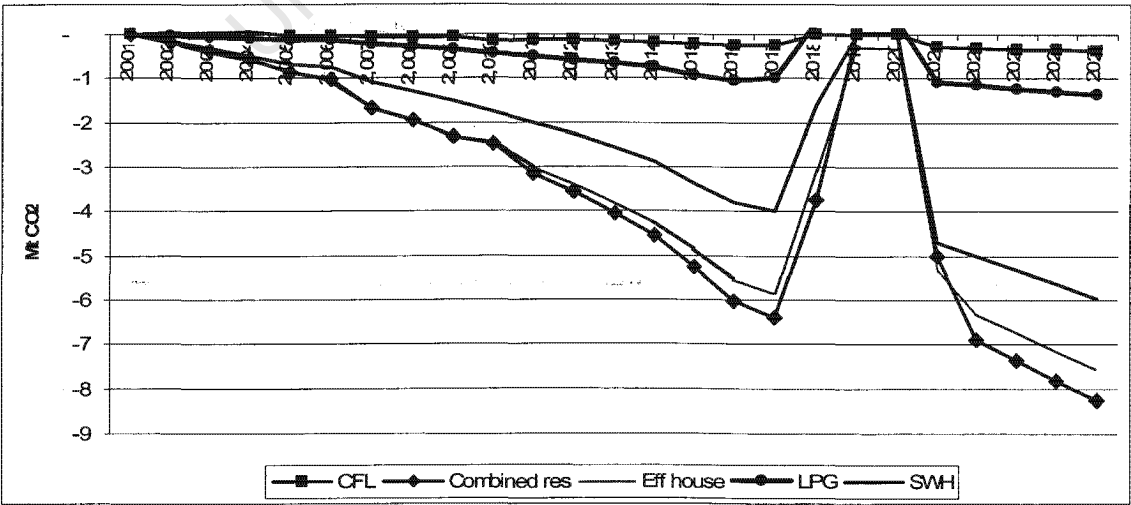
South Africa’s national climate change response strategy (DEAT 2004) is centered around the concept of sustainable development. The analysis in this thesis suggests specific ways in which this policy can be realized.

South Africa’s climate policy will be more “durable” (Munasinghe & Swart 2005) if it does not give sole priority to reducing costs, but also achieves social and local environmental benefits. The policies modeled, evaluated and analysed in the preceding chapters can make important contributions to both energy and climate policy.

Figure 9.5 shows the emissions *avoided* in each of the residential policy cases, i.e. reduced from the emissions level in the base case. The upwards movement in all cases between 2018 and 2020 seems to be an artifact of a sharp increased in generation from two pumped storage plants (Steenberg and Palmiet). The largest reductions are seen in the combined, efficient housing and SWH / GB cases in that order. In the simple estimate of abatement costs in chapter 8, the efficient housing case was also the most cost-effective.

The efficient housing and SWH / GB cases were already identified in previous chapters are ‘win-win’ opportunities, reducing local air pollutants, economic costs and the burden on households. What can be seen from Figure 9.5 is that emissions in the order of 1- 10 M CO₂-equiv / year can be avoided through these policies.

Figure 9.5: GHG emissions avoided in residential policy cases



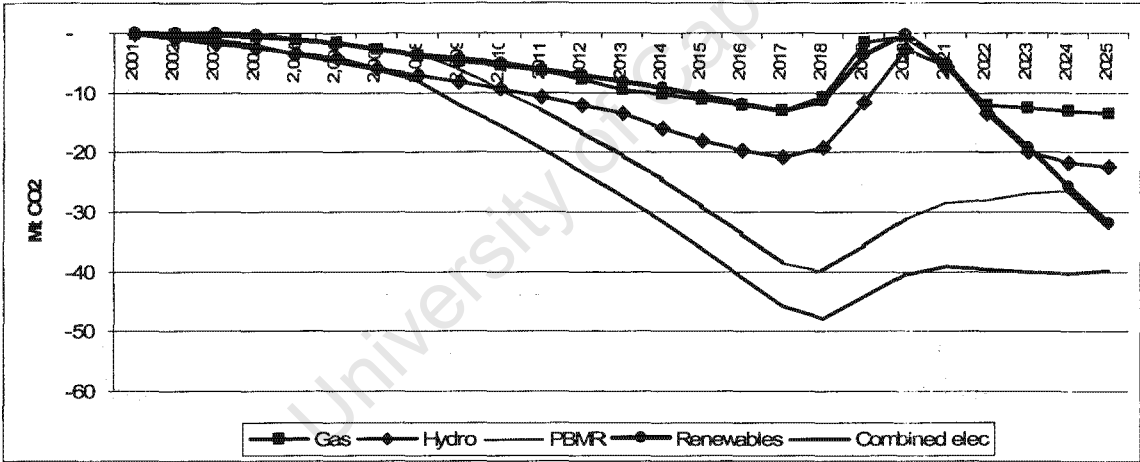
The avoided emissions in the case of efficient houses constitute 1.2% of the emission of GHGs (CO₂, CH₄ and N₂O) compared to 2025 emissions in the base case. For comparison, they

amount to 1.9% if divided by 2001 emissions in the base case. Energy policies such as efficient housing and SWH / GB should make up an important component of South African climate policy. They are cost-effective, address both social sustainability, local environmental issues and GHG emissions.

The scale of emission reductions that might be required in the future, however, will need to come from higher-emitting sectors. Emissions in the base case are projected to increase 80% from 2001 to 2025. The electricity supply sector is central in this regard, accounting for 48% of South Africa’s CO₂ emissions and 37% of all greenhouse gases (Van der Merwe & Scholes 1998; RSA 2004a).

Avoided emissions for electricity supply options are shown in Figure 9.6, again showing the difference of emissions between policies and the base case. The scale of avoided emissions is indeed larger, reaching up to 50 Mt CO₂ / year in the combined case. If SA is to make a contribution to the emission reductions of 50 -70% from current levels which the science tells us is required (IPCC 1995) then changes in this sector will be needed.

Figure 9.6: GHG emissions avoided in electricity policy cases



The combined policy case shows the largest absolute emission reductions, followed by the PBMR. As will be recalled from chapters 7 and 8, however, the investment costs associated with these two cases are larger than for others. The two domestic cases reduce 5% of the emissions projected for the base case in 2025.

Simple estimates of abatement costs indicated that renewables are most cost-effective in achieving larger scale emission reductions, slightly cheaper at R 2.5 / t CO₂ than the PBMR at R2.9. Even the relatively higher costs of the combined case (R 4.8) and the two import cases (R3.9 for hydro and R5.6 for gas) are well below market prices for carbon.

economic effects of climate policies, including direct GHG taxes or energy taxes, using a CGE model (see section 4.4.2 above). The use of a CGE model means that not only direct costs, but the indirect economic benefits and costs are counted. However, note the limitations on the approach to GHG analysis, as discussed in section 4.4.2. The authors argue that energy in South Africa is complementary to capital and that this factor together with tax recycling that increases unskilled labour demand can produce a double or even 'triple dividend'. They find that recycling environmental tax revenues through reduction in food costs is particularly effective in achieving CO₂ reduction, economic growth and poverty alleviation (Van Heerden et al. 2006). Macro-economic analysis thus provides an indication that there may be synergies at the societal level; yet climate policy would affect individual sectors, with winners and losers. Hence a degree of trade-off is likely to remain.

The need for trade-offs should not be taken to suggest that no attention is paid to economic costs. The electricity supply policies described in this thesis provide options to meet environmental goals cost-effectively. And there are significant synergies that remain, even if not all dimensions can be optimized at once. Synergies exist in meeting goals for improving local air quality and reducing GHG emissions. Local benefits also accrue from greater diversity, both in lessening dependence on coal and increasing resilience by increasing the number of alternatives.

Combining residential and electricity policies would provide a mix that overall provides a durable balance of economic development, social sustainability, and both local and global environmental benefits. Together with other sectoral policies that are not the focus of this thesis, an approach that starts from meeting sustainable development objectives can make a major contribution to the multi-lateral effort to mitigate climate change.

9.2.2 Implications for approaches to climate negotiations⁵⁵

South Africa's climate change policy is still in early stages of formulation, and influenced by views from different interest groups. Early climate mitigation policy took a strict 'no regrets' approach, refusing to contemplate any actions other than those that were beneficial even without climate change. Recently, the climate change response strategy has put sustainable development at the centre (DEAT 2004), providing the basis for a more pro-active engagement with the international climate framework (Van Schalkwyk 2005a). SA increasingly seeks to play a bridge-building role (Van Schalkwyk 2005b) and an approach built around sustainable development provides for important first steps towards a commitment by developing countries such as South Africa. Forward-looking approaches have great potential to leverage funds to promote energy policy objectives such as increasing access, diversity of supply, stimulating

⁵⁵ This section draws on a peer-reviewed book chapter led by the author (Winkler et al. 2002b).

Table 9.3: Order of magnitude of carbon revenues for different carbon prices

		2005	2010	2015	2020	2025
Avoided emissions from both combined cases	Mt CO ₂	4	18	41	41	48
Revenue at €10 / tCO ₂	R million	355	1,444	3,315	3,245	3,840
Revenue at €20 / tCO ₂	R million	710	2,887	6,629	6,491	7,680
Revenue at €30 / tCO ₂	R million	1,065	4,331	9,944	9,736	11,520

The first row of Table 9.3 adds up the values of avoided emissions from the two combined case, in other words avoiding double-counting of reductions. The carbon price is set at three values, with €10 / t CO₂ being close to 2005 prices, and expected higher levels in future represented by modest increases to € 20 and 30 / t CO₂. Further assuming a fixed exchange rate at R 8 / € 1, revenues in the order of Rand millions to Rand billions per year are possible (over R 10 billion in 2025 at to € 30 / t CO₂).

What is not clear is whether South Africa would be able to sell credits for avoided emissions as currently through the Clean Development Mechanism (CDM). By 2025, SA might need to reduce emissions for meet a future commitment of its own. This question raises the implications of the policies described so far for the international climate change regime, which is considered in section 9.2.2 below.

The implications of energy policies for sustainable development for domestic climate policies are two-fold. Firstly, residential energy policies permit growth of energy services and reduce costs of those services, but also reduce local environmental pollution, provide social benefits. These policies, in particular efficient housing and SWH / GB, can contribute to a thrust of climate policy that is strongly allied to social sustainability and poverty alleviation. By including these policies in an overall portfolio, climate policy will be made more relevant to local development.

Since the absolute emission reductions achievable in this way are not adequate to the task, a second component is needed. In the electricity supply sector, there is potential to make development more sustainable, but no clear 'winners' emerge that are superior in every dimension. A long-term climate perspective is one reason to make short-term changes to begin a long-term transition. Greater flexibility will be needed in trading off some degree of economic optimality, in favour of both local and global environmental benefits.

Recent analysis suggests that there may be means to soften the trade-offs. The thesis focuses on the direct costs of energy policies. Complementary recent work has examined the broader

economic development and managing energy-related environmental impacts. Notably, a more sustainable approach to the development of the critical electricity sector has the potential to both promote local sustainable development and contribute to global efforts to mitigate climate change.

The policies examined here have been called sustainable development policies and measures (SD-PAMs) (Winkler et al. 2002b). The SD-PAMs approach suggest a way of linking national sustainable development policies into the multi-lateral climate regime under the UN Framework Convention on Climate Change (UNFCCC).

To put it another way, the sustainable development approach to climate mitigation reduces emissions from the reference case. Changing current development trends (e.g. coal in South Africa's electricity sector) to a more sustainable path contributes to mitigation by avoiding emissions. "Assessing the climate challenge from a sustainable development perspective immediately reveals that countries differ in ways that have dramatic implications for scenario baselines and the range of mitigation options that can be considered" (Banuri & Weyant 2001: 76). Such an approach reflects the understanding that the reference scenario matters at least as much, if not more than climate change policy (IPCC 2001b).

The steps involved in the SD-PAMs approach are similar to the methodology for this thesis. The SD-PAMs approach starts with the development objectives and needs of developing countries. Countries begin by examining their development priorities and identify how these could be achieved more sustainably, either by tightening existing policy or by implementing new measures. The next step is to identify synergies between sustainable development and climate change, that is, those SD-PAMs that also result in reductions of greenhouse gas (GHG) emissions. To obtain a realistic picture of the impact of a basket of SD-PAMs, those policies and measures that increase GHG emissions also need to be identified (Winkler et al. 2002b). What the SD-PAMs concept offers is the formalisation of the pledge to make development more sustainable, in an approach that can be negotiated.

The SD-PAMs pledge builds on existing commitments of developing countries. Almost all developing countries are signatories to the Convention. Under Article 4.1(b), all Parties commit themselves to 'formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases.' This commitment is currently not quantified for developing countries in the same way as for industrialized countries listed in Annex B of the Kyoto Protocol. SD-PAMs as a pledge-to-implement policies for sustainable development would be consistent with Article 10 of the Protocol, which re-affirms existing Convention commitments and aims to 'advance the

implementation of these commitments in order to achieve sustainable development' (UNFCCC 1997).

9.2.2.1 Sustainable development policies and measures (SD-PAMs)

The SD-PAMs pledge would be to implement and accelerate national sustainable development plans. The 'commitment' would not be measured directly in GHG emissions units, but rather in SD units – building a 100 000 energy efficient homes, rather than a specified reduction in tons of CO₂ emissions. Indirectly – as a co-benefit – SD-PAMs contribute to considerably lower emissions than current development trends. The motivation for taking action, however, is to pursue sustainable development at the national level, and hence the pledge is framed in terms of action taken.

Energy-efficient low-cost housing in South Africa is one example of a SD-PAM. Other examples could include the Brazilian ethanol programme (Moreira et al. 2005), China's efforts to reduce air pollution in the process of motorisation (Wei-Shiuen & Schipper 2005), or a renewables-led approach to rural electrification in India (Dubash & Bradley 2005). Taking the Brazilian case, the ethanol programme produces approximately one third of Brazil's transport fuel, reduces foreign exchange expenditure, has created over a million rural jobs and has climate co-benefits estimated at 574 million tons of CO₂ over the lifetime of the programme (Moreira et al. 2005).

SD-PAMs commitments would initially be voluntary, although they could be made mandatory for at least some developing countries. To formalize the approach, some need for reporting and oversight through the Climate Change Convention would be necessary. Reporting would assist in monitoring whether SD-PAMs are actually implemented, and this would require some institutional capacity in the pledging country. At the same time, reporting can help to correct the misperception that developing countries are doing nothing on climate change. As outlined in section 2.2, the associated changes in GHG emissions are quantified.

While the SD-PAMs commitment would initially be voluntary, a simple reporting system should be established in order to formalize the commitment of those countries who pledge to implement SD-PAMs. National capacity to monitor, report and verify that targets are being met would be an important dimension of the country's capacity to implement SD-PAMs.

At the international level, reviewing the pledges would require a decision of the Conference of the Parties to establish a registry of SD-PAMs. Rather than creating an entirely new institution, a special SD-PAMs reporting registry would be created within the existing framework of the UNFCCC (Bodansky et al. 2004). Such a registry would record data based on regular reporting by Parties on their SD-PAMs, and support from the Secretariat for maintaining the records of

implementation. If voluntary reporting proves successful, a next step would be to make reporting of SD-PAMs mandatory for a group of middle-income developing countries. Some developing countries might view this as intergovernmental control over national policy making, which could present a political obstacle. However, there need be no prescribed list of SD-PAMs, leaving it to the country to define its own policies, much as this thesis has examined energy policies that would make South Africa's development more sustainable.

Reporting would primarily review progress assessed in the metric of the target. For efficient housing, for example, the pledge could be to implement a national programme building x00,000 houses more efficiently per year. In the electricity sector, the implementing and reaching the renewable energy target of 10 000 GWh could be the SD-PAMs pledge.

Reporting would assist the joint assessment of pledged actions. Associated GHG abatement could also be reported, in order to change the perception of some Annex I countries that developing countries are not participating in climate protection. This reporting would be similar in spirit to Article 12.4 of the Convention, where developing countries may voluntarily propose mitigation projects. The proposed reporting would extend to all SD-PAMs, including those that are not project-based. In order to assess progress against SD-PAMs pledges, a system of indicators for sustainable development could be adapted.

Reporting of SD-PAMs could be included in national communications. This would have the advantage that the information would be addressed in the in-depth reviews. However, the process of national communications has become highly politicized, in particular around the provision of technical and financial resources (See the language in UNFCCC (1992), Article 12.7). Given that some developing countries are not submitting their initial national communications, it might be preferable to separate the register of SD-PAMs from this process.

In short, developing countries would formulate, implement and report on SD-PAMs. Reporting and international review seem consistent with a facilitative approach to compliance.

9.2.2.2 Financing SD-PAMs

The issue of increasing access to finance was raised for residential policies above, and the PBMR and renewable electricity supply options clearly have incremental costs above the base case. Formalizing the SD-PAMs approach would offer the opportunity to channeling funding for climate change into policies that meet *local* sustainable development objectives.

Determining who pays for SD-PAMs is integrally related to the question of formalizing the pledge in the manner suggested above. Countries are unlikely to fulfill pledges unless they have the resources for implementation. Under Article 4.3 of the Convention, developed country Parties are already committed to paying 'full agreed incremental costs' of activities under Article 4.1. The commitment to funding is repeated in Article 11 of the Protocol. If SD-PAMs

are adopted under Article 4.1b, the question of payment should in principle be decided already. The challenge is to ensure that funds actually flow.

The sources of funding would differ between those SD-PAMs that have synergies with GHG reduction and those that are neutral or conflict. SD-PAMs that do not decrease GHG emissions would need to use development funding, both domestic, bi-lateral and multi-lateral.

SD-PAMs with GHG reduction potential could receive climate change-related funding, including investment through the Clean Development Mechanism (CDM), climate change funds through the Global Environmental Facility (GEF), and the funds established at Marrakech under the Convention (Special Climate Change Fund, LDC fund) and Protocol (Adaptation Fund). Some of these funds would be most suited to projects (CDM), others to enabling activities (GEF) or policy changes (e.g. under sectoral CDM).

SD-PAMs that reduce GHG emissions are likely to be good candidates for investment under the Clean Development Mechanism (CDM.) The CDM requires that projects reduce emissions and promote the sustainable development objectives of the host country, implying a clear synergy with the SD-PAMs approach. Through the CDM and the certified emission reductions generated, developing countries would have some link to the emerging market for carbon credits. However, the SD-PAMs approach would be broader in scope, including emissions reduction due to policies (such as changes in prices of energy) that could not qualify as CDM projects, which tend to focus on investment in technologies, infrastructure or programmes.

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

9.3 Conclusion

The policy analysis in this chapter considered the implications of the foregoing chapters for energy and climate policy in South Africa. Opportunities for social sustainability are particularly marked in residential energy policies, while large environmental benefits require trade-off in the longer-term perspective of choosing electricity supply options. Economic dimensions are important both for society as a whole, and for the budgets of poor households as well.

Policies that make South Africa's energy development path more sustainable are a good approach to climate policy as well. Not only do they provide a firm basis for domestic climate policy, but sustainable development policies and measures (SD-PAMs) could also provide a fresh approach in the multi-lateral climate negotiations. Having considered the implications for energy and climate policy, a summary of key findings concludes the thesis in the following chapter.

University of Cape Town

CHAPTER 10

10. Conclusion

The overall research question of the thesis was whether there are energy policies to make the development in South Africa's residential and electricity sectors more sustainable economically, socially and environmentally - particularly in the local environment - while also producing GHG emission reductions as co-benefits. A methodology was outlined that deliberately starts the assessment of practice in the residential energy sector from development objectives. Three major components of the methodology were modeling, evaluation against indicators of sustainable development and policy analysis. A contribution of the thesis lies in combining these analytical tools to identify policies that promote both sustainable development and mitigate climate change.

The first step in answering the research question was to start with a review of the concept of sustainable development as applied to the energy sector. A literature review provided a working definition of sustainable development. *Sustainable energy development* was taken to mean that a set of 'development indicators' is increasing over time, contributing to economic welfare, without being threatened by 'feedback' from either biophysical impacts, social disruption, making it durable or sustainable.

Against the background of the development objectives for the broader South African energy system, key energy policies were identified. The particular focus for making energy development more sustainable was the residential and electricity sectors. Chapter 4 emphasised the priority given to the energy policy goal of affordable access, to which any future policy in the sector will have to contribute.

A review of current energy policy issues laid the basis for identifying potential future ones for modeling. Tools for modeling energy policies were critically reviewed, and an energy-economic-environmental framework chosen. Policy options were identified that can make energy development in the residential and electricity sectors more sustainable, and were implemented in an energy-economic model. Policy options thus included both demand- and supply-side interventions; short-term opportunities, as well as interventions – such as changes in the fuel mix – that require longer time-frames.

A wide variety of data sources was used, drawing on statistical information, official energy data, utility statistics, journal articles and research reports. Data for the residential sector, both primary and secondary, was gathered for the thesis and disaggregated into six household types. This level of analysis within a national energy model goes beyond previous work, in showing distinctive energy use patterns for these household types. The projections made about future

urban / rural dynamics, levels of poverty, household size and the impact of AIDS make an important difference, and impact on the projections of residential energy demand.

The results of modeling were discussed and interpreted first by individual policy. Secondly, they were analysed against indicators of sustainable development, laying the basis for the policy analysis that answered the research question. In this way, the thesis demonstrated that policies in the residential demand and electricity supply sectors that can help move South Africa's energy sector onto a more sustainable path. Detailed policy analysis for the residential demand and electricity supply sectors elaborated what would be needed for implementation.

Overall then, the thesis argues that there are indeed policies that meet local sustainable development objectives, and also deliver GHG co-benefits. It finds that the residential sector is of particular importance for social sustainability. Extending access to affordable, modern energy services is a policy imperative which all energy policies have to follow. The challenge of access, it is contended, increasingly also has an economic dimension, as issues of affordability come to the fore. This argument has particular bearing in South Africa where high emissions intensity (per GDP and per capita) presents major problems, but will resonate with many middle income nations where increased energy consumption drives growing emissions without noticeable progress in meeting development targets.

The analysis of the residential sector identified opportunities that are sustainable economically, socially and environmentally. Many of the near-term opportunities for contributing to climate change mitigation lie in efficiency. CFLs provide efficient lighting, LPG allows better cooking, houses can be designed with better thermal properties, and SWH use a cleaner energy source and produce hot water more efficiently. The residential sector, it is argued on the basis of the analysis, has some clear 'winners' that rank higher than alternatives in all dimensions of sustainable development.

The thesis finds that solar water heating and efficient housing are durable policies for sustainable development. Not only do they achieve the greatest fuel savings in aggregate, but they also save the most energy costs for households. The latter is significant in reducing the electricity burden, particularly for poorer urban households. The two policies contribute most among environmentally by promoting cleaner fuel use, which helps to reduce local air pollution and GHG emissions. It is also found that it is possible to combine residential policies in a combined case that yields more benefits than any individual case. However, care should be taken to undertake integrated assessments, such as in a modeling framework, to avoid double counting and obtain an accurate picture of the cumulative effects. The whole is typically smaller than the sum of the parts.

The greatest energy savings from efficiency were consistently found in UHE households – which have higher consumption. The thesis argued, however, that this should not automatically lead to a policy conclusion to target this household type. Taking into account the reduction in the energy burden for households, the social benefits of promoting interventions in poorer households become more apparent. The social benefits of savings from better water heating and improved indoor air quality would motivate this policy among ULE households, rather than least-cost optimality. Interventions that address energy poverty promote a more equitable *distribution* of energy services, which would favour social sustainability and help reduce inequality. For richer households, interventions that can be promoted through market mechanisms – such as CFLs – were found appropriate. The thesis argued that low-cost measures, such as geyser blankets, can be aimed at poorer household types.

The investment requirement is relatively modest per household, with less than a thousand Rand per household making efficient housing attractive to ULE and RLN households, as well as UHE. The thesis suggested that subsidies and direct financing for residential energy policies can work together to alleviate energy poverty.

Considered in the context of the broader energy sector, the residential sector will not deliver the largest absolute energy savings (and associated emission reductions). Levels of energy consumption are relatively low, yet the sector is critical for social development. Changing development paths in this sector will need to focus on multiple dimensions. The thesis argues that policies in the electricity sector will also be important for climate policy based on energy for sustainable development. In this sector, the challenges are longer-term and more trade-offs are required. Not all solutions are economically optimal, not all policies can be ‘win-win’.

The base case for the electricity sector shows that SA will clearly remain dependent on coal for electricity generation up to 2025. Cleaner coal technology in the form of fluidised bed combustion also enters the base case. Four major supply options were analysed – renewable energy, PBMR nuclear, importing hydro or natural gas.

The thesis argues that a cleaner fuel mix can make a major contribution to managing the environmental impacts of electricity generation. While the social dimensions of choices about electricity supply are not always readily apparent, the impacts on access and affordability through the electricity price is considerable. South African policy-makers will have to consider whether the lowest-cost option, coal, is to be pursued exclusively, or whether investment in other options increases durability.

The two domestic electricity supply options increase energy system costs over the coal-dominated base case. Importing gas or hydro-electricity reduces domestic capital expenditure and overall system costs. Of the two domestic options, the PBMR is more expensive than

renewables. The thesis argues that both the PBMR and imported gas should be phased in gradually.

The PBMR achieves the greatest diversity of supply in moving away from coal dependency, but the thesis argues that it should be phased in more gradually than building 32 modules by 2020 to avoid underutilised capacity. The renewables case achieves a higher diversity among the non-coal fuels. Both domestic options achieve reduced local air pollutants and GHGs by similar percentages from the base case. The abatement cost of renewables appears to be lower. While showing increased costs, these were of the same order of magnitude as other policy cases. The renewables case demonstrated that a mix of renewable energy technologies can supply 'real' electricity. The 2013 targets was met, and continued beyond that year, driven by decreasing costs.

The challenge for electricity supply options, then, is not to pick a single energy source to supply all future needs. Rather, diversity should be sought in both moving away from over-reliance on a single source, coal, and diversifying the alternative as much as possible. A transition to a more sustainable electricity supply sector will take several decades. Long-term goals help set a direction. Yet changes in the near-term are needed, as capacity begins to be replaced. Given the long life-times of energy infrastructure, choices made in the near-term will shape the system for several decades.

The thesis argues that changes in the electricity supply sector need to consider changes in the short-term to initiate a long-term transition to sustainable development. The long life-times of power plants mean that decisions have implications well into the future – when South Africa will likely face some kind of carbon constraint. Small changes in the near-term can create the basis – institutionally and technologically – for larger changes in the future.

The evaluation against indicators of sustainable development showed that no single electricity supply option is preferable economically, socially and environmentally. One implication is that more trade-offs are required. Another is that short-term economic costs can not be the only factor in providing solutions that are durable in the longer-term.

South Africa needs to replace significant parts of its electricity generation capacity over the next few decades *and* provide for growing demand. The investments required present an opportunity to 'lock-in' to a cleaner energy development path. This opportunity was conceptualized in the form of six 'wedges', each equivalent to a coal-fired power station. The thesis argues that making two of these wedges something other than coal would represent a major shift to sustainability in the electricity sector.

Based on the findings for both the residential and electricity sectors, the thesis contends that the appropriate starting point - conceptually and methodologically – for both energy and mitigation

policy is sustainable development. Climate change mitigation policy specifically, it is argued, should start with *local* sustainable development, rather than goals set in climate terms.

The policies examined here have been called sustainable development policies and measures (SD-PAMs) (Winkler et al. 2002b). While ‘backcasting’ from development objectives has been outlined as a conceptual approach internationally, it has not been implemented in national energy models in developing countries, and not in South Africa. The SD-PAMs approach provides a conceptual framework to elaborate national climate change policy and be integrated into the international negotiating framework.

The analysis in this thesis suggests concrete ways by which South Africa’s climate change response strategy, based on sustainable development, could be implemented. Emissions in the order of 1- 10 Mt CO₂-equiv / year can be avoided through efficient housing and SWH / GB cases. These reductions are relative to the reference case, an approach which the thesis argues is critical for developing countries (as distinct from absolute emission reductions for industrialised countries). Sustainable residential energy policies should make up an important part of SA climate policy, addressing the social, environmental and economic dimensions of sustainability. By including residential energy policies, the overall climate change mitigation portfolio will be made more relevant to local development. Pursuing a goal motivated by development policy is more appropriate for developing countries like South Africa.

However, the scale of emission reductions required will need to come from the larger emitters. Electricity supply options could avoid emissions up to 50 Mt CO₂ / year in the combined case. However, electricity policy cases are not easily combined, and the combined case carries the highest absolute cost – and similarly, the highest-reducing single policy case, the PBMR, has the highest cost. By simple estimates of abatement cost, renewables are found to be most cost-effective. Revenues from selling emission reductions in the emerging carbon markets are found to be in the order of Rand millions to Rand billions. Synergies with improving local air quality while reducing GHG emissions should also be taken into account. A durable approach to the development of the critical electricity sector should promote local sustainable development and contribute to climate change mitigation.

The policies analysed in this thesis can make energy development more sustainable. Combining residential and electricity policies would provide a mix that overall provides a durable balance of economic development, social sustainability, and both local and global environmental benefits. Much of what is good for sustainable development in the national energy system also has global benefits in mitigating climate change. The approach has been demonstrated for South Africa, but will resonate with other rapidly industrialising developing countries. The thesis demonstrates that there are indeed policies that meet local sustainable development objectives, and reduce greenhouse gases as a co-benefit.

Appendices

Figure 10.1: Electricity generation from all plants in the base case

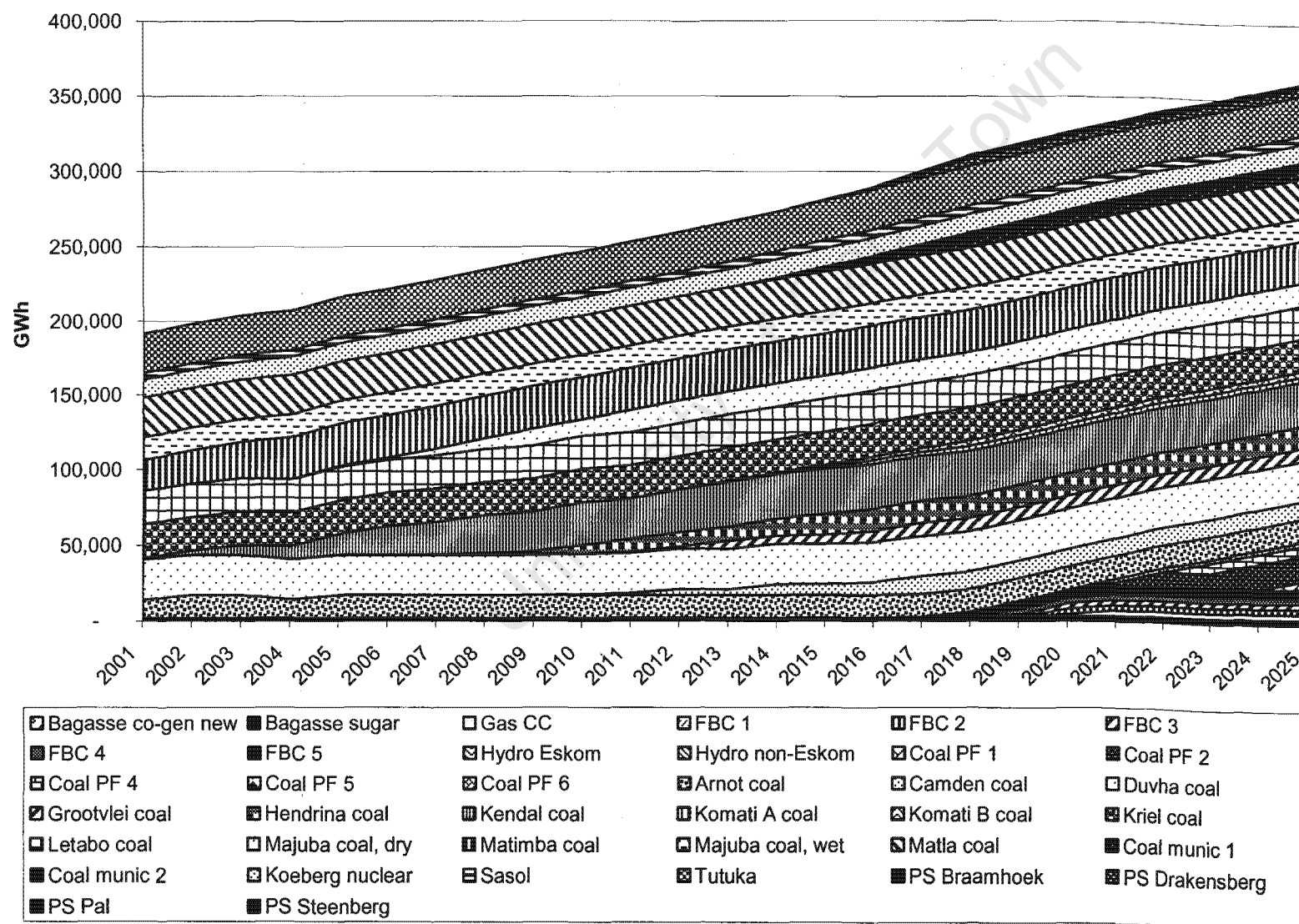


Figure 10.2: Electricity capacity in the base case, all power plants

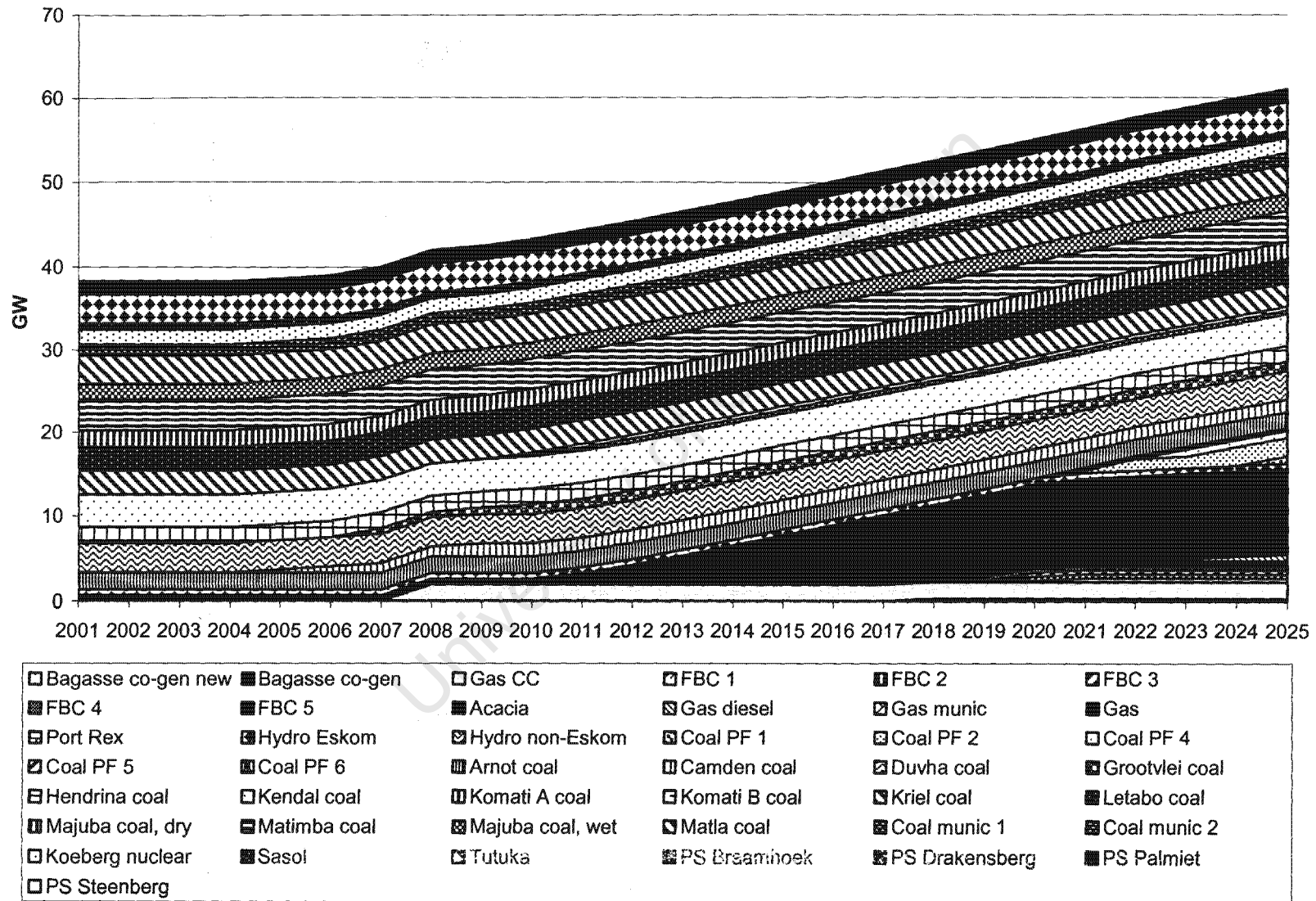


Table 10.1: Monthly expenditure on electricity by household type and policy case, 2001

Units of expenditure: R / (HH*mth) 2001	Price (R / MJ)	Base case	CFLs	Efficient houses	LPG for cooking	Water heating - SWH / GB	Residential policies combined	Sum of expenditure per household
Consumption (MJ / (HH*mth))	x	0.0593	0.0513	0.0513	0.0513	0.0513	0.0513	
RHE	747	44	38	38	38	38	38	236
RLE	124	7	6	6	6	6	6	39
UHE	1,530	91	78	78	78	78	78	483
ULE	614	36	31	31	31	31	31	194

References

- AEJ 2005. Who's ahead in the HTR race - China or South Africa? *African Energy Journal* 7 (3): pp. 12-15.
- Afrane-Okese, Y 2003. Operational challenges of large scale off-grid programme in South Africa. *NER Quarterly Journal* 1 (4): 33-52. http://www.ner.org.za/documents/NERQJNL_issue1iv.pdf.
- AGAMA 2003. Employment potential of renewable energy in South Africa. A study commissioned by Sustainable Energy and Climate Change Partnership, a project of Earthlife Africa Johannesburg, in partnership with WWF, Denmark. Johannesburg, SECCP.
- Agarwal, A & Narain, S 1991. *Global Warming in an Unequal World: A Case of Environmental Colonialism*. New Delhi, Center for Science and Environment.
- Agarwal, A 2000. Making the Kyoto Protocol work: ecological and economic effectiveness, and equity in the climate regime. New Delhi, Centre for Science and Environment.
- Alfstad, T 2004a. Meeting South African renewable energy targets. *reCOMMEND* 1 (2): pp. 1-3.
- Alfstad, T 2004b. The application of energy models in developing countries. *reCOMMEND*.
- ANC (African National Congress) 1994. *The Reconstruction and Development Programme: A policy framework*. Johannesburg, Umanyano.
- Arrow, K J 1962. The economic implications of learning by doing. *Review of Economic Studies* 29: 155-173.
- ASSA (Actuarial Society of South Africa) 2002. ASSA AIDS and demographic models: ASSA2002lite. <http://www.assa.org.za/aidsmodel.asp>.
- Atkinson, G, Dubourg, R, Hamilton, K, Munasinghe, M, Pearce, D & Young, C 1997. *Measuring sustainable development: Macroeconomics and the environment*. Cheltenham, Edward Elgar.
- Auerbach, R & Gandar, M 1994. Energy and small-scale agriculture. Report no. 7 South African energy policy research and training project. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Auf der Heyde, T & Thomas, S 2002. The PBMR project: an assessment of its economic viability. *South African Journal of Science* 98 (Jan / Feb): 36-42.
- Auf der Heyde, T 2000. South African nuclear policy since 1993: too hot to handle? *Energy for Sustainable Development* 4 (4): 18-26.
- Bailie, A, Bernow, S, Dougherty, W, Lazarus, M & Kartha, S 2001. *The American Way to the Kyoto Protocol: An economic analysis to reduce carbon pollution*. A study for the World Wildlife Fund. Boston, Tellus Institute.
- Bank, L, Mlomo, B & Lujabe, P 1996. Social determinants of energy use in low-income metropolitan households in East London. Report No. EO9421. Pretoria, Department of Minerals and Energy.
- Banks, D 1999. The consumer discount rate applicable for low-income households in South Africa. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Banks, D 2005. Personal communication. Remote Area Power Supply consulting. 15 September 2005.
- Banuri, T & Weyant, J P 2001. Setting the stage: Climate change and sustainable development. *Climate Change 2001: Mitigation: Contribution of WG III to the Third Assessment Report of the IPCC*. Intergovernmental Panel on Climate Change, Cambridge University Press: 74-114.
- Barborton, C 1999. Restructuring the electricity generation industry: factors likely to impact on environmental performance. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Baumert, K, Bhandari, R & Kete, N 1999. What might a developing country climate commitment look like? Washington DC, World Resources Institute. May 1999.
- Berk, M M, Van Minnen, J G, Metz, B & Moomaw, W R 2001. Keeping our options open - a strategic vision on near-term implications of long-term climate policy options. Concise summary of the results of the Global Dialogue of the COOL-project (Climate OptiOns for the Long term). Bilthoven, RIVM.
- Biggs, R & Greyling, A 2001. Project energy. Report for the Paraffin Safety Association of Southern Africa. Cape Town, Markinor.
- Blignaut, J & De Wit, M 1999. Integrating the natural environment in macroeconomic policy: recommendations for South Africa. *Agrekon* 38 (3): 113-127.
- Blignaut, J 2004. Personal communication. Renewables - market rules. Professor of economics, University of Pretoria. 11 June.
- Bond, P 2000. Economic growth, ecological modernization or environmental justice? Conflicting discourses in South Africa today. Johannesburg, Municipal Services Project.
- Borchers, M 2005. Personal communication. Sustainable Energy Africa. 14 March.

- Borchers, M, Qase, N, Gaunt, T, Mavhungu, J, Winkler, H, Afrane-Okese, Y & Thom, C 2001. National Electrification Programme evaluation: Summary report. Evaluation commissioned by the Department of Minerals & Energy and the Development Bank of Southern Africa. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Bossel, H 1998. Indicators for Sustainable Development: Theory, Method, Applications, a report to the Balaton Group. Winnipeg, Canada, International Institute for Sustainable Development. <http://www.iisd.ca>.
- Bradley, R, Baumert, K & Pershing, J (Eds) forthcoming. *Saving the climate by putting development first: sustainable development policies and measures*. Washington DC, World Resources Institute.
- Bredenkamp, B 2005. Personal communication. Efficient Lighting Initiative, Eskom manager. 23 February.
- Brown, L 1981. *Building a sustainable society*. Washington DC, Worldwatch Institute.
- Byrne, J, Wang, Y-D, Lee, H & Kim, J-d 1998. An equity- and sustainability-based policy response to global climate change. *Energy Policy* 26 (4): 335-43.
- Calitz, J M 1996. Population of South Africa: Updated estimates, scenarios and projections, 1990 - 2020. Johannesburg, Development Bank of Southern Africa.
- Calitz, J M 2000a. Provincial population projections, 1996-2001: Low HIV/AIDS impact. August. Johannesburg, Development Bank of Southern Africa.
- Calitz, J M 2000b. Provincial population projections, 1996-2001: High HIV/AIDS impact. September. Johannesburg, Development Bank of Southern Africa.
- CCT & SEA 2003. 'State of Energy' report for Cape Town. Situation assessment of energy issues and state of energy data of Cape Town. Cape Town, City of Cape Town & Sustainable Energy Africa.
- CCT (City of Cape Town) 2004. City of Cape Town a leading African and world city in the energy sector. Media release. www.capetown.gov.za/press.
- CDC 2004. Investment opportunity. by Coega Development Corporation. www.coega.co.za.
- CEF 2005. iGas web-site. Central Energy Fund. 14 September 2005, <http://www.cef.org.za/group/iGas/index.htm>
- Chalmers, R 2001a. SA needs to invest in the generation of its electricity. *Business Day*. 12 July.
- Chalmers, R 2001b. SA must get it right first time. *Business Day*. 17 July.
- Chamber of Mines (Chamber of Mines of South Africa) 2001. Annual Report 2000 / 2001: South Africa - mining for the world. Johannesburg.
- Clark, A & Mavhungu, J 2000. Promoting public benefit energy-efficiency investment in new power contexts in South Africa. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Clark, A 1997. Economic analysis of Eskom's energy-efficient lighting programme for low-income households. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Clark, A 2000a. Demand-side management in restructured electricity industries: An international review. Energy & Development Research Centre, University of Cape Town.
- Clark, A 2000b. Demand-side management in South Africa: barriers and possible solutions for new power sector contexts. *Energy for Sustainable Development* 4 (4): 27-35. December.
- Clark, A 2001a. Implications of power sector reform in South Africa on poor people's access to energy: Lessons for Africa. Proceedings of the African high-level regional meeting on energy and sustainable development for the ninth session of the Commission on Sustainable Development, Nairobi, United Nations Environment Programme.
- Clark, A 2001b. Making provision for energy-efficiency investment in changing markets: An international review. *Energy for Sustainable Development* V (2): 26-38.
- Consult 101, EC & IDC (Consult 101, Environmental Counsel & Industrial Development Corporation of South Africa) 2001. How will responses of the developed countries to the United Nations Framework Convention on Climate Change affect South Africa? Submitted to the Fund of Research into Industrial Development, Growth and Equity (FRIDGE). Johannesburg, NEDLAC.
- COSATU (Congress of South African Trade Unions) 2001. Submission on the electricity restructuring. Submitted to the Minerals and Energy Portfolio Committee, 19 September 2001. Cape Town.
- Cowan, B & Mohlakoana, N 2005. Barriers to access modern fuels in low-income households: Khayelitsha. Cape Town, Energy Research Centre, University of Cape Town.
- Cowan, B 2003. Understanding electricity and rural electrification in South Africa. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Cowan, B 2005. Personal communication. Senior researcher, Energy Research Centre.
- CSD (Commission on Sustainable Development) 1995. Indicators of sustainable development: guidelines and methodologies. New York, United Nations. www.un.org/esa/sustdev/indisd/indisd-mg2001.pdf.
- Daly, H E & Cobb, J B, Jr. 1989. *For the common good: Redirecting the economy towards community, the environment and a sustainable future*. Boston, Beacon Press.
- Davidson, O & Nakicenovic, N 2001. Linking climate change to sustainable development. Nairobi, United Nations Environment Programme.

- Davidson, O & Sokona, Y 2002. Think bigger, act faster: a new sustainable energy path for African development. Cape Town and Dakar, Energy & Development Research Centre, University of Cape Town & ENDA Tiers Monde.
- Davidson, O & Turkson, J 2001. Overcoming financial barriers to wider use of renewable energy technology in Africa. *International Journal of Global Energy Issues* 15 (1-2): 117-131.
- Davidson, O 1996. A sustainable energy path for Africa. *Renewable Energy for Development* 7 (3).
- Davis, M & Horvei, T 1995. *Handbook for economic analysis of energy projects*. Johannesburg, Development Bank of Southern Africa.
- Davis, M & Steyn, G 1998. *Electricity in South Africa*. London, Financial Times Energy.
- Davis, M & Steyn, G 1999. Environmental effects of electricity in South Africa. *ESI Africa* 1.
- Davis, M & Ward, S 1995. Household energy-use patterns in rural areas: the effects of access to electricity. Cape Town, Energy & Development Research Centre, University of Cape Town.
- De Villiers, M & Matibe, K 2000. Greenhouse gas baseline and mitigation options for the residential sector. Cape Town, Energy & Development Research Centre.
- DEAT & DME (Department of Environmental Affairs and Tourism & Department of Minerals and Energy) 2003. Joint implementation strategy for the control of exhaust emissions from road-going vehicles in the Republic of South Africa. Final draft, November. Pretoria. <http://www.polity.org.za/pdf/notice3324.pdf>.
- DEAT (Department of Environmental Affairs and Tourism) 2004. A national climate change response strategy. Pretoria.
- DEAT, DOH, DME & DWAF (Department of Environmental Affairs and Tourism, Department of Housing, Department of Minerals and Energy & Department of Water Affairs and Forestry) 1998. Environmentally Sound Low Cost Housing: Draft Guidelines for Implementation. Pretoria, Department of Housing.
- DME (Department of Mineral and Energy Affairs) 2003b. Green power: Business opportunities in South Africa for renewable energy independent power producers. Pretoria.
- DME (Department of Minerals & Energy) 2003f. Electricity basic services support tariff (free basic electricity) for the Republic of South Africa. Government Gazette, vol. 457 no. 25088. Pretoria, Republic of South Africa. <http://www.info.gov.za/gazette/notices/2003/25088.pdf>.
- DME (Department of Minerals & Energy) 2004c. Minerals and Energy budget vote (vote 31). Cape Town, Parliament.
- DME (Department of Minerals & Energy) 2005b. Radioactive waste management policy and strategy for the Republic of South Africa. Pretoria. http://www.dme.gov.za/newscentre/media_rel/radwaste_policy_2005%20.pdf.
- DME (Department of Minerals and Energy) 1998. White Paper on Energy Policy for South Africa. Pretoria, DME. <http://www.dme.gov.za>.
- DME (Department of Minerals and Energy) 1999. South African Energy and Demand Efficiency Guidelines. Pretoria, DME.
- DME (Department of Minerals and Energy) 2000a. Background research on renewable energy independent power production, South Africa. Supported by DANCED. Pretoria.
- DME (Department of Minerals and Energy) 2000b. Energy Balances for South Africa 1993-98. Pretoria, DME.
- DME (Department of Minerals and Energy) 2001a. South Africa National Energy Balance 1999. Microsoft Excel Spreadsheet. Pretoria.
- DME (Department of Minerals and Energy) 2001b. South African National Energy Database. Energy prices. Pretoria, DME.
- DME (Department of Minerals and Energy) 2001c. Strategy on renewable energy. Draft. Pretoria.
- DME (Department of Minerals and Energy) 2001d. Annual Report 2000 - 2001. Pretoria.
- DME (Department of Minerals and Energy) 2002a. South Africa National Energy Balance 2000. Pretoria, DME.
- DME (Department of Minerals and Energy) 2002b. South Africa's mineral industry 2001/2002. Pretoria. <http://www.dme.gov.za>.
- DME (Department of Minerals and Energy) 2002d. Draft white paper on the promotion of renewable energy and clean energy development. June. Pretoria.
- DME (Department of Minerals and Energy) 2003a. South Africa National Energy Balance 2001. Pretoria, DME.
- DME (Department of Minerals and Energy) 2003c. White paper on renewable energy. Pretoria. www.dme.gov.za.
- DME (Department of Minerals and Energy) 2003d. Integrated energy plan for the Republic of South Africa. Pretoria. www.dme.gov.za.
- DME (Department of Minerals and Energy) 2003e. Electricity basic services support tariff (free basic electricity) policy for the Republic of South Africa. Pretoria.

- DME (Department of Minerals and Energy) 2004a. Economic and financial calculations modelling for the renewable energy white paper and strategy formulation. Report No. 2.3.4 - 19, prepared by Conningarth Economists. Pretoria, DME - Capacity Building in Energy Efficiency and Renewable Energy project.
- DME (Department of Minerals and Energy) 2004b. Free basic energy policy guidelines (Low income household energy support programme). Pretoria.
- DME (Department of Minerals and Energy) 2004d. Draft energy efficiency strategy of the Republic of South Africa. April 2004. Pretoria, DME. www.dme.gov.za/energy/pdf/energy_efficiency_strategy.pdf.
- DME (Department of Minerals and Energy) 2004e. South Africa's mineral industry 2003/2004. Pretoria. <http://www.dme.gov.za>.
- DME (Department of Minerals and Energy) 2005a. Energy efficiency strategy of the Republic of South Africa. March 2005. Pretoria, DME. http://www.dme.gov.za/energy/pdf/ee_strategy_05.pdf.
- DME 2002c. Table 59: Labour statistics - main mining commodity - coal. by Department of Minerals & Energy Pretoria. <http://www.dme.gov.za/publications/pdf/stats/minerals/tables/tbl59.pdf>.
- DME, Eskom & CSIR (Department of Minerals and Energy, Eskom & Council for Scientific and Industrial Research) 2001. South African renewable energy resource database. Pretoria. www.csir.co.za/environmentek/sarerd/contact.html.
- Dos Santos, M A, Pinguelli-Rosa, L, Sikar, B, Sikar, E & dos Santos, E O 2006. Gross greenhouse gas fluxes from hydro-power reservoir compared to thermo-power plants. *Energy Policy* 34 (4): 481-488.
- DOT (Department of Transport) 1999. Moving South Africa. Pretoria, DOT.
- DPE (Department of Public Enterprises) 2000. Eskom Conversion Bill. Government Gazette, Vol. 424, No. 21628, 13 October 2000. Pretoria.
- DTI (Department of Trade and Industry) 1996. Growth, Employment and Redistribution: A macro-economic strategy. Pretoria.
- DTI (Department of Trade and Industry) 2002. Creating new wealth in Southern Africa. Pretoria, Regional Spatial Development Initiative Support Unit.
- Dubash, N & Bradley, R 2005. Pathways to rural electrification in India: Are national goals also an international opportunity? R Bradley, K Baumert and J Pershing (Eds). *Growing in the greenhouse: Protecting the climate by putting development first*. Washington DC, World Resources Institute.
- Dubash, N (Ed) 2002. *Power politics: Equity and environment in electricity reform*. Washington DC, World Resources Institute.
- DWAF 1998. The National Water Act.
- Eberhard, A & Van Horen, C 1995. *Poverty and Power: Energy and the South African state*. London, Pluto Press and UCT Press.
- Eberhard, A 2000. Competition and regulation in the electricity supply industry in South Africa. Paper for the Competition Commission. University of Cape Town.
- Eberhard, A 2003. The political, economic, institutional and legal dimensions of Electricity Supply Industry reform in South Africa. Political Economy of Power Market Reform conference, 19-20 February, Stanford University.
- Eberhard, A A & Williams, A 1988. *Renewable energy resources and technology development in South Africa*. Cape Town, Elan Press.
- EC, DBSA & ISES (European Commission DG XVII, Development Bank of Southern Africa, International Solar Energy Society) 2000. Renewable energy technologies in SADC - a guide for investors. Midrand, Development Bank of Southern Africa.
- EDRC (Energy & Development Research Centre) 2003a. Policies and measures for renewable energy and energy efficiency in South Africa. Prepared for the Sustainable Energy & Climate Change Partnership. Cape Town, EDRC, University of Cape Town.
- EDRC (Energy & Development Research Centre) 2003b. The potential for increased use of LPG for cooking in South Africa: A rural case study. by B Cowan Energy & Development Research Centre, University of Cape Town.
- EEU (Environmental Evaluation Unit) 2000. Green financing feasibility study for low income housing in South Africa. Cape Town, University of Cape Town.
- Ehrlich, P 1968. *The population bomb*. New York, Ballantyne Books.
- ELI (Efficient Lighting Initiative) 2005. Monitoring & evaluation report: Country chapters - South Africa. by B Bredenkamp.
- Ellis, J, Corfee-Morlot, J & Winkler, H 2004. Taking stock of progress under the Clean Development Mechanism (CDM). COM/ENV/EPOC/IEA/SLT(2004)4/FINAL. Paris, Organisation for Economic Co-operation and Development/International Energy Agency. www.oecd.org/dataoecd/58/58/32141417.pdf.
- Ellman, M J 2001. The Wholesale Electricity Pricing System (WEPS). *Electricity Regulatory Journal* February 2001 pp. 1-2.

- Energy Caucus (South African NGO / civil society energy caucus) 2002. Energy position paper for the World Summit on Sustainable Development. Johannesburg.
- Energy Innovations 1997. Energy innovations: a prosperous path to a clean environment. Washington, D.C., Alliance to Save Energy, American Council for an Energy Efficient Economy, Natural Resources Defense Council, Tellus Institute, Union of Concerned Scientists.
- Ensor, L 2001. Eskom wins support for big tariff hikes. *Business Day*. 10 May.
- ERC (Energy Research Centre) 2003. Unpublished modeling data. Cape Town.
- ERC 2004a. Energy for sustainable development: South African profile. Phase 1 final report. Cape Town, Energy Research Centre, University of Cape Town.
- ERC 2004b. Solar electrification by the concession approach in the rural Eastern Cape: Phase 2 monitoring survey. Cape Town, Energy Research Centre, University of Cape Town.
- ERI (Energy Research Institute) 2000b. The 3E strategy: energy efficiency earnings. Management summary. University of Cape Town.
- ERI (Energy Research Institute) 2001. Preliminary energy outlook for South Africa. 10 October. University of Cape Town. www.dme.gov.za.
- ERI 2000a. The 3E strategy: energy efficiency earnings. *Energy Management News* 6 (3): 1-2. Energy Research Institute. September.
- Erwin, A 2004. Government commitment to restructuring of State-Owned Enterprises. Pretoria, Department of Public Enterprises.
- Eskom 1987. Statistical Yearbook 1987. Sandton, Eskom.
- Eskom 1989. Statistical Yearbook 1989. Johannesburg, Eskom.
- Eskom 1996. Eskom Statistical Yearbook 1996. Sandton, Eskom.
- Eskom 1997. Integrated Electricity Planning 6 (IEP6). Sandton, Eskom.
- Eskom 2000a. Environmental report 2000: Towards sustainability. Sandton, Eskom.
- Eskom 2000b. Annual Report 2000. Sandton, Eskom. www.eskom.co.za.
- Eskom 2000c. Efficient Lighting Initiative. Menlo Park, Eskom.
- Eskom 2001. Annual Report 2001: Embracing sustainable development. Sandton, Eskom. www.eskom.co.za.
- Eskom 2002a. Eskom environmental data: Statistics, acronyms: Performance statistics. www.eskom.co.za/Enviro%20data%202002/report01/stats.htm
www.eskom.co.za/Enviro%20data%202002/report01/stats.htm
- Eskom 2002b. Annual Report 2002: Vision Excellence Leadership. Sandton, Eskom. www.eskom.co.za.
- Eskom 2003. Wholesale Electricity Pricing System (WEPS) customer information brochure. Draft - subject to NER approval. Johannesburg, Eskom. www.eskom.co.za/tariffs/weeps.doc.
- Eskom 2005. Annual Report: Building capacity, embracing the future. Sandton, Eskom Holdings. www.eskom.co.za.
- Eto, J, Stoft, S & Kito, S 1998. DSM shareholder incentives: recent designs and economic theory. *Utilities Policy* 7: 47-62.
- Eunomia & UP (Eunomia research & consulting and University of Pretoria) 2004. Development of a framework for market-based instruments to support environmental fiscal reform in South Africa. A draft final report for National Treasury of South Africa. Not for citation. Pretoria, Treasury.
- Fankhauser, S & Tol, R S J 1996. Climate change costs: Recent advancements in the economic assessments. *Energy Policy* 24 (7): 665-673.
- Fine, B & Rustonjee, Z 1996. *The political economy of South Africa: from minerals-energy complex to industrialization*. London, C. Hurst.
- Fisher, J & Grubb, M 1997. The use of economic models in climate change policy analysis. 5. Royal Institute of International Affairs. October 1997.
- Flavin, C & Lenssen, N 1995. *Power surge: A guide to the coming energy revolution*. London, Earthscan Publications.
- Fowles, P 2004. Implementation of a free basic electricity allocation. Domestic use of energy, Cape Town, Cape Technikon. pp. 23-29.
- Games, D 2002. Pooling resources: Special report - Eskom. *Business in Africa* July / August pp. 50-51.
- Gaunt, T 2003. Researching a basic electricity support tariff in South Africa. Domestic Use of Energy Conference, Cape Town, Cape Technikon. pp. 23-28.
- GEF (Global Environment Facility) 2004. Program study on climate change. Prepared by the GEF Office of Monitoring and Evaluation. Document GEF/ME/C.24/Inf.2. Washington DC. www.thegef.org.
- Gosling, M 1999. Koeberg pocket nuke plan sparks outrage. Independent Online. 5 October, 1999. <http://www.iol.co.za/news>
- Graeber, B & Spalding-Fecher, R 2000. Regional integrated resource planning and its role in the regional electricity co-operation and development in Southern Africa. *Energy for Sustainable Development* 4 (2): 32-37. September.

- Guha, R & Martinez-Alier, J 1997. *Varieties of environmentalism: Essays North and South*. London, Earthscan.
- Halsnaes, K, Callaway, J M & Meyer, H J 1998. Economics of greenhouse gas limitations: Methodological guidelines. Roskilde, Denmark, UNEP Collaborating Centre on Energy and Environment.
- Helio International 2000. Guidelines for observer-reporters. November 28, 2000. www.helio-international.org/anglais/reports/reports2000.html
- Holm, D 2000. Performance assessment of baseline energy-efficiency interventions and improved designs. D K Irurah (Ed). *Environmentally sound energy efficient low-cost housing for healthier, brighter and wealthier households, municipalities and nation. Final report*. Pretoria, Environmentally Sound Low-cost Housing Task Team and USAID: A-1-1 to A-2-27.
- Howells, M 1999. Baseline and greenhouse gas mitigation options for bulk energy supply, South African Country Study on Climate Change. Draft. Energy Research Institute, University of Cape Town.
- Howells, M I & Solomon, M 2002. An optimal energy and greenhouse gas mitigation path for South Africa in the short to medium term. *Journal of Energy in Southern Africa* 13 (4): 123-129.
- Howells, M I 2000. Baseline and greenhouse gas mitigation options for bulk energy supply. Energy Research Institute, University of Cape Town.
- Howells, M I 2004. Modelling multiple goals: Greenhouse gas mitigation and socio-economic development. Cape Town, Energy Research Centre, University of Cape Town.
- Howells, M, Alfstad, T, Cross, N, Jefftha, L & Goldstein, G 2002. Rural energy modeling: Working Paper # 11. Presented to the Rural Energy Transitions conference, New Delhi, 5-7 November 2002.
- Howells, M, Alfstad, T, Victor, D G, Goldstein, G & Remme, U 2005. A model of household energy services in a low-income rural African village. *Energy Policy* 33: 1833-1851.
- Hughes, A, Howells, M & Kenny, A 2002. Energy efficiency baseline study. Capacity building in energy efficiency and renewable energy (CABEERE) Report No. 2.3.4. Report no. P-54126. Pretoria, Department of Minerals & Energy.
- IAEA; UNDESA; IEA; Eurostat; EEA (International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat and European Environment Agency) 2005. Energy indicators for sustainable development: Guidelines and methodologies. Vienna.
- IEA & OECD (International Energy Agency, Organisation for Economic Cooperation and Development) 2000. Experience curves for energy technology policy. Paris.
- IEA (International Energy Agency) 2001. Key World Energy Statistics from the IEA. Paris, IEA.
- IEA (International Energy Agency) 2002a. Key World Energy Statistics from the IEA. Paris, IEA.
- IEA (International Energy Agency) 2002b. World Energy Outlook: Energy & Poverty. Paris, IEA.
- IEA (International Energy Agency) 2003. Renewables for power generation: Status & prospects. Paris, OECD/IEA.
- IEA (International Energy Agency) 2004a. Key World Energy Statistics from the IEA. Paris, IEA.
- IEA (International Energy Agency) 2004b. World Energy Outlook. Paris, IEA.
- IES & AGAMA (Integrated Energy Solutions & Agama Energy) 2004. LPGas Rural Energy Challenge Workshop: Workshop background briefing paper. Report for Department of Minerals and Energy and the United Nations Development Programme. Pretoria, DME.
- IIASA (International Institute for Applied Systems Analysis) 2005. Fuel combustion in stationary sources: PM emission factors. Laxenburg. <http://www.iiasa.ac.at/~rains/PM/docs/documentation.html>.
- IIM (Indian Institute of Management) 2003. Development and climate: An assessment for India. Project team: PR Shukla, Rajesh Nair, Manmohan Kapshe, Amit Garg, S Balasubramaniam, Deepa Menon, KK Sharma. Ahmedabad.
- IPCC (Intergovernmental Panel on Climate Change) 1995. Second assessment synthesis of scientific-technical information relevant to interpreting Article 2 of the UN Framework Convention on Climate Change. Rome.
- IPCC (Intergovernmental Panel on Climate Change) 1996. Revised 1996 guidelines for national greenhouse gas inventories. Paris, Organisation for Economic Co-operation and Development.
- IPCC (Intergovernmental Panel on Climate Change) 2001b. Climate Change 2001: Mitigation. Contribution of WG III to the Third Assessment Report of the IPCC. by B Metz, O Davidson, R Swart and J Pan Cambridge, Cambridge University Press for Intergovernmental Panel on Climate Change.
- IPCC (Intergovernmental Panel on Climate Change) 2001c. Summary for policymakers: Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report. Accra.
- IPCC (Intergovernmental Panel on Climate Change) 2005. Special report on carbon dioxide capture and storage. Technical summary. Geneva.
- IPCC 2001a. Setting the stage: Climate change and sustainable development. T Banuri and J P Weyant (Eds). *Climate Change 2001: Mitigation: Contribution of WG III to the Third Assessment Report of the IPCC*. Geneva, Intergovernmental Panel on Climate Change: 74-114.

- Irurah, D K (Ed) 2000. *Environmentally sound energy efficient low-cost housing for healthier, brighter and wealthier households, municipalities and nation. Final report*. Pretoria, Environmentally Sound Low-cost Housing Task Team and USAID.
- IUCN, UNEP, WWF, FAO & UNESCO (International Union for the Conservation of Nature, United Nations Environment Programme, Worldwide Fund for Nature, Food and Agricultural Organisation & United Nations Economic and Social Commission) 1980. *The World Conservation Strategy: Living resource conservation for sustainable development*. Gland, Switzerland, International Union for the Conservation of Nature.
- IWG (Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies) 2000. *Scenarios for a Clean Energy Future*. Oak Ridge, TN and Berkeley, CA, Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory.
- Jannuzzi, G 2005. Power sector reforms in Brazil and its impacts on energy efficiency and research and development activities. *Energy Policy* 33: 1753–1762.
- Jeffha, L 2003. Energy efficiency and job creation: An input-output model approach. *Journal of Energy in Southern Africa* 14 (2): 54–62.
- Jochem, E 2000. Energy end-use efficiency. United Nations Development Programme, United Nations Department of Economic and Social Affairs and World Energy Council (Eds). *World energy assessment: energy and the challenge of sustainability*. New York, United Nations Development Programme: 173–217.
- Johannson, T B & Goldemberg, J (Eds) 2002. *Energy for sustainable development: A policy action agenda*. New York, United Nations Development Programme.
- Jones, S, Aitken, R & Luckin, L 1996. Power, poverty and posterity: the social determinants of energy use in low-income metropolitan households in Durban. DME Report EO9422. Pretoria, Department of Minerals and Energy.
- Jourdaan, P 1998. Spatial development initiatives (development corridors): their potential contribution to investment and employment creation. Pretoria, Department of Trade and Industry.
- Karekezi, S & Kimani, J 2002. Status of power sector reform in Africa: the impact on the poor. *Energy Policy* 30 (11–12): 923–946. September.
- Karekezi, S 2002. Poverty and energy in Africa—A brief review. *Energy Policy* 30: 915–919.
- Kartha, S, Collin, K, Cornland, D, Bernow, S & Lazarus, M 1998. 'Meaningful participation' for North and South under the Kyoto Protocol. Paper presented during the Fourth Conference of the Parties to the United Nations Framework Convention on Climate Change. 8 November, Buenos Aires, Stockholm Environment Institute - Boston.
- Kenny, A & Howells, M 2001. Energy futures: trends and options for the world and for South Africa, with emphasis on the generation of electricity. *Energy Management News* June. 7 (2): pp. 10–17. <http://www.eri.uct.ac.za/Energy%20Managment%20News/June2001/01.pdf>.
- Kofod, C 1996. Large CFL potential in European homes. *IAEEL newsletter* 3 / 96.
- Kotze, I A 2001. Letter from DME to off-grid concessionaries on evaluation of business plans. Pretoria, Department of Minerals and Energy. 11 July.
- Krause, F, De Canio, S J, Hoerner, A & Baer, P 2002. Cutting carbon emissions at a profit (part 1): Opportunities for the US. *Contemporary Economic Policy* 20 (4): 339–365.
- Laitner, J A 2002. LBD technology data. Spreadsheet. Washington DC, US Environmental Protection Agency.
- Laitner, S 2001. Energy efficiency investments: A dynamic link between environmental quality and positive job benefits for South Africa. Proceedings of the ninth conference on Domestic Use of Energy Conference, Cape Town, 10–12 April. Cape Technikon.
- Laitner, S, De Canio, S J & Peters, I 2001. Incorporating behavioral, social and organizational phenomena in the assessment of climate change mitigation options. E Jochem, D Bouille and J Sathaye (Eds). *Society, behavior and climate change*. Amsterdam, Kluwer.
- Law, S & McDaid, L 2001. Trading in nuclear power and pebble-beds. Cape Town, Environmental Monitoring Group.
- Lloyd, P J D & Trikam, A 2004. The determination of emission factors for South African power stations. Eskom Contract 1RE-000046. Cape Town, Energy Research Centre, University of Cape Town.
- Lloyd, P J D 2002. The safety of paraffin & LPG appliances for domestic use. Proceedings of the tenth conference on the Domestic Use of Energy, Cape Town, 2–3 April. Cape Technikon. pp. 79–84.
- Lloyd, P J D 2005. Personal communication. Honorary research fellow, Energy Research Centre.
- Loxton, L 2004. SA 'needs a nuclear reactor'. *Business Report*. 23 June Johannesburg: 8.
- Lukamba-Muhiya, J M & Davidson, O R 2003. Dissemination of solar water heaters in South Africa: Policy Perspectives. *Journal of Energy in Southern Africa* 14 (3): 99–105. August 2003.
- Lumby, A 1996. Towards a sustainable energy strategy for South Africa: Landfill gas as a renewable energy option. *Development Southern Africa* 13 (2): 205–216.
- Manuel, T 2005. Finance Ministry budget votes: Address to Parliament by Minister of Finance, 24 May 2005. Cape Town, Parliament. 24 May 2005. <http://www.info.gov.za/speeches/2005/05052414451001.htm>.

- Mapako, M & Prasad, G 2005. The Free Basic Electricity (FBE) policy and rural grid-connected households, solar home system (SHS) users and unelectrified households. Domestic Use of Energy conference, Cape Town, 28-31 March. Cape Technikon.
- Markandya, A & Halsnaes, K (Eds) 2002. *Climate change & sustainable development: Prospects for developing countries*. London, Earthscan.
- Markandya, A & Halsnaes, K 2001. Costing Methodologies. IPCC (Ed). *Climate Change 2001: Mitigation: Contribution of WG III to the Third Assessment Report of the IPCC*. Intergovernmental Panel on Climate Change, Cambridge University Press: 451-498.
- Marrs, D 2000a. Sasol takes over stakes in Temane gas field. *Business Day*. *Business Day*. 3 March Johannesburg.
- Marrs, D 2000b. Cape power station likely after gas find. *Business Day*. 3 April Johannesburg.
- Mathews, E, Kleingeld, M & Lombard, C 1998. The role of thermal performance of houses in strategic RDSM planning. Proceedings of the fifth Domestic Use of Electrical Energy Conference, Cape Town, 30 March - 1 April.
- Mbeki, T 2004a. State of the Nation address by the President of South Africa, 21 May 2004. Cape Town, Republic of South Africa. www.gov.za/speeches/sotn2004.
- Mbeki, T 2004b. The poor of this world rich in faith. *ANC Today* 16-22 July 2004. 4 (28): pp. 1-6. www.anc.org.za/ancdocs/ancoday/2004/at28.htm.
- Mbeki, T 2005. State of the Nation address by the President of South Africa, 11 February 2005, at the Second Joint sitting of the third Democratic Parliament. Cape Town, Republic of South Africa. <http://www.info.gov.za/speeches/2005/05021110501001.htm>.
- Meadows, D, Meadows, D, Randers, J & Brehrens III, W W 1972. *The limits to growth: A report for the Club of Rome's project on the predicament of mankind*. New York, Universe Books.
- Mehlwana, A M & Qase, N 1998. The contours of domesticity, energy consumption and poverty. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Mehlwana, A M & Qase, N 1999. The contours of domesticity, energy consumption and poverty: The social determinants of energy use in low-income urban households in Cape Town's townships (1995-1997). Cape Town, Energy & Development Research Centre, University of Cape Town.
- Mehlwana, A M 1998. The anthropology of fuels: situational analysis and energy use in low-income townships of South Africa. *Energy for Sustainable Development* 3 (5): 5-15.
- Mehlwana, A M 1999a. The anatomy of a disaster: case studies of fuel-use problems in the shack areas of Greater Cape Town. *Urban Health and Development Bulletin* 2 (3): 29-37.
- Mehlwana, A M 1999b. The economics of energy for the poor: fuel and appliance purchases in low-income urban households. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Metz, B, Berk, M M, Den Elzen, M, De Vries, B & Van Vuuren, D 2002. Towards an equitable global climate change regime: compatibility with Article 2 of the Climate Change Convention and the link with sustainable development. *Climate Policy* 2 (2-3): 211-230.
- Michie, J & Padayachee, V 1998. Three years after Apartheid: Growth, employment and redistribution? *Cambridge Journal of Economics* 22: 623-635.
- MIND 2005. Action Impact Matrix (AIM) application to climate change: Mitigation users manual. Prepared for C3D Project. Colombo, MIND.
- Mintzer, I M, Leonard, J A & Schwartz, P 2003. US energy scenarios for the 21st century. Arlington, Pew Center on Global Climate Change.
- Mlambo-Ngcuka, P 2002a. Parliamentary media briefing: Minister of Minerals & Energy, 15 February.
- Mlambo-Ngcuka, P 2002b. Minister of Minerals and Energy. Parliamentary media briefing. 15 February. Cape Town, Ministry of Minerals and Energy.
- Mlambo-Ngcuka, P 2002c. Budget vote speech by Minister of Minerals and Energy, Ms. Phumzile Mlambo-Ngcuka. Cape Town. 7 May 2002.
- Mlambo-Ngcuka, P 2003. Budget vote speech by Minister of Minerals and Energy, Ms. Phumzile Mlambo-Ngcuka. Minerals and energy: a catalyst in pushing back frontiers of poverty. Cape Town, Parliament. 15 May 2003.
- Mlambo-Ngcuka, P 2004. Budget vote speech by Minister of Minerals and Energy, Ms. Phumzile Mlambo-Ngcuka. 22 June. Cape Town, Parliament. 22 June 2004.
- Mlambo-Ngcuka, P 2005. Budget vote speech by Minister of Minerals and Energy, Ms. Phumzile Mlambo-Ngcuka. 22 June. Cape Town, Parliament. 22 June 2004.
- Mokgatle, D & Pabot, J L 2002. Highlighting the opportunities for taking the energy grid across Africa. 4th Annual Sub-saharan Power Conference, Midrand, 19-21 February.
- Moreira, J R, Nogueira, L A H & Parente, V 2005. Biofuels for transport, development and climate change: Lessons from Brazil. R Bradley, K Baumert and J Pershing (Eds). *Growing in the greenhouse: Protecting the climate by putting development first*. Washington DC, World Resources Institute.

- Morita, T & Robinson, J 2001. Greenhouse gas emission mitigation scenarios and implications. IPCC (Ed). *Climate Change 2001: Mitigation: Contribution of WG III to the Third Assessment Report of the IPCC. Chapter 2*. Intergovernmental Panel on Climate Change, Cambridge University Press: 115-166.
- Morris, G 2005. Personal communication. Director, AGAMA Energy.
- Munasinghe, M & Swart, R 2005. *Primer on climate change and sustainable development: Facts, policy analysis and applications*. Cambridge, Cambridge University Press.
- Munasinghe, M 1992. *Electric power economics*. Colombo, IRPC.
- Munasinghe, M 1995. Making growth more sustainable. *Ecological Economics* 15: 121-4.
- Munasinghe, M 2000. Development, equity and sustainability (DES) in the context of climate change. R K Pachauri, T Taniguchi and K Tanaka (Eds). *Cross-cutting issues guidance papers: IPCC supporting material for the Third Assessment Report*. Geneva, Intergovernmental Panel on Climate Change.
- Munasinghe, M 2001. Sustainable development and climate change: Applying the sustainomics transdisciplinary meta-framework. *International Journal of Global Environmental Issues* 1 (1): 13-55.
- Munasinghe, M 2002. The sustainomics trans-disciplinary meta-framework for making development more sustainable: Application to energy issues. *International Journal for Sustainable Development* 5 (1/2): 135-182.
- Munasinghe, M, Dreyer, S & Kurukulasurivy, P (Eds) 1999. *Greening the national accounts: Relevance for South Asia*. Colombo, Lanka International Forum on Environment and Sustainable Development and German Cultural Institute.
- Mwandosya, M J 2000. *Survival emissions: A perspective from the South on global climate change negotiations*, Dar es Salaam University Press and the Centre for Energy, Environment, Science and Technology.
- Nakicenovic, N 2000. Energy scenarios. Chapter 9. *World Energy Assessment*. New York, United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council.
- Nash, R 1982. *Wilderness and the American mind*. New Haven, Yale University Press.
- National Treasury 2003a. Intergovernmental Fiscal Review 2003. Pretoria, Republic of South Africa.
- National Treasury 2003b. Market-based instruments to support environmental fiscal reform in South Africa: A discussion document. Pretoria, National Treasury.
- National Treasury 2006. A framework for considering market-based instruments to support environmental fiscal reform in South Africa. Draft policy paper. Pretoria, National Treasury Tax Policy Chief Directorate. <http://www.treasury.gov.za/tax/default.htm>.
- Naude, C M, Coovadia, T & Pretorius, J 2000. Mitigation options: Transport sector. South African Country Studies on Climate Change. Pretoria.
- NDA (National Department of Agriculture) 2000. Abstract of agricultural statistics. Pretoria. <http://www.nda.agric.za/> see publications - statistics.
- NECC (National Electrification Coordinating Committee) 2000. Electrification funding: Report from Fund & Levy Task Team of NECC.
- Nedergaard, M 2002. The application of economic instruments in energy and climate change policies. Sustainable Energy & Climate Change Partnership: A project of WWF Denmark and Earthlife Africa Johannesburg.
- NEPAD (New Partnership for Africa's Development) 2002. A summary of NEPAD action plans. Midrand and Ibadan.
- NER (National Electricity Regulator) 1999. Electricity supply statistics for South Africa 1999. Sandton, NER.
- NER (National Electricity Regulator) 2000. Electricity supply statistics for South Africa 2000. Pretoria, NER.
- NER (National Electricity Regulator) 2001/2. National Integrated Resource Plan. Pretoria.
- NER (National Electricity Regulator) 2001a. Electricity supply statistics for South Africa 2001. Pretoria, NER.
- NER (National Electricity Regulator) 2001c. Lighting up South Africa 2001. Pretoria.
- NER (National Electricity Regulator) 2002a. Electricity supply statistics for South Africa 2002. Pretoria, NER. www.ner.org.za/pubs.htm.
- NER (National Electricity Regulator) 2002b. Independent Power Producers regulatory framework. Policy NER 01 - 2002 IPP Rev I Draft 01. Pretoria.
- NER (National Electricity Regulator) 2002c. An integrated electricity outlook for South Africa. Pretoria, NER. www.ner.org.za/pubs.htm.
- NER (National Electricity Regulator) 2002d. Framework for Integrated Resource Planning in the electricity supply industry. Policy framework NER 01 - 2002 - IRP. Pretoria.
- NER (National Electricity Regulator) 2002e. Progress with the formation of the Regional Electricity Regulators' Association (RERA) of SADC. Johannesburg. www.ner.org.za.
- NER (National Electricity Regulator) 2003a. Lighting up South Africa. Pretoria.
- NER (National Electricity Regulator) 2003b. Monitoring the implementation of energy policy requirements at the NER (1998-2003). Johannesburg. www.ner.org.za/NERRegistry_3130.pdf.

- NER (National Electricity Regulator) 2003c. Wholesale electricity pricing system. WEPS – Information on NER Website. Accessed June 2004. Johannesburg. www.ner.org.za/Weps/Weps.htm.
- NER (National Electricity Regulator) 2004a. National Integrated Resource Plan 2003/4: Reference Case. Draft 27 February. Compiled by ISEP - Eskom (Resources and Strategy) and Energy Research Institute, University of Cape Town and the National Electricity Regulator. Pretoria, National Electricity Regulator. www.nersa.org.za.
- NER (National Electricity Regulator) 2004b. Regulatory policy on energy efficiency and demand side management for South African electricity industry. Pretoria. <http://www.ner.org.za/>.
- NER (National Electricity Regulator) 2004c. National Integrated Resource Plan 2 (NIRP2) 2003/4. Pretoria, National Electricity Regulator. www.ner.org.za.
- NER 2001b. EDI restructuring update. *Electricity Regulatory Journal* August 2001 pp. 1-3.
- NER 2001d. Non-grid electrification. *Electricity Regulatory Journal* February. pp. 4-5.
- Newbery, D M 1995. A template for power reform. New York, World Bank.
- Norgaard, R B 1994. *Development betrayed: The end of progress and a coevolutionary revisioning of the future*. London, Routledge.
- NREL (National Renewable Energy Laboratory) 1999. The potential for low-cost Concentrating Solar Power systems. Report NREL/CP-550-26649. Golden, Colorado, NREL.
- OECD 2000. Ancillary benefits and costs of greenhouse gas mitigation. IPCC co-sponsored workshop, Washington, Organisation for Economic Co-operation and Development.
- Oliver, T, Lew, D, Redlinger, R & Prijyanonda, C 2001. Global energy efficiency and renewable energy policy options and initiatives. *Energy for Sustainable Development* V (2): 15-25.
- Omar, I & Mncwango, S 2003. Landfill gas recovery and potential applications. Paper for the Domestic Use of Energy Conference. 31 March - 3 April, Cape Town, Cape Technikon.
- Ott, H E, Winkler, H, Brouns, B, Kartha, S, Mace, M, Huq, S, Kameyama, Y, Sari, A P, Pan, J, Sokona, Y, Bhandari, P M, Kassenberg, A, La Rovere, E L & Rahman, A 2004. South-North dialogue on equity in the greenhouse. A proposal for an adequate and equitable global climate agreement. Eschborn, Gesellschaft für Technische Zusammenarbeit. www.erc.uct.ac.za/recentpub.htm or www.south-north-dialogue.net.
- Otto, A 2004. Personal communication. Principal Energy Officer: Renewable Energy, Department of Minerals & Energy.
- Pacala, S & Socolow, R H 2004. Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science* 305 (13 August): 968-972.
- Pan, J 2002. Understanding human development potentials and demands for greenhouse gas emissions: with empirical analysis using time series and cross-sectional data. Beijing, Chinese Academy of Social Sciences.
- PBMR Ltd (Pebble Bed Modular Reactor (Proprietary) Limited) 2002. PBMR: Report on the proposed demonstration module and potential commercialization of the pebble bed modular reactor. 011252-160. Sandton.
- Pearce, D, Markandya, A & Barrier, E 1989. *Blueprint for a green economy*. London, Earthscan.
- PEER Africa 1997. Housing as if people mattered. The story of Kutlwanong, South Africa. A no regrets case study. United Nations Framework Convention on Climate Change Third Conference of the Parties, Kyoto, November.
- Pezzoli, K 1997. Sustainable development: A transdisciplinary overview of the literature. *Journal of Environmental Planning and Management* 40 (5): 459-574.
- Philpott, J & Clark, A 2002. South Africa: Electricity reform with a human face? N Dubash (Ed). *Power politics: Equity and environment in electricity reform*. Washington DC, World Resources Institute: 139-156.
- Pinheiro, H J (Ed) 1999. *Bulletin 113: A techno-economic and historical review of the South African coal industry in the 19th and 20th centuries and Analyses of coal product samples of South African collieries 1998-1999*. Pretoria, South African Bureau of Standards.
- Prasad, G & Ranninger, H 2003. The social impact of the basic electricity support tariff (BEST). Domestic use of energy, Cape Town, 2003. Cape Technikon. pp. 17-22.
- Prozzi, J P & Sperling, D 2002. Transportation in developing countries: Greenhouse gas scenarios for South Africa. Arlington, Pew Center on Global Climate Change.
- PWC (PriceWaterhouseCoopers) 2000. Consolidated emerging views. Electricity distribution industry restructuring project: Working paper 7. Johannesburg.
- Qase, N, Lloyd, P J D & Van Zyl, H 2000. Intervention potential for low smoke fuels in the coal distribution chain, final report. Cape Town, Energy & Development Research Centre.
- Raskin, P, Gallopin, G, Gutman, P, Hammond, A & Swart, R 1998. Bending the curve: Toward global sustainability. A report of the Global Scenario Group. Boston, Stockholm Environment Institute.
- Repetto, R & Austin, D 1997. The costs of climate protection: A guide for the perplexed. Washington, World Resources Institute.
- Robinson, J 2004a. Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics* 48: 369-384.
- Robinson, V 2004b. No job, no food, please help. *Mail & Guardian*. May 14 to 20: 37.

- Robinson, V 2004c. Tough times need new policies. *Mail & Guardian*. May 14 to 20: 37.
- RSA (Republic of South Africa) 2001a. Technical Background Document for the Development of a National Ambient Air Quality Standard for Sulphur Dioxide. Government Gazette Vol 432, No. 22134, 1 June 2001. Pretoria, Department of Environmental Affairs & Tourism.
- RSA (Republic of South Africa) 2001b. Eskom Conversion Act (Act No. 13 of 2001). Pretoria.
- RSA (Republic of South Africa) 2003. A national climate change response strategy. Draft October 2003. Pretoria. unfccc.int/resource/docs/natc/zafnc01.pdf.
- RSA (Republic of South Africa) 2004a. South Africa: Initial National Communication under the United Nations Framework Convention on Climate Change. Submitted at COP-9. Pretoria. unfccc.int/resource/docs/natc/zafnc01.pdf.
- RSA (Republic of South Africa) 2004b. National environmental management: Air Quality Act (No. 39 of 2004). Government Gazette 27318, Notice No. 163, 24/2/2005. Pretoria, Department of Environmental Affairs & Tourism. <http://www.info.gov.za/gazette/acts/2004/a39-04.pdf>.
- RSA (Republic of South Africa) 2005. Government's programme of action - 2005: Economic cluster. Pretoria. <http://www.info.gov.za/aboutgovt/poa/report/economic05.htm>.
- Sachs, W 2000. Globalization and sustainability. Berlin, Heinrich Böll Stiftung.
- Sachs, W, Loske, R & Linz, M 1998. *Greening the north: a post industrial blueprint for ecology and equity*. London, Zed Books.
- SACN (South African Cities Network) 2004. State of cities report. Johannesburg.
- Sad-elec 2003. Review of Eskom Power Pool. Phase 2 of development of guidelines (market rules) for the introduction of independent power producers (IPPs) and private service providers (PSPs) in the South African electricity supply industry (ESI). Submitted to the Department of Mineral and Energy and the Multi-Market Model Working Group. Pretoria, Submitted by Sadelec leading the consortium with The Marketplace Company, Econ, PPA, Tsutsuma Energy Solutions and Canca.
- SANEA (South African National Energy Association) 1998. South Africa Energy Profile. Sandton.
- SANEA (South African National Energy Association) 2003. South African Energy Profile 2003. Melville, South Africa.
- SARB (South African Reserve Bank) 2001. Quarterly Bulletin. Pretoria, SARB.
- SARB (South African Reserve Bank) 2002. Quarterly Bulletin March 2002. Pretoria.
- SARB (South African Reserve Bank) 2005. Quarterly Bulletin, March. Pretoria.
- SARB (South African Reserve Bank) various. Quarterly Bulletin. Pretoria.
- Sari, A P 1998. On equity and developing country participation. Berkeley, Energy & Resources Group, University of California, Berkeley.
- SARPN (Southern African Regional Poverty Network) 2005. South Africa: Millenium development goals country report. <http://www.sarpn.org.za/documents/d0001538/index.php>.
- Sasol 2004. Annual review and summarised financial information. Johannesburg.
- SECCP (Sustainable Energy and Climate Change Partnership) 2002. Nuclear energy costs the earth. Johannesburg, SECCP, a project of Earthlife Africa Johannesburg, in partnership with WWF, Denmark.
- SEED 2002. Innovative housing projects pave the way for others. *Urban SEED Update* 1 (2): pp. 1-10.
- SEIB 2002. LEAP Long-range Energy Alternatives Planning System: User guide for LEAP version 2003. Boston, Stockholm Environment Institute.
- Shell (Shell International) 2001. Energy needs, choices and possibilities: Scenarios to 2050. London.
- Shukla, P R, Tudela, F, Davidson, O, Mwakasonda, S, Spalding-Fecher, R, Winkler, H, Mukheibir, P, Alpan-Atamer, S, Chandler, W, J. Secrest, T, Logan, J, Schaeffer, R, Szklo, A S, Schuler, M E, Dadi, Z, Kejun, Z, Yuezhong, Z & Huaqing, X 2002. Climate change mitigation in developing countries: Brazil, China, India, Mexico, South Africa, and Turkey. Washington DC, Pew Center on Global Climate Change. October.
- Simmonds, G & Clark, A 1998. Energy strategies for the urban poor. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Simmonds, G & Mammon, N 1996. Energy services in low-income urban South Africa: A quantitative assessment. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Simmonds, G 1997. Financial and economic implications of thermal improvements. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Smith, I, Smit, R & Beckman, R 2003. Eskom's first experience with wind energy. *Journal of Energy in Southern Africa* July (Eskom special edition): 19-25.
- Spalding-Fecher, R & Matibe, D K 2003. Electricity and externalities in South Africa. *Energy Policy* 31 (8): 721-734.
- Spalding-Fecher, R 2000a. Environmental benefits of electrification in developing countries: a quantitative assessment in South Africa. International Society for Ecological Economics 2000 Conference, Canberra, 5-8 July.

- Spalding-Fecher, R 2000b. Does electrification reduce national health costs? A first assessment for South Africa. Proceedings of the seventh conference on the Domestic Use of Energy, Cape Town, Cape Technikon. pp. 117-122.
- Spalding-Fecher, R 2001. Energy and sustainability in South Africa: the 2001 Sustainable Energy Watch Report. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Spalding-Fecher, R 2002a. Energy and energy policies in South Africa: an overview. *NER Quarterly Journal* 1 (1): 1-18. October.
- Spalding-Fecher, R 2002b. Financial and economic analysis of CDM projects. O Davidson and D Sparks (Eds). *Developing energy solutions for climate change: South African research at EDRC*. Cape Town, Energy & Development Research Centre, University of Cape Town: 83-103.
- Spalding-Fecher, R 2002c. Energy sustainability indicators for South Africa. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Spalding-Fecher, R 2002d. Energy sustainability indicators for South Africa. Report prepared for the Sustainable Energy & Climate Change Partnership. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Spalding-Fecher, R 2003. Indicators of sustainability for the energy sector: a South African case study. *Energy for Sustainable Development* 7 (1): 32-46. March.
- Spalding-Fecher, R 2005. Health benefits of electrification in developing countries: a quantitative assessment in South Africa. *Energy for Sustainable Development* IX (1): 23-32.
- Spalding-Fecher, R, Afrane-Okese, Y, Davis, M & Matibe, K 2000a. Electricity & the environment. Paper No. 5: World Wildlife Fund Macroeconomic Reforms and Sustainable Development in Southern Africa Project. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Spalding-Fecher, R, Clark, A, Davis, M & Simmonds, G 1999. Energy efficiency for the urban poor: Economics, environmental impacts and policy implications. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Spalding-Fecher, R, Clark, A, Davis, M & Simmonds, G 2002a. The economics of energy efficiency for the poor - a South African case study. *Energy: The International Journal* 27 (12): 1099-1117. December.
- Spalding-Fecher, R, Roy, J, Wang, Y & Lutz, W 2004. Potential for energy efficiency: Developing nations. C J Cleveland (Ed). *Encyclopedia of Energy*. San Diego, California, Academic Press/Elsevier Science. 5: 117-133.
- Spalding-Fecher, R, Thorne, S & Wamukonya, N 2002b. Residential solar water heating as a potential Clean Development Mechanism project: a South African case study. Mitigation and adaptation strategies for global change. *Mitigation and adaptation strategies for global change* 7 (2): 135-153.
- Spalding-Fecher, R, Williams, A & Van Horen, C 2000b. Energy and environment in South Africa: charting a course to sustainability. *Energy for Sustainable Development* 4 (4): 8-17. December.
- Spalding-Fecher, R, Winkler, H & Tyani, L 2001. Affordability of energy efficient low cost housing - estimating financing and grant requirements. Proceedings of ninth conference on Domestic Use of Energy, Cape Town, 10-12 April. Cape Technikon. pp. 17-20.
- SSA (Statistics South Africa) 1996. Census in Brief: The people of South Africa: population census 1996. Pretoria.
- SSA (Statistics South Africa) 2000. Measuring poverty. Pretoria, SSA.
- SSA (Statistics South Africa) 2002. Earning and spending in South Africa: Selected findings and comparisons from the income and expenditure surveys of October 1995 and October 2000. Pretoria.
- SSA (Statistics South Africa) 2003a. Census in Brief: Census 2001. Pretoria. www.statssa.gov.za/SpecialProjects/Census2001/HTML/CinBrief/CIB%202001.htm.
- SSA (Statistics South Africa) 2003b. Census 2001. Pretoria.
- SSA (Statistics South Africa) 2004a. Mid-year population estimates, South Africa. Statistical release P0302. Pretoria, Statistics South Africa.
- SSA (Statistics South Africa) 2004b. Stats in brief: Ten years of democratic governance. Pretoria, SSA.
- SSA (Statistics South Africa) 2005. Stats in brief. Pretoria, SSA.
- SSN (SouthSouthNorth) 2004. Project design document for the Kuyasa project. Submitted to the Executive Board of the Clean Development Mechanism. <http://cdm.unfccc.int>. Cape Town, SouthSouthNorth Project. www.southsouthnorth.org.
- Standards SA (Standards South Africa - a division of SABS) 2004a. DRAFT: South African national standard: Ambient air quality — Limits for common pollutants. SANS 1929:200x Edition 1. Pretoria.
- Standards SA (Standards South Africa - a division of SABS) 2004b. DRAFT: Framework for setting and implementing national ambient air quality standards. SANS 69:200X Edition 1. Pretoria.
- Stassen, D 2001. Personal communication. 1 March.
- Statement by the office of Marthinus van Schalkwyk, Minister of Environmental Affairs & Tourism, on 5 May 2005. Cape Town, Ministry of Environmental Affairs and Tourism. <http://www.environment.gov.za>.

- Steyn, G 2000. A competitive electricity market for South Africa: The need for change and a strategy for restructuring South Africa's electricity supply industry. Pretoria, for the Department of Minerals & Energy.
- Steyn, G 2001. Governance, Finance and Investment: Decision making and risk in the Electric Power Sector. Doctoral thesis. Science Policy Research Unit. Sussex, University of Sussex.
- Streak, J C 2004. The Gear legacy: Did Gear fail or move South Africa forward in development. *Development Southern Africa* 21 (2): 271-288.
- Surridge, A D 2005. Personal communication. Director: Coal & gas, Department of Minerals & Energy.
- Swisher, J, Jannuzzi, G & Redlinger, R 1997. *Tools and Methods for Integrated Resource Planning*. Roskilde, UNEP Collaborating Centre on Energy & Environment.
- Tellus (Tellus Institute) 2001. Halfway to the future: Reflections on the global condition on the occasion of the 25th anniversary of the Tellus Institute. Boston.
- Thom, C & Afrane-Okese, Y 2001. Institutional arrangements in the South African off-grid electrification programme. Based on a paper presented at the World Solar Energy Congress. Energy & Development Research Centre, University of Cape Town.
- Thom, C 2000. Use of grid electricity by rural households in South Africa. *Energy for Sustainable Development* 4 (4): 36-43. December.
- Thorne, S, Spalding-Fecher, R & Wamukonya, N 2000. Residential solar water heating as a potential CDM project: A South African case study. Paper presented at workshop on Forging New Links and Reinforcing National Capacities on Climate Change: Challenges and Opportunities for CDM in Africa, 8-10 May 2000, Cape Town.
- TNI (Transnational Institute) 2002. Lights off! Debunking the myths of power liberalisation. by D Chavez Amsterdam.
- TNI (Transnational Institute) 2003. The sky is not the limit. TNI Briefing Series No. 2003/1. Amsterdam. www.tni.org/reports/ctw/skytext.pdf Accessed June 2005.
- Toth, F L & Mwandosya, M J 2001. Decision-making frameworks. IPCC (Ed). *Climate Change 2001: Mitigation: Contribution of WG III to the Third Assessment Report of the IPCC*. Intergovernmental Panel on Climate Change, Cambridge University Press: 603-688.
- Turkson, J (Ed) 2000. *Power sector reform in Sub-saharan Africa*. London, Macmillan Press.
- Tyani, L 2000. Energy efficiency in a restructuring electricity distribution industry in South Africa: Analysis and policy strategies. MPhil. Energy & Development Research Centre. Cape Town, University of Cape Town: 90.
- UCT (University of Cape Town) 2002. Options for a basic electricity support tariff: Analysis, issues and recommendations for the Department of Minerals & Energy and Eskom. Cape Town.
- UCT 2003. Options for a basic electricity support tariff: supplementary report. Research project 400903. Cape Town, University of Cape Town. 2003.
- UN DSD (United Nations Division of Sustainable Development) 1996. Indicators of Sustainable Development: Framework and Methodologies. New York, UN Department of Economic and Social Affairs. <http://www.un.org/esa/sustdev/isd.htm>.
- UN GA (United Nations General Assembly) 2000. United Nations Millennium Declaration. Resolution adopted by the General Assembly A/RES/55/2. Washington DC. <http://www.un.org/millenniumgoals/>.
- UNDP, UNDESA & WEC (United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council) 2000. World Energy Assessment. New York.
- UNFCCC (United Nations Framework Convention on Climate Change) 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. Bonn, UNFCCC Secretariat. <http://unfccc.int/resource/convkp.html>.
- UNFCCC 1992. United Nations Framework Convention on Climate Change. New York, United Nations. <http://unfccc.int/resource/conv/index.html>.
- US EPA (United States Environmental Protection Agency) 2000. Air Chief: Emission factors. Washington.
- Vajpayee, S A B 2002. Speech of India's Prime Minister at the High Level Segment of the Eighth Session of Conference of the Parties to the UN Framework Convention on Climate Change. 30 October. New Delhi. http://unfccc.int/cop8/latest/ind_pm3010.pdf.
- Van der Merwe, M R & Scholes, R J 1998. South African Greenhouse Gas Emissions Inventory for the years 1990 and 1994. Pretoria, National Committee on Climate Change.
- Van der Riet, M 2003. Personal communication. Technology Services International, Eskom.
- van Gass, I 1999. All Africa Games village: showcase for water- and energy efficiency. *Energy Management News* 5 (2): 1,6,9. June.
- Van Heerden, J, Gerlagh, R, Blignaut, J, Horridge, M, Hess, S, Mabugu, R & Mabugu, M 2006. Searching for triple dividends in South Africa: Fighting CO2 pollution and poverty while promoting growth. *The Energy Journal* 27 (2): 113-141.
- Van Horen, C & Simmonds, G 1998. Energy efficiency and social equity: seeking convergence. *Energy Policy* 26 (11): 893-903. September.

- Van Horen, C 1996a. *Counting the social costs: Electricity and externalities in South Africa*. Cape Town, University of Cape Town Press and Elan Press.
- Van Horen, C 1996b. The cost of power: externalities in South Africa's energy sector. Doctoral dissertation. School of Economics. Cape Town, University of Cape Town.
- Van Ryneveld, P, Parnell, S & Muller, D 2003. Indigent policy: Including the poor in the City of Cape Town's income strategy. Cape Town, City of Cape Town.
- Van Schalkwyk, M 2005a. SA braces for impacts of climate change; major conference to be held in October.
- Van Schalkwyk, M 2005b. SA receives "Champion of the Earth" Award: Recognised for global enviro leadership. Speech by the Minister of Environmental Affairs & Tourism, Marthinus van Schalkwyk. New York, UNEP. 20 April 2005. <http://www.info.gov.za/speeches/2005/05042011151001.htm>.
- Venter, I 2001. Africa's big gas adventure begins. *Engineering News* October 5-11 pp. 16-17.
- Villavicencio, A forthcoming. The sustainability of energy systems. Roskilde, UNEP Collaborating Centre on Energy & Environment.
- Visser, M, Spalding-Fecher, R & Leiman, A 1999. Manufacturing and economic growth. Paper No. 10: World Wildlife Fund Macroeconomic Reforms and Sustainable Development in Southern Africa Project. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Wamukonya, N 2003a. Power sector reform in developing countries: Mismatched agendas. *Energy Policy* 31: 1273-1289.
- Wamukonya, N 2003b. African power sector reforms: Some emerging lessons. *Energy for Sustainable Development* VII (1): 7-16.
- Ward, S 2002. *The Energy Book for urban development in South Africa*. Cape Town, Sustainable Energy Africa.
- WCD (World Commission on Dams) 2000. Dams and development: A new frame-work for decision-making. London, Earthscan Publications.
- WCED (World Commission on Environment and Development) 1987. Our Common Future. Oxford, Oxford University Press.
- Wei-Shiuen, N & Schipper, L 2005. China motorization trends: Policy options in a world of transport challenges. R Bradley, K Baumert and J Pershing (Eds). *Growing in the greenhouse: Protecting the climate by putting development first*. Washington DC, World Resources Institute.
- Weyant, J P & Hill, J 1999. Introduction and Overview. *The Costs of the Kyoto Protocol: A Multi-Model Evaluation. Special Issue The Energy Journal*: vii-xliv.
- White, C, Crankshaw, O, Mafokoane, T & Meintjies, H 1998. Social determinants of energy use in low-income metropolitan households in Soweto. Report No. EO9423. Pretoria, Department of Minerals and Energy.
- Wicking-Baird, M C, Dutkiewitz, R K & De Villiers, M 1997. Cape Town Brown Haze Study. Report No. GEN 182. Cape Town, Energy Research Institute, University of Cape Town.
- Wilson, E O 1989. National Academies Press. Washington DC, National Academies Press.
- Winkler, H & Mavhungu, J 2001. Green power, public benefits and electricity industry restructuring. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Winkler, H & Mavhungu, J 2002. Potential impacts of electricity industry restructuring on renewable energy and energy efficiency. *Journal of Energy in Southern Africa* 13 (2): 43 - 49.
- Winkler, H 2005. Renewable energy policy in South Africa: Policy options for renewable electricity. *Energy Policy* 33 (1): 27-38.
- Winkler, H, Borchers, M, Hughes, A, Visagie, E & Heinrich, G 2005c. Cape Town energy futures: Policies and scenarios for sustainable city energy development. Report for the COMMEND network. Cape Town, Energy Research Centre, University of Cape Town. www.erc.uct.ac.za.
- Winkler, H, Howells, M & Alfstad, T 2005a. South African energy policies for sustainable development. Report for the International Atomic Energy Agency. Cape Town, Energy Research Centre.
- Winkler, H, Howells, M & Baumert, K 2005b. Sustainable development policies and measures: Institutional issues and electrical efficiency in South Africa. Washington DC, Center for Clean Air Policy.
- Winkler, H, Spalding-Fecher, R & Tyani, L 2001. What could potential carbon emissions allocation schemes and targets mean for South Africa? Cape Town, Energy & Development Research Centre, University of Cape Town.
- Winkler, H, Spalding-Fecher, R & Tyani, L 2002c. Comparing developing countries under potential carbon allocation schemes. *Climate Policy* 2 (4): 303-318.
- Winkler, H, Spalding-Fecher, R & Tyani, L 2002e. Energy efficiency in low-cost housing: Costs and benefits of global and local externalities. O Davidson and D Sparks (Eds). *Developing energy solutions for climate change: South African research at EDRC*. Cape Town, Energy & Development Research Centre, University of Cape Town: 44-57.

- Winkler, H, Spalding-Fecher, R, Mwakasonda, S & Davidson, O 2002a. Sustainable development policies and measures: Tackling climate change from a development perspective. O Davidson and D Sparks (Eds). *Developing energy solutions for climate change: South African research at EDRC*. Cape Town, Energy & Development Research Centre, University of Cape Town: 176-198.
- Winkler, H, Spalding-Fecher, R, Mwakasonda, S & Davidson, O 2002b. Sustainable development policies and measures: starting from development to tackle climate change. K Baumert, O Blanchard, S Llosa and J F Perkaus (Eds). *Building on the Kyoto Protocol: Options for protecting the climate*. Washington DC, World Resources Institute: 61-87.
- Winkler, H, Spalding-Fecher, R, Tyani, L & Matibe, K 2000. Cost-benefit analysis of energy-efficiency in low-cost housing. Cape Town, Energy & Development Research Centre, University of Cape Town.
- Winkler, H, Spalding-Fecher, R, Tyani, L & Matibe, K 2002d. Cost-benefit analysis of energy efficiency in urban low-cost housing. *Development Southern Africa* 19 (5): 593-614. December.
- World Bank 1998. Greenhouse gas assessment handbook: a practical guidance document for the assessment of project-level greenhouse gas emissions. Washington, D. C., World Bank Global Environment Division. September.
- World Bank 1999. Cost reduction study for solar thermal power plants. Prepared by Enermodal Engineering Ltd. Washington DC, World Bank.
- World Bank 2000. *World Development Report 2000/2001*. Oxford, Oxford University Press.
- WRI (World Resources Institute) 2003. Climate Analysis Indicators Tool (CAIT). Washington DC. www.wri.org.
- WRI (World Resources Institute) 2005. Climate Analysis Indicators Tool (CAIT), version 3.0. Washington DC. <http://cait.wri.org/>.
- WSSD (World Summit on Sustainable Development) 2002. Johannesburg Plan of Implementation. Adopted by the United Nations World Summit on Sustainable Development. Johannesburg.
- Yohe, G 2001. Mitigative capacity - the mirror image of adaptive capacity on the emissions side: An editorial. *Climatic Change* 49: 247-262.
- Zhou, P 2001. North-South dialogue. *Tiempo: Global Warming and the Third World* (40/41): pp. 1-7.