Clean Energy and Development for South Africa: Results

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Report 3 of 3

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Abbreviations and acronyms used

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

Energy Units

Power

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

Energy

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

1. Introduction

This report is the third and final report for the project entitled *Clean Energy and Development for South Africa* funded by the British Foreign Commonwealth office.

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

The objective of this document is to report on the scenarios considered and compare the costs and social impacts using the sustainability indicators. The scenarios reported on are the energy efficiency improvements in the commercial, industrial, transport and residential sector, an increased penetration of biofuels and renewables and increased use of nuclear energy. The scenarios contain alternative fuel and appliance choices. Deviations from the base case are introduced in order to determine the effect specific policies or actions will have on the final energy demand and related emissions and costs of the system.

In addition to the scenarios the study includes a base case sensitivity analysis with a lower GDP growth rate and another with technology learning on electricity generation technologies. The first report entitled *Background Data* makes reference to the attempt to include the effect exchange rate would have on technology choices that rely on large foreign input, such as future power stations. It has been estimated that a large portion of investment into generation capacity may not be spent locally unless there is investment in local capacity. At the onset, the aim was to include a gradual increase in the exchange rate in the base case which was applied to the investment costs of power stations. This was aborted however, as it was felt results were unrealistic. For demonstration purposes the results of the base case with the increased cost of generation technologies due to the increase in exchange rate are included in the third report.

This report has four sections, the first includes all base case results and sustainability indicators needed for the analysis. The second covers the energy efficiency scenarios. The third covers the scenarios that relate to alternative policies for generation technologies, the last section reports on the sensitivity analyses. Finally there are conclusions and recommendations.

2. Base Case Results

The base case represents a business as usual growth in energy demand in South Africa. It includes all current development plans being implemented, but does not include the aggressive policies needed to reach the targets set out in the energy efficiency strategy and the renewable energy policy. The background data and assumptions used to model the base case are discussed in detail in the first report entitled *Background data*.

The base case shows a steady upward trend of energy consumption dominated by the industrial sector. This is illustrated in Figure 1 which shows the growth in final energy demand of each sector between 2001 and 2030. Table 1 includes the percentage growth in demand of each sector between 2001 and 2030. Demand grows from 2 209 PJ in 2001 to 6 655PJ in 2030. This is a 300 percent increase in demand over the period.

Although the base case does include a change in the composition of sectors, the technologies meeting demand and the percentage of demand required by each end use remain largely the same over the period.

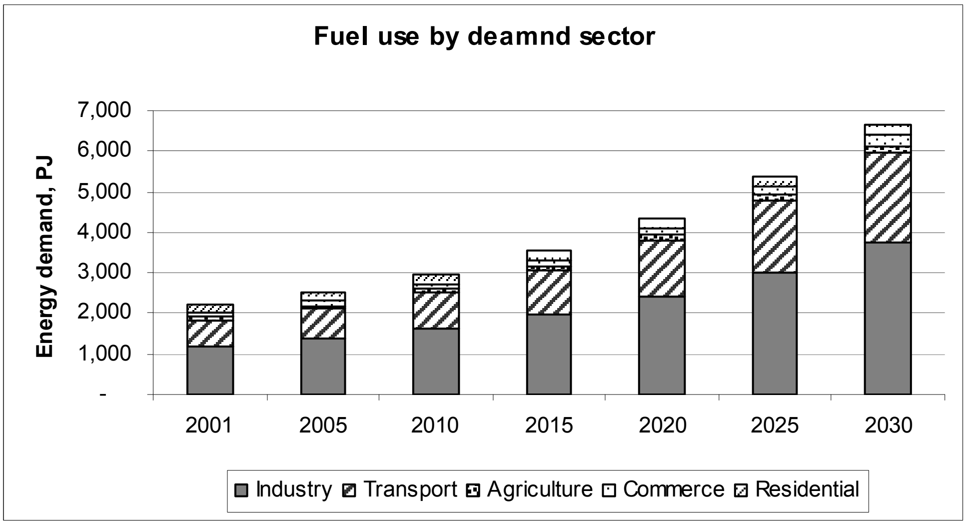


Figure 1: Fuel consumption by major energy demand sector

Table 1: Fuel consumption by major energy demand sector and percentage growth

	2001	2005	2010	2015	2020	2025	2030	Percentage increase
Industry	1,206	1,387	1,639	1,962	2,408	3,014	3,765	312.27%
Transport	634	720	882	1,112	1,407	1,783	2,218	349.83%
Agriculture	73	76	82	93	109	129	153	210.56%
Commerce	100	112	132	156	186	222	262	262.48%
Residential	197	209	221	231	240	249	257	130.49%
Total	**2,209**	**2,504**	**2,956**	**3,555**	**4,350**	**5,397**	**6,655**	

The growth in demand in each of the sectors differs significantly over the period. Industry and transport are the sectors in which we anticipate the most significant growth in demand. The small growth in demand in the residential sector is due to the slowing down of population growth and the continued electrification of households allowing a shift from fuels and appliances that are used at lower efficiencies and therefore demand more final energy.

The anticipated increase in electricity demand is shown in Figure 2. The increase in electricity demand over the period is in line with that of the high growth rate scenario considered in NIRP2 (NER, 2004). Demand for electricity increases the most in the industrial sector, although all sectors see electricity demand double over the period. Electricity demand in the agricultural and commercial sectors goes up by 144% and in the industrial and commercial sectors demand increases by 200% over the period.

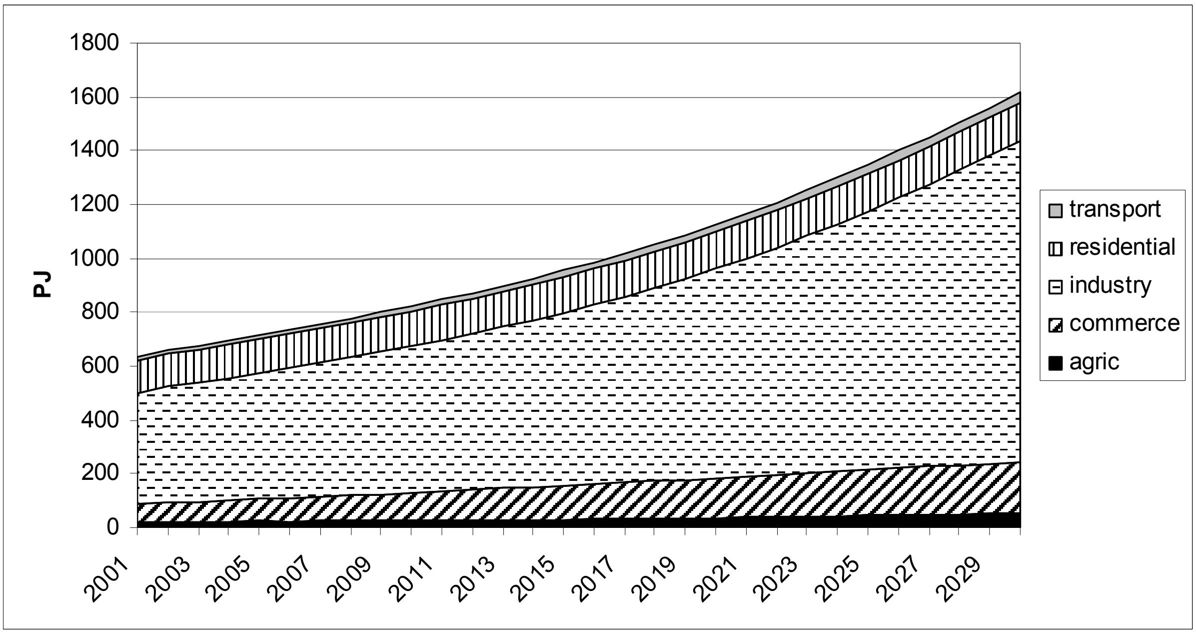


Figure 2: Projected electricity demand by sector

The expansion of generating capacity needed to meet the demand, given our base case assumptions, is shown in Figure 3. There is a loss of generating capacity of existing coal plants during the period and an introduction of new pulverised fuel coal plants, supercritical coal plants, landfill gas, OCGT's, CCGT's and the mothballed coal stations

It is worth noting here that due to the limited number of periods within the model, the peak and baseload demand can not be very accurately represented and whilst this gives a flavour of the type of plant needed and when, models such as TIMES and EAGES which allow more accurate representation of the load curve within the model would improve the reliability of the outcome.

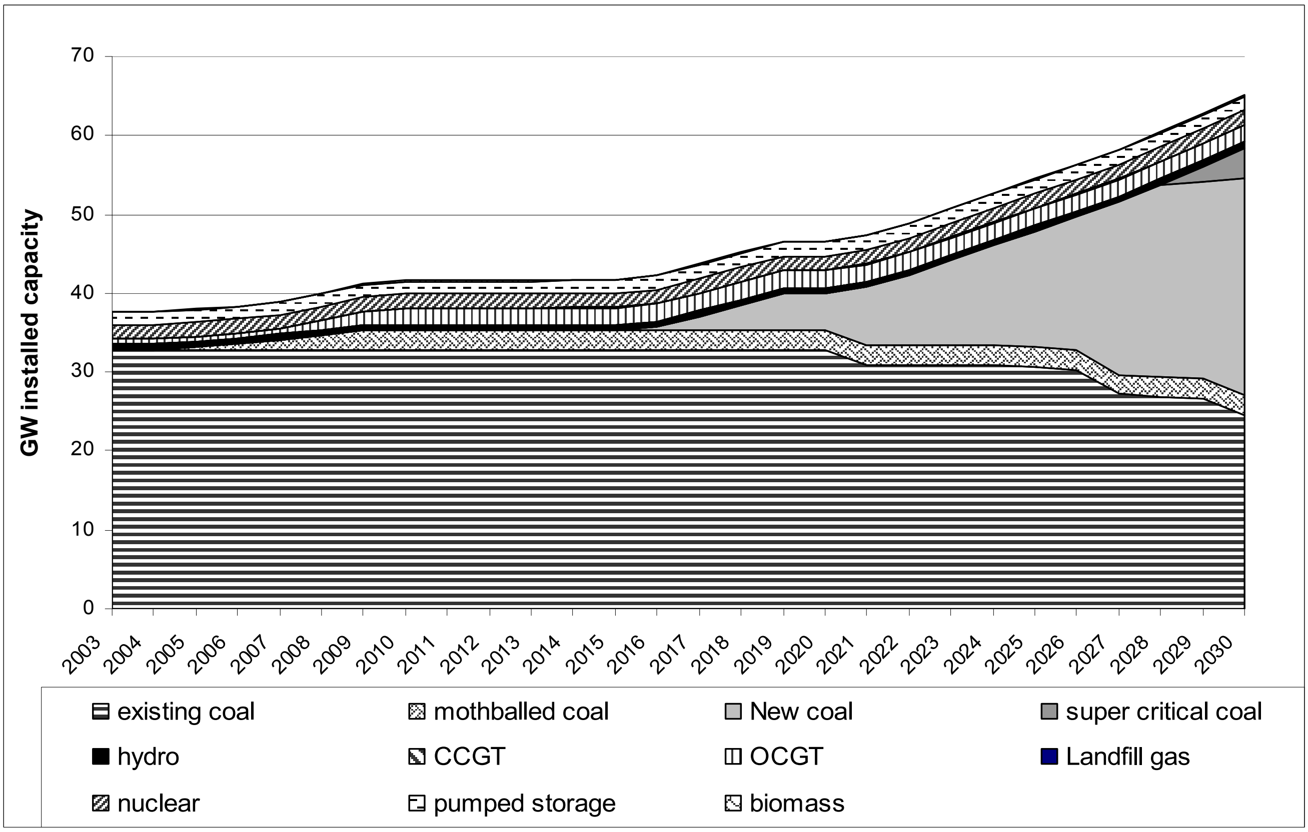


Figure 3: Electricity generation capacity by plant type

The capacity of the plant types invested in is shown below in Table 2. By the end of the period the capacity has not yet doubled. This is less than was expected, but is probably due to the assumption that less peaking plant will be required by the end of the period. This is modelled by lowering the reserve margin, which decreases the capacity needed, and therefore the ratio of capacity to demand is slightly less at the end of the period.

Table 2: Electricity generating capacity by generation type

	2003	2005	2015	2020	2025	2030
Existing coal stations	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.38	2.49	2.49	2.49	2.49
New coal stations	0	0	0	4.65	14.7	27.48
Super Critical coal	0	0	0	0	0	3.85
FBC	0	0	0	0	0	0
CCGT	0	0	0	0.01	0.02	0.02
OCGT	0.64	0.64	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	0
Pumped storage	1.58	1.58	1.58	1.84	1.8	1.8
Landfill gas	0	0	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0
Solar Parabolic	0	0	0	0	0	0
Wind	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	38.0	41.7	47	54	65

Due to rapid growth in the transport sector, and an upper limit of 15% of demand set on all imports of petrol and diesel, there is a need to invest in additional refining capacity. In the base case the investment is firstly into Sasol type coal to liquid plants, which is capped at a maximum investment of 3 additional plants of that type during the period. There is also the introduction of smaller scale biodeisel and bioethanol plants. They are introduced to meet the additional demand required for biofuels due to the assumed E4 B2 fuel blends. There is no additional investment or move towards biofuels in the base case due to their increased cost. Towards the end of the period, there is a need to invest in additional crude oil refining capacity.

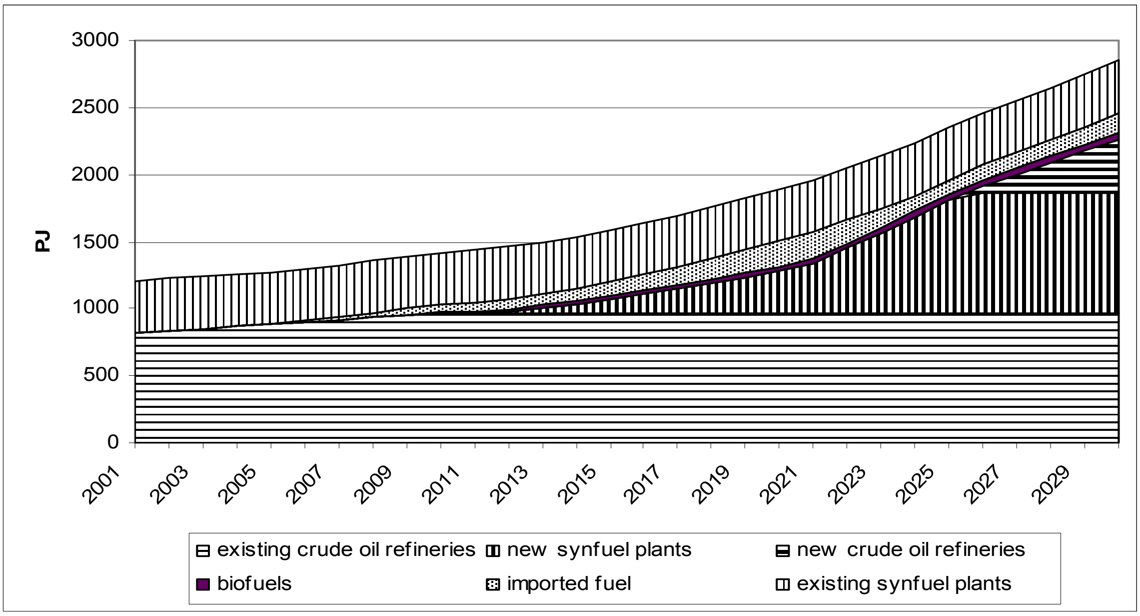


Figure 4: Refinery capacity by plant type

The increase in fuel demand by type by sector is shown in Figure 5. There is increased use of all fuels in all sectors in the base case, the notable exception is the use of coal in the residential sector.

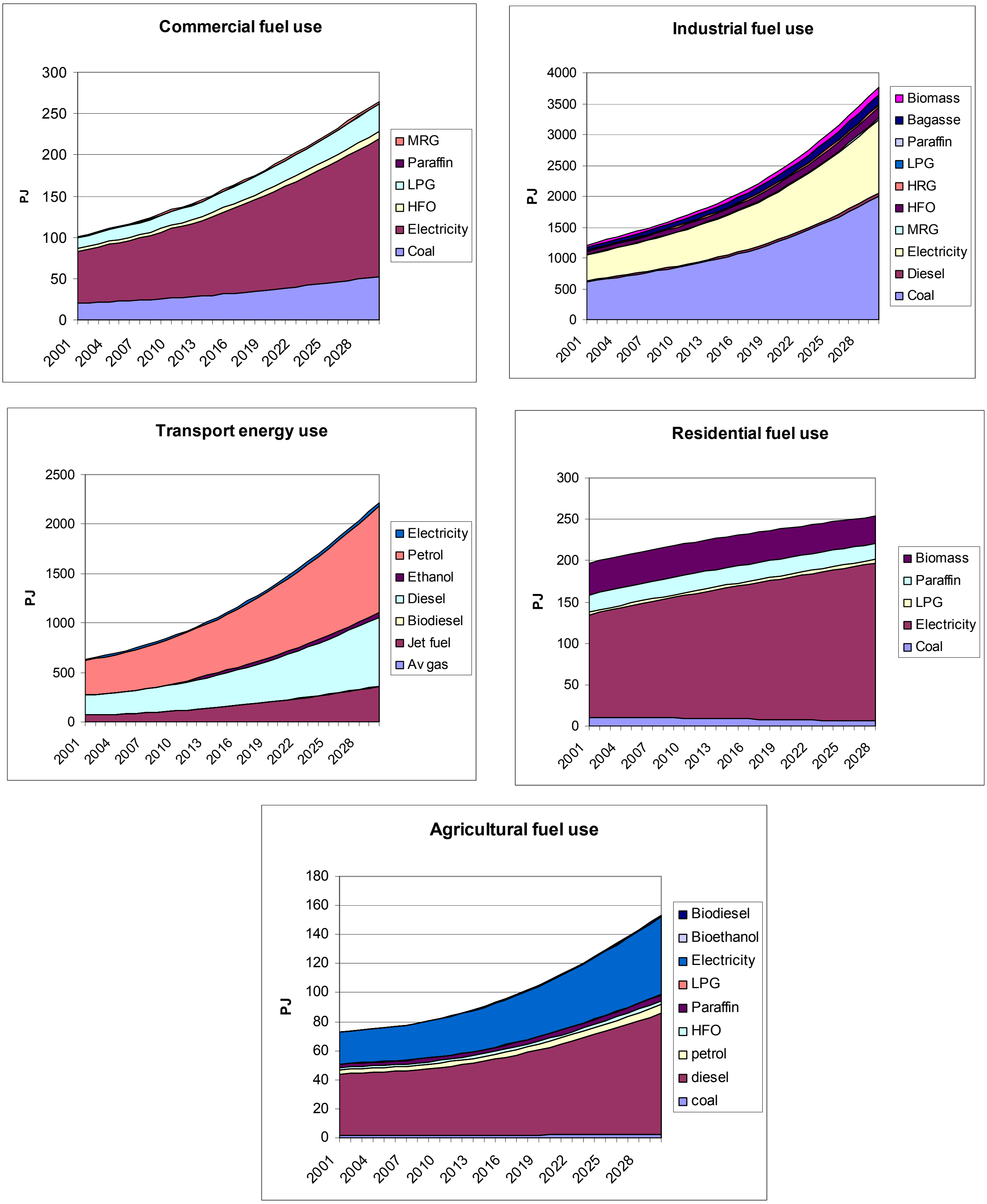


Figure 5: Fuel demand in each sector

The contribution of renewables and non -renewables to electricity supply and energy supply in South Africa between 2001 and 2030 is shown in Table 3. The contribution of renewables to total energy supply increases over the period, whilst the contribution of renewables to electricity generation decreases after peaking in 2004 with the addition of land fill gas generating capacity.

Table 3: Renewable and Non-renewable fractions of Electricity and Total Energy supply

Electricity	shares	**2001**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
	non-renewable	99.63%	99.67%	99.72%	99.56%	99.61%	99.65%	99.71%
	renewable	0.37%	0.33%	0.28%	0.44%	0.39%	0.35%	0.29%
Total Energy Supply								
	non-renewable	97.4%	97.4%	97.2%	96.7%	96.5%	96.5%	96.4%
	renewable	2.6%	2.6%	2.8%	3.3%	3.5%	3.5%	3.6%

Total Carbon dioxide emissions and carbon dioxide emissions from electricity generation are shown below in Figure 6. The increasing difference between total CO_2 emissions and emissions from power stations is due to the rapid increase in fuel demand in the transport sector.

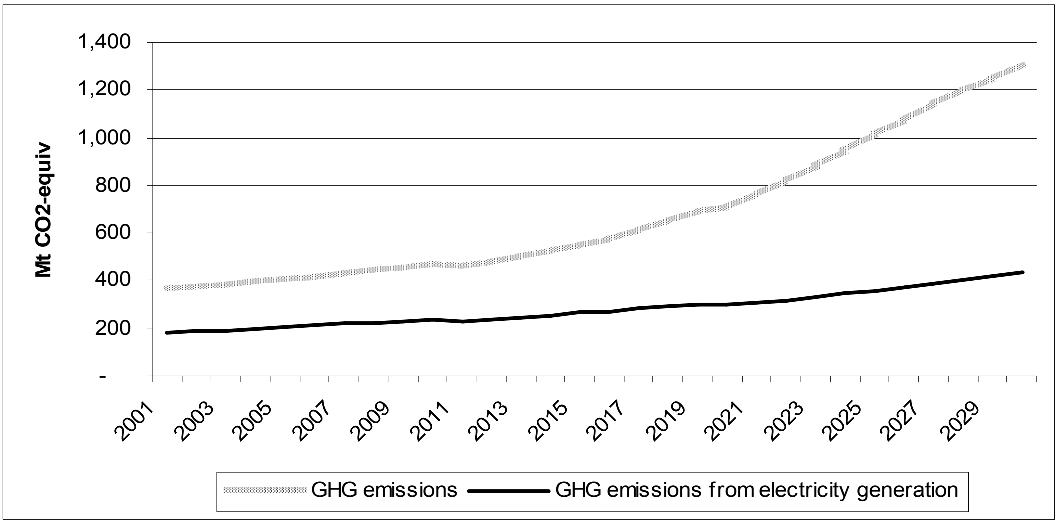


Figure 6: Total CO_2 emissions and CO_2 emissions from electricity generation

An index of GDP, total primary energy supply (TPES) and greenhouse has emissions (GHG emissions) is shown below in Figure 7. Here it is evident that emissions are rising more rapidly than TPES.

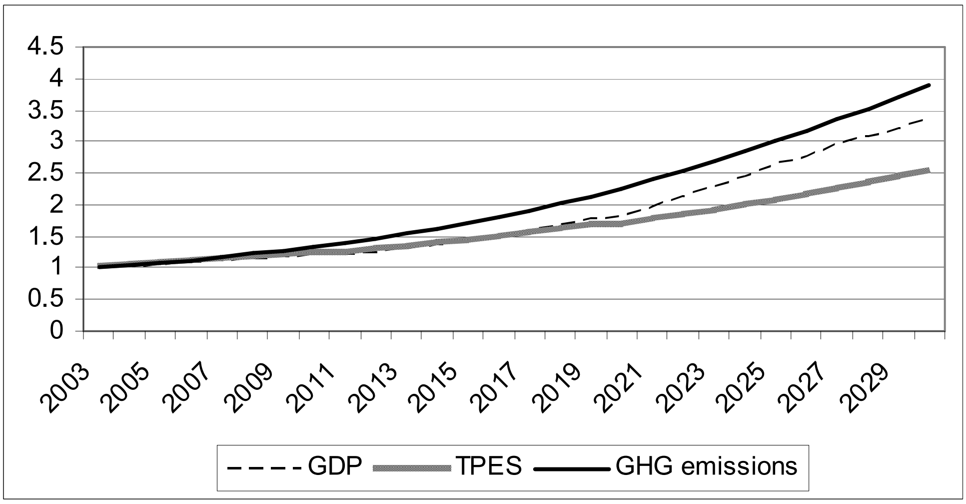


Figure 7: Total CO_2 emissions and CO_2 emissions from electricity generation

Figure 8 shows the local air pollutants in the residential sector. With the large-scale electrification program that has been assumed in the base case, we can see a very noticeable downward trend in local air pollutants.

Local air pollutants are not restricted to this sector but this is the sector in which they have the most noticeable impact on health.

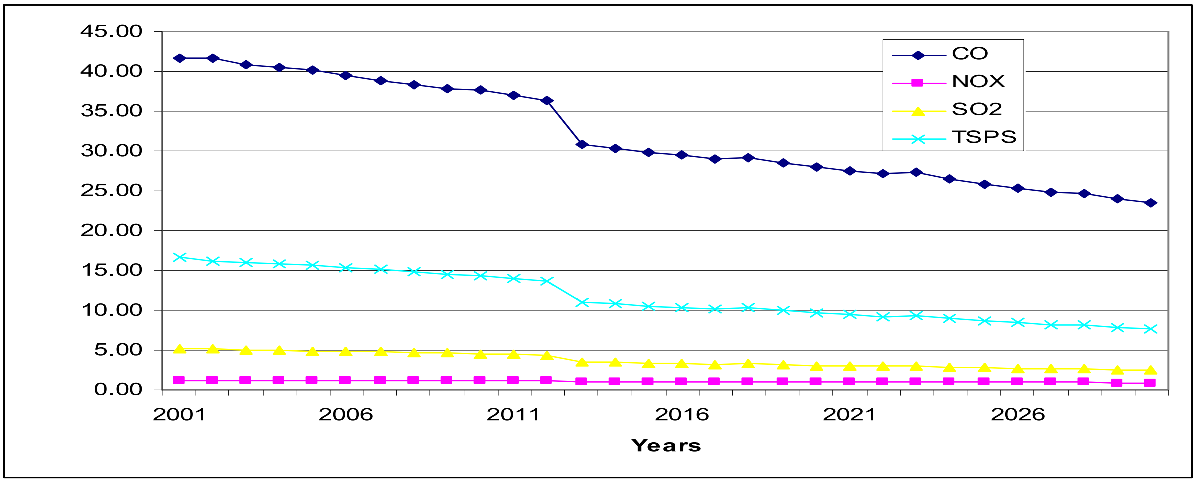
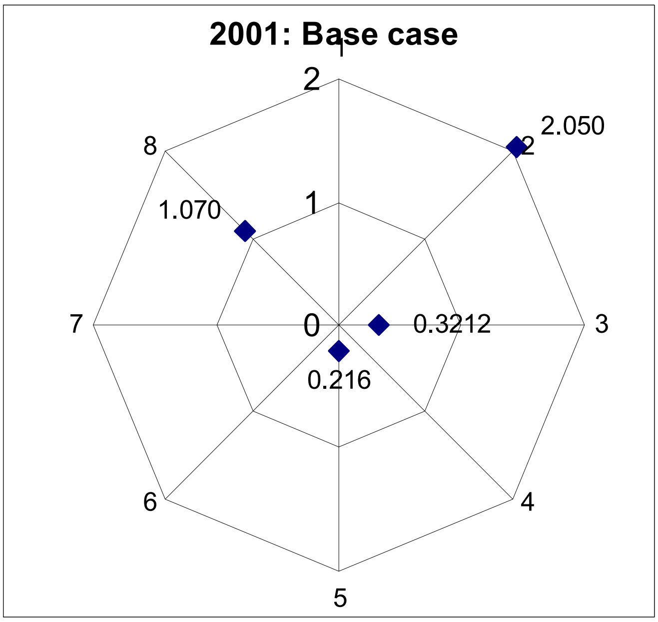


Figure 8: Local air pollutants in the Residential Sector

2.1 Base case sustainability indicators

South Africa's base case sustainability indicator "Snowflakes" for 2001 and 2030 are shown on the following page in Figure 9. The calculated value of the sustainability indicators are given in Table 4. There is an improvement in the indicators for local air pollutants and households with access to electricity (although it should be noted that this indicator refers to pollutants in the residential sector only). The improvement is largely due to the assumption that the electrification of households will continue and that households electrified will want to switch from other fuels to electricity. Households here are switching away from coal and paraffin. Biomass use tends to continue after electrification due to the low cost of the fuel and this is seen in the model.

There is a move away from sustainability in terms of energy use per capita and energy intensity. This may be due to the large increase in demand for transport fuels, which is seen in two places; firstly in increased demand for coal in coal to liquid plants, where only about one third of the energy is transferred to the liquid fuels, and in the simultaneous increase in the quantities of liquid fuels required by the transport sector. There is also increased industry and commercial activity towards the end of the period, whilst population according to the ASSA projection flattens off accompanied by an increase in per capita GDP.



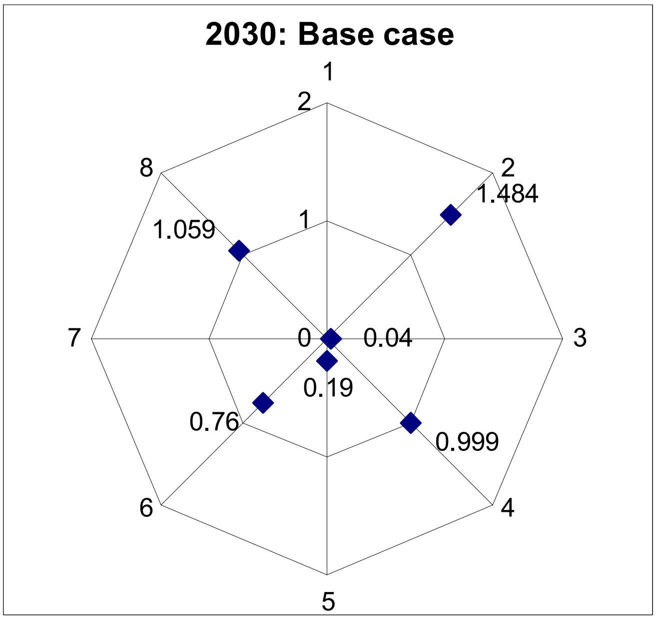


Figure 9: South African base case sustainability indicators

Table 4: Base case sustainability indicators

Indicator	Description	2000 (literature)	2001	2030
1	Global impacts: energy C/capita	2.35	2.35	8.29
2	Local impacts: local energy pollutant	0.85	2.050	1.484
3	Households with access to electricity	0.34	0.3212	0.04
4	Investment in clean energy	0.99		0.999
5	Resilience to trade impacts	0.21	0.216	0.19
6	Public investments in NRE	0.05		0.76
7	Energy intensity	2.19	5.51	3.49
8	RE as a share of total energy supply	1.05	1.070	1.059

3. Energy efficiency scenario

Energy efficiency scenarios were run for each sector and then combined into one scenario. The agricultural sector which is a small user of energy was not included. The results for the scenarios are presented for each sector and sustainability indicators are presented for the combined scenario.

3.1 Energy efficiency in the commercial sector

Energy efficiency improvements in the commercial sector are seen mainly in lighting, HVAC systems and the reduction in demand for cooling resulting from improvements in the thermal design of buildings. There is an increase in the savings in water heating in 2015 to achieve the energy efficiency target, Variable speed drives (VSD's) are introduced around this time as well. The target saving of 15% is not achieved in this scenario with the suite of efficiency measures offered, although it is possible to achieve the target soon after 2015. Figure 10 represents an 11% savings in 2015. Without the forced penetration of efficiency measures the efficiency improvements are lower. This indicates that some measures are not initially attractive, although over the time period as new investments in generation capacity are needed and the marginal price of electricity increases, this changes and all measures are adopted.

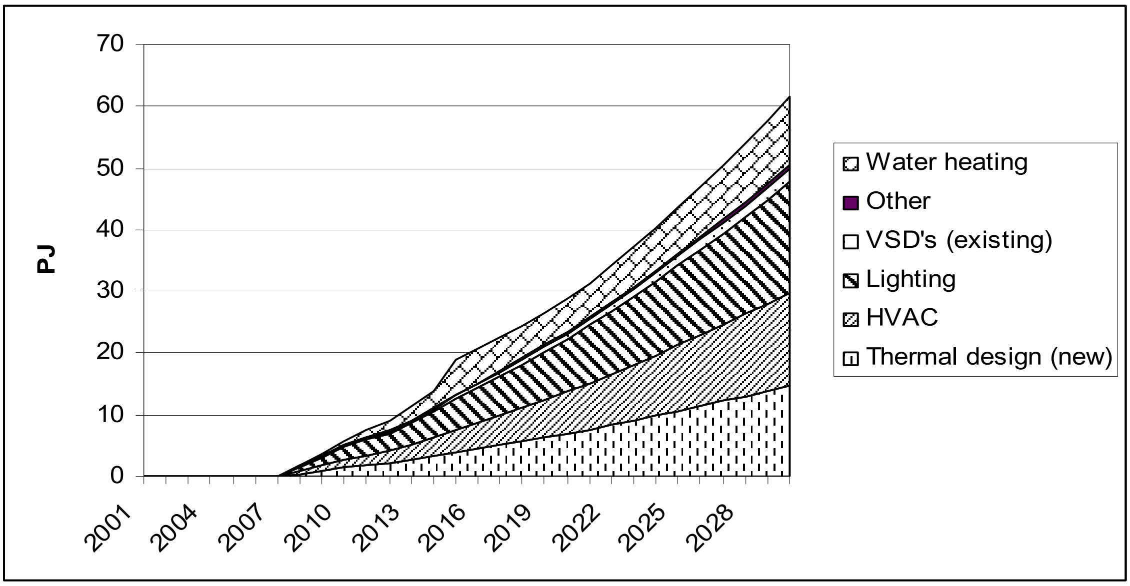


Figure 10: Savings through energy efficiency measures in the Commercial sector

The fuel savings achieved through the measures are shown in Figure 11 below.

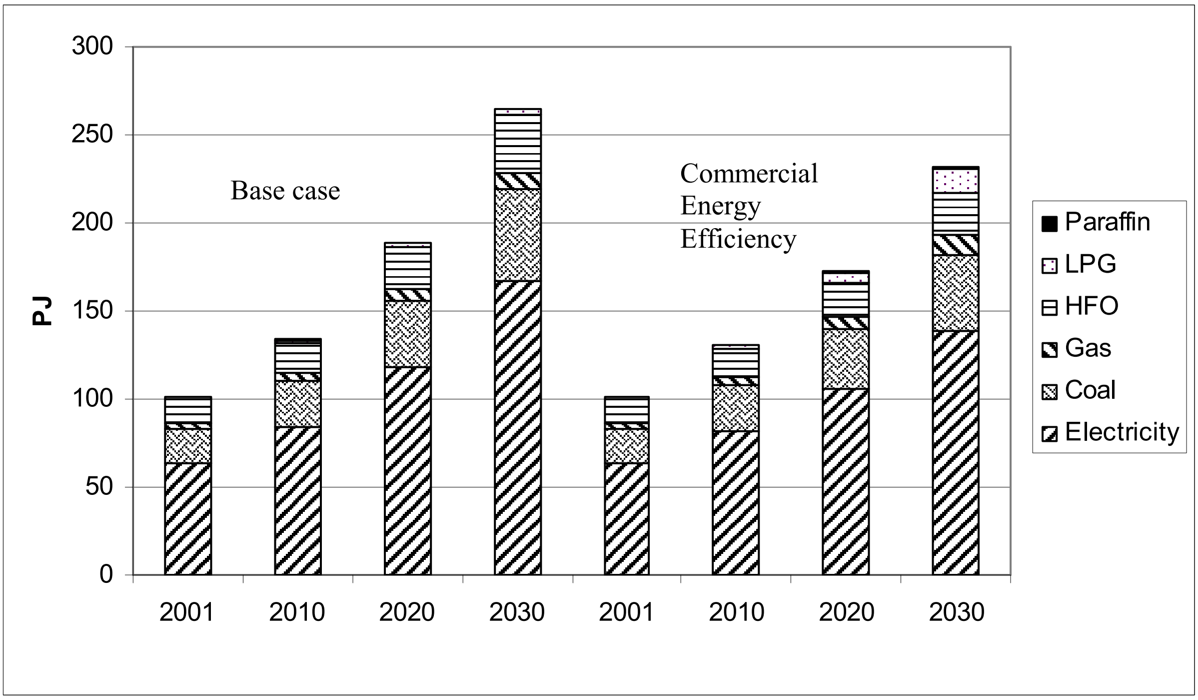
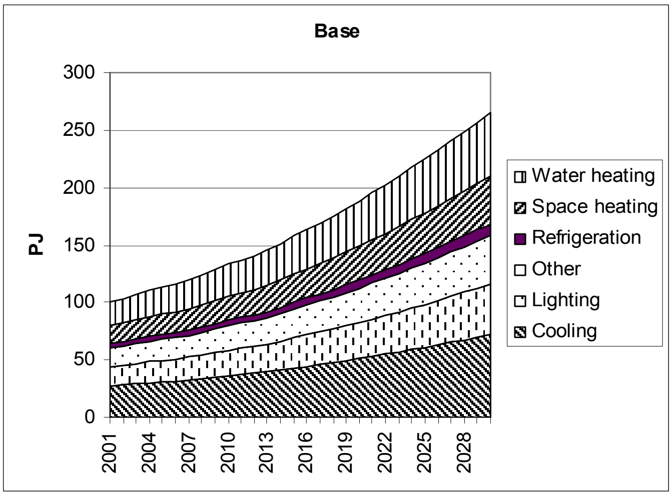


Figure 11: Savings by fuel in the Commercial sector

There are savings in all fuels except LPG and gas (methane rich and hydrogen rich gas). This is due to the relaxing of constraints in the scenario around the type of appliances and fuels that can be used to meet demand. There is also an increased use of solar water heating which is included in the savings.

The final demand in the base and commercial energy efficiency scenario for each end use is shown below in Figure 12.



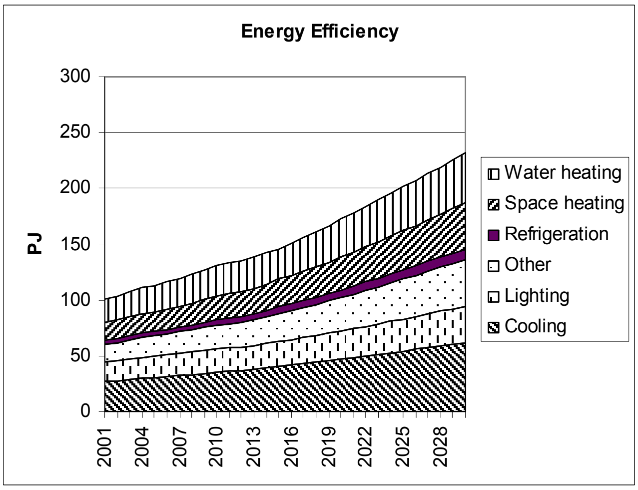


Figure 12: Final energy demand by end use in the base and energy efficiency scenarios

There is a reduction in CO_2 in 2030 of 1.5 million tons, the cumulative reduction is 19 million tons over the period. The reduction in CO_2 of the scenario versus that of the base case can be seen in Figure 13 below. These emissions represent total CO2 emissions from non-electricity energy carriers used in the commercial sector. These energy carriers include coal, paraffin, Heavy Fuel Oil, natural gas and LPG. The emissions saved by electricity savings are not represented in this graph as the emissions occur at the power station which is de-coupled from the commercial sector itself.

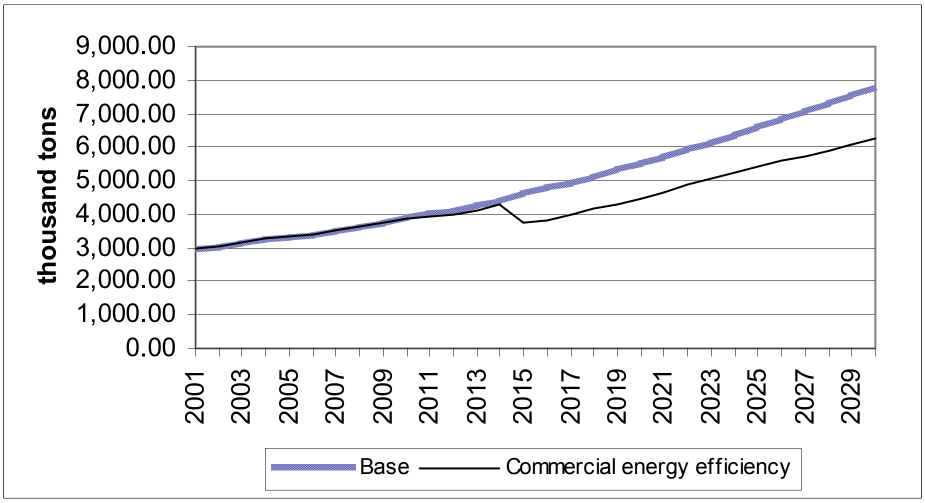


Figure 13: CO_2 emissions reduction in the commercial energy efficiency scenario

3.2 Energy efficiency in the industrial sector

Energy efficiency improvements in the Industrial sector are seen mainly in improved boiler efficiency and a reduction in the use of coal. Within electricity demand they are seen mainly in improved motor efficiency and the introduction of VSD's. Savings rise rapidly to meet the target of 15% savings in 2015, but similar to the commercial sector, the assumed penetration rates of savings over that period do not allow the target to be met. Again it is possible to meet the target a few years thereafter. A 13% savings is possible by 2015 in this scenario with the options available. It is worth noting that the savings in boiler fuel are achieved both through improvements in the steam system and use as well as improvements in boiler management.

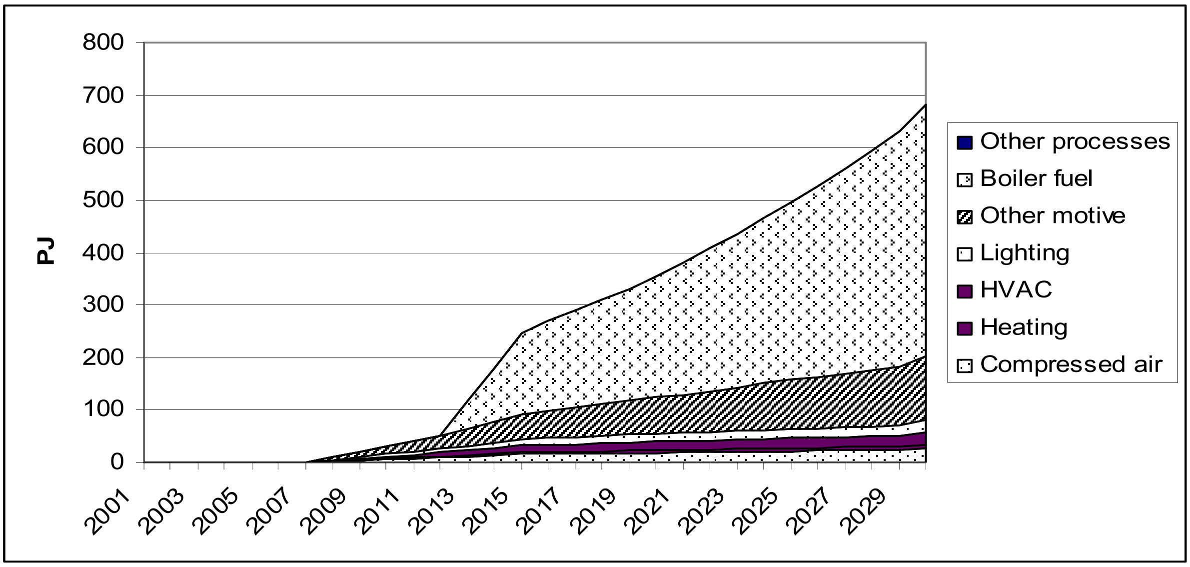


Figure 14: Savings through energy efficiency measures in the Industrial sector

The largest fuel savings in the industrial sector are seen in coal and electricity. This is not surprising as these are the fuels with the largest demand in this sector. The total savings in 2030 for the sector are 685 PJ. There is also a noticeable reduction in CO_2 emissions from this sector which can be seen in Figure 16. CO_2 reductions begin in 2008 and increase dramatically to reach the target in 2015. The sudden decrease in CO_2 levels between 2013 and 2015 is due to savings in boiler fuel. All CO2 emissions over the entire energy system are accounted for (boiler fuels as well as fuel for power stations), however reductions in emissions are due only to changes in the industrial sector.

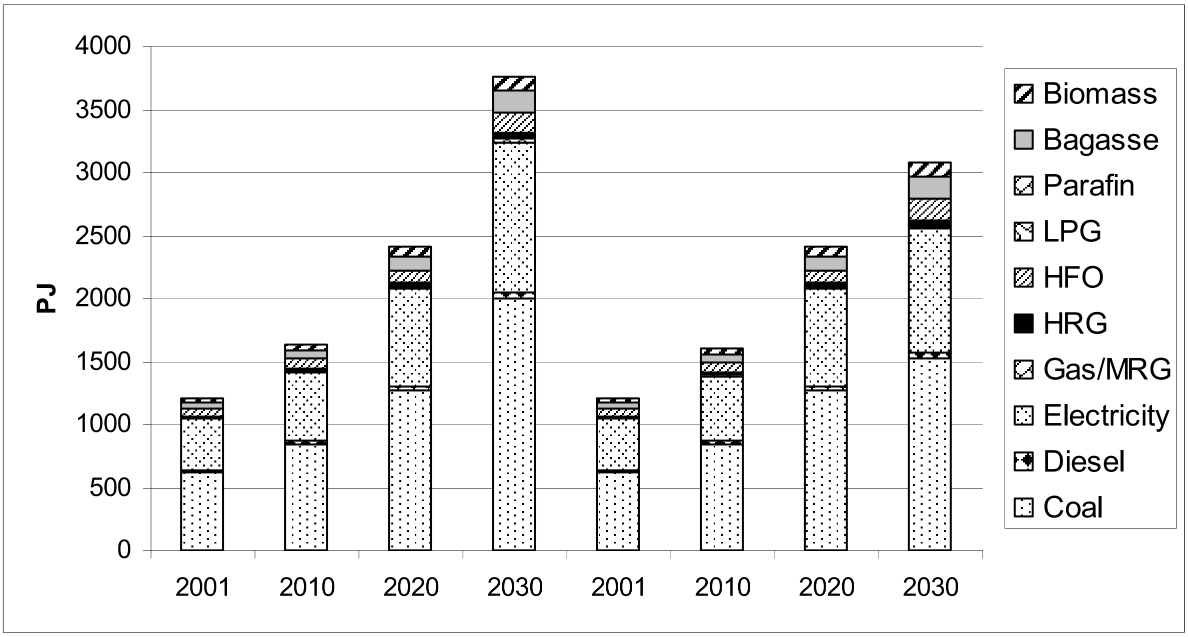


Figure 15: Savings by fuel in the Industrial sector

The emissions reduction in the industrial sector in 2030 is 45 million tonnes of CO_2, the cumulative reduction in CO_2 between 2008 and 2030 is 486 million tonnes. The CO2 emissions represented here are from all non-electricity energy carriers used in the industrial sector. These include coal, diesel, HFO, HRG, natural gas, LPG and paraffin. Emissions reductions from electricity savings are not represented in this graph since emissions occur at the power station and are not associated with the sector itself.

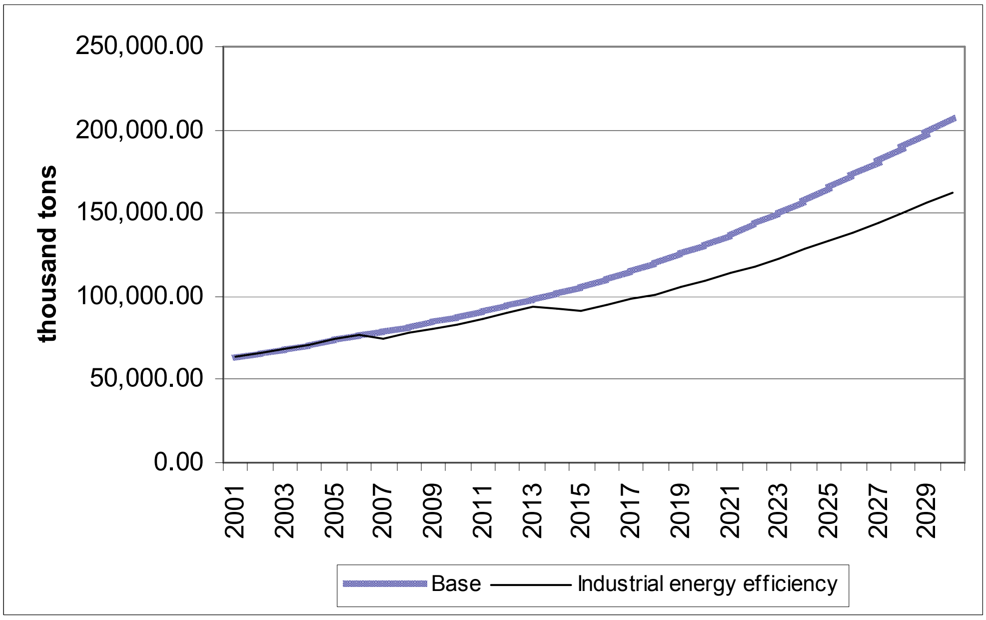


Figure 16: CO_2 emissions reduction in the industrial energy efficiency scenario

3.3 Energy efficiency in the residential sector

Energy efficiency improvements in the Residential sector are seen mainly in improvements in demand for water heating, lighting and cooking. Water heating gives the largest savings and occurs through the introduction of solar water heaters as well as the use of additional insulation on geysers. No savings are seen in space heating, as here there is a movement towards fuels that are less efficient most notably wood in higher income households, which offsets savings through additional insulation of households in the lower income groups.

The target savings in the residential energy efficiency scenario of 10% in 2015, is achieved. If the target savings had been set at a higher level towards the end of the period, savings in space heating would be introduced.

Figure 17 shows the savings achieved in water heating, lighting and cooking during the period.

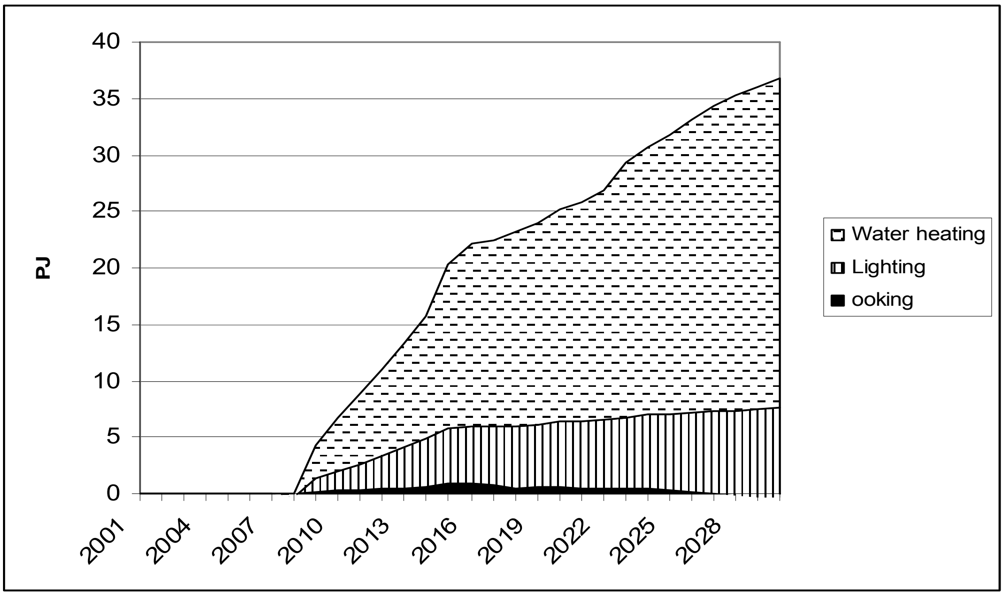


Figure 17: Savings through energy efficiency measures in the Residential sector

Although the use of gel fuel is introduced in the scenario for both lighting and cooking, it is not taken up. This is due to it being more costly than other fuels. It also does not have an efficiency advantage over other fuels. The largest savings are in electricity and biomass, even though there is a shift towards the use of biomass for space heating in higher income households. There is increased use of LPG, Solar for water heating and Paraffin over the period. The increased use of paraffin occurs largely in low income households and is seen mainly in the increased use of paraffin for water heating and space heating requirements in these households. Figure 18 shows the reduction in fuel use over the period. Solar is shown in this figure although there is no demand for fuel by solar water heaters. The energy saving in 2030 is 32PJ.

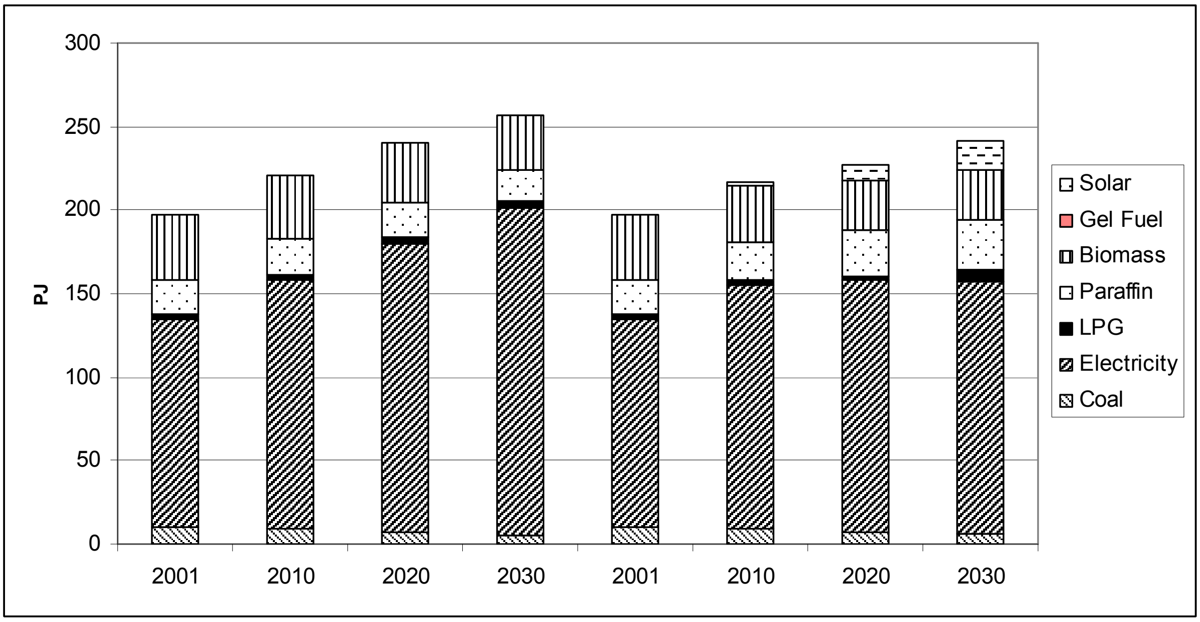


Figure 18: Savings by fuel in the residential sector

The final demand in the base case and efficiency case in the residential sector is shown below in Figure 19. Again it should be noted that other savings are possible, but to meet the target set, only the savings in water heating, lighting and cooking are needed.

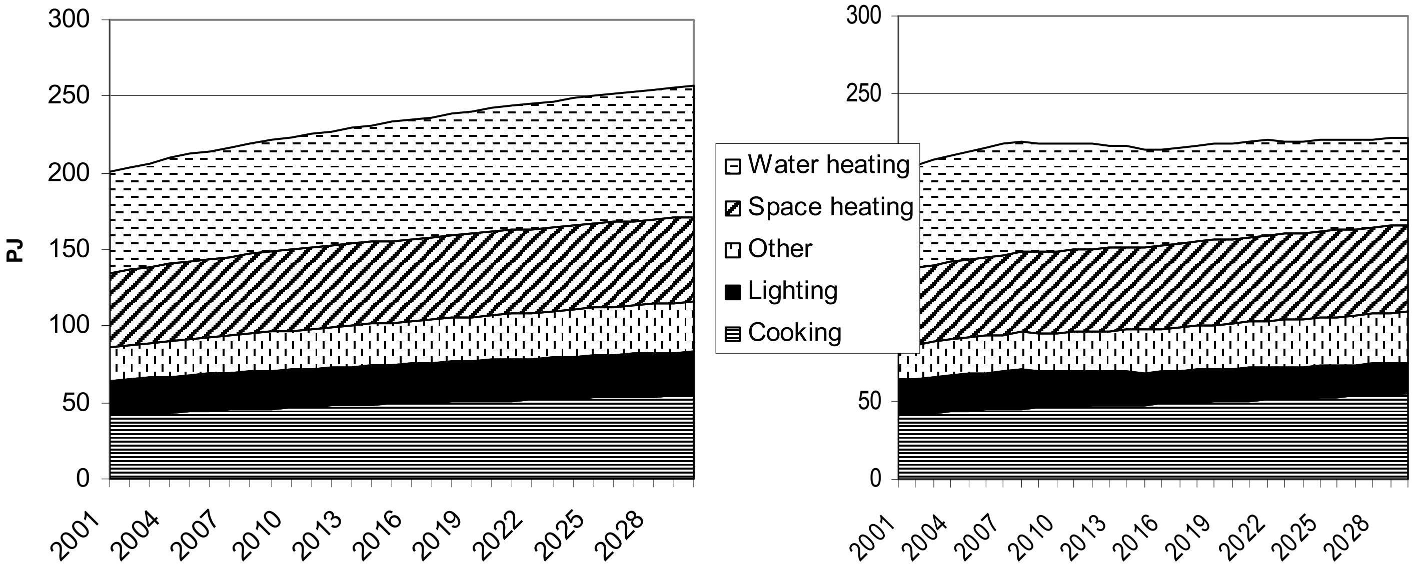


Figure 19: Final energy demand by end use in the base and energy efficiency scenarios

The savings in CO_2 emissions and indoor particulate emissions seen through measures in the residential sector are shown in Figure 20 and Figure 21. The emissions presented are all emissions from non-electricity energy carriers used in the residential sector. There is a reduction in CO_2 emissions initially and then an increase towards the end of the period. While this may seem counter-intuitive, it is important to remember that the model is a least-optimizing model and in this case, more fuels such as paraffin are used later in the period, thus causing greater CO2 emissions. This may be an important point to note for future domestic fuel policies: Pricing and availability of domestic fuels is important in CO2 emissions reduction. It is also important to note that these reductions of CO2 do not represent emissions reduction due to electricity savings.

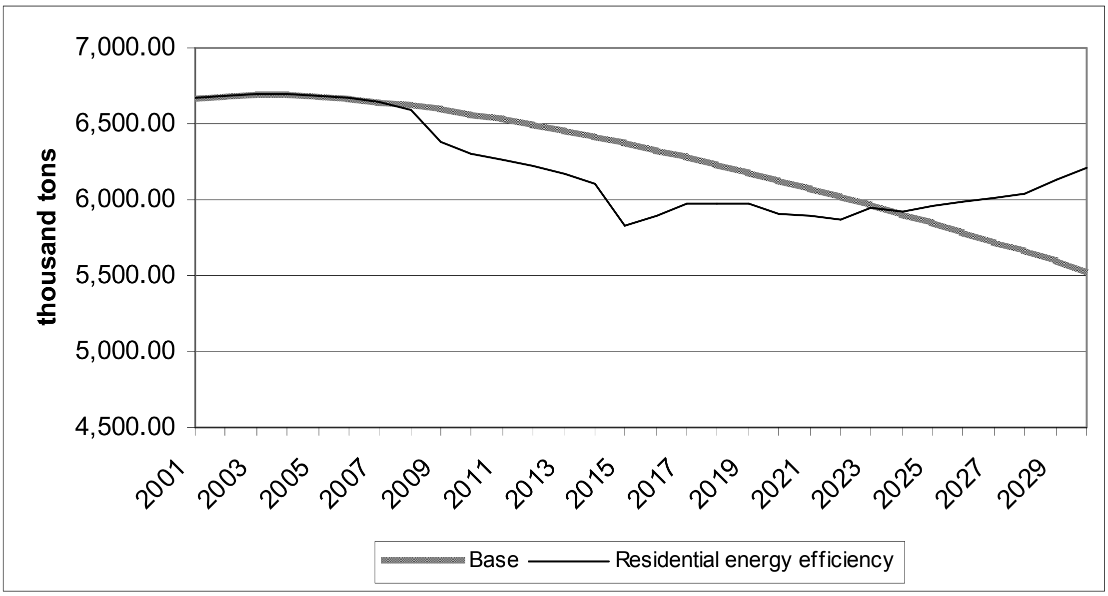


Figure 20: CO_2 emissions reduction in the residential energy efficiency scenario

There is a dramatic reduction in TSPS emissions in both the base case and the energy efficiency case. This is largely due to the assumption that the current electrification programme will continue. Even though the base case emissions reduce over the period, there is still benefit to be gained from adopting further energy efficiency policies in the residential sector.

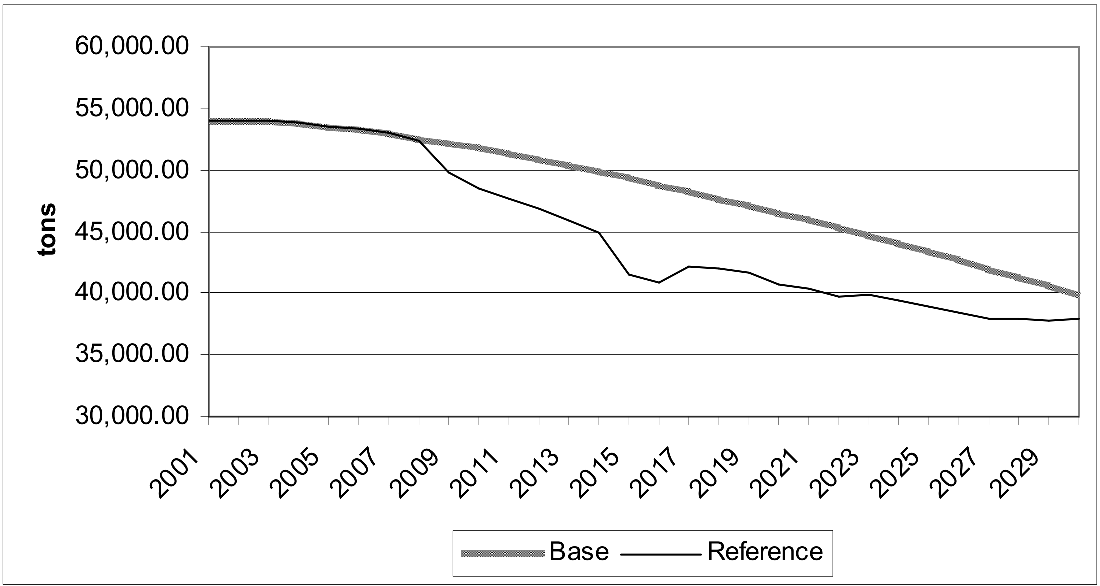


Figure 21:TSPS emissions in the residential sector

3.4 Energy efficiency in the Transport sector

The transport sector is a difficult sector to analyse as there are many factors at play within the scenario. There is a shift towards alternative fuels, a modal shift towards public transport both rail, bus and taxi, the use of more efficient cars such as hybrid vehicles, and the assumption that the number of passengers per vehicle-km will increase from 2.1 to 2.2.

The sudden decrease in demand in 2008 seen in Figure 22 is largely due to the assumption that the passenger occupancy per car will increase. The total savings in 2030 is 322.08PJ, i.e. the graph represents the sum of savings and not the savings of each individual technology or, said more simply, diesel busses do not save 264PJ in 2030 on their own, the saving comes from the combined savings of Taxis, lower SUV penetration, and the reduced demand for diesel buses. This is offset by the increased demand for Hybrid vehicles, diesel cars and passenger rail which have increased fuel use over the period and therefore savings are negative.

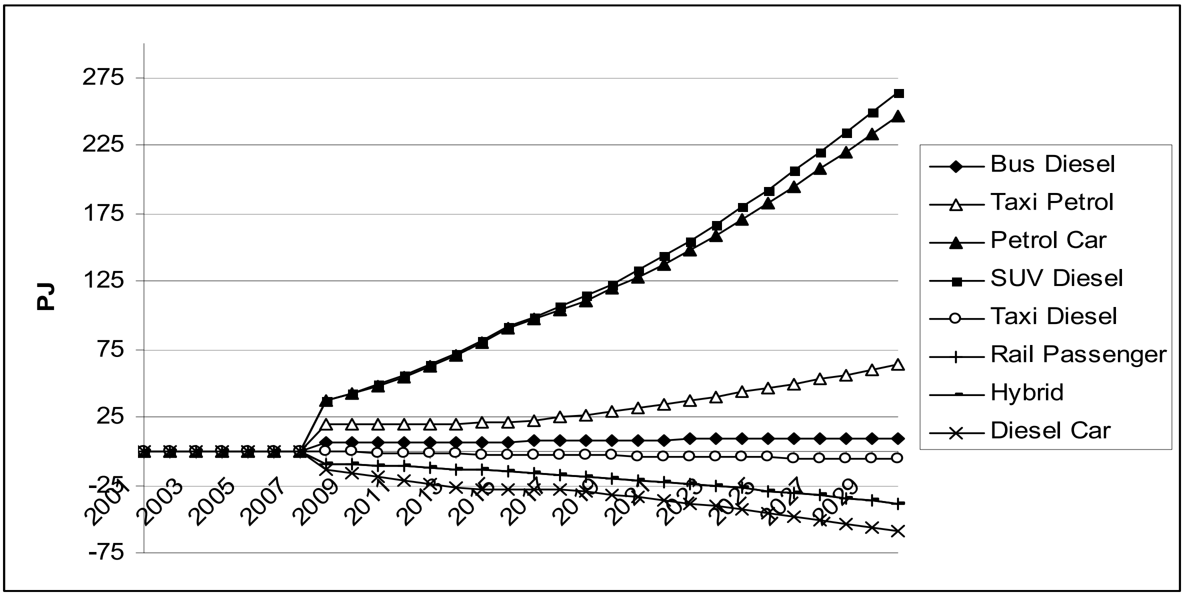


Figure 22: Sum of savings in the transport energy efficiency scenario

In freight the demand for heavy commercial vehicles which use diesel increases, but there is a reduction in energy use by the light commercial vehicles and in rail. This is anticipated as there are no measures in place which improve the efficiency of heavy commercial vehicles.

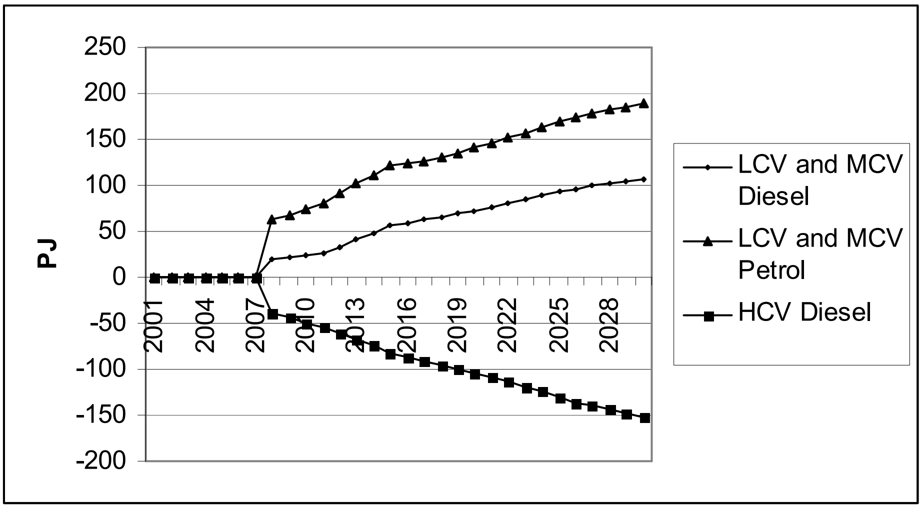


Figure 23: Sum of savings in the transport energy efficiency scenario

The change in demand by fuel can be seen below in Figure 24. Overall there is a large decrease in demand over the period, although it appears small it is a large saving in fuel use when you consider that it is almost half of our current fuel requirement. The saving in 2030 is 240PJ.

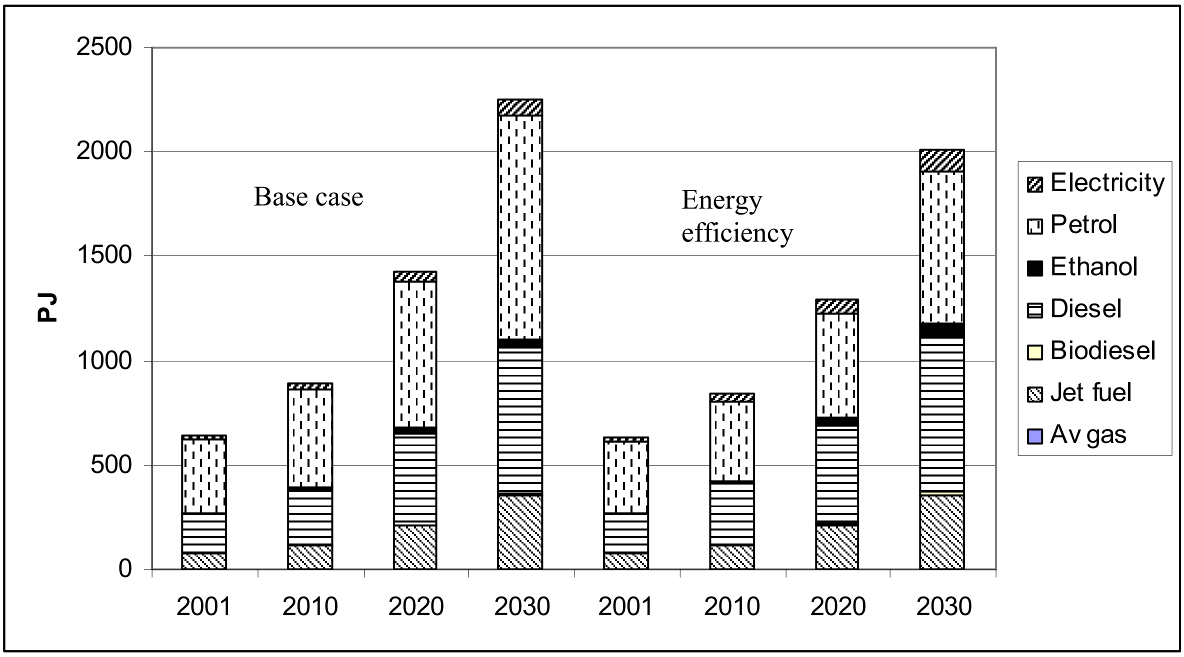


Figure 24: Sum of savings in the transport energy efficiency scenario

The reduction in CO_2 levels emitted by the transport sector are shown in Figure 25 on the following page. The emission reduction in 2030 is 20.6 million tonnes. Between 2013 and 2030, the cumulative reduction in CO_2 is 234 million tonnes.

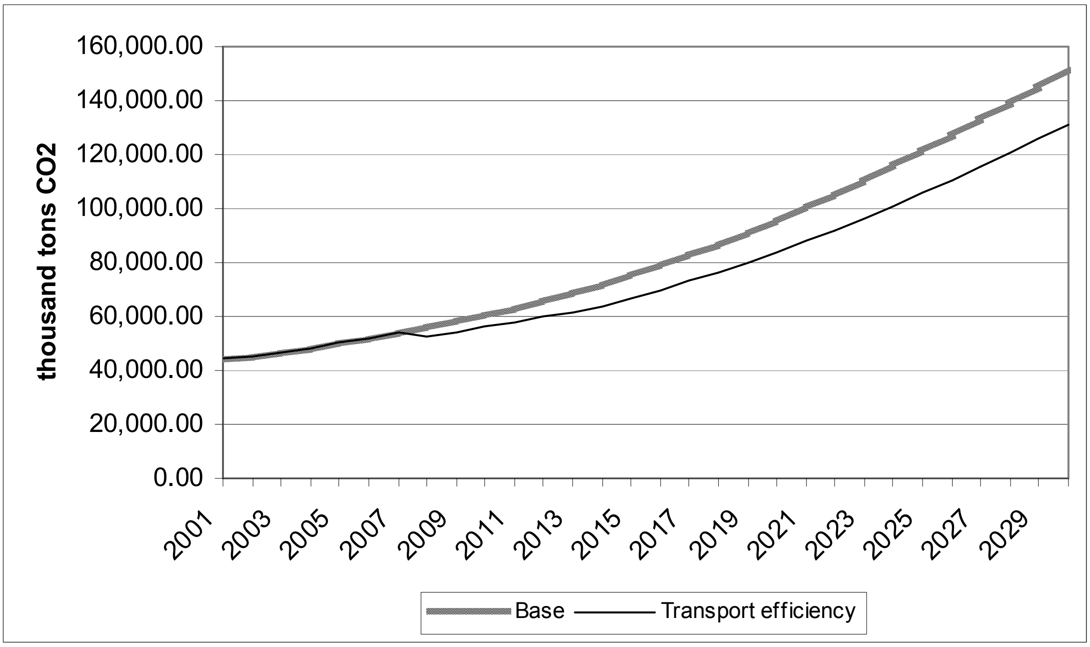


Figure 25: Emissions reduction in the transport energy efficiency scenario

3.5 Combined energy efficiency scenario

It was decided to combine the transport, industry, commercial and residential energy efficiency scenarios sectors into a single case study and examine the effect on the overall primary energy supply and sustainability indicators. These results are presented in this section. The combined savings are shown below in Figure 26. The effect that these savings have on green house gas emissions and the sustainability indicators can be seen in Figure 27 and Table 6.

The largest savings are in the industrial sector, which has a savings target of 15% in 2030, transport shows the second largest savings. Again it should be noted that industrial savings are optimised by the model whereas the energy savings in the transport sector are simulated or forced in and are therefore not necessarily least cost options.

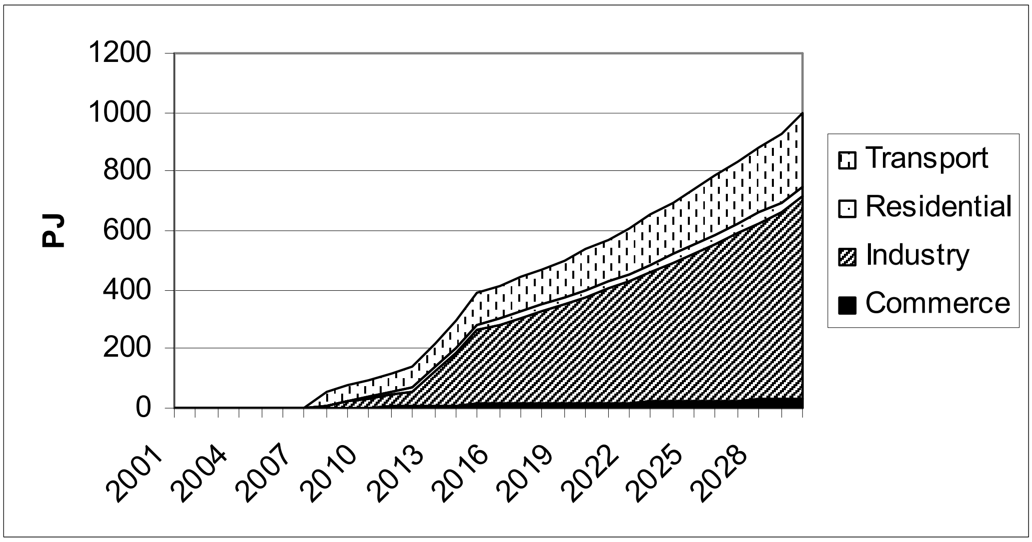


Figure 26: Combined energy efficiency savings over the period

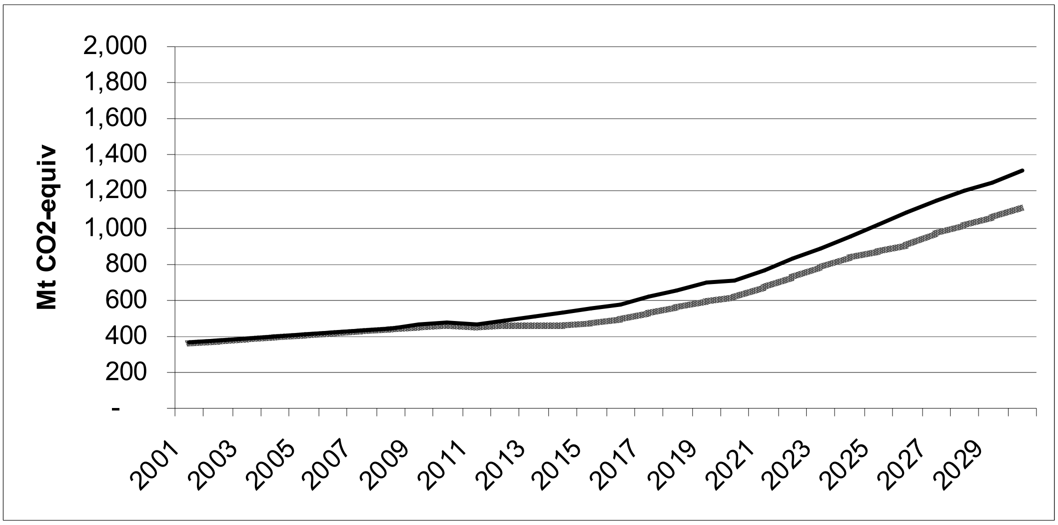


Figure 27: Greenhouse Gas emissions in the Base and summed Energy Efficiency Scenario

The generation capacity required in this study is shown in Figure 28. There is a clear delay in investment in new capacity when energy efficiency is introduced. In the base case additional coal capacity is commissioned in 2016, in the energy efficiency scenario, additional coal capacity is commissioned in 2021.

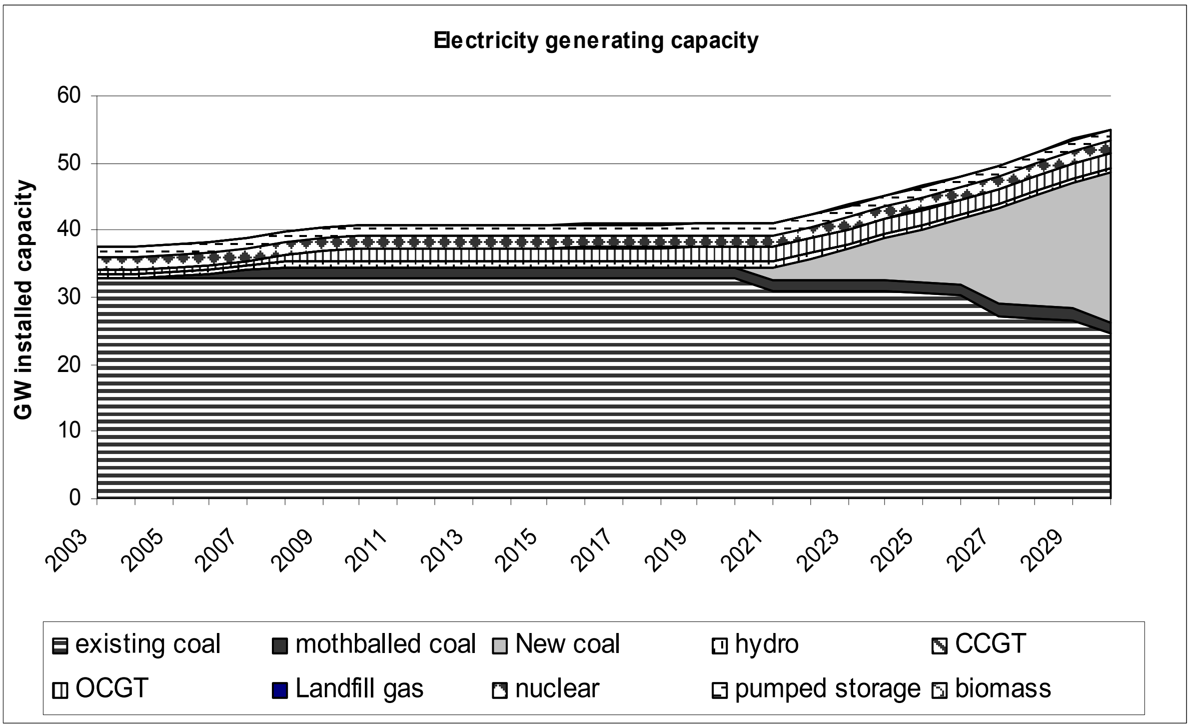


Figure 28: Electricity generation capacity by plant type in the combined energy efficiency scenario

Table 5: Renewable and Non-renewable fractions of Electricity and Total Energy supply in the energy efficiency scenario

	2003	2005	2010	2015	2020	2025	2030
Existing coal stations	32.8	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.22	1.73	1.73	1.73	1.73	1.73
New coal stations	0	0	0	0	0	7.79	22.22
Super Critical coal	0	0	0	0	0	0	0
FBC	0	0	0	0	0	0	0
CCGT	0	0	0	0	0.02	0.02	0.02
OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	0	0
Pumped storage	1.58	1.58	1.58	1.58	1.8	1.66	1.66
Landfill gas	0	0	0	0	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0	0
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	37.8	40.9	40.9	41	47	55

In liquid fuels, a reduction in the amount of imported fuels is seen in the energy efficiency scenario. The additional refining output needed to meet demand in this scenario is shown in Figure 29 below. Refining output in the scenario is higher than that of the base case. In this scenario large quantities of petrol are exported due to the increasing demand for diesel. An alternative would be to import additional diesel. In the model diesel imports were capped at 15% of diesel demand. New crude oil refineries have a petrol to diesel ratio of 32:34 versus existing crude oil refineries which have a petrol diesel ratio of 24:36, and coal to liquid plants which have a petrol diesel ratio of 57:20.

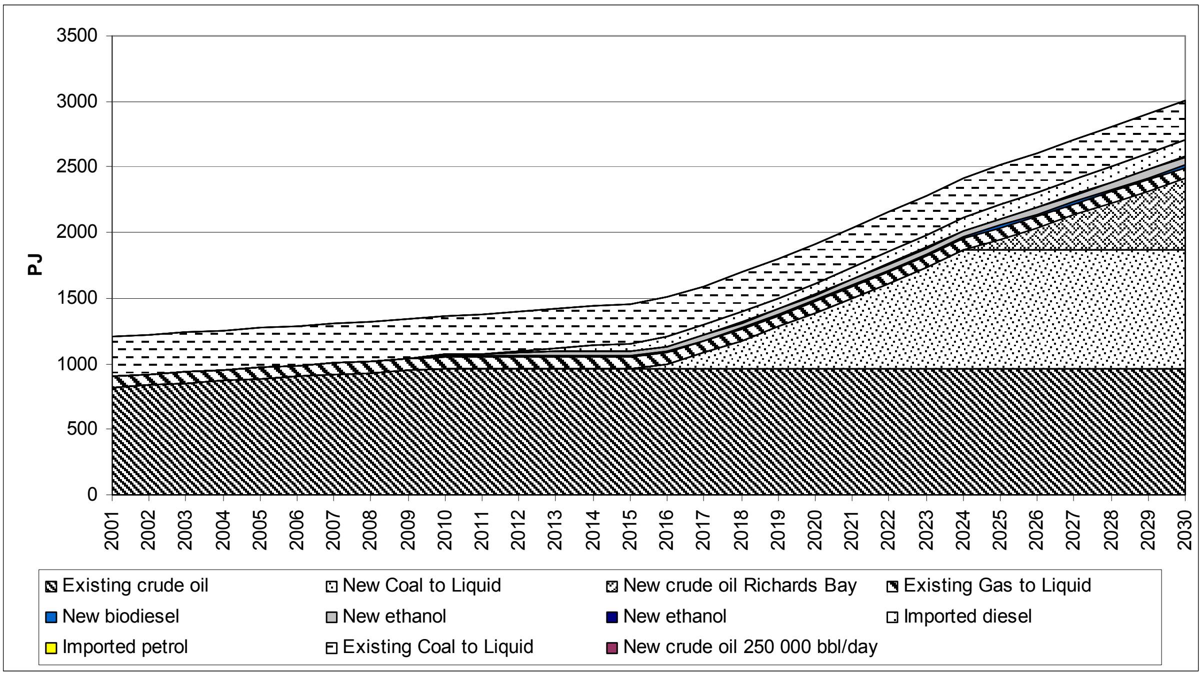


Figure 29: Refinery output by plant type in the energy efficiency scenario.

Energy efficiency provides a means of moving towards sustainability objectives, although it would seem that the energy efficiency measures examined in this study cannot on their own provide all that is needed to reduce the energy intensity of the economy. It also does not significantly contribute towards a move towards renewable energy or provide sufficient reduction in local energy pollutants. This indicator is a measure of the most significant local air pollutant (Total Suspended Particulate Solids in this case) from domestic energy use.

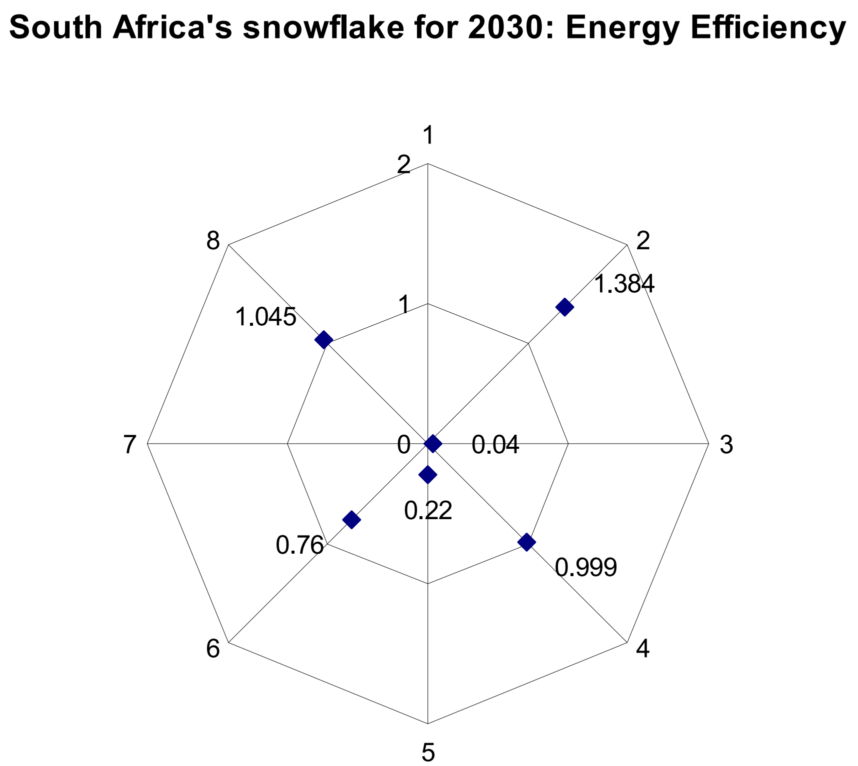
In the residential sector, using least cost optimisation, there is a move towards some of the less efficient and dirtier fuels to supply space heating. This is something that requires further investigation, as it may be that policies are required to address this as energy efficiency alone does not achieve the required reduction in pollutant levels.

The “snowflake” representation of the sustainability indicators for the energy efficiency case is presented in Figure 30.

Table 6: Comparison of sustainability indicators in the base and energy efficiency scenario

	2001	2030	
Description	Base Case	Base Case	Reference Case
Global impacts: energy C/capita	2.34	8.29	6.94
Local impacts: local energy pollutant	2.05	1.48	1.38
Households with access to electricity	0.32	0.04	0.04
Investment in clean energy		1.00	1.00
Resilience to trade impacts	0.22	0.19	0.22
Public investments in NRE		0.76	0.76
Energy intensity	5.50	3.49	3.12
RE as a share of total energy supply	1.07	1.06	1.05

Figure 30: Snowflake representation of the energy efficiency sustainability indicators



3.6 Technology Learning

The reduction of investment costs of power stations due to technology learning plays an important role in the types of electricity generating capacity chosen by the model. As a sensitivity analysis on our base case assumptions, a scenario without technology learning was run to determine the impact that this assumption has on the outcome of the model. Figure 31 shows the results of this run.

There noticeable difference between this scenario and the base case is the solar power tower technology introduced towards the end of the period. Previous studies have seen an introduction in wind, with the rates of technology learning used here wind is only introduced in 2033, with parabolic trough coming in around 2037. What is noticeable is that around 2030 the renewable options become cheaper than the clean coal options and are included in the generation mix.

Due to the small increase in the use of renewables there is no marked difference in the level of greenhouse gas emissions in this scenario. And very minor changes to the sustainability indicators.

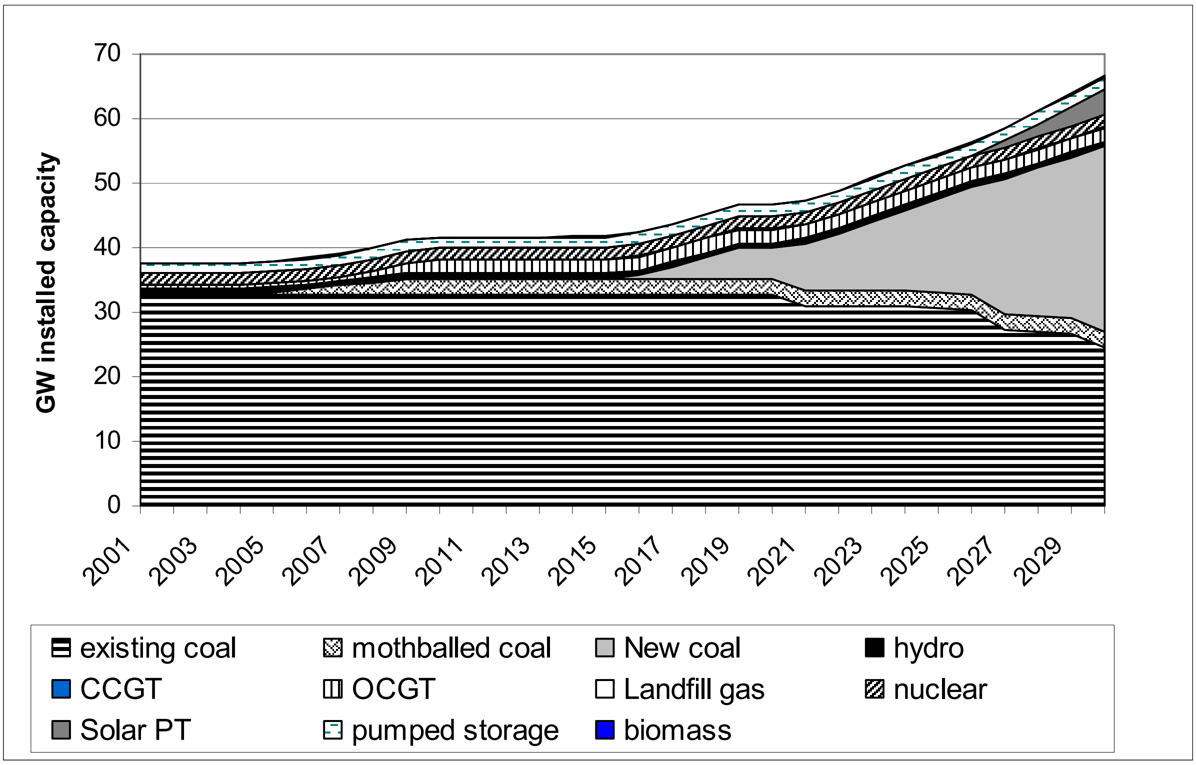


Figure 31: Electricity generating capacity by plant type with technology learning

Although it looks as if the investment towards the end of the period in the solar technology is large, 4GW, it translates to a much smaller reduction in the amount of new pulverised fuel capacity built. This is due to the lower availability factors of the solar technologies. Care was taken in this study to match availability of renewable technologies to their cost, although there are few studies with conclusive reporting in this area and fewer in areas with solar radiation levels as high as those in South Africa. This is an area where further research would benefit South Africa.

Table 7: Electricity generating capacity by generation type (GW)

	2001	2005	2010	2015	2020	2025	2030
Existing coal stations	32.8	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.38	2.49	2.49	2.49	2.49	2.49
New coal stations	0	0	0	0	4.65	14.55	28.61
Super Critical coal	0	0	0	0	0	0	0
FBC	0	0	0	0	0	0	0
CCGT	0	0	0	0	0.01	0.02	0.02

OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	0	0
Pumped storage	1.58	1.58	1.58	1.58	1.84	1.94	1.94
Landfill gas	0	0	0	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0	4
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	38.0	41.6	41.7	47	54	67

3.7 Tax on CO_2

Results are presented here for cases in which a R100/ton and R150/ton CO_2 tax is placed on emissions from power stations. The tax is not applied to emissions from other sectors. It should be noted that emissions from refineries and coal to liquid plants (excluding emissions from the transformation process, i.e. the emissions released in gasification) are represented within industry and are thus not taxed in this scenario.

When the CO_2 tax is applied at R100/ton to emissions from power stations new FBC, CCGT (with natural gas as fuel), nuclear and towards the end of the period, supercritical coal are introduced. These are brought in before the pulverised fuel coal fired stations that come in immediately in the base case. Noticeable here is that the PBMR is introduced before additional PWR capacity. Again bounds on technology choices result in the uptake of capacity of one type until the bound is reached before alternative capacity is introduced.

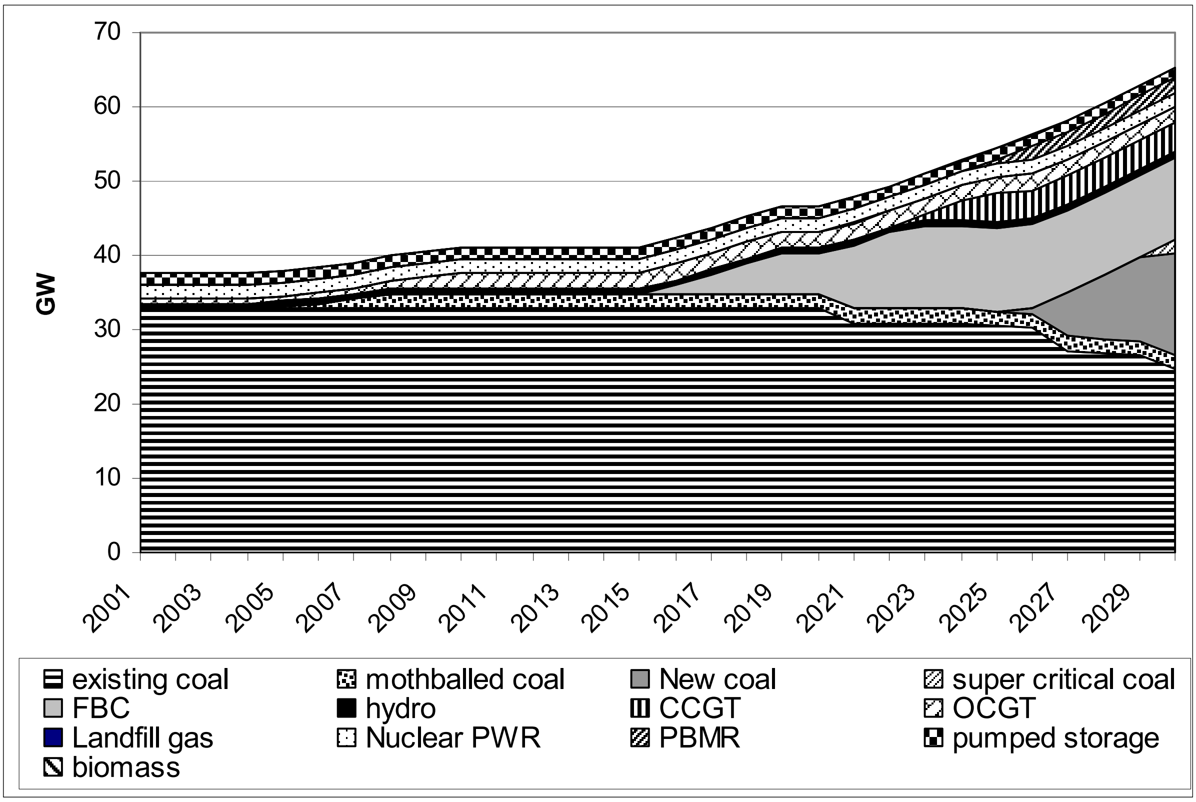


Figure 32: Energy generating capacity by plant type: CO_2tax of R100/ton CO_2

When the R150/ton tax is applied, new nuclear, FBC and CCGT plants are brought in as alternatives to new pulverised coal plants seen in the base case. Towards the end of the period, the first PBMR units are commissioned. A tax at this level is still not does not appear to encourage the introduction of renewable technologies. Results from this case study are shown in Figure 33 on the following page.

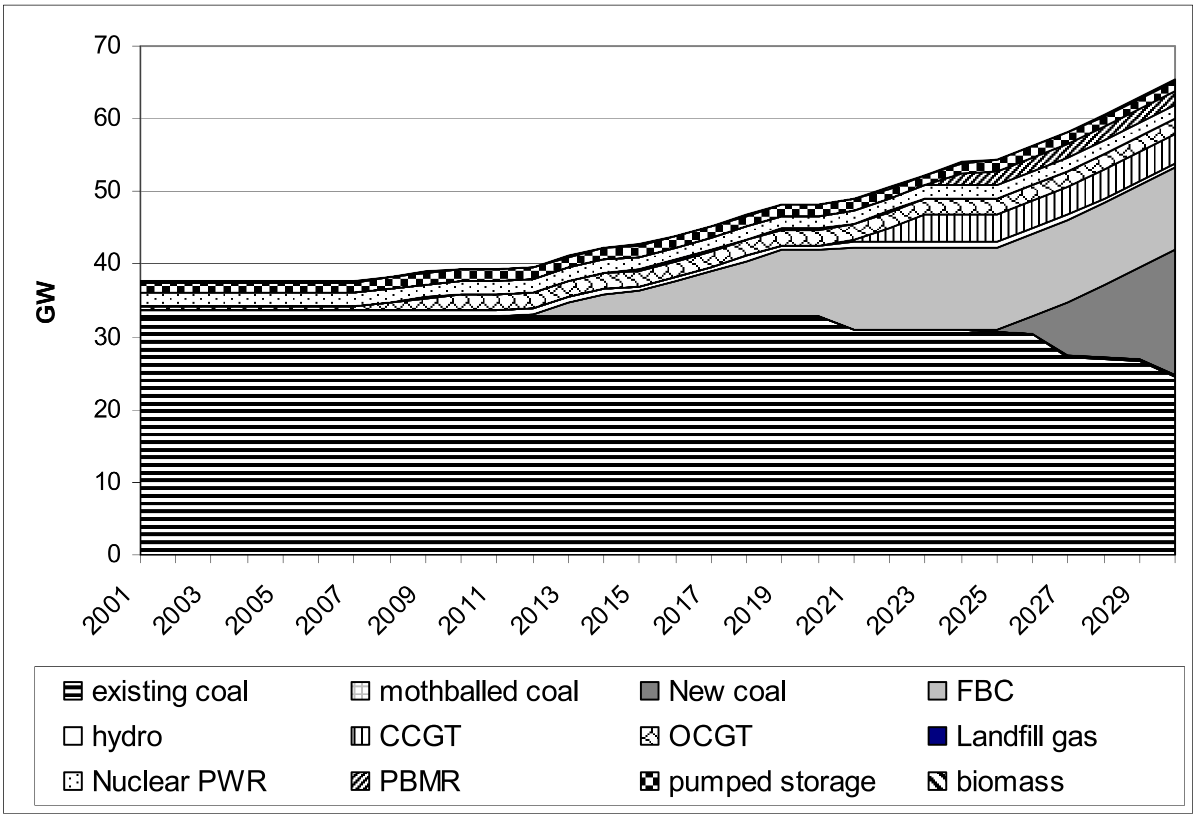


Figure 33: Energy generating capacity by plant type: CO_2tax of R150/ton CO_2

A comparison of two tax levels is included in Table 8. The share of generating capacity of each type does not change much between the scenarios before 2030. One noticeable difference is that when the R150 tax is applied mothballed coal stations are not brought back to the full extent of the available capacity.

Table 8: Comparison of generation technology capacity at R100 and R150/ton CO_2

Electricity generating capacity by generation type (GW) at a R100/ton CO_2 tax							
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Existing coal stations	32.8	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.38	1.89	1.89	1.89	1.89	1.89
New coal stations	0	0	0	0	0	0	13.85
Super Critical coal	0	0	0	0	0	0	1.72
FBC	0	0	0	0.02	5.58	11.18	11.18
CCGT	0	0	0	0	0.01	3.89	3.89
OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	0.64	1.98
Pumped storage	1.58	1.58	1.58	1.58	1.58	1.4	1.4
Landfill gas	0	0	0.07	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0	0
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	38.0	41.1	41.1	47	54	65
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Share of coal	87%	87%	84%	84%	86%	80%	81%
Share of nuclear	5%	5%	4%	4%	4%	4%	6%

Share of gas	2%	2%	5%	5%	5%	11%	9%
Electricity generating capacity by generation type (GW) at a R150/ton CO_2 tax							
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Existing coal stations	32.79	32.79	32.79	32.79	32.79	30.61	24.62
Mothballed coal	0	0	0.17	0.17	0.17	0.17	0.17
New coal stations	0	0	0	0	0	0.31	17.25
Super Critical coal	0	0	0	0	0	0	0
FBC	0	0	0	3.32	8.92	11.18	11.18
CCGT	0	0	0	0	0.01	3.89	3.89
OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	1.98	1.98
Pumped storage	1.58	1.58	1.58	1.58	1.58	1.4	1.4
Landfill gas	0	0	0.07	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0	0
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.62	37.62	39.38	42.7	48.31	54.38	65.33
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Share of coal	87%	87%	84%	85%	87%	78%	81%
Share of nuclear	5%	5%	5%	4%	4%	7%	6%
Share of gas	2%	2%	5%	5%	4%	11%	9%

The reduction in CO_2 is seen in Figure 34 for the entire system and Figure 35 for the power sector only. The tax results in a maximum CO_2 saving of 13 percent when the R150 tax is applied in 2008. Towards the end of the period the reduction in CO_2 levels is very similar and 82 percent of base case CO_2 emissions.

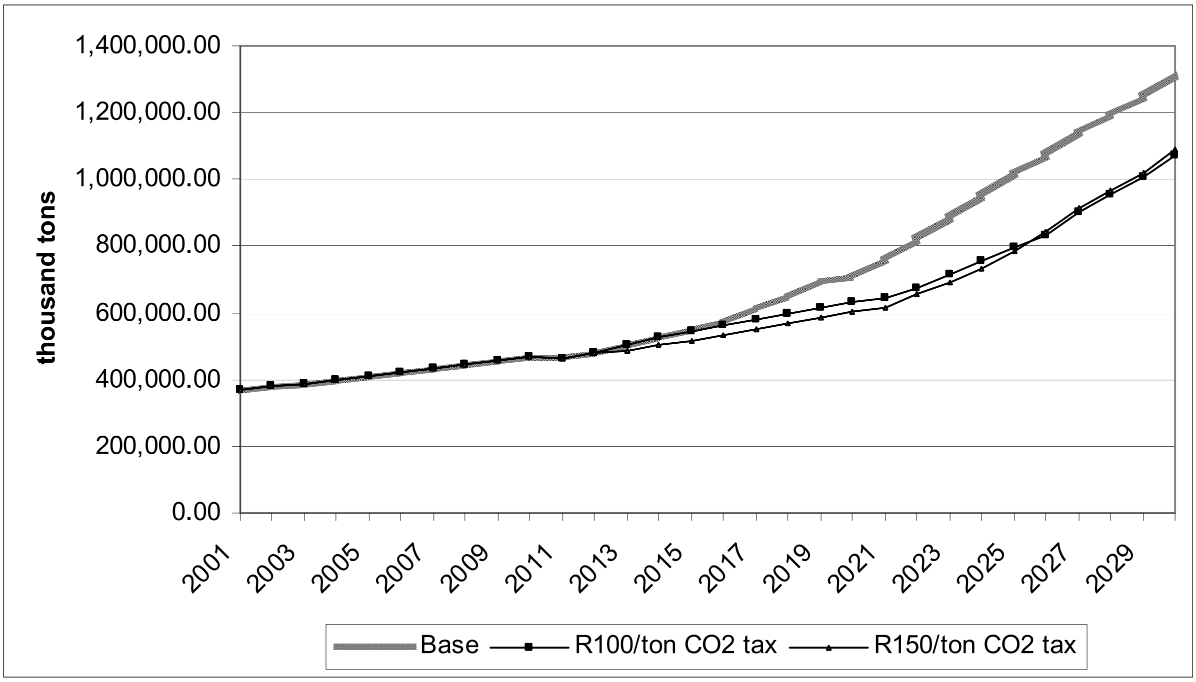


Figure 34: Reduction in CO_2 levels with CO_2 tax

Figure 35 shows the CO2 emissions reduction in the power sector. The dips in emissions in 2012 and 2020 are most likely due to an initial investment in a cleaner technology that has lower emissions.

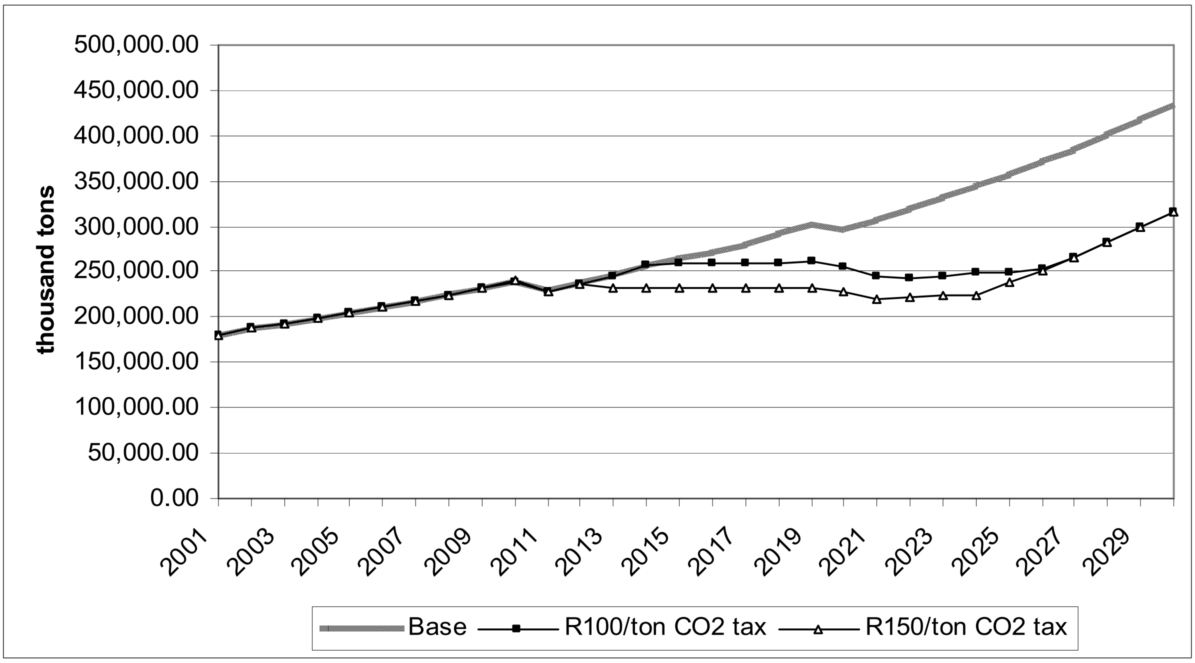


Figure 35: Reduction in power sector CO_2 emissions

3.8 Forced penetration of renewable electricity generating technologies

In this scenario, renewables must provide 10 000GWh (36PJ) of electricity by 2014, this is increased to 15% of electricity (247PJ) in 2030. This scenario sees the introduction of solar power towers, hydro, landfill gas, wind and additional biomass by 2030. The extent to which each is introduced can be seen in Figure 36. Again, the power tower comes through strongly and is the main source of additional renewable generating capacity. Each of these technologies has an upper limit of capacity that can be built over the period, and an upper limit, per plant type is also applied to the amount of capacity that can be built per year.

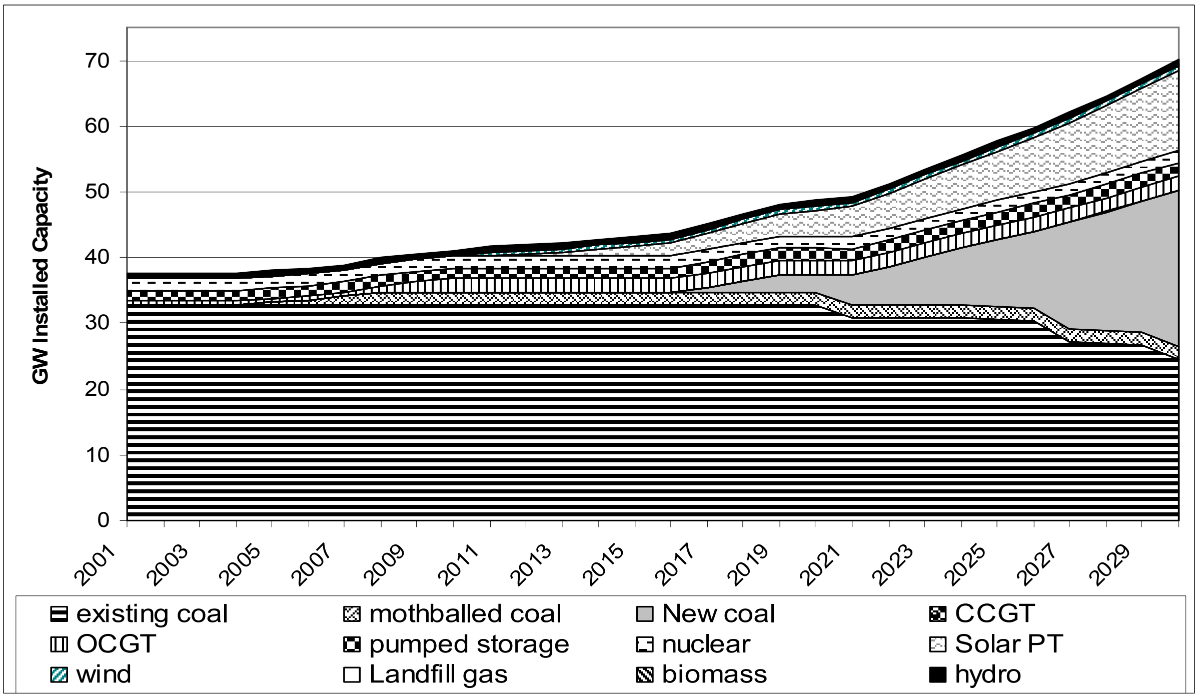


Figure 36: Electricity generating capacity by plant type: forced renewables

The model makes use of most of the renewable technologies available due to the bounds set on each technology. For instance, if bounds on the solar power tower were raised, we may see more solar and less wind in the mix. The addition of renewable technologies to meet the target does not delay the building of the first coal fired power station. Although it does significantly reduce the amount of new coal capacity introduced by 2030.

When renewables such as wind are introduced into the generation mix it is anticipated that additional peaking plant will be needed as renewables are traditionally a non-dispatchable technology, ie you can not run them when you need them and therefore they can not be relied on to meet peak demand and additional "backup" capacity that can be dispatched to meet peak demand must be installed. In this case, large amounts of Solar are built, which has the ability to store energy to meet peak demand and thus the additional OCGT or capacity is not needed.

Table 9: Electricity generating capacity by generation type (GW): Renewable energy scenario

Electricity generating capacity by generation type (GW)							
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Existing coal stations	32.8	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.38	1.89	1.89	1.89	1.89	1.89
New coal stations	0	0	0	0	2.7	10.18	23.78
Super Critical coal	0	0	0	0	0	0	0
FBC	0	0	0	0	0	0	0
CCGT	0	0	0	0	0.01	0.02	0.02
OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	0	0
Pumped storage	1.58	1.58	1.58	1.58	1.84	2.01	2.01
Landfill gas	0	0	0.07	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	1.5	4.01	7.5	12.17
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0.61	0.61	0.61	0.72
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	38.0	41.1	43.2	49	58	70
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Share of coal	87%	87%	84%	80%	77%	74%	72%
Share of coal + nuclear	92%	92%	89%	84%	80%	77%	74%
Share of gas	2%	2%	5%	5%	4%	4%	3%
Share of renewables	2%	2%	2%	7%	11%	16%	20%

The avoided CO_2 in the base and renewables scenario for the period are shown in Figure 37 on the following page. Whilst the target at the beginning of the period differs from that of nuclear technologies as the options available can be commissioned sooner, at the end of the period the percentage of electricity to be supplied by renewables is the same: 15% of total electricity demand. The dips in emissions in about 2012 and 2020 are most likely due to rapid initial investments in cleaner technologies with lower emissions.

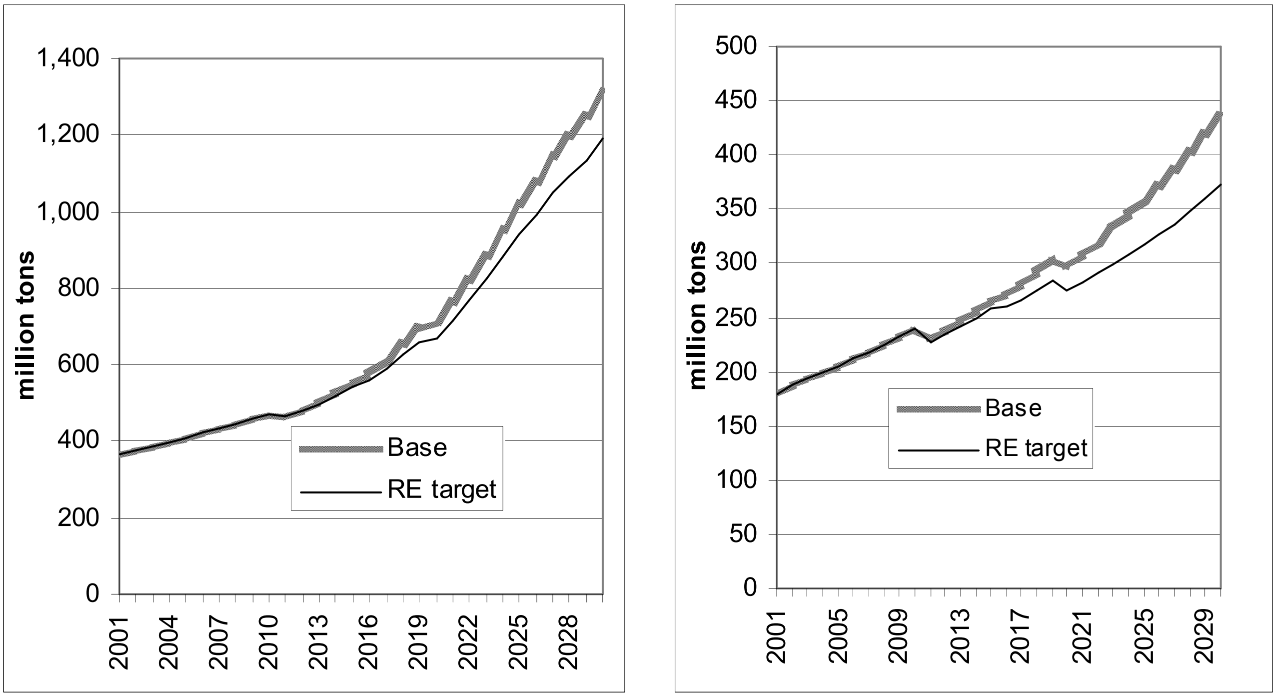
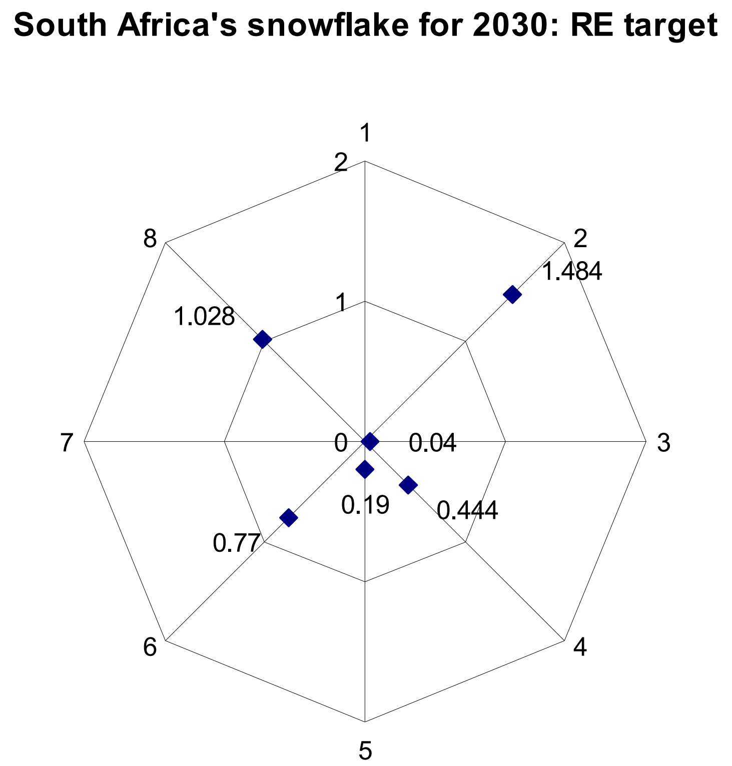


Figure 37: CO_2 emissions in the Base and Renewable energy scenarios

Sustainability indicators for this scenario are shown in Table 10. Indicators 1, 4, 5 and 8 change in this scenario. All indicators show an improvement over the indicators in the base case.

Table 10: Sustainability indicators for the renewable energy scenario

Indicator	Description	2001 value	2030 Value
1	Global impacts: energy C/capita	2.35	7.50
2	Local impacts: local energy pollutant	2.050	1.484
3	Households with access to electricity	0.3212	0.04
4	Investment in clean energy		0.444
5	Resilience to trade impacts	0.216	0.19
6	Public investments in NRE		0.77
7	Energy intensity	5.51	3.33
8	RE as a share of total energy supply	1.070	1.028



3.9 Forced penetration of nuclear electricity generating technologies

In this scenario, either the Pebble Bed Modular Reactor, or new PWR nuclear plants must provide 15% of electricity by 2030. No new nuclear capacity can be commissioned before 2015. In this scenario the PBMR is introduced first, and when that reaches the upper limit of capacity allowed for PBMR plants, the PWR is introduced.

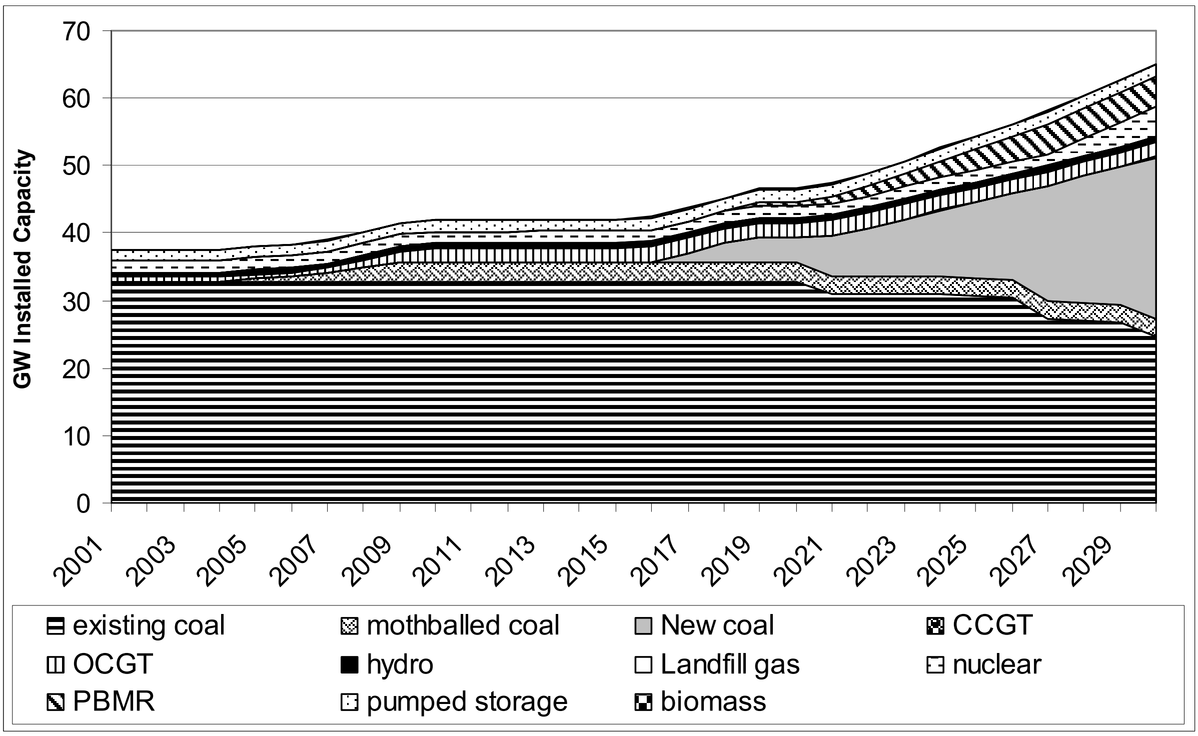


Figure 38: Electricity generating capacity by generation type (GW): Nuclear scenario

Table 11: Electricity generating capacity by generation type (GW): Nuclear scenario

Electricity generating capacity by generation type (GW)							
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Existing coal stations	32.8	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.38	2.76	2.76	2.76	2.76	2.76
New coal stations	0	0	0	0	3.8	11.2	23.87
Super Critical coal	0	0	0	0	0	0	0
FBC	0	0	0	0	0	0	0
CCGT	0	0	0	0	0.01	0.02	0.02
OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	4.49
Nuclear (PBMR)	0	0	0	0	0.56	3.13	4.44
Pumped storage	1.58	1.58	1.58	1.58	1.84	1.83	1.83
Landfill gas	0	0	0	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0	0
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	38.0	41.9	42.0	47	54	65
	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Share of coal	87%	87%	85%	85%	84%	82%	79%
Share nuclear	5%	5%	4%	4%	5%	9%	14%
Share of gas	2%	2%	5%	5%	5%	4%	3%
Share of renewables	2%	2%	2%	2%	2%	2%	1%

The reduction in CO_2 emissions which result from this scenario can be seen in Figure 39. The total reduction in CO_2 in 2030 is 103 million tons, with a cumulative reduction of 595 million tons between 2015 and 2030.

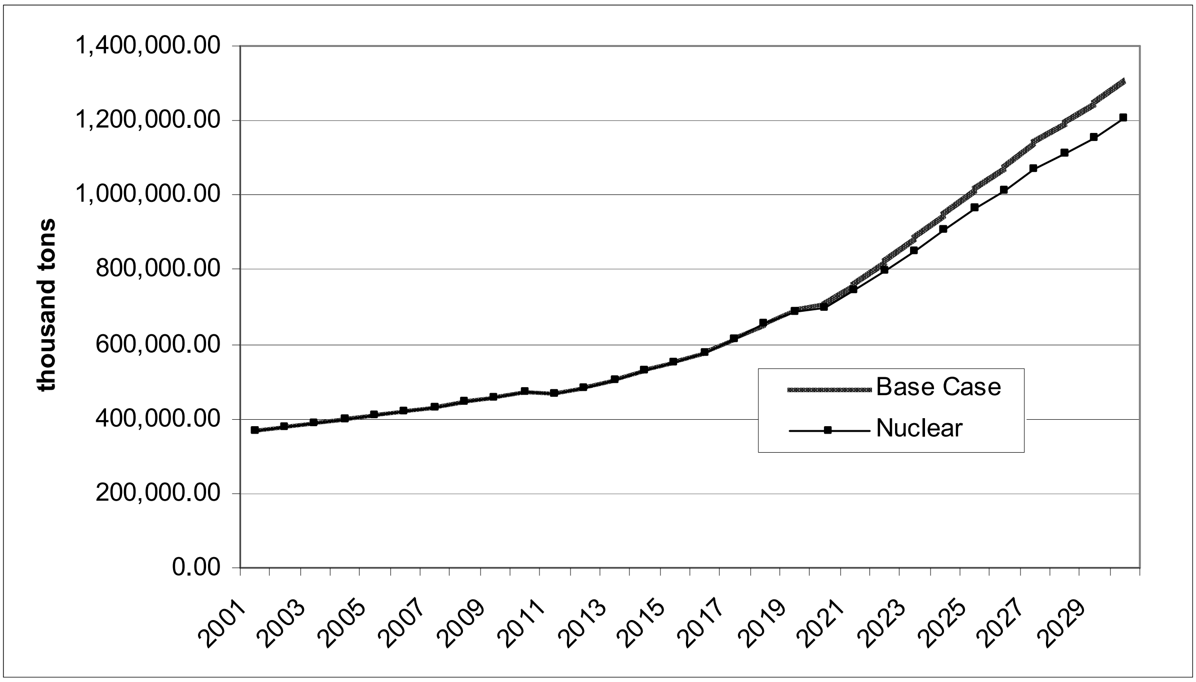
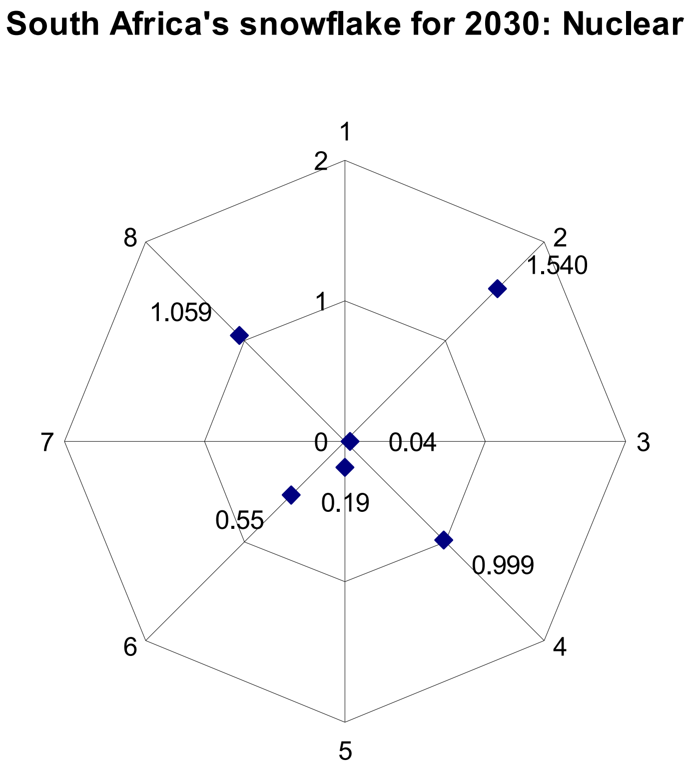


Figure 39: Reduction in CO_2 levels in the nuclear scenario

The sustainability indicators calculated for this scenario are shown below in Table 12. In this scenario, only sustainability indicators 1 and 4 are calculated as the rest will remain unchanged. It is debated whether nuclear technologies are a source of clean energy, and this is reflected in the indicator. Indicator 1 shows an improvement over that of the base case.

Table 12: Sustainability indicators for the nuclear scenario

Indicator	Description	2001	2030
1	Global impacts: energy C/capita	2.45	7.59
2	Local impacts: local energy pollutant	2.126	1.540
3	Households with access to electricity	0.3212	0.04
4	Investment in clean energy		0.999
5	Resilience to trade impacts	0.216	0.19
6	Public investments in NRE		0.55
7	Energy intensity	5.51	3.49
8	RE as a share of total energy supply	1.070	1.059



3.10 Low GDP growth

The low growth scenario is included as a sensitivity analysis. In this case the growth rate is reduced to an average GDP growth rate of 3.9% between 2001 and 2030. GDP growth and demand in the commercial, transport and industrial sector are linked with elasticities, therefore lowering the GDP growth, lowers demand in these sectors. Demand in the residential sector is driven by population growth and therefore remains unchanged.

Sectoral demand reaches a maximum of 5300PJ in the low GDP growth analysis. In the base case sectoral demand reaches 6600PJ. Demand for each sector is shown in Figure 40. The lower

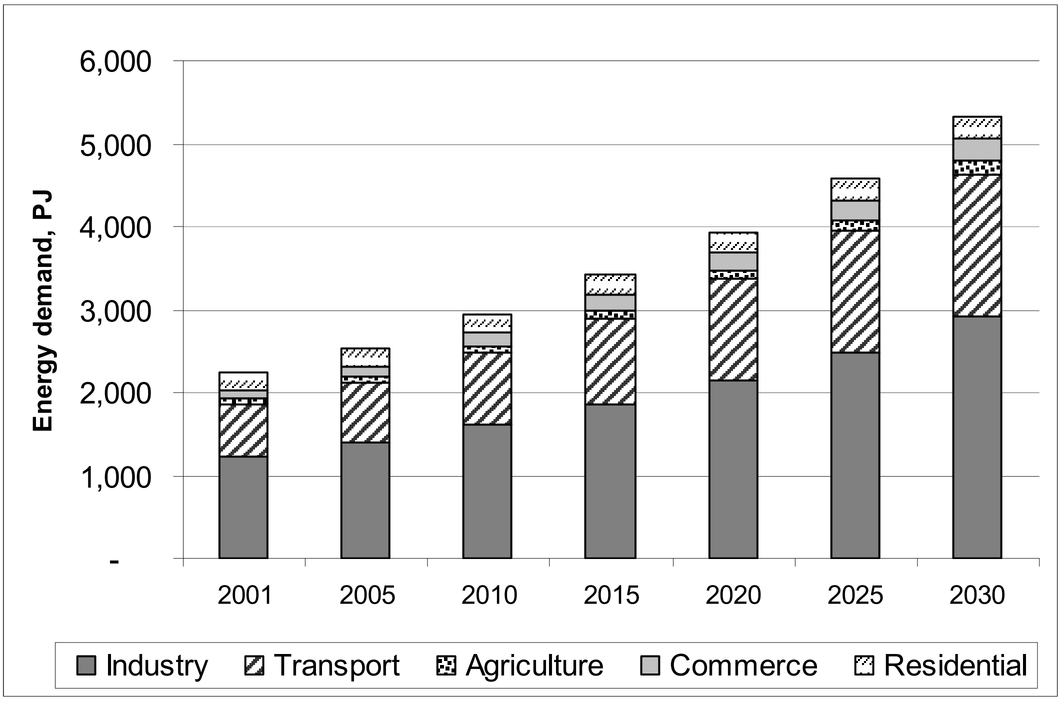


Figure 40: Fuel consumption by major energy demand sectors: low GDP

Electricity demand by sector is shown in Figure 41. Here demand in 2030 reaches 1355PJ, versus that of the base case at 1616PJ.

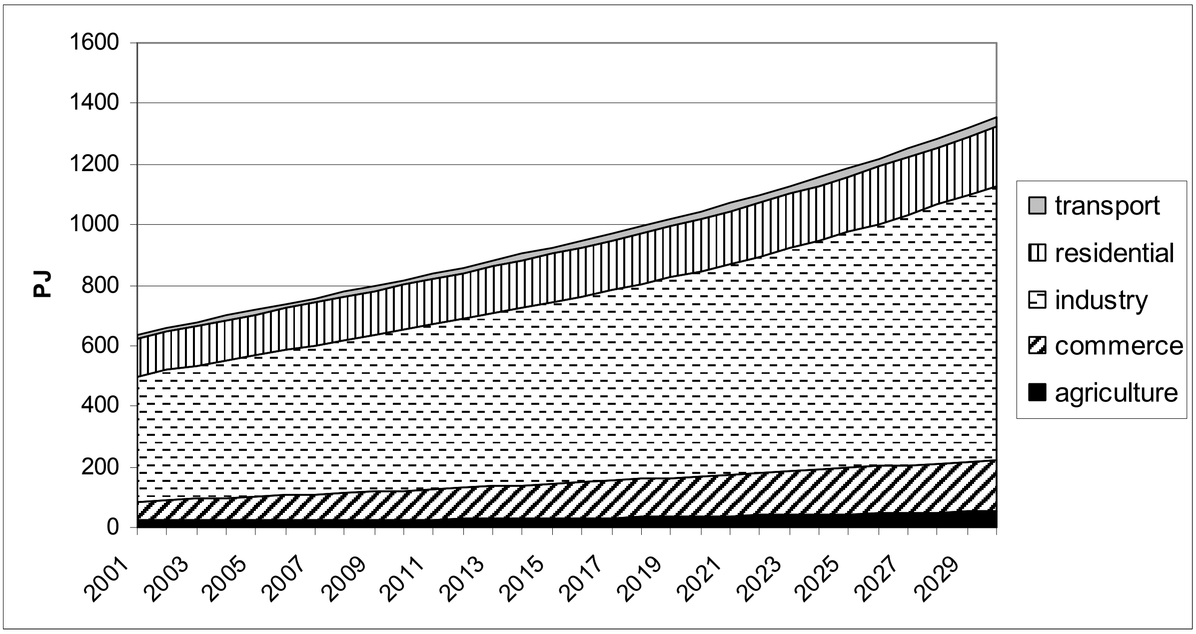


Figure 41: Projected electricity demand by sector: low GDP

The lower electricity demand results in less power station capacity being built over the period. In the base case supercritical coal plants are commissioned towards the end of the period, this capacity is not needed here.

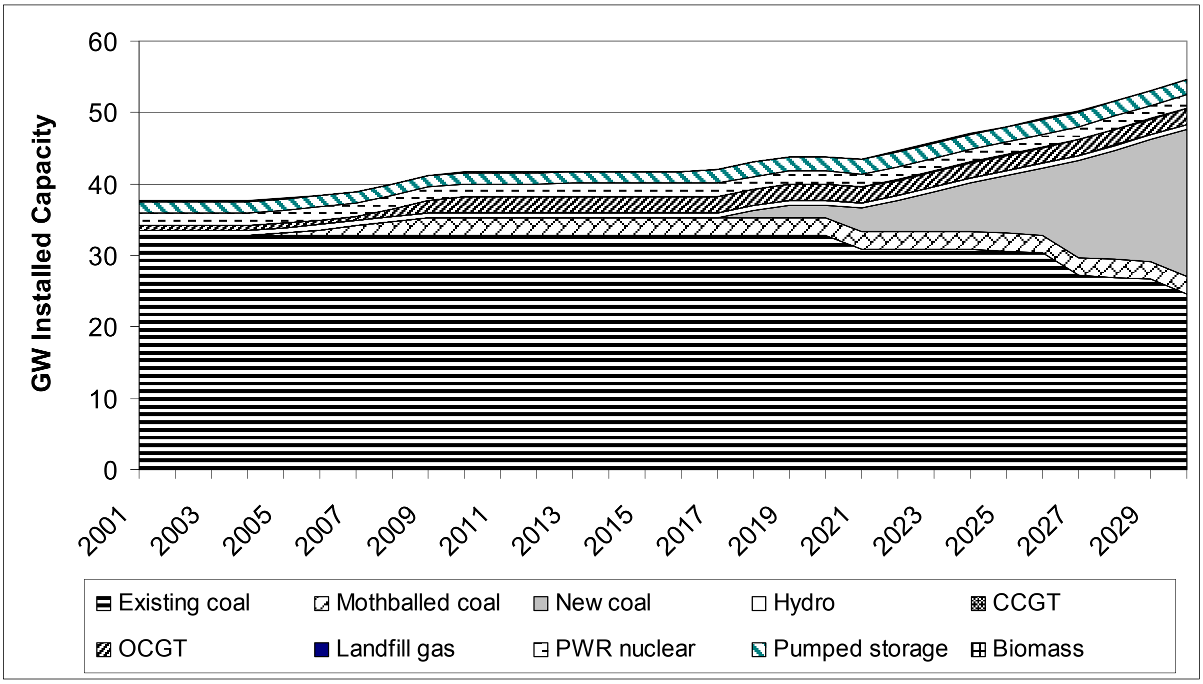


Figure 42: Electricity generating capacity by plant type: low GDP

Table 13: Electricity generating capacity by generation type (GW): Low GDP growth

	2003	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Existing coal stations	32.8	32.8	32.8	32.8	32.8	30.6	24.6
Mothballed coal	0	0.38	2.49	2.49	2.49	2.49	2.49
New coal stations	0	0	0	0	1.74	8.01	20.53
Super Critical coal	0	0	0	0	0	0	0
FBC	0	0	0	0	0	0	0
CCGT	0	0	0	0	0	0	0.02
OCGT	0.64	0.64	2.16	2.16	2.16	2.16	2.16
Nuclear (PWR)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nuclear (PBMR)	0	0	0	0	0	0	0
Pumped storage	1.58	1.58	1.58	1.58	1.94	2.1	2.1
Landfill gas	0	0	0	0.07	0.07	0.07	0.07
Hydro	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Solar PT	0	0	0	0	0	0	0
Solar Parabolic	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0	0
Biomass	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total	37.6	38.0	41.6	41.7	44	48	55

The lower demand also results in a lower output of CO_2 emissions over the period. Figure 43 on the following page shows the marked reduction in total CO2 emissions in a case where a lower GDP growth is assumed. At the end of the period, the CO2 emissions level from the lower GDP scenario is 78% of the emissions from the base case.

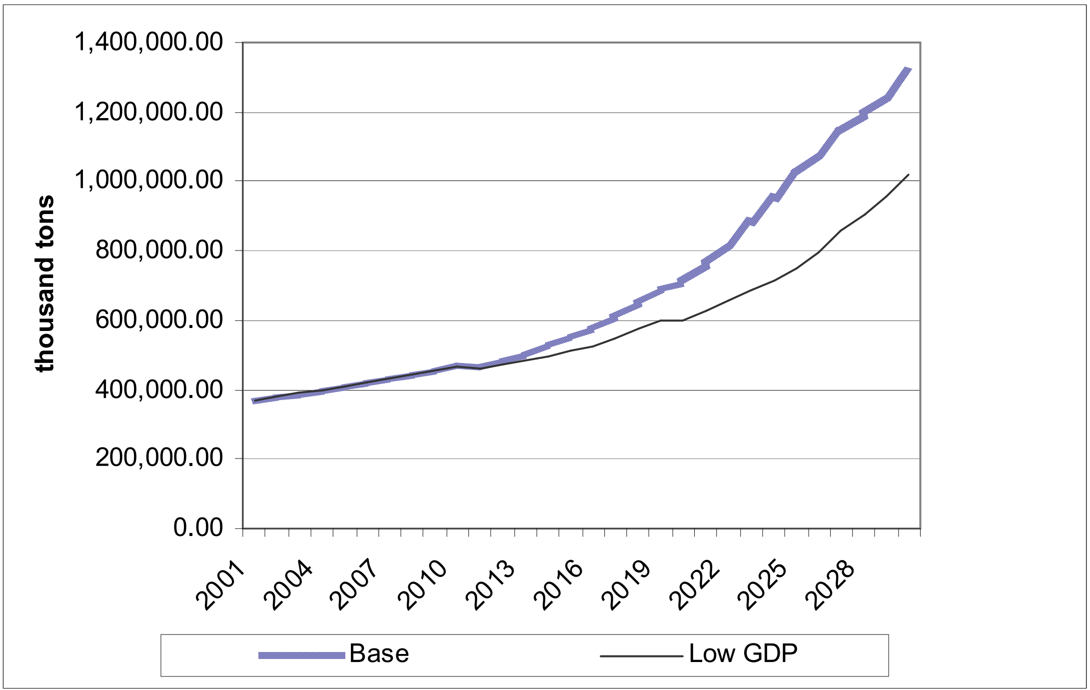


Figure 43: Reduction in CO2 levels with lower GDP

3.11 Exchange rate

In this scenario the exchange rate is raised slightly each year over the period. The exchange rate affects the price of oil and the investment cost of new electricity generation technologies. Initially the change in exchange rate was to be included in the base case. When the results were seen (over a 50 year period) it was decided to exclude it as it was felt that the results were unrealistic. One of the reasons is that the exchange rate was only applied to the investment costs and not to the transmission and distribution costs of the technologies. The investment into additional generating technology using the base case assumptions and the changing exchange rate can be seen in Figure 44. Over this period there is no significant change compared to the base case, however if the timeline is extended, technologies such as OCGT begin to be used as baseload plants.

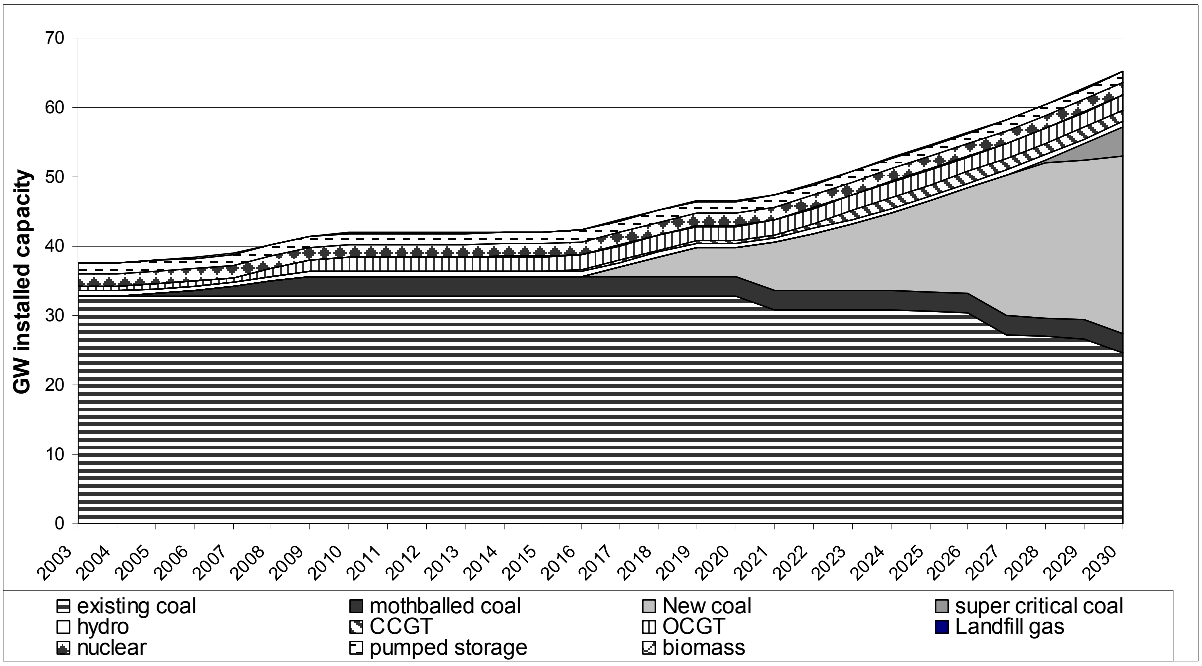


Figure 44: Electricity generating technology by plant type with changing exchange rate.

4. Scenario comparisons

A summary of the sustainability indicators is shown below in Table 14. In all cases, the indicator for households with access to electricity remains unchanged. This is because this indicator is an input assumption to the model. In almost all indicators energy efficiency showed the largest improvement, the exception being the share of total energy supply from renewables and investment in clean energy. Nuclear energy was not considered an investment in clean energy in the indicators.

Table 14: Summary of sustainability indicators

Indicator	Description	Base Case	Efficiency measures	RE target	Nuclear target
1	Global impacts: energy C/capita	8.287	6.936	7.503	7.59
2	Local impacts: local energy pollutant	1.484	1.384	1.484	1.54
3	Households with access to electricity	0.041	0.041	0.041	0.04
4	Investment in clean energy	0.999	0.999	0.444	0.999
5	Resilience to trade impacts	0.185	0.222	0.194	0.19
6	Public investments in NRE	0.481	0.761	0.768	0.55
7	Energy intensity	3.494	3.122	3.335	3.49
8	RE as a share of total energy supply	1.059	1.045	1.028	1.059

Figure 45 on the following page shows a summary of the CO2 emissions reductions for all major scenarios. The most effective way in reducing CO2 emissions is by placing a heavy tax on CO2 emissions. The energy efficiency scenario also shows a significant reduction in CO2 emissions while the renewable and nuclear scenarios show less of a marked difference in total CO2 emissions reduction. A similar pattern is visible in Figure 46 which shows the reduction in CO2 emissions from electrical generation. The CO2 tax scenarios show a greater percent reduction since the tax is only placed on emissions from power stations so this sector is where all the savings take place.

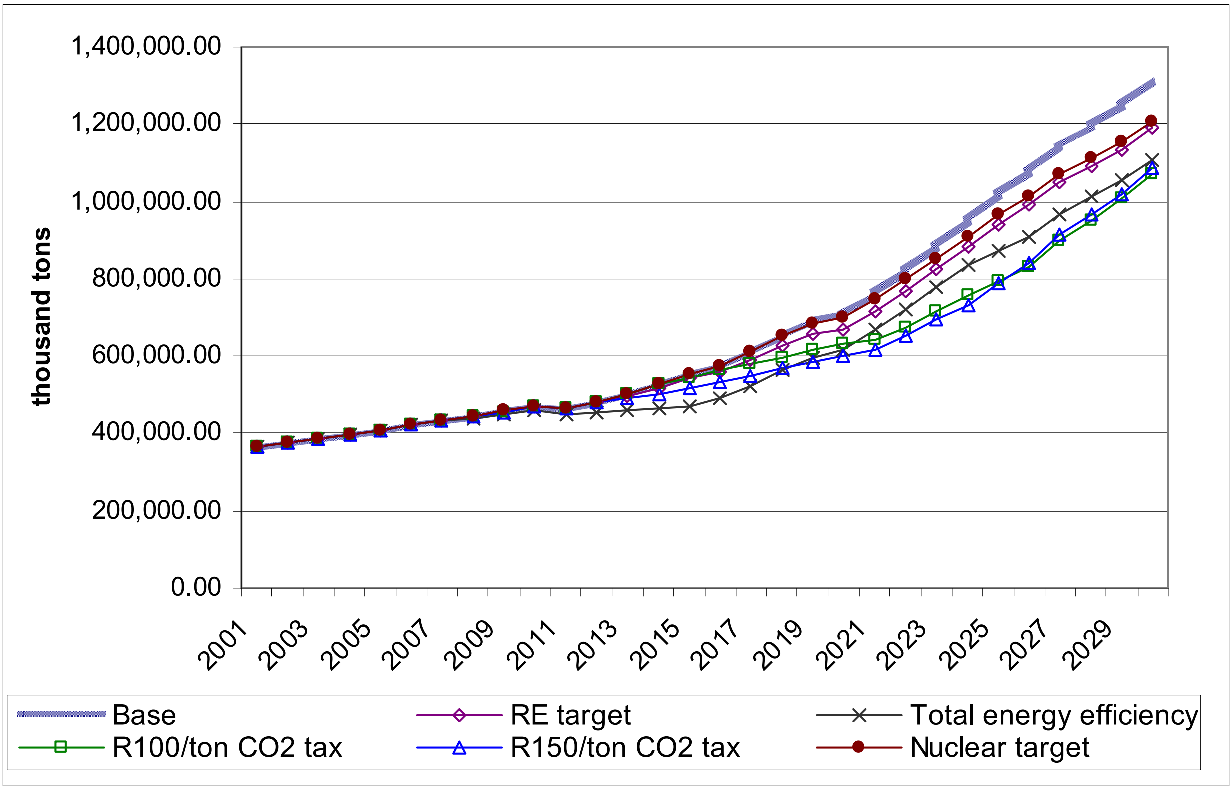


Figure 45: Total CO2 emissions reduction for all major scenarios

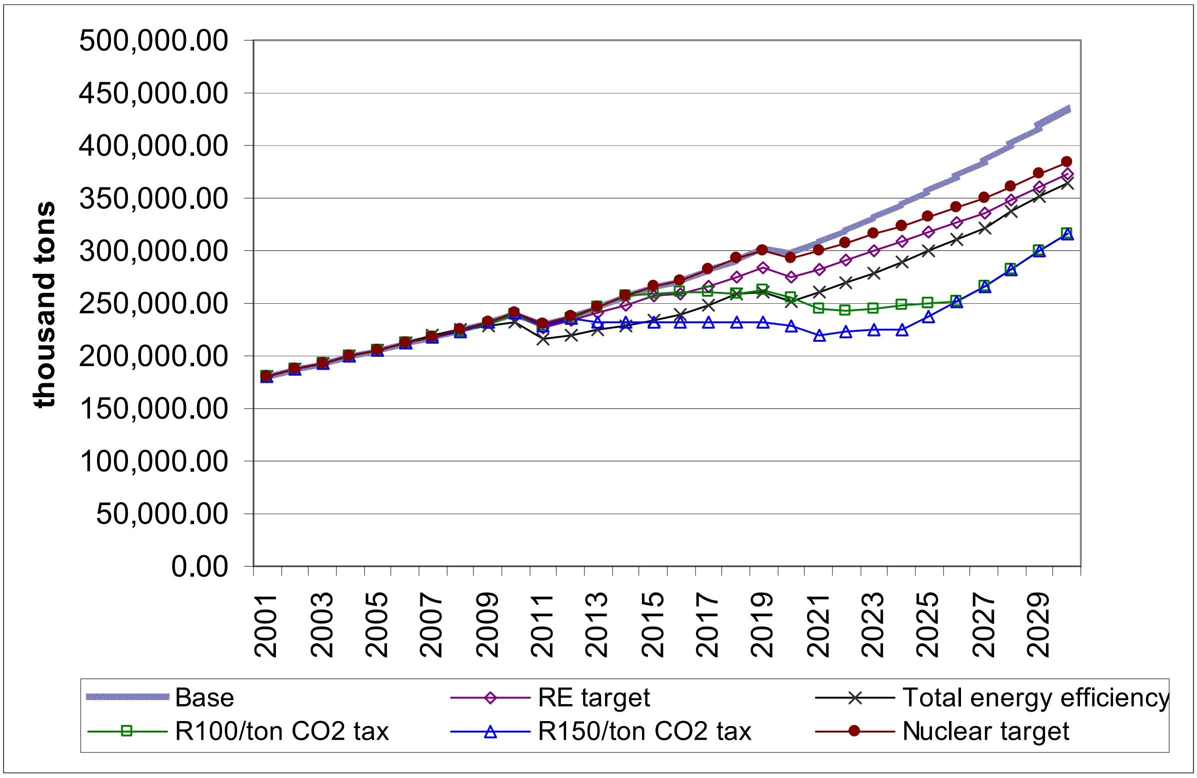


Figure 46: CO2 emissions from the power sector for all major scenarios

Table 15 on the following page gives a summary of the savings in energy and financially in each sector in the energy efficiency scenario. The most energy can be saved in the industrial sector however, the most money can be saved in the transport sector. This is largely due to an increase in efficiency in vehicles that results in a decrease in fuel use. A move to higher occupancy vehicles also reduces costs.

Table 15: Summary of energy and financial savings in the energy efficiency scenario

	energy savings [PJ]	money saved [million R]	[million R saved/PJ saved]
Base	0	0	0
Agriculture	0	0	0
Commercial	1395.39	6,406.20	4.59
Industry	44341.91	18,018.60	0.41
Residential	1535.18	9,130.90	5.95
Transport	18496.57	235,556.20	12.74
TOTAL	64901.98	268,900.80	4.14

The cost for each scenario is an important measure of determining the most appropriate energy policies for development planning. While exact costs are unlikely to be accurate given the many assumptions made about costs now and in the future, it is useful to calculate the additional cost of a scenario, over and above the cost of the base case. Table 16 below gives a summary of the additional discounted total system costs for each scenario from 2001-2030 in millions of 2003 Rand.

Table 16: Summary of total additional costs for each scenario

RE target	23,769.70	[2003 million Rand]
R100 CO2 tax	5,689.90	[2003 million Rand]
R150 CO2 tax	12,399.50	[2003 million Rand]
Nuclear target	4,510.20	[2003 million Rand]

The most expensive scenario is the Renewable target scenario while the nuclear scenario shows the lowest additional cost. As mentioned above, the energy efficiency scenario shows a savings in total system cost.

5. Conclusions and Recommendations

This project has attempted to achieve three main goals, firstly to update base year data and develop LEAP and MARKAL models for South Africa with the data. Secondly, to review base case results and scenarios with the use of sustainability indicators develop sustainable pathways for energy supply in South Africa and thirdly to develop additional modelling capacity in South Africa.

Background data is reported in the first report. There are many areas where data is lacking and in some cases although references appear recent, data collection took place in the nineties. It became apparent during the study that there is a need for primary data collection in South Africa and a documented database. Whilst modelling itself cannot achieve this, it does highlight areas where data is most needed, for instance, the industrial sector is a large user of energy and will remain so in the future. This is a sector however, where data is scarce and therefore disaggregation into demand end uses is difficult. The model would gain accuracy if detailed sectoral studies were undertaken to update base year data.

We have attempted during this study to create a referenced dataset for all data collected and all model inputs and assumptions. If additional data collection was to take place with the view to using it for national models, these could be used as templates.

The scenarios examined looked at the use of additional renewables and nuclear generating technologies, as well as an aggressive programme to improve energy efficiency in the sectors. Energy efficiency improvements are savings of both energy and money, whereas the other scenarios tend to add costs to the system. Energy efficiency also has significant impact on local and indoor air pollution.

The sectors with the most to gain from energy efficiency are transport and industry. Transport benefits in two ways, firstly additional coal to liquid capacity is introduced early on in the base case. These plants have a conversion efficiency of around 35%, therefore every PJ of liquid fuel saved through improvements in transport efficiency, result in a saving of 2.86 PJ of coal. There were significant reductions in energy use resulting from energy efficiency improvements in transport in the model, however many of these rely on the introduction of policy and behavioural changes. Changing behaviour in the transport sector is very difficult since the choice of what mode of transport to use is seldom a least-cost option. Fashion, convenience and private ownership play important roles in the types of transport people choose. While the model shows large potential to save energy in the transport sector, this cannot happen without significant pressure from government on vehicle manufacturers, vehicle owners and public transport co-ordinators.

Although the residential sector is one of the smaller sectors, it does show significant cost-effective energy savings: for each PJ of energy saved, almost R6 million can be saved. Since many of these savings filter down to the individual household, it is important to implement changes in household energy use to save domestic income as well as energy. Indoor air pollution is also an important reason for changing fuel type in households. While cleaner fuels may not be the least-cost option as demonstrated by the model's choosing fuels with greater emissions later in the time period, there are many externalities not taken into account in the price of a fuel. For example, paraffin is significantly cheaper than gel fuel and will thus be the fuel of choice in the model. However, paraffin has a number of risks associated with it such as emissions that lead to adverse health effects, risk of ingestion by children and the potential for serious fires. If these issues could be included in the cost of the fuel, paraffin may not look as attractive. If government is to curb such problems, perhaps a subsidy is required for a safer fuel option such as gel fuel.

Two levels of CO_2 tax were applied: R100/ton and R150/ton. Whilst the CO_2 tax encouraged the use of nuclear technologies, it was unsuccessful in introducing additional renewable technology to the mix. It appears that the renewable generation technologies are not at this stage economic options for electricity generation and require policy if they are to supply our electricity in future.

The PBMR is commissioned before additional PWR in the nuclear scenario. This result is significant as it indicates that if PBMR investment and maintenance costs are correct and the technology is successful, investment into the development of the technology could benefit South Africa.

Solar seems to be a particularly promising option for South Africa both for domestic and commercial use as well as for electricity generation. This technology appears to be the renewable resource of choice. As a generation technology it allows storage and therefore can be used to meet peak demand. Costs associated with storage capacity and increased availability of the technology are not well defined, and this is an area where additional work is required in order to make the results more robust.

The model does not include additional combined heat and power (CHP) or carbon capture and storage (CCS). It has been estimated that CHP could replace up to 1GW of generating capacity. This is therefore an area that should be included in future studies. CCS technologies are applicable to coal and supercritical coal which appear prominently in the base case generating options. Future work in this are should therefore include CCS as an option with these technologies.