DEPARTMENT OF ENERGY

DRAFT 2012 INTEGRATED ENERGY PLANNING REPORT

ANNEXURE A – TECHNICAL REPORT ON MODEL OUTPUT
(PART 2 - OPTIMISATION MODEL OUTPUT)
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1. Introduction

This document presents the results of the model runs for the Base Case and each of the test cases. While the ultimate objective is to conduct demand projections for all energy services (cooking, lighting, industrial processes, transportation, etc.) within each major energy demand sector (residential, commercial, industrial and agricultural), due to paucity of energy consumption data at an energy end-use level, two different demand modelling approaches were used to project demand for the various sectors.

- For the agricultural, commercial, industrial, mining and residential sectors, energy demand was estimated and projected for individual energy carriers (i.e. electricity, natural gas, LPG, coal, diesel, etc.); and

- For the transport sector, demand was projected for energy end-use (i.e. mobility measured by passenger kilometres or freight tonne kilometres) as opposed to individual fuels (i.e. petrol, diesel, jet fuel, etc.). This second approach makes it possible to quantify the extent to which different fuels can be used to meet the same end-use/need.

The desired approach was therefore only conducted in the transport sector. The demand technology assumptions and methodology for transportation modelling relied heavily on previous work which had been commissioned by the South African National Energy Development Institute (SANEDI) and which had been conducted by the Energy Research Centre (ERC). Detailed analysis on demand technologies is therefore only provided for the transport sector.

Each section is structured as follows:

- Transport demand technologies investments: suggestions from the modelling process for new vehicle fleet capacity are discussed and the total vehicle fleet activity, including the existing vehicle fleet, is provided;

- Transformation: discusses transformation technologies (electricity generation and liquid fuels production) and their installed capacities and activities over the planning period. The mix of energy carriers used in electricity generation and liquid fuels production as well as the share of technology types contributing to electricity generation and liquid fuels production is considered. Carbon emissions and water usage are presented for each group of technologies;

- Primary energy use: the sources of primary energy are discussed as well as the change in the primary energy mix over the modelled period;

- Discounted costs: the discounted costs for all technology types for the planning period are provided;

- Overall emissions and water use: the implications for water demand and carbon dioxide emissions are presented; and

- A summary of the results for the Test Case.
In the model output and analysis sections, 'primary energy resource' refers to: energy extracted locally or imported, this includes coal, crude oil, natural gas, nuclear fuels, hydro, solar, wind and biomass mined or extracted and crude oil, natural gas nuclear fuels and petroleum products imported.
2. Base Case

This section presents the results of the optimisation model run for the Base Case. A summary of the key assumptions for the Base Case are as follows:

- Electricity supply options are informed by current commitments. These are Eskom’s pre-IRP determinations and NERSA’s 2011 and 2012 determinations;
- All renewable energy technologies as per the 2011 and 2012 NERSA determinations are available to the model but no renewable energy targets are set;
- No annual emission constraints are set;
- No emission penalties (carbon taxes) are set; and
- No constraints are defined for liquid fuel production except for the assumption that if CTL is invested in then an 80000 bbl/day constraint is in place based on proposed capacity of a new CTL plant.

2.1 Transport Demand Technologies

Transport consumes a significant amount of the total energy used in South Africa. In comparison to many other countries, South Africa has high greenhouse gas emissions driven partly by the use of coal to produce liquid fuels for the transport sector.

2.1.1 Private Car Fleet

Investments in new vehicles for the car fleet are presented in Figure 2.1. Most new vehicles in the vehicle fleet up to about 2040 are fuelled by petrol. Hybrid and diesel vehicles are not selected as their price premiums are not justified by their fuel savings based on the assumed average annual vehicle kilometres travelled by cars. In reality, there are likely to be new hybrid and diesel cars as there will be a small proportion of vehicles driven more than threshold to justify the additional cost. In addition, the refinery slates assumed in the modelling and demand for diesel in the freight subsector favour petrol vehicles to balance the quantities of petrol and diesel being produced.

The initial uptake of electric vehicles is slow due to the low base at which they start (200 vehicles in 2013). While electric vehicles have the lowest total cost over the model period based on the vehicle costs and the energy value chain there are practical limits to their adoption as suggested in the assumptions i.e. a maximum increase of 40% per annum. The escalation of fuel prices, presented in the “Inputs and Assumptions section”, and the higher relative costs of liquid fuels compared to electricity is significant contributors to the uptake of electric vehicles in the later years of the modelled period.
The results presented meet the electric vehicle targets set by the Department of Transport’s National Transport Plan for the year 2050, i.e. 60% electric vehicles, based on the assumed penetration rates. Other aspects not considered which would impact on electric vehicle penetration rates are the required charging infrastructure, market conditions and range limitations of electric vehicles.

Figure 2.1: Investment in car fleet capacity in Base Case
The energy consumption by private cars is shown in Figure 2.2. It is evident that the introduction of electric vehicles has a profound impact of the demand for final energy used in transport, with final energy used by cars almost dropping to 2012 levels by 2050 despite the considerable increase in the size of the vehicle fleet. As will be shown in the following two subsections, electric vehicles impact liquid fuels production significantly but only have a mild impact on electricity generation. This is due to the relative size of the electricity generation and liquid fuels production subsectors (electricity demand is two to three times the size of the liquid fuel demand in terms of final energy).

Figure 2.2: Energy used by car fleet in Base Case
The modelled investment in SUV fleet is shown in Figure 2.3. The model chose petrol SUV vehicles for new investments mainly due to the definition of SUVs in that they include smaller delivery type vehicles which are dual purpose and are predominantly fuelled by petrol. The energy used by SUVs is shown in Figure 2.4 and is proportional to the SUV activity as no electric or other drive trains technologies were considered for SUV type vehicles.
2.1.2 Public Transport

In the public transport sector (new capacity in Figure 2.5 and total vehicle activity in Figure 2.6), busses are the cheapest option to providing passenger kilometres. The model suggests scrapping most of the existing minibus taxis and replacing them with new busses. The capital investment and resistance to replacing minibus taxis with busses limit this as a practical solution and closer consideration of these options is needed. It may also be argued that busses and taxis do not provide the same type of service based on trip length, frequency of service and other conveniences.
The energy used by public transport vehicles is presented in Figure 2.7. A modal shift from taxis to busses has a significant impact on energy demand in public transport. As suggested in the assumptions, it may not be suitable to compare busses and taxis as they may be perceived to provide different services.
2.1.3 Freight Transport

Freight transport investments and activity are presented in Figure 2.8.

Figure 2.7: Energy used by public road transport in Base Case

Figure 2.8: Investment in new freight fleet capacity in Base Case
Investments in heavy and medium commercial vehicles correspond with historical investment trends and are directly related to the demand for these services as there are no alternative technologies considered.

While the shifting of freight from road to rail has significant advantages, including lower costs and fewer externalities, further work and additional consultations are needed to properly assess the impact of the rail expansion plan currently underway by Transnet.

From a policy perspective electric vehicles should be facilitated and encouraged as a least cost option for proving private passenger transport based on the model assumptions without the need to consider the costs of emissions. More details about the penetration rates of electric vehicles due to these parameters and finer details and analysis of the vehicle fleet structure are required for a more complete analysis. Other technologies should be considered for SUV and freight vehicles in future modelling.

Decisions made by vehicle buyers drive the nature of demand on the transport energy supply sector. This is due to the costs of vehicles relative to the cost of the fuel they use over the vehicles life. There are also other values placed on the ownership of cars such as status which are difficult to qualify.

### 2.1.4 Total Transport Energy Use

The energy used by road transport over the modelled period is shown in Figure 2.9. In 2010, the fuel mix is slightly biased towards diesel. Throughout the period, the trend continues toward a diesel preference driven by road freight. Electricity replaces a considerable amount of petrol in the last ten years of the period and also reduces the final demand significantly due the greater end-use efficiency of electric vehicles.

**Figure 2.9: Energy used road transport in Base Case (PJ)**
2.2 Transformation Technologies

Requirements for new transformation infrastructure and the expected level of activity are presented in this section. These technologies include power stations, refineries, coal to liquid (CTL) and gas to liquid (GTL) plants.

2.2.1 Electricity generation

This section represents investments in electricity generation and considers new and total generation capacity, the energy input into electricity generation and the electricity produced by the different types of technologies.

2.2.1.1 Generation capacity

Existing electricity generation capacity is shown in Figure 2.10. Periods of significant plant retirements are 2031, 2036 and 2038-2042 requiring substantial additional capacity. The years 2021 and 2028 also show significant drops in available capacity. In practise, however, power plants will not be abruptly switched off but units within power plants will be phased out over a few years.

![Figure 2.10: Retirement of existing electricity generation capacity (GW)](image)

The new generation capacity by technology type for the least cost Base Case is provided in Figure 2.11. There are considerable capacity increases from about 2032 to replace retiring plant and to meet additional demands. Fluidised bed combustion coal plants mostly meet this need until 2042 after which more efficient integrated gasification combined cycle plants are used. Small amounts of pulverised fuel plant are used throughout the period. The current coal plant builds underway – i.e. Medupi and Kusile are included in the existing capacity above as these are already committed, although not yet generating. The remainder of the new capacity is made up predominantly of photovoltaic generation (both thin film and crystalline) followed by a small amount of wind installations.
and CSP towers. Gas does not feature in the new capacity of the Base Case as it is not price competitive.

**Figure 2.11: New electricity generation capacity in Base Case (GW)**

Total electricity generation capacity over the planning period for the Base Case is shown in Figure 2.12 and the electricity generated by the technology types is shown in Figure 2.13. Total capacity for 2010, 2030 and 2050 as well as the percentage share of installed capacity and share of electricity generated by the various technology types are shown in Table 2.1.

Electricity generation capacity grows by almost 250% between 2010 and 2050 and coal technologies remain the dominant type of technology for electricity generation in the Base Case. There are, however, substantial investments in solar driven by lower costs of these technologies due to technology learning and retirement of old power stations.

Coal capacity declines between 2020 and 2030 in line with the 2011 and 2012 determinations but increase after 2030 as the model is allowed to choose the least cost technologies without any emissions constraints, this is reflected in Figure 2.12 and Table 2.1.
Figure 2.12: Total electricity generation capacity in Base Case (GW)

Figure 2.13: Electricity generated by technology type in Base Case (PJ)

Note that pumped storage is not included in the Figure 2.13 because it is a net consumer of electricity.
Table 2.1: Electricity generation in Base Case (2010, 2030 and 2050)

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology Type</th>
<th>Capacity</th>
<th>Electricity Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GW</td>
<td>PJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>2010</td>
<td>Electricity generation coal</td>
<td>35.9</td>
<td>740.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80%</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>2.1</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>53.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.6</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>0.3</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>2010 Total</td>
<td></td>
<td>44.8</td>
<td>845.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2030</td>
<td>Electricity generation coal</td>
<td>37.5</td>
<td>920.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52%</td>
<td>73%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation solar</td>
<td>9.9</td>
<td>69.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>5.8</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>4.6</td>
<td>88.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>3.6</td>
<td>32.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>48.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>53.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation biomass</td>
<td>0.9</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation gas</td>
<td>0.7</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>2030 Total</td>
<td></td>
<td>72.0</td>
<td>1256.1</td>
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<tr>
<td></td>
<td></td>
<td>100%</td>
<td>100%</td>
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<tr>
<td>2050</td>
<td>Electricity generation coal</td>
<td>61.2</td>
<td>1640.8</td>
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<tr>
<td></td>
<td></td>
<td>64%</td>
<td>86%</td>
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<tr>
<td></td>
<td>Electricity generation solar</td>
<td>24.0</td>
<td>158.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>48.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>3.1</td>
<td>48.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.5</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation gas</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2050 Total</td>
<td></td>
<td>95.9</td>
<td>1900.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

While the share of coal generation capacity constitutes 64% of the capacity by 2050, coal technologies still contribute a large proportion of the electricity generated 88%, 73% and 86% for 2010, 2030 and 2050 respectively. This is as a result of the capacity factors of the various technologies. The local availability and relatively low cost of coal provide cheaper options in the absence of emissions constraints or accounting for the external costs of emissions. While plant life extension is a possibility it has not been considered.

2.2.1.2 Energy input into electricity generation

The energy input into electricity generation is shown in Figure 2.14 and summarised in Figure 2.15. The amount of electricity generated from the various technology types is shown in Figure 2.13 above. The relationship between Figure 2.14 and Figure 2.13 is the efficiency of the respective generation technologies. Electricity from solar, wind and hydro is considered to be primary energy for modelling purposes and there are no tangible input energy commodities or associated commodity costs. The power plants which have commodities as an input, however, have energy conversion efficiencies and the electricity produced by the technology is lower than the energy input into the technology. This reduces the contribution of the relevant combustion technologies to the total electricity generated.
2.2.1.3 Water use and CO₂ emissions in electricity generation

Freshwater use and CO₂ emissions from electricity generation are presented in Figure 2.16 and Figure 2.17 respectively. Water is mainly used for cooling and there is a significant drop in the use of water use due to the implementation of dry cooling in new coal fired plants. The step changes in the
use of water take place when significant coal generation capacity is retired (2030 and 2036) and replaced by technologies which use less water.

![Figure 2.16: Water used in electricity generation in Base Case (Mt)](image)

Carbon dioxide emissions are primarily driven by coal use. As there are no emissions limits in the Base Case coal remains the dominant resource for electricity generation. The use of coal for electricity generation continues to drive the country's carbon dioxide emissions which consequently double over the modelled period.
2.2.2 Liquid fuels production

Suggested investments in refineries, GTL plants and CTL plants from the modelling exercise are presented in this subsection.

2.2.2.1 Liquid fuels production capacity

Existing capacity and suggested new capacity for liquid fuels production technologies are provided in Figure 2.18. The costs of producing liquid fuels from coal are lower than that of both conventional refineries and gas to liquids as presented in the assumptions. In the Base Case new CTL plants are built to the maximum constraint set in the input parameters of 80 000 barrels per day, after which conventional refineries are added to provide for the liquid fuel demand. The total liquid fuel production slows down by 2034 and plateaus to 2040 after which it declines as a result of electric vehicle penetration.

Due to the lead time for constructing a new refinery, a restriction has been placed on new refining capacity coming on stream prior to 2020. After 2020 the demand is high enough and the difference between the crude oil price and imported petroleum product prices are great enough to justify additional local refining capacity.

It is assumed that the existing conventional refineries are not retired within the modelling period due to their operational life being extended through on-going maintenance, occasional upgrades (usually related to fuel specification changes) and the low cost continuing to run the refineries relative to the cost of the crude oil they process.
2.2.2.2 Energy input into liquid fuels production

The energy inputs into the liquid fuels production are presented in Figure 2.19. There are three distinct phases of activity – the first phase is while and the existing conventional refineries, CTL and GTL plants are available and combined with imports meet demand; the second phase is when increasing demand is sufficient to justify additional refining capacity and new CTL and conventional refining capacity is added to the total capacity; and the third phase is when electric vehicles start making a considerable impact to liquid fuel demand and to such an extent that some of the additional capacity installed in previous years is no longer required. Certain liquid fuels are imported from 2040 (see primary energy supply section) to make up for the imbalance in the slates due to the shift from petrol to electric vehicles. During the whole period, a small amount of gas is used in the GTL plants due to assumed minimum activity. It should be noted that gas and electricity are used in all three types of liquid fuel production.
The liquid fuels produced by all the liquid fuel production plants are shown in Figure 2.20 and summarised for 2010, 2030 and 2050 in Table 2.2. The average refinery slates (which were assumed to remain constant) determine the proportions of fuels produced by each plant type. Petrol and diesel are the main products followed by aviation fuels, secondary petroleum products, LPG and paraffin. While there is demand for most of these products either explicitly or as a result of transport demand, certain of the products are produced without knowing the market requirements. This is minimised by an increase in the importation of products which are required but do not justify the additional refining capacity.
Table 2.2: Liquid fuels production by technology 2010, 2030 and 2050 in Base Case

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
<th>Capacity</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PJ/a</td>
<td>mbbl/d</td>
</tr>
<tr>
<td>2010</td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>37</td>
</tr>
<tr>
<td>2010 Total</td>
<td></td>
<td>1362</td>
<td>613</td>
</tr>
<tr>
<td>2030</td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>New refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>176</td>
<td>79</td>
</tr>
<tr>
<td>2030 Total</td>
<td></td>
<td>2529</td>
<td>1138</td>
</tr>
<tr>
<td>2050</td>
<td>New refinery</td>
<td>1196</td>
<td>538</td>
</tr>
<tr>
<td></td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>176</td>
<td>79</td>
</tr>
<tr>
<td>2050 Total</td>
<td></td>
<td>2358</td>
<td>1061</td>
</tr>
</tbody>
</table>

2.2.2.3 Water Use and CO₂ emissions in liquid fuels production

Carbon dioxide emissions and water requirements for liquid fuel production are provided in Figure 2.21 and Figure 2.22. Both of these profiles are strongly influenced by the activity of coal to liquids production. As presented in the document on model input and assumptions, CTL plants have a carbon emissions factor which is an order of magnitude greater than the emissions of conventional refineries. With the new CTL capacity that comes on stream in the Base Case, the emissions and water use increase considerably. When the existing CTL plants are retired and electric vehicles...
become a significant share of the vehicle fleet after 2040, the emissions and water use decrease substantially.
2.2.2.4 Transportation of liquid fuels

Liquid fuels are transported via pipeline, rail tank cars and road tankers. As no spatial aspects with regard to the transport and distribution of liquid fuel were considered, an average costs per unit of energy is placed on the cost of supplying liquid fuels based on the fuel margins.

2.3 Primary Energy

This subsection represents analysis of the primary energy mix as a result of the cost optimisation for the Base Case. In the model output and analysis sections, “primary energy resource” refers to coal, crude oil, natural gas, nuclear fuels, hydro, solar, wind and biomass extracted or harnessed in South Africa and end-use forms of energy or fuels that enter the South African energy system through importation (e.g. imported petroleum products).

2.3.1 Primary energy use

Primary energy use determined for the Base Case is presented in Figure 2.23. Extraction of coal for coal to liquids increases in 2019 and continues to 2040 for new coal to liquids plants. Coal for electricity generation is a considerable share of the total use for coal. A small amount of natural gas is extracted and used for gas to liquids over the whole study period. Considerable amounts of petroleum product are imported between 2012 and 2020 as there the refinery economics favour imports based on the levels of demand and price differential between crude oil and petroleum product imports. The significant increase in crude oil imports from 2020 is due to new conventional refining capacity which comes on stream from 2020 onwards and the increased demand which improves new refinery viability.

![Primary energy use: Base Case](image)

**Figure 2.23: Total primary energy use in Base Case (PJ)**
While the share of coal used for electricity generation increases through the modelling period, its share as a proportion of the total energy mix decreases. This is because demand for liquid fuels grows at a higher rate than the growth in demand for electricity. In 2050 there is also a significant amount of petroleum products imported to balance the demand for liquid fuels and refinery slates.
2.3.2 Energy imports

Imports of crude oil and natural gas for the Base Case are included in Figure 2.25. These imports increase with the expected growth in the transport sector and final consumption of gas. There is a decline in the growth of crude oil imports from about 2040. This is due to the increase in the number of electric vehicles in the vehicle fleet reducing the demand for petroleum products.

![Imports of Crude Oil and Natural Gas: Base Case](image)

**Figure 2.25: Imports of crude oil and natural gas in Base Case**

Imports of petroleum products are provided in Figure 2.26. Based on the assumptions made regarding the cost of local extraction and production of natural gas, imports still remain relatively more cost effective. This informs the continued growth of natural gas imports to meet projected demand. The costs for constructing new gas import terminals, increasing port capacities (such as Durban harbour) and other related infrastructure requirements have not been considered. In relation to crude oil and liquid fuels transport costs, however, the margin per unit energy is assumed to be adequate for any new transport infrastructure requirements.
2.4 Discounted Costs

The discounted costs for each year in the Base Case are presented in Figure 2.27 and show the contribution of the various components of the energy system to the total costs.

An important aspect of the discounted costs is the information it provides about the characteristics of an energy system. Imports of crude oil and other energy carriers represent about 75% of the total cost of providing energy to South Africa. Indigenous production (mining of coal, extraction of oil and gas and biomass production) represent about 15% of the costs (the costs of coal used for electricity generation are included in these costs). The remaining costs are related to the capital investments in infrastructure to transform energy to produce electricity, liquid fuels and other energy carriers.

The large share by imports indicates a susceptibility to global energy prices and a lack of diversity from an energy cost point of view. Imports, be they crude oil or finished product, of energy are also a major concern for the balance of trade. More detailed information about the costs of imports are provided in Figure 2.28. The main import costs before 2020 are for petrol, diesel and then LPG. After 2020, with new refining capacity, the main costs are crude oil and diesel imports.
2.5 CO₂ Emissions

Carbon dioxide emissions from transport, total final use of energy carriers, electricity generation, resource extraction and liquid fuel production are shown in Figure 4.27. New CTL plants increase
emissions in 2020 but the end of the operational life of the existing CTL plant reduces emissions in 2040. Emissions from electricity generation continue to grow throughout the planning period.

![Carbon Dioxide Emissions from Transport, Final Demand and Energy Supply: Base Case](image)

**Figure 2.29: Total CO₂ emissions from all energy use in Base Case (Mt)**

### 2.6 Water Use

Water consumption related to energy resource extraction and production, electricity generation and liquid fuels production is shown in Figure 2.30. Water consumption is mainly from electricity generation using coal as well as from CTL activity. Overall the total water demand drops in the second part of the modelling period. This is due to both changes in technology, and activity in electricity generation and CTL. The larger share of renewable energy technologies, which use less water, and the use of dry cooling for electricity generation cause the drop in water consumption for electricity generation whereas the reduction of CTL activity and the uptake of electric vehicles cause the reduction of water use for from liquid fuels production.
2.7 Base Case Summary

Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the Base Case over the model period are presented in Figure 2.31. The energy intensity indicates the primary energy supplied used per unit of economic output. Based on the economic growth projections and primary energy use, determined by the model, energy intensity decreases from just under 2.5 TJ/Rm to just above 1.2 TJ/Rm over the period considered. The energy intensity is influenced by improvements in energy efficiency and shifts in the economic structure of the country. Carbon dioxide emissions, energy intensity and water use are all impacted by the use of coal to liquids in the Base Case. This is evident in the increases in 2020 and the decreases in 2041. Water use decreases at a higher rate that the reduction in carbon emissions.

Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the Base Case costs R2484 billion (2010 Rand), 22101 Mt of CO₂ are emitted and 12538 Mt of water are consumed.
Figure 2.31: Emissions, water use and energy intensity in Base Case
3. Emissions Limit Case

The Emissions Limit Test Case seeks to analyse the effect of the emission limit constraints on energy supply options and costs. This section presents the results of the optimisation model run for the Emissions Limit Case and does this by presenting alternative energy supply technology options and the associated financial implications which would be required in order to ensure that the energy sector meets the emission reduction targets defined in the National Climate Change Response Policy. Transformation technology investments and activity are detailed and the sources of primary energy are discussed. Finally, the costs, carbon dioxide emissions and water consumption implications are presented. A summary of the key assumptions for the Emissions Limit Case are as follows:

- All technology assumptions for the Base Case are applied;
- Annual emission limit constraints are set for electricity generation and liquid fuels production in line with the peak plateau decline constraints and in proportion to their current share of total emissions; and
- No emission penalties (carbon taxes) are set.

3.1 Transport Demand Technologies

There are no deviations to the suggested vehicle fleet in the Emissions Limit Case in comparison to the Base Case therefore all the observations made in the Base Case remain true and no further discussion of the transport sector is presented here.

3.2 Transformation Technologies

Requirements for new transformation technologies and the expected level of activity are presented in this section under electricity generation and liquid fuels production.

3.2.1 Electricity generation

This section represents investments in electricity generation and considers new and total generation capacity, the energy input into electricity generation and the electricity produced by the different types of technologies.

3.2.1.1 Generation capacity

The existing electricity generation technologies were presented in the Base Case. New capacities for electricity generation in the Emissions Limit Case are detailed in Figure 3.1.

In the Emissions Limit Case a wide range of electricity generation technologies are added to the future mix in comparison to the Base Case. By 2050, solar technologies play a dominant role, followed by wind, coal and nuclear. Petroleum products, hydro, biomass and natural gas continue to play a less significant role.

The model suggests four types of solar energy: PV thin film, PV crystalline, CSP tower with 12 hours storage and CSP trough with 9 hours of storage. While practical limits were placed on solar PV, the concentrating solar power technologies were not limited during the modelling and total CSP capacity reaches 35GW by 2050. The practical limits of CSP within the modelled period are expected to be
determined by the Solar Energy Technology Roadmap running concurrently to the IEP. Initial discussions indicate a 22GW limit.

The main reason for the increased share in renewable energy technologies is to keep total CO\textsubscript{2} emission from electricity generation within the set emissions limits. Substantial additional capacity of just under 40GW is needed by 2050 compared to the Base Case requirements. This is due primarily to renewable energy technologies having lower capacity factors (related to the availability of sunlight and the probability of wind) compared to coal in the Base Case.

![New Electricity Generation Capacity: Emissions Limit Case](image)

**Figure 3.1: New electricity generation capacity in Emissions Limit Case (GW)**

The total electricity generation capacity over the planning period for the Emissions Limit Case is provided in Figure 3.2. Total capacity for 2010, 2030 and 2050 as well as the percentage share of each technology towards the electricity generated is summarised in Table 3.1. As can be seen from the graphs as well as the table, coal technologies lose their dominance in electricity generation capacity by 2030 and there are substantial investments in solar and wind. The timing of new investments occur with the retirement of old power stations.

When electricity output is considered, as in Figure 3.3, efficiencies of the various technologies alter the picture further with the change in perspective as highlighted in the Base Case results. About 35% of the electricity generated comes from coal in 2050. The electricity demand is slightly lower than in the Base Case due to the liquid fuels sector as coal to liquids capacity is reduced as a result of emissions constraints.
Figure 3.2: Total electricity generation capacity in Emissions Limit Case (GW)

Figure 3.3: Electricity generated by technology type in Emissions Limit Case (PJ)
Table 3.1: Electricity generation in Emissions Limit Case (2010, 2030 and 2050)

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology Type</th>
<th>Capacity (GW)</th>
<th>%</th>
<th>Electric Energy Produced (PJ)</th>
<th>%</th>
</tr>
</thead>
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<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Electricity generation coal</td>
<td>35.9</td>
<td>80%</td>
<td>720.8</td>
<td>87%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>5%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>2.1</td>
<td>5%</td>
<td>45.0</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>4%</td>
<td>53.9</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.6</td>
<td>4%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>2%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>0.3</td>
<td>1%</td>
<td>5.8</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>2010 Total</td>
<td>44.8</td>
<td>100%</td>
<td>825.6</td>
<td>100%</td>
</tr>
<tr>
<td>2030</td>
<td>Electricity generation coal</td>
<td>37.3</td>
<td>53%</td>
<td>896.1</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation solar</td>
<td>9.4</td>
<td>13%</td>
<td>66.4</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>5.8</td>
<td>8%</td>
<td>6.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>4.2</td>
<td>6%</td>
<td>81.1</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>3.6</td>
<td>5%</td>
<td>32.8</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>5%</td>
<td>48.2</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>2.9</td>
<td>4%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>3%</td>
<td>53.9</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation biomass</td>
<td>0.9</td>
<td>1%</td>
<td>19.8</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>1%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation gas</td>
<td>0.7</td>
<td>1%</td>
<td>6.6</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>2030 Total</td>
<td>70.9</td>
<td>100%</td>
<td>1210.9</td>
<td>100%</td>
</tr>
<tr>
<td>2050</td>
<td>Electricity generation solar</td>
<td>58.1</td>
<td>45%</td>
<td>595.0</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation coal</td>
<td>25.4</td>
<td>20%</td>
<td>676.4</td>
<td>36%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>25.0</td>
<td>19%</td>
<td>240.0</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>9.6</td>
<td>7%</td>
<td>278.0</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>3%</td>
<td>48.2</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>3.1</td>
<td>2%</td>
<td>48.3</td>
<td>3%</td>
</tr>
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<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>2%</td>
<td>4.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.5</td>
<td>1%</td>
<td>0.0</td>
<td>0%</td>
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<td></td>
<td>Electricity generation gas</td>
<td>0.2</td>
<td>0%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>2050 Total</td>
<td>128.8</td>
<td>100%</td>
<td>1889.9</td>
<td>100%</td>
</tr>
</tbody>
</table>

3.2.1.2 Energy input into electricity generation

While the capacities above present a diminished amount of coal generation capacity and increase in renewable energy capacity, an analysis of the actual energy used and electricity produced presents a significantly different picture. Coal remains the dominant energy input into electricity generation making up approximately 60% of the energy input in 2050 followed by wind, solar and nuclear as presented in Figure 3.4. The emissions constraints therefore put coal at a significant disadvantage emanating from the environmental costs associated with its use. Solar and wind have an increasing presence in the energy mix for electricity generation primarily due to the expected decrease in costs of these technologies. Nuclear energy also plays a significant role as nuclear power plants produce no GHGs and are not constrained by the imposed emissions limits.
Energy Input into Electricity Generation: Emissions Limit Case

Figure 3.4: Energy input into electricity generation in Emissions Limit Case (PJ)

Energy Input into Electricity Generation: Emissions Limit Case

Figure 3.5: Energy input into electricity generation in Emissions Limit Case (2010, 2030 and 2050)

The above differences in defining the “share” of renewable energy when setting targets needs to be carefully considered and stated as the desired outcomes can be significantly different. In summary coal is 18% share of electricity generation capacity, 60% of the energy input and 35% of the electricity
output. The specification of the desired outcome in terms of emissions limits would reduce this ambiguity as opposed to shares of a particular technology.

### 3.2.1.3 Water use and CO₂ emissions in electricity generation

Freshwater use and CO₂ emissions from electricity generation in the emissions limit case are presented in Figure 3.6 and Figure 3.7 respectively. Water is mainly used for cooling. There is a significant drop in the use of water due to the use of dry cooling in new coal fired plant and the use of renewable technologies which use less water.

![Water Used in Electricity Generation: Emissions Limit Case](image)

**Figure 3.6: Water used in electricity generation in Emissions Limit Case (Mt)**

Carbon dioxide emissions are primarily driven by coal use and therefore, due to the emissions limits and the reduction of coal dominance, emissions peak in about 2035 and start to decline in absolute terms in line with the imposed emissions constraints. The move away from coal in this test case significantly reduces the country's carbon emissions.
3.2.2 Liquid fuels production

Suggested investments in refineries, GTL and CTL are presented in this subsection.

3.2.2.1 Liquid fuels production capacity

Existing capacity and suggested new capacity for liquid fuel production technologies are provided in Figure 3.8. The total discounted costs of providing liquid fuel from CTL plants are lower than that for both conventional refineries and GTL plants as presented in the assumptions. The activity of CTL plants, however, is constrained by the associated high carbon dioxide emissions when the carbon emissions limits are considered. New CTL plants do not feature and in 2040 the existing CTL plant is decommissioned. The use of electric vehicles combined with increased imports of final product reduces emissions for the sector below the set limit.

Based on the costs of new refining capacity, crude oil prices and imported liquid fuel prices the modelling suggests new refining capacity of about 500,000 bbl/day to come on line in about 2020. Liquid fuels production capacity starts dropping from about 2040 and no new capacity is added. The liquid fuel imports make up the shortfall between liquid fuel demand and refining capacity. There is also substitution of liquid fuels with electricity in the outer years due to the increased uptake of electric vehicles.
Figure 3.8: Total capacity in liquid fuels production in Emissions Limit Case (kbbl/d)

Table 3.2: Liquid fuels production by technology 2010, 2030 and 2050

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
<th>Capacity</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PJ/a</td>
<td>kbbl/d</td>
<td>%</td>
</tr>
<tr>
<td>2010</td>
<td>Existing refinery</td>
<td>986</td>
<td>503</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td><strong>2010 Total</strong></td>
<td>1362</td>
<td>613</td>
</tr>
<tr>
<td>2030</td>
<td>Existing refinery</td>
<td>986</td>
<td>503</td>
</tr>
<tr>
<td></td>
<td>New refinery</td>
<td>723</td>
<td>369</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td><strong>2030 Total</strong></td>
<td>2085</td>
<td>938</td>
</tr>
<tr>
<td>2050</td>
<td>Existing refinery</td>
<td>986</td>
<td>503</td>
</tr>
<tr>
<td></td>
<td>New refinery</td>
<td>493</td>
<td>251</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>119</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td><strong>2050 Total</strong></td>
<td>1598</td>
<td>719</td>
</tr>
</tbody>
</table>

Inputs into liquid fuels production are shown in Figure 3.9. The majority of the input into liquid fuel production is crude oil followed by coal and a small amount of gas, used for both GTL and within the conventional refineries. Electricity usage remains virtually constant throughout the planning period. The use of crude oil decreases from about 2045 due to the growth of the electric vehicle fleet and increased imports of final product. New CTL plants effectively replace decommissioned CTL plants and there is little impact on the use of coal in liquid fuel production.
Figure 3.9: Feedstock into liquid fuels production in Emissions Limit Case (PJ)

Outputs from liquid fuel plants are shown in Figure 3.10 (and summarized in Table 3.2). The main outputs are petrol and diesel used for road transport. Residual fuel oil, aircraft fuel, liquid petroleum gas and paraffin are produced at a smaller scale. Decreases in production after 2045 are largely as a result of an increase in imports in order to meet the emissions limit. It should be noted that the absence of a carbon tax on imports in this test case results in increased imports. Imposing an emissions limit on production as well as imports would result in a different set of model output. The possible impact of a carbon tax is considered in a separate test case.
Carbon dioxide emission from liquid fuels production by plant type is shown in Figure 3.11 and water use is shown in Figure 3.12. The emissions profiles of liquid fuels production mirror the emissions constraints placed on the sector. Water use increases substantially with new refining capacity coming on stream in 2020.
3.3 Primary Energy

This section represents analysis of the primary energy mix as a result of the cost optimisation for the Emissions Limit Case.

3.3.1 Primary energy use

Extraction and import of primary energy for the Emissions Limit Case are presented in Figure 3.13. The import of crude oil for refining remains unchanged up until about 2020 when new crude-oil refining capacity comes on-stream. The liquid fuel demand for this period is met through imports which get partly replaced by crude oil and refining capacity but continue to grow steadily throughout the planning horizon. Biomass continues to play a small role in the energy mix and is used for electricity generation. Biofuels play no role in the production of liquid fuels as no firm policy decisions have been made regarding the blending of biofuels into petrol and diesel.

Coal continues to play a dominant role for the foreseeable future; however its contribution to the primary energy mix decreases gradually from 2010 through to 2050.

Natural gas shows a mild but steady increase as its share in the total energy mix increases from 3% in 2010, to 5% in 2030 and 9% in 2050. A small amount of natural gas is extracted and used for gas to liquids until around 2041 when the existing PetroSA gas-to-liquid plant reaches its end-of-life. The remainder of the natural gas is used directly in industrial purposes and to a certain extent within the commercial and residential sectors.

No new hydro is assumed, however as South Africa has recently signed a treaty for the Grand Inga project with the Democratic Republic of Congo, it could play a more promising and significant role in...
the future. Given the political challenges and the turmoil in the region, the potential for hydro from the Grand Inga is still highly uncertain.

There is an increase of nuclear energy in the primary energy supply as a new nuclear capacity comes on-stream in 2034. Wind and solar continue to play a role which becomes more significant from around 2039 when the costs of renewable technologies are expected to be much lower and local manufacturing capability may become well-established.

![Primary energy use: Emissions Limit Case](image)

**Figure 3.13: Total primary energy use in Emissions Limit Case (PJ)**

Coal plays a dominant role into the foreseeable future, however, by 2050 its contribution to primary energy supply decreases from 74% in 2010 reducing to 58% in 2030 and to 38% in 2050. Crude oil continues to also play a significant role in the medium-term (10% in 2030), but by 2050 its share of the primary energy mix decreases to 5% as refining of crude oil is replaced by imports of final petroleum products. This is supported by the contribution of imported petroleum products which increases from 18% in 2010 to 30% by 2050. The share of renewable energy sources (including biomass and hydro) increases from 1% in 2010 to 5% in 2030 and finally to 13% by 2050. As no new biomass and hydroelectric plants come on-stream, renewables are dominated by wind and solar (with a share of 7% and 5% respectively by 2050).
Crude oil and natural gas imports are presented in Figure 3.15 and the model output indicates a significant increase in imported final product (see Figure 3.16) which increases from 22m$^3$ in 2010 to 63m$^3$ by 2050.

The sudden drop in imports of refined product in 2020 is as a result of new refining capacity that comes on stream during that period. The current import capacity at Durban harbour is already constrained and imports of this magnitude will not be sustainable if at all possible. Transnet has embarked on a massive project to increase the capacity of the Durban harbour. This will include increases in the port and berth capacity for bulk liquid fuel imports and will significantly alleviate current constraints. No costs have been explicitly placed on new import and export capacities. In relation to crude oil and liquid fuels these are included in the margin costs per unit energy which are assumed to be infrastructure requirements.

Natural gas imports for the Emissions Limit Test Case are the same as for the Base Case.
3.4 Discounted Costs

The discounted costs for each year in the Emissions Limit Case are presented in Figure 3.17 and show the contribution of the various components of the energy system to the total costs.
The total discounted costs of the energy supply system (the area under the curve in Figure 3.17) for the Emissions Limit Case are 8.76% higher than the Base Case. The Emissions Limit Case has a higher dependence on imported energy which increases from about 80% of the total costs in 2010 to 90% of the total costs in 2050. The Emissions Limit Case favours imported energy to indigenous energy due to the high carbon content of local resources.

Figure 3.17: Total discounted costs in Emissions Limit Case (Rm‘2010)

More detailed information about the costs of imports are provided in Figure 3.18. The main import costs before 2020 are for diesel, petrol, LPG, paraffin and then natural gas. After 2020, with new refining capacity, the main costs are crude oil, diesel, petrol and natural gas imports.
3.5 CO₂ Emissions

Carbon dioxide emissions from transport, total final use of energy carriers, electricity generation, resource extraction and liquid fuel production are shown in Figure 3.19. Total emissions reach a peak of around 450Mt per annum in 2035 and start to decline to about 400Mt per annum by 2050.

Emissions from electricity generation increase only marginally through to around 2040. These start declining substantially from 2037 and by 2050 have reached levels below those in 2010. Emissions from liquid fuel production follow a similar peak plateau decline profile to the set emissions limit. However, emissions as a result of energy end-use continue to increase - the reason for this being that emission limits are only imposed on the supply-side and not on energy end-use in this test case. Additional data on energy end-use within individual demand sectors need to be obtained for the effect of constraints on emissions on the entire energy sector (supply-side and demand-side) to be analysed.
3.6 Water Use

Water consumption related to energy resource extraction and production, electricity generation and liquid fuels production is shown in Figure 3.20. Water consumption for electricity generation reduces substantially over the planning period: first after 2030 when some of the existing coal-fired fleet are decommissioned, followed by another step decrease around 2038 when even more are decommissioned. After this water consumption remains relatively flat up until 2050 as the remaining fleet is still largely in operation and new additions to capacity use little if any water. Water consumption for liquid fuel production remains relatively unchanged over the planning horizon as conventional refining technologies have little scope for reducing water use.
3.7 Emissions Limit Case Summary

Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the Emissions Limit Case over the model period are presented in Figure 3.21. Energy intensity decreases from ~2.2 TJ/Rm in 2010 to just under 1.5 TJ/Rm in 2030 and less than 1 TJ/Rm in 2050.

Water energy intensity reduces significantly during the planning period. A reduction from close to 0.075 Mt/PJ in 2010 to around 0.02 Mt/PJ in 2030 is observed. The small increase in 2031 is as a consequence of older power plants performing at a higher load factor to meet increasing demand before new plants come on-stream.

Overall the carbon energy intensity of the energy sector reduces from an average of ~0.09 Mt CO$_2$/PJ in 2010 to ~0.06 Mt CO$_2$/PJ by 2050 reflecting a 25% improvement over the modelled period.

Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the Emissions Limit Case costs R2701 billion (2010 Rand), 16811 Mt of CO$_2$ are emitted and 9630 Mt of water are consumed.
Figure 3.21: Emissions, water use and energy intensity in Emissions Limit Case
4. Emissions Limit - No New Nuclear Case

Given the country’s commitment to reduce carbon emissions, coupled with the public debate regarding the cost of nuclear technology, this Test Case seeks to test the impact of ensuring that emission reduction targets as defined in the National Climate Change Response Policy are met without nuclear as a supply technology option. It therefore seeks to analyse the effect of embarking upon or not embarking upon the New Nuclear Build Programme in terms of future energy security, as well as meeting the emission limit targets defined in the National Climate Change Response Policy.

This section presents the results of the optimisation model run for the Emissions Limit - No Nuclear Case and presents alternative energy supply technology options and the associated financial implications are presented, however system adequacy is not analysed. Transformation technology investments and activities are detailed and the sources of primary energy are discussed. Finally, the cost, carbon dioxide emissions and water consumption implications are presented. A summary of the key assumptions for the No Nuclear Case are as follows:

- All technology assumptions for the Base Case are applied;
- Annual emission limit constraints are set for electricity generation and liquid fuels production in line with the peak plateau decline constraints (i.e. Emissions Limit Case);
- No emission penalties (carbon taxes) are used; and
- No new nuclear plants are allowed.

4.1 Transport Demand Technologies

There are no deviations to the suggested vehicle fleet in the Emissions Limit - No Nuclear Case in comparison to the Base Case therefore all the observations made in the Base Case are relevant to this test case and no further discussion of the transport sector is presented here.

4.2 Transformation Technologies

Suggested new transformation infrastructure and the expected level of activity to meet demand are presented in this section. These technologies include power stations, refineries, coal to liquid and gas to liquid plants.

4.2.1 Electricity generation

This section represents investments in electricity generation and considers new and total generation capacity, the energy input into electricity generation and the electricity produced by the different types of technologies.

4.2.1.1 Generation capacity

A detailed breakdown of the new investments in electricity generation technologies is shown in Figure 4.1. Four types of solar energy are used, solar PV thin film, PV crystalline, solar CSP (tower with 12 hours storage and trough with 9 hours of storage). There is also considerable wind uptake. In comparison the Emissions Limit Case the No Nuclear Case deploys more wind capacity. The wind is limited to a maximum potential of 25 GW.
The large share of solar (45GW) implied by this test case need to be considered in more detail in terms of their variability and the impact on the national grid and overall system adequacy. As discussed in the Emissions Limit Case any CSP capacity above 22GW is likely to be impractical and further sources of energy such as natural gas technologies (which were not cost competitive with the unconstrained CSP technologies) will need to be considered.

![New Electricity Generation Capacity: No Nuclear Case](image)

**Figure 4.1: New electricity generation capacity in No Nuclear Case (GW)**

Total electricity generation capacity over the planning period for the No Nuclear Case is shown in Figure 4.2. The percentage share of each installed capacity towards the total electricity generation energy mix for 2010, 2030 and 2050 is summarised in Table 4.1.

As can be seen from the graphs and table, coal technologies lose their dominance in electricity generation capacity by 2030 and there are substantial investments in solar and wind (from around 2030). Solar technologies play the dominant role by 2050 followed by wind then coal. Petroleum products, hydro, biomass and natural gas continue to play a less significant role. The main reason for the increased share in renewable energy technologies is to keep within the specified emissions limits. Substantial additional capacity of just under 45GW is needed in 2050 compared to the Base Case requirements as the renewable energy technologies have lower capacity factors related to the availability of sunlight and the intermittency of wind. This is an additional 5GW more than the Emissions Limit Case as the nuclear technologies have higher capacity factors compared with the renewable energy technologies which make up the shortfall when new nuclear plants are excluded.
Figure 4.2: Total electricity generation capacity in No Nuclear Case (GW)

Figure 4.3: Electricity generated by technology type in No Nuclear Case (PJ)
Table 4.1: Electricity generation in No Nuclear Case (2010, 2030 and 2050)

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology Type</th>
<th>Capacity (GW)</th>
<th>Capacity (% of total)</th>
<th>Electricity Produced (PJ)</th>
<th>Electricity Produced (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Electricity generation coal</td>
<td>35.9</td>
<td>80%</td>
<td>720.8</td>
<td>87%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>5%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>2.1</td>
<td>5%</td>
<td>45.0</td>
<td>5%</td>
</tr>
<tr>
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<td>1.8</td>
<td>4%</td>
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<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.6</td>
<td>4%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>2%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>0.3</td>
<td>1%</td>
<td>5.6</td>
<td>1%</td>
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<tr>
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<td>2010 Total</td>
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</tr>
<tr>
<td>2030</td>
<td>Electricity generation coal</td>
<td>37.3</td>
<td>53%</td>
<td>903.1</td>
<td>74%</td>
</tr>
<tr>
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<td>Electricity generation solar</td>
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<td>14%</td>
<td>69.7</td>
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<tr>
<td></td>
<td>Electricity generation biomass</td>
<td>0.9</td>
<td>1%</td>
<td>19.8</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>1%</td>
<td>0.0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>2030 Total</td>
<td>70.7</td>
<td>100%</td>
<td>872.9</td>
<td>46%</td>
</tr>
<tr>
<td>2050</td>
<td>Electricity generation solar</td>
<td>80.1</td>
<td>57%</td>
<td>872.9</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation coal</td>
<td>25.4</td>
<td>18%</td>
<td>676.4</td>
<td>36%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>25.0</td>
<td>18%</td>
<td>240.0</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>2%</td>
<td>48.2</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>3.1</td>
<td>2%</td>
<td>48.3</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>2%</td>
<td>3.4</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.5</td>
<td>1%</td>
<td>0.9</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>2050 Total</td>
<td>141.0</td>
<td>100%</td>
<td>1889.3</td>
<td>100%</td>
</tr>
</tbody>
</table>

4.2.1.2 Energy input into electricity generation

While the capacities above present a large decrease in the amount of coal generation capacity and increase in renewable energy capacity an analysis of the actual energy used and electricity produced presents a significantly different picture.

Coal remains the dominant energy input into electricity generation making up approximately 61% of the energy input in 2050 followed by wind and solar as presented in Figure 4.4. The emissions constraints therefore put coal at significant disadvantage emanating from the environmental costs associated with its use. Solar and wind have an increasing presence in the energy mix for electricity generation primarily due to the expected decrease in costs of these technologies. The nuclear energy shown is due to the existing nuclear plant which is allowed to continue operation until the end of its life.

When the electricity output is considered, as in Figure 4.5, efficiencies of the various technologies alter the picture further with the change in perspective as discussed in the Emissions Limit test case.
4.2.1.3 Water use and CO₂ emissions in electricity generation

Freshwater use and CO₂ emissions from electricity generation in the Emissions Limit – No Nuclear Case are presented in Figure 4.6 and Figure 4.7 respectively. Water is used mainly for cooling and there is a significant drop in the use of water due to the use of dry cooling in new coal fired plants.
Due to the emissions limits and the reduction of coal dominance, emissions peak at around 2038 and start to decline in absolute terms. The move away from coal in this test case significantly reduces the country’s carbon emissions. The exclusion of new nuclear plants has no significant impact on the water use or emissions in relation to the Emissions Limit Case.
4.2.2 Liquid fuels production
The exclusion of nuclear energy has no significant impact of the liquid fuels sector in comparison to the Emissions Limit Case.

4.3 Primary Energy
This subsection represents analysis of the primary energy mix as a result of the cost optimisation for the Emissions Limit - No Nuclear Case.

4.3.1 Primary energy use
Primary energy use in the No Nuclear Case differs from the Emissions limit Case only in relation to electricity generation. Extraction and import of primary energy for the No Nuclear Case are presented in Figure 4.8. Coal continues to play a dominant role for the foreseeable future; however its contribution to the primary energy mix decreases from 2034 through to 2050. Biomass continues to play a small role in the energy mix and is used for electricity generation. In comparison to the Emissions Limit Case more wind and solar energy technologies are used in this test case as are the next most cost effective technologies available when nuclear technologies are excluded from the list of options. As in the Emissions Limit Case the implications of the practical limits to CSP need further consideration.

![Figure 4.8: Total primary energy use in No Nuclear Case (PJ)](image-url)
4.3.2 Energy imports
Imports of crude oil and petroleum product are not influenced by the exclusion of nuclear technologies in the productions of electricity in relation to the Emissions Limit – No Nuclear Case.

4.4 Discounted Costs
Only the electricity generation costs in the Emissions Limit – No Nuclear Case vary from the costs in the Emissions limit case. The discounted costs for electricity generation are presented in Figure 4.10. Costs due to solar and wind investments are evident throughout the period, with wind being dominant in the first half of the period and solar being dominant in the second half. In the first half of the period, however, there are considerable costs related to coal, biomass and hydro electricity generation. The cost presented provide the overnight cost of investments and when they are required; final electricity prices are determined by how these investments are financed and who they are financed by.
Figure 4.10: Total discounted costs for electricity generation in the Emissions Limit - No Nuclear Case (Rm)

4.5 CO₂ Emissions
The carbon emissions profile of the Emissions Limit - No Nuclear Case are very similar to that for the Emissions Limit Case. The reason for this is that they are both limited by the same emissions limit constraint. The renewable energy technologies which replace the nuclear capacity in this test case do not emit CO₂ but there may be slight changes to the loading of carbon emitting technologies during peak periods.

4.6 Water Use
Water consumption related to energy extraction and production, electricity generation and liquid fuels production is shown in Figure 4.11. Water use for the Emissions Limit – No New Nuclear Case is slightly higher than for the Emissions Limit Case as a result of the solar energy technologies, used for operating and maintaining the plants, whereas the nuclear plants in the Emissions Limit Case are assumed to use sea water.
4.7 Emissions Limit - No New Nuclear Case Summary

Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the Emissions Limit - No Nuclear Case over the model period are presented in Figure 4.12.

Overall the carbon energy intensity of the energy sector reduces from an average of ~0.09 Mt CO$_2$/PJ in 2010 to ~0.06 Mt CO$_2$/PJ by 2050 reflecting on average a 25% improvement throughout the planning period.

Water energy intensity reduces significantly during the planning period. A reduction from close to 0.7 Mt/PJ in 2010 to around 0.04 Mt/PJ in 2030 is observed. The small increase in 2031 is as a consequence of older power plants performing at a higher load factor to meet increasing demand before new plants come on-stream. This reduces again to levels just above 0.01 Mt/PJ by 2050.

Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the No Nuclear Case costs R2705 billion (2010 Rand), 16808 Mt of CO$_2$ are emitted and 9845 Mt of water are consumed.
Figure 4.12: Emissions, water use and energy intensity in No Nuclear Case
5. Renewable Energy Target Case

In the Renewable Energy Target Case, no emission limit constraints are set but renewable energy targets are gradually increased in the energy mix from 2010 to 2030 such that by 2030, 10% of total energy output (electricity generation and liquid fuel production) is from renewable energy resources. From 2031 onwards, the target of 10% is maintained as a minimum. This Test Case seeks to analyse the efficacy of setting renewable energy targets for reducing emissions within the energy sector in the absence of other policy efforts to reduce emissions.

This section presents the results of the optimisation model run for a Renewable Energy Target Case. Transformation technologies investments and activities are detailed. The sources of primary energy are discussed and finally the implications for water demand and carbon dioxide emissions are presented. A summary of the key assumptions for the Renewable Energy Target are as follows:

- Electricity supply options are informed by current commitments. These are Eskom’s pre-IRP determinations and NERSA’s 2011 and 2012 determinations;
- All renewable energy technologies as per the 2011 and 2012 NERSA determinations are available to the model;
- No annual emission limit constraints are set;
- No emission penalties (carbon tax) are set;
- No constraints are defined for liquid fuel production except for the assumption that if CTL is invested in then an 80000 bbl/day constraint is in place based on proposed capacity of a new CTL plant; and
- A minimum renewable energy target, of the total primary energy, increasing linearly from 0% in 2010 to 10% by 2030 was set.

5.1 Transport Demand Technologies

There are no deviations to the suggested vehicle fleet in the Renewable Energy Target Case in comparison to the Base Case therefore all the observations made in the Base Case remain true and no further discussion of the transport sector is presented here.

5.2 Transformation Technologies

Requirements for new transformation infrastructure and the expected level of activity are presented in this section. These technologies include power stations, refineries, coal to liquid and gas to liquid plants.

5.2.1 Electricity generation

This section represents investments in electricity generation and considers new and total generation capacity, the energy input into electricity generation and the electricity produced by the different types of technologies.
5.2.1.1 Generation capacity

A detailed breakdown of the new investments in electricity generation technologies for the Renewable Energy Target Case is shown in Figure 5.1. The Renewable Energy Target Case has the same technologies as the Emissions Limit Case but contains more coal and less CSP capacity. The CSP trough, which is the most expensive solar technology, has 5GW of capacity built but there is 30GW of new coal built. The capacity factor for coal technologies compared to solar technologies reduces the total capacity required for this test case compared to the Emissions Limit Case.

![New Electricity Generation Capacity: Renewable Energy Target Case](image)

Figure 5.1: New electricity generation capacity in Renewable Energy Target Case (GW)

Total electricity generation capacity over the planning period for the Renewable Energy Target Case is shown in Figure 5.2. New capacity and total capacity for 2010, 2030 and 2050 as well as the percentage share of each technology towards the electricity generated is summarised in Figure 5.3 and Table 5.1. As can be seen from the graph and the table, coal technologies lose their dominance in electricity generation capacity by 2030 and there are substantial investments in solar and wind. By 2050, solar technologies play a dominant role, followed by coal and then wind. Petroleum products, hydro, biomass and natural gas continue to play a less significant role. The main reason for the increased share in renewable energy technologies to 2030 is to obtain the renewable energy target after which lower renewable energy technology costs maintain the increase in these technologies.
Figure 5.2: Total electricity generation capacity in Renewable Energy Target Case (GW)

Figure 5.3: Electricity generated by technology type in Renewable Energy Target Case (PJ)
Table 5.1: Electricity generation in Renewable Energy Target Case (2010, 2030 and 2050)

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Capacity</th>
<th>%</th>
<th>Electricity Produced</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GW</td>
<td></td>
<td>GW</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Electricity generation coal</td>
<td>35.9</td>
<td>80.15%</td>
<td>740.3</td>
<td>87.60%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>5.36%</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>2.1</td>
<td>4.69%</td>
<td>45.0</td>
<td>5.33%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>4.02%</td>
<td>53.9</td>
<td>6.38%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.6</td>
<td>3.63%</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>1.70%</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>0.3</td>
<td>0.66%</td>
<td>5.8</td>
<td>0.69%</td>
</tr>
<tr>
<td>2030</td>
<td>Total</td>
<td>44.8</td>
<td>100.00%</td>
<td>845.1</td>
<td>100.00%</td>
</tr>
<tr>
<td>2050</td>
<td>Electricity generation coal</td>
<td>41.2</td>
<td>33.99%</td>
<td>1103.7</td>
<td>58.07%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>20.9</td>
<td>17.25%</td>
<td>200.8</td>
<td>10.56%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation biomass</td>
<td>3.4</td>
<td>2.62%</td>
<td>76.6</td>
<td>4.03%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>1.99%</td>
<td>4.6</td>
<td>0.24%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>3.1</td>
<td>2.56%</td>
<td>48.3</td>
<td>2.54%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.5</td>
<td>1.25%</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>2.62%</td>
<td>48.2</td>
<td>2.53%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation solar</td>
<td>45.0</td>
<td>37.12%</td>
<td>418.5</td>
<td>22.02%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation gas</td>
<td>0.2</td>
<td>0.20%</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td>Total</td>
<td>121.2</td>
<td>100.00%</td>
<td>1900.6</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Total electricity usage in this test case is similar to that in the Base Case and higher than the emissions limited test cases. This is due primarily to renewable energy technologies which have lower capacity factors (related to the availability of sunlight and the intermittency of wind) but is also impacted by increased electricity demand in the liquid fuels sector as additional CTL capacity is built in the absence of emissions constraints.

5.2.1.2 Energy input into electricity generation

For the Renewable Energy Target Case coal remains the dominant energy input into electricity generation making up approximately 76% of the energy input in 2050 followed by solar, wind and biomass as presented in Figure 5.4. Solar and wind have an increasing presence in the energy mix for electricity generation primarily due to the expected decrease in costs of these technologies. Their growth, however, is much slower than the emissions limit related test cases. The energy input into electricity generation for the Renewable Energy Target Case shows that a renewable energy target can be met without necessarily decreasing over reliance on coal and absolute as well as relative reductions in emissions. While coal use in electricity generation initially drops (due to existing plant being retired), new coal generation capacity is built at the same time as renewable energy technologies to meet growing demand after 2030.
5.2.1.3 Water use and CO₂ emissions in electricity generation

Freshwater use and CO₂ emissions from electricity generation are presented in Figure 5.6 and Figure 5.7 respectively. Water for electricity generation is mainly used for cooling in coal-fired power plants.
and there is a significant drop in the use of water due to the use of dry cooling in new coal fired plant. However, more water is required for biomass plants and solar plants than in the Base Case.

**Figure 5.6: Water used in electricity generation in Renewable Energy Target Case (Mt)**

Emissions decrease between 2020 and 2030 due to the determinations but continue increasing from about 2030 as new coal plants are built with the retirement of existing plants. The increase is less pronounced than in the Base Case.
5.2.2 Liquid fuels production

The renewable energy target has no impact on liquid fuel production capacity, in comparison to the Base Case, as renewable energy resources have currently only been implemented for electricity generation.

5.3 Primary Energy

This subsection represents analysis of the primary energy mix as a result of the cost optimisation for the Renewable Energy Target Case.

5.3.1 Primary energy use

Extraction and import of primary energy are presented in Figure 5.8. The Renewable Energy Target Case is similar to the Base Case but there is less dependence on coal in favour of wind and biomass for electricity generation in the second half of the modelled period. The Renewable Energy Target Case has lower penetration of renewable energies compared to the emissions limited cases as the renewable energy targets do not translate into the same level of GHG mitigation ambition as the emissions constraints.
5.4 Discounted Costs

The discounted costs for electricity generation in the Renewable Energy Target Case are presented in Figure 5.10 and show the contribution of the various components of the energy system to the total electricity generation costs.
The total discounted costs of the energy supply system for the Renewable Energy Target Case are 3.5% higher than the Base Case. The Renewable Energy Target Case has a lower cost component due to imported energy but it still increases from about 75% of the total costs in 2010 to 85% of the total costs in 2050. This is a concern from for energy diversity and balance of trade.

![Discounted Costs (electricity generation): Renewable Energy Target Case](image)

**Figure 5.10: Total discounted costs for electricity generation in Renewable Energy Target Case (Rm)**

### 5.5 CO₂ Emissions

Carbon dioxide emissions from transport, total final use of energy carriers, electricity generation, resource extraction and liquid fuel production are shown in Figure 5.11.
Emissions from electricity generation increase slightly to 2020 then decrease by 20 Mt to 2030 and then increase steadily for the rest of the modelled period. Emissions from liquid fuel production increase with the suggested new CTL in 2020 and then drop when existing CTL is taken off line. Emissions as a result of energy end-use continue to increase - the reason for this being that no emission limits constraints are imposed on energy end-use.

Figure 5.11: Total CO$_2$ emissions from all energy use in Renewable Energy Target Case (Mt)
5.6 Water Use
The water consumption profile for the Renewable Energy Target Case is similar to the Base Case with the exception of the slightly lower water requirements for biomass plants and solar plants in this case compared to the coal plants they displace from the Base Case (Figure 5.12).

![Water Use in the Energy Sector: Renewable Energy Target Case](image)

Figure 5.12: Total water use in energy sector in Renewable Energy Target Case (Mt)

5.7 Renewable Energy Target Case Summary
Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the Renewable Energy Target Case over the model period are presented in Figure 5.13. Energy intensity decreases from ~2.4TJ/Rm in 2010 to just over 1.5 TJ/Rm in 2030 and just above 1.1 TJ/Rm in 2050.

Overall the carbon energy intensity of the energy sector reduces from an average of ~0.09 Mt CO$_2$/PJ in 2010 to ~0.065 Mt CO$_2$/PJ by 2050 reflecting a 20% improvement throughout the planning period.

Water energy intensity reduces significantly during the planning period. A reduction from close to 0.08 Mt/PJ in 2010 to around 0.05 Mt/PJ in 2030 is observed. This reduces again to levels just below 0.03 Mt/PJ by 2050.

Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the Renewable Energy Target Case costs R 2570 billion (2010 Rand), 20419 Mt of CO$_2$ are emitted and 11800 Mt of water are consumed.
Figure 5.13: Emissions, water use and energy intensity in Renewable Energy Target Case
6. Carbon Tax Case

The Carbon Tax Case considers the impact of the proposed Carbon Tax Policy on the structure of the energy system and its costs. Transformation technologies investments and activities are detailed. The sources of primary energy are discussed and finally the implications for water demand and carbon dioxide emissions are presented. A summary of the key assumptions for the Carbon Tax Case are as follows:

- All technology assumptions for the Base Case are applied;
- The proposed Carbon Tax Policy is used as a guide for testing the impact of a carbon tax. An exact implementation of the policy was not possible as individual emitters are not considered in the context of the IEP – rather groups of technologies are considered;
- For emissions excluding those from the petroleum sector, an initial R48 per ton of CO$_2$ is assumed from 2015 (to accommodate threshold allowances) with an annual increase of 10% on the effective tax rate up to a maximum of R120/ton which is then maintained for the remainder of the planning period. An additional allowance for trade exposure is taken into consideration for the petroleum sector with a starting tax rate of R36/ton with the same increase rate and R120/ton limit applied.

6.1 Transport Demand Technologies

There are no deviations to the suggested vehicle fleet in the Carbon Tax Case in comparison to the Base Case therefore all the observations made in the Base Case remain true and no further discussion of the transport sector is presented here.

6.2 Transformation Technologies

Requirements for new transformation infrastructure and the expected level of activity are presented in this section. These technologies focus on electricity generation.

6.2.1 Electricity generation

This section represents investments in electricity generation and considers new and total generation capacity, the energy input into electricity generation and the electricity produced by the different types of technologies.

6.2.1.1 Generation capacity

A detailed breakdown of the new investments in electricity generation technologies for the Carbon Tax Case is shown in Figure 6.1. The technologies used for the new generation capacity are similar to those determined in the Emissions Limit Case. The new capacity has an even mix of generation technologies and the CSP technologies are within the expected practical capacity limits (of 22GW).
Figure 6.1: New electricity generation capacity in Carbon Tax Case (GW)

Total electricity generation capacity over the planning period for the Carbon Tax Case is shown in Figure 6.2. New capacity and total capacity for 2010, 2030 and 2050 as well as the percentage share of each technology towards the electricity generated are summarised in Figure 6.3 and Table 6.1. As with the Base Case, coal technologies lose their dominance in electricity generation capacity by 2030 and there are substantial investments in solar, wind and nuclear technologies. By 2050, solar technologies make up a considerable part of total capacity, followed by coal and then wind. Petroleum products, hydro, biomass and natural gas continue to play a less significant role. The main reason for the increased share in renewable energy technologies to 2030 is the increasing costs of carbon dioxide emissions and the reducing costs of renewable energy.
Figure 6.2: Total electricity generation capacity in Carbon Tax Case (GW)

Figure 6.3: Electricity generated by technology type in Carbon Tax Case (PJ)
### Table 6.1: Electricity generation in Carbon Tax Case (2010, 2030 and 2050)

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Total Capacity</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Electricity generation coal</td>
<td>35.9</td>
<td>80.15%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>2.4</td>
<td>5.36%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>2.1</td>
<td>4.69%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>4.02%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>1.6</td>
<td>3.53%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>1.70%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>0.3</td>
<td>0.56%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>44.8</td>
<td>100.00%</td>
</tr>
<tr>
<td>2030</td>
<td>Electricity generation coal</td>
<td>37.3</td>
<td>51.54%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation solar</td>
<td>10.5</td>
<td>14.52%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation petroleum</td>
<td>5.8</td>
<td>8.06%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>4.6</td>
<td>6.36%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>3.6</td>
<td>4.97%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>4.72%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>2.9</td>
<td>4.02%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>1.8</td>
<td>2.49%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation biomass</td>
<td>0.9</td>
<td>1.21%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation other</td>
<td>0.8</td>
<td>1.13%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation gas</td>
<td>0.7</td>
<td>0.98%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>72.4</td>
<td>100.00%</td>
</tr>
<tr>
<td>2050</td>
<td>Electricity generation solar</td>
<td>37.0</td>
<td>31.30%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation coal</td>
<td>36.0</td>
<td>30.41%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation wind</td>
<td>25.0</td>
<td>21.14%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation nuclear</td>
<td>9.6</td>
<td>8.12%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation DSM</td>
<td>3.4</td>
<td>2.89%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation hydro</td>
<td>3.1</td>
<td>2.63%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation pumped storage</td>
<td>2.4</td>
<td>2.04%</td>
</tr>
<tr>
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<td>Electricity generation other</td>
<td>1.5</td>
<td>1.28%</td>
</tr>
<tr>
<td></td>
<td>Electricity generation gas</td>
<td>0.2</td>
<td>0.20%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>118.3</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

#### 6.2.1.2 Energy input into electricity generation

For the Carbon Tax Case coal remains the dominant energy input into electricity generation making up approximately 76% of the energy input in 2050 followed by solar, wind and biomass as presented in Figure 6.4. Solar and wind have an increasing presence in the energy mix for electricity generation primarily due to the expected decrease in costs of these technologies. Their growth, however, is much slower than the emissions limit related test cases.

The energy use for electricity generation in this test case is shown to be similar to the Base Case and higher than the emissions limited test cases. This is due to renewable energy technologies having lower capacity factors (related to the availability of sunlight and the probability of wind) but is also impacted by increased electricity demand in the liquid fuels sector as additional coal to liquids capacity built in the absence of emissions constraints.
6.2.1.3 Water use and CO₂ emissions in electricity generation

Freshwater use and CO₂ emissions from electricity generation are presented in Figure 6.6 and Figure 6.7 respectively. The water used in the Carbon Tax Case is between the consumption in the Base Case and Emissions Limit Case.
Carbon dioxide emissions for the Carbon Tax Case are different from both the Base Case and the Emissions Limit Case. It shares the peaks around 2020 and the mid 2030’s with the Emissions limit Case but remains relatively flat and below 250 Mt/a to 2050 when the Emissions Case drops and the Base case continues increasing.
6.2.2 Liquid fuels production

Liquid fuels production in the Carbon Tax Case is the same as the liquid fuels production in the Base Case. Unlike the Emissions Limit Case which constrains the emissions from electricity generation and liquid fuels production separately the Carbon Tax Case is flexible to determining the most cost effective way to minimise the energy system costs by determine trade-offs between electricity generation and liquid fuels production. The Carbon Tax Case results electricity generation as the most cost effective subsector for emissions mitigation. The carbon tax also does not significantly impact liquid fuels production and use as the tax relative to the price of the fuels is quite small (in the order of 1%). However, it does have a significant impact on the cost using coal in CTL. Liquid fuels production for the Carbon Tax Case will not be considered any further here.

6.3 Primary Energy Use

This subsection represents analysis of the primary energy mix as a result of the cost optimisation for the Carbon Tax Case.

6.3.1 Primary energy use

Primary energy use in the Carbon Tax Case is presented in Figure 6.8. The profile of primary energy use in the Carbon Tax Case is similar to the Base Case but the slope is shallower. The profile is still influenced by additional CTL in 2020 and the retirement of old CTL in 2041. The overall slope of the profile is reduced by coal use in the electricity sector.

![Figure 6.8: Total primary energy use for Carbon Tax Case (PJ)](image-url)
6.4 Discounted Costs

The discounted costs for each year in the Carbon Tax Case are presented in Figure 6.10 and show the contribution of the various components of the energy system to the total costs. The total discounted costs of the energy supply system for the Carbon Tax Case are 3.5% higher than the Base Case. Most of this cost difference is due to electricity infrastructure investment. A more detailed breakdown of the timing and amount of investments in electricity generation are shown in Figure 6.11.

The timing of electricity generation investments in the Carbon Tax Case is the same as the Emissions Limit Case but the type of technologies and magnitudes of investment are different. In the Carbon Tax Case there is more investment in coal, nuclear and biomass technologies whereas in the Emissions Limit Case investments are mainly in solar and wind technologies.
Figure 6.10: Total discounted costs for energy supply in Carbon Tax Case (Rm)

Figure 6.11: Total discounted costs for electricity generation in Carbon Tax Case (Rm)

6.5 CO₂ Emissions
Carbon dioxide emissions from transport, total final use of energy carriers, electricity generation, resource extraction and liquid fuel production for the Carbon Tax Case are shown in Figure 6.12.
Emissions from electricity generation increase slightly to 2020 and plateau to 2031 and then after a small decrease remain to 2048 where there is a small increase. Emissions from liquid fuel production increase with the suggested new CTL in 2020 and then drop when existing CTL is taken off line. The emissions from liquid fuels production and final energy use show no change from the Base Case.

![Graph showing CO2 emissions from transport, final demand, and energy supply: Carbon Tax Case](image)

**Figure 6.12: Total CO2 emissions from all energy use in Carbon Tax Case (Mt)**

### 6.6 Water Use

Water consumption related to energy extraction and production, electricity generation and liquid fuels production is shown in Figure 6.13. Water consumption reflects a combination of the Base Case and the Emissions Limit case with water use in electricity generation resembling the Emissions Limit Case whereas water consumption from liquid fuels production resembles the Base Case.
6.7 Carbon Tax Case Summary

Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the Carbon Tax Case over the model period are presented in Figure 6.14. Although the projected demand increases substantially, the energy intensity - measured in Terajoules per Million Rand (TJ/Rm) – reduces to less than half on 2010 levels. For the industrial, commercial, agricultural and residential sectors, this assumes that the rate of historical efficiency improvements continues into the future. For the transport sector, the penetration of more efficient vehicle technologies (such as electric vehicles) contribute to improved efficiencies in this sector. Energy intensity decreases from ~2.3 TJ/Rm in 2010 to just under 1.5 TJ/Rm in 2030 and less than 1 TJ/Rm in 2050.

Overall the carbon energy intensity of the energy sector reduces from an average of ~0.09 Mt CO$_2$/PJ in 2010 to ~0.06 Mt CO$_2$/PJ by 2050 reflecting a 33% improvement throughout the planning period.

Water energy intensity reduces significantly during the planning period. A reduction from close to 0.08 Mt/PJ in 2010 to around 0.06 Mt/PJ in 2030 is observed. This reduces again to levels just above 0.02 Mt/PJ by 2050.

Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the Carbon Tax Case costs R2644 billion (2010 Rand), 19833 Mt of CO$_2$ are emitted and 12043 Mt of water are consumed.
Figure 6.14: Emissions, water use and energy intensity in Carbon Tax Case
7. High Oil Price Case

Sensitivity analyses were conducted on the Base Case in order to test the impact of different crude oil price scenarios on decisions for new refining capacity.

This section presents the results of the optimisation model run for the High Oil Price Case. The purpose of this test case is to consider the sensitivity of the energy system to high crude oil prices (and prices of petroleum products derived from crude oil prices) applied to the Base Case. Transformation technology investments and activity are detailed and the sources of primary energy are discussed. Finally, the costs, carbon dioxide emissions and water consumption implications are presented.

7.1 Transport Demand Technologies

The High Oil Price Case deviates from the Base Case in terms of the private vehicle fleet investments but the other transport types are not impacted due to the limited technology options considered. The private vehicle fleet is discussed below.

7.1.1 Private Car Fleet

Investments in new vehicles for the car fleet are presented in Figure 7.1. As with the Base Case there is significant uptake of electric vehicles in the second half of the modelled period. There is, however, also investment in hybrid vehicles in the medium term as the high oil prices justify the additional costs for this technology due to the savings in the cost of fuel.

![Figure 7.1: Investment in car fleet capacity in High Oil Price Case](image)

The energy consumption by private cars is shown in
Figure 7.2. The shape of the fuel use curve for the High Oil Price Case is similar to the Base Case in that they both start at current consumption levels and increase into about the mid 2030's and then decline for the rest of the period. The peak annual consumption, however, is lower for the High Oil Price Case (350 PJ per annum) compared to the Base Case (425 PJ per annum) due to the uptake of the hybrid vehicles in the medium term.

Figure 7.2: Energy used by car fleet in High Oil Price Case

7.2 Transformation Technologies
Requirements for new transformation technologies and the expected level of activity are presented in this section. These technologies are considered under electricity generation and liquid fuels production.

7.2.1 Electricity generation
The range of oil prices considered in the modelling has no impact on the capacities of the various electricity generation technologies in comparison to the Base Case and will not be discussed further.

7.2.2 Liquid fuels production
Suggested investments in refineries, GTL and CTL are presented in this subsection.

7.2.2.1 Liquid fuels production capacity
Existing capacity and suggested new capacity for liquid fuels production technologies for the High Oil Price Case are provided in Figure 7.3. The total discounted costs of providing liquid fuels from GTL are lower than both conventional refineries and CTL as opposed to the Base Case. This is due to the higher oil price while the international gas prices were assumed to remain unchanged.

The capacity of new GTL would need to be about 500 000 bbl/day and come on line in about 2020.
Figure 7.3: Total capacity in liquid fuels production in High Oil Price Case (kbbl/d)

Inputs into liquid fuels production are shown in Figure 7.4. In the High Oil Price Case GTL essentially replaces the conventional refinery capacity that would be built in the Base Case.

Figure 7.4: Feedstock into liquid fuels production in High Oil Price Case (PJ)

Outputs from liquid fuel plants are shown in Figure 7.5 and summarized in Table 7.1. The main outputs are petrol and diesel used primarily for road transport. Residual fuel oil, aircraft fuel and liquid
petroleum gas are produced at a smaller scale and paraffin is largely displaced by LPG. The output varies from the Base Case due to the uptake of hybrid vehicles in the medium term and the different slates assumed for CTL and GTL, where GTL is assumed to have a bias towards diesel production.

![Petroleum Products Produced: High Oil Price Case](image)

**Figure 7.5: Liquid fuels production in High Oil Price Case (million m$^3$)**
Table 7.1: Liquid fuels production by technology 2010, 2030 and 2050

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
<th>Capacity PJ/a</th>
<th>Production kbbl/d</th>
<th>% Production PJ/a</th>
<th>% Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
<td>72%</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>132</td>
<td>22%</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>37</td>
<td>6%</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>2010 Total</td>
<td>1362</td>
<td>613</td>
<td>100%</td>
<td>445</td>
</tr>
<tr>
<td>2030</td>
<td>New GTL</td>
<td>993</td>
<td>447</td>
<td>39%</td>
<td>893</td>
</tr>
<tr>
<td></td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
<td>39%</td>
<td>907</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>132</td>
<td>12%</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>176</td>
<td>79</td>
<td>7%</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>37</td>
<td>3%</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>2030 Total</td>
<td>2530</td>
<td>1139</td>
<td>100%</td>
<td>2299</td>
</tr>
<tr>
<td>2050</td>
<td>New GTL</td>
<td>1505</td>
<td>677</td>
<td>56%</td>
<td>1354</td>
</tr>
<tr>
<td></td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
<td>37%</td>
<td>907</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>176</td>
<td>79</td>
<td>7%</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>2050 Total</td>
<td>2667</td>
<td>1200</td>
<td>100%</td>
<td>2420</td>
</tr>
</tbody>
</table>

Carbon dioxide emission from liquid fuels production by plant type is shown in Figure 7.6 and water use is shown in Figure 7.7. The carbon dioxide emissions are about 10% higher in the High Oil Price Case compared to the Base Case as the GTL has higher emissions compared to crude oil refineries for the same amount of products produced.

Figure 7.6: CO₂ emissions from liquid fuels production in High Oil Price Case (Mt)
7.3 Primary Energy

This subsection represents analysis of the primary energy mix as a result of the cost optimisation for the High Oil Price Case.

7.3.1 Primary energy use

Extraction and import of primary energy are presented in Figure 7.8. In comparison to the Base Case, the High Oil Price Case has significantly lower imports of crude oil for refining and a correspondingly higher level of natural gas imports for GTL. The primary energy input into the system is unchanged for electricity production when comparing the High Oil Price Case and the Base Case.
7.3.2 Energy imports

Crude oil and natural gas imports are presented in Figure 7.10 and imported final product are shown in Figure 7.11. Low levels of imported crude oil and gas occur to 2020 due to the economic viability of local refining in this period largely because of the difference in price between internationally traded
petroleum products and crude oil. Gas levels are low during this period as there is significantly less existing GTL capacity available. The lead times for both conventional and GTL refineries also play a role in determining when imported products are used.

![Imports of Crude Oil and Natural Gas: High Oil Price Case](image1)

**Figure 7.10: Imports of crude oil and natural gas in High Oil Price Case**

![Imports of Petroleum Products: High Oil Price Case](image2)

**Figure 7.11: Imports of petroleum products in High Oil Price Case**
7.4 Discounted Costs

The discounted costs for the High Oil Price Case are the same as the Base Case for electricity generation but the imports and liquid fuels production are different and presented in Figure 7.12. As with the other test cases the trade-offs between new refining capacity with corresponding primary energy imports and imported final products are evident. Before 2020, imports of final product are makeup the majority of the costs, mainly for diesel and petrol. After 2020, imports still include diesel but crude oil and natural gas are also imported. The crude oil is used in existing refineries but the Gas is used in new GTL.

The total discounted costs of the energy system for the High Oil Price Case is 20% higher than the Base Case and it has a higher dependence on imported energy which increases from about 80% of the total costs in 2010 to 90% of the total costs in 2050. This is a concern from an energy diversity and balance of trade. High oil prices make the extraction and use of indigenous energy resources more viable albeit with additional emissions.

![Discounted costs: High Oil Price Case](image)

**Figure 7.12: Total discounted costs for imports and liquid fuels production in High Oil Price Case (Rm'2010)**

7.5 CO₂ Emissions

Carbon dioxide emissions from transport, total final use of energy carriers, electricity generation, resource extraction and liquid fuel production are shown in Figure 7.13. Emissions for the High Oil Price Case have the same overall profile as the Base Case. In the High Oil Price, however, absolute emissions are 3% higher due to GTL being used as opposed to crude oil refineries in the Base Case.
7.6 Water Use

Water consumption related to energy extraction and production, electricity generation and liquid fuels production is shown in Figure 7.14.
7.7 High Oil Price Case Summary

Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the High Oil Price Case over the model period are presented in Figure 7.15. Although the projected demand increases substantially over the planning period, the energy intensity - measured in Terajoules per Million Rand (TJ/Rm) – reduces to less than half on 2010 levels. For the industrial, commercial, agricultural and residential sectors, this assumes that the rate of historical efficiency improvements continues into the future. For the transport sector, the penetration of more efficient vehicle technologies (such as electric vehicles) and the increases use of mass transportation such as busses contribute to improved efficiencies in this sector. Energy intensity decreases from ~2.5TJ/Rm in 2010 to just under 1.75 TJ/Rm in 2030 and less than 1.25 TJ/Rm in 2050.

Overall the carbon energy intensity of the energy sector reduces from an average of ~0.09 Mt CO₂/PJ in 2010 to ~0.07 Mt CO₂/PJ by 2050 reflecting on average a 25% improvement throughout the modelled period.

Water energy intensity reduces significantly during the planning period. A reduction from close to 0.08 Mt/PJ in 2010 to around 0.02 Mt/PJ in 2030 is observed. Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the High Oil Price Case costs R2977 billion (2010 Rand), 22425 Mt of CO₂ are emitted and 11048 Mt of water are consumed.

![Figure 7.15: Emissions, water use and energy intensity in High Oil Price Case](image-url)
8. Low Oil Price Case
This section presents the results of the optimisation model run for the Low Oil Price Case. The purpose of this test case is to consider the sensitivity of the energy system to low crude oil prices (and prices of petroleum products derived from crude oil prices) applied to the Base Case. Transport and transformation technology investments and activity are detailed and the sources of primary energy are discussed. Finally, the costs, carbon dioxide emissions and water consumption implications are presented.

8.1 Transport Demand Technologies
There are no deviations to the suggested vehicle fleet in the Low Oil Price Case in comparison to the Base Case therefore all the observations made in the Base Case remain true and no further discussion of the transport sector is presented here.

8.2 Transformation Technologies
Requirements for new transformation technologies and the expected level of activity are presented in this section. These technologies are considered in two sections under the topics electricity generation and liquid fuels production.

8.2.1 Electricity generation
The results for electricity generation in the Low Oil Price Case are not discussed here as they are the same as the Base Case.

8.2.2 Liquid fuels production
Suggested investments in refineries, gas to liquids and coal to liquids are presented in this section.

8.2.2.1 Liquid fuels production capacity
Existing capacity and suggested new capacity for liquid fuels production technologies are provided in Figure 8.1. As with the Base Case both CTL and crude oil refining capacity are added. Slightly more conventional crude oil refining capacity is added in the Low Oil Price Case as the refinery economics are more favourable with a greater difference between crude oil prices and international petroleum product prices.
Inputs into liquid fuels production are shown in Figure 8.2. The majority of the input into liquid fuels production is crude oil and coal with a small amount of gas, used for both gas to liquids and within the conventional refineries, and electricity.
Outputs from liquid fuel plants are shown in Figure 8.3 and summarized in Table 8.1. With lower oil prices local refining is economically viable in this test case. The main outputs are petrol and diesel used primarily for road transport. Residual fuel oil, aircraft fuel and liquid petroleum gas are produced at a smaller scale and paraffin is largely displaced by LPG.

![Petroleum Products Produced: Low Oil Price Case](image)

**Figure 8.3: Liquid fuels production (million m³)**

**Table 8.1: Liquid fuels production by technology 2010, 2030 and 2050**

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
<th>Capacity</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PJ/a</td>
<td>kbbld</td>
</tr>
<tr>
<td>2010</td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>37</td>
</tr>
<tr>
<td>2010 Total</td>
<td></td>
<td>1362</td>
<td>613</td>
</tr>
<tr>
<td>2030</td>
<td>Existing refinery</td>
<td>1074</td>
<td>483</td>
</tr>
<tr>
<td></td>
<td>New refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>Existing CTL</td>
<td>293</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>176</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Existing GTL</td>
<td>83</td>
<td>37</td>
</tr>
<tr>
<td>2030 Total</td>
<td></td>
<td>2612</td>
<td>1176</td>
</tr>
<tr>
<td>2050</td>
<td>New refinery</td>
<td>1519</td>
<td>683</td>
</tr>
<tr>
<td></td>
<td>Existing refinery</td>
<td>986</td>
<td>444</td>
</tr>
<tr>
<td></td>
<td>New CTL</td>
<td>176</td>
<td>79</td>
</tr>
<tr>
<td>2050 Total</td>
<td></td>
<td>2681</td>
<td>1206</td>
</tr>
</tbody>
</table>

**8.2.2.2 Water use and CO₂ emissions in liquid fuels production**

Carbon dioxide emissions from liquid fuels production by plant type are shown in Figure 8.4 and water use is shown in Figure 8.5. The majority of the carbon emissions are due to the coal to liquids process which is carbon intensive. Water use is strongly influenced by coal to liquids but conventional
refineries also use a considerable amount of water because of their absolute size in relation to the total national capacity.

Figure 8.4: CO₂ emissions from liquid fuels production in Low Oil Price Case (Mt)

Figure 8.5: Water used in liquid fuels production in Low Oil Price Case (Mt)
8.3 Primary Energy

This subsection represents analysis of the primary energy mix as a result of the cost optimisation for the Low Oil Price Case.

8.3.1 Primary energy use

Extraction and import of primary energy are presented in Figure 8.6. Import of crude oil for refining grows slightly throughout the modelling period. Crude oil continues to play a significant role in the medium-term (13% in 2030). By 2050 its share of the primary energy remains unchanged as imports of final petroleum products increase. This is evident as the contribution of petroleum products increases from 11% in 2010, drops to 9% in 2030 and increases again to 16% by 2050.

There is also a steady growth of imported liquid fuels throughout the planning horizon, although at a slightly higher growth than crude imports.
Figure 8.7: Shares of total primary energy in Low Oil Price Case (2010, 2030 and 2050)

8.3.2 Energy imports

Crude oil and natural gas imports are presented in Figure 8.8. There is a substantial increase in imported crude with lower crude oil prices. The profile of natural gas imports is unaffected by the low crude oil price and remains similar to that in the Base Case.

Imported final products are shown in Figure 8.9. The imports are considerably lower than in the Base Case due to the existing refining capacity being used in the short term and new refining capacity coming online in the medium to long term. Imports only increase again between 2045 and 2050 due to the lower volumes of petroleum products as a result of electric vehicles and the existing refineries at the time becoming uneconomical to operate.
Figure 8.8: Imports of crude oil and natural gas in Low Oil Price Case

Figure 8.9: Imports of petroleum products in Low Oil Price Case
8.4 Discounted Costs

The discounted costs for each year in the Low Oil Price Case are presented in Figure 8.10 and show the contribution of the various components of the energy system to the total costs.

The total discounted costs of the energy system for the Low Oil Price Case is 28% lower than the Base Case. The Low Oil Price Case has a higher dependence on imported energy which increases from about 70% of the total costs in 2010 to 80% of the total costs in 2050.

![Figure 8.10: Total discounted costs for the Low Oil Price Case (Rm'2010)](image)

Imports and liquid fuels production costs are separated from the total costs in Figure 8.11 to show details more relevant to this test case. The investment in new CTL facilities is evident in 2020 along with the decrease in import costs after this year.
8.5 CO₂ Emissions

Carbon dioxide emissions from transport, total final use of energy carriers, electricity generation, resource extraction and liquid fuel production are shown in Figure 8.12.

Emissions from electricity generation are insignificantly different to the Base Case but emissions from liquid fuel production, while following the same profile of the Base Case emissions are marginally higher (by about 3%) due to more local refining and less imports.
8.6 Water Use

Water consumption related to energy extraction and production, electricity generation and liquid fuels production is shown in Figure 8.13. Water consumption for electricity generation is the same as the Base Case. For liquid fuels consumption the water consumption only varies between the Base Case and Low Oil Price Case from 2012 to 2020 because imports are used in the Base Case but local refining (and hence water consumption) is used in the Low Oil Price Case.
8.7 Low Oil Price Case Summary

Energy intensity, water use and carbon emissions per unit of total primary energy supplied for the Low Oil Price Case over the model period are presented in Figure 8.14. Energy intensity decreases from ~2.4 TJ/Rm in 2010 to just over 1.6 TJ/Rm in 2030 and a little more than 1.2 TJ/Rm in 2050.

Overall the carbon energy intensity of the energy sector fluctuates but reduces slightly from ~0.098 Mt CO\(_2\)/PJ in 2010 to ~0.095 Mt CO\(_2\)/PJ by 2050.

Water energy intensity reduces significantly during the planning period. A reduction from close to 0.09 Mt/PJ in 2010 to around 0.07 Mt/PJ in 2030 is observed. This reduces again to levels just above 0.03 Mt/PJ by 2050.

Over the entire period (2010 to 2050) the energy infrastructure and energy consumed in the Low Oil Price Case costs R1779 billion (2010 Rand), 22393 Mt of CO\(_2\) are emitted and 13019 Mt of water are consumed.
Figure 8.14: Emissions, water use and energy intensity in Low Oil Price Case
9. Comparison of Test Cases

This section summarises the test cases and provides a comparison of results. It focuses on primary energy supply, discounted costs, energy security, energy diversity, and environmental impacts.

9.1 Transport Demand Technologies

Electric vehicles were shown to be the most cost effective means to provide private passenger transport for all test cases in the long term. When no emissions limits are applied to the energy system and oil prices are high hybrid vehicles provide a transition technology from conventional petrol and diesel vehicles to electric vehicles. While SUVs and light commercial vehicle used for passenger kilometres had fewer options for technologies the least cost option for them is petrol technologies as opposed to diesel technologies. This is due to the average distance travelled per year by these vehicle types, the refinery slates and the requirements for diesel for freight vehicles producing a surplus of petrol. Busses provide the cheapest option for public passenger transport but more work is required in the comparison of the service offered by busses and minibus taxis to clarify the assumption of the maximum penetration of busses in the vehicle fleet (15% per annum). Freight vehicles had no alternative fuel or drive train options. Demand for freight is met with conventional diesel technologies. More work is needed in alternative freight technologies and fuels to assist in any emission limiting scenarios.

9.2 Primary Energy

The primary energy use in the test cases are summarised in Figure 9.1. In all three Test Cases with emissions limits (Emissions Limit Case and No New Nuclear Case) the primary energy use is lower than the Base Case due to replacing coal used in CTL with imported crude and petroleum products. This improves the efficiency of the supply system as imports and refineries are more efficient than CTL plants. There is very little difference (<1%) in the costs of the Emissions Limit and No Nuclear test cases. In the No Nuclear test case the next cheapest electricity supply options are used when nuclear technologies are not used.

Due to the demand modelling approach used for all sectors besides transport (i.e. projecting demand for energy carriers), the potential for fuel switching could not be analysed. Therefore the renewable energy targets could only be applied to electricity generation and not necessarily for demand-side interventions (i.e. home solar PV panels). When the renewable target is set the energy mix becomes more diverse and a significant amount of biomass is used.

The emissions limits force the energy system towards more import orientated energy system.
9.3 Discounted Costs

The total discounted costs represent all the costs of the energy system discounted to a single number per year for comparison purposes. It is the main variable used to compare the various test cases developed for the Integrated Energy Plan.

Total discounted costs per year for each of the test cases is shown in Figure 9.2 and a breakdown of these costs into the various components of the energy supply systems and provided in Table 9.1. Imported energy (mostly imported crude oil and petroleum products) forms the largest component of the energy supply system costs for all test cases. This dependence increases during the modelling period. Imports increase from about 70% to 80% of the total energy supply costs for the Base Case between 2010 and 2050, 80% to 90% in the Emissions Target and No Nuclear cases and 70% to 80% in the RE Target case. Extraction of primary energy resources, such as mining coal or drilling for oil or gas and electricity generation, constitutes the second and third largest costs depending on the test case. In test cases which depend on renewables the costs of the electricity generation infrastructure are larger than that for the other test cases but the other test cases have high extraction costs.
In comparison to Base Case, the Emissions Limit cases have an estimated 9% higher total discounted costs for the energy supply system. The increase in costs is due to an increase in the share of imported energy and the use of technologies which are less carbon intensive. Coal to liquids and coal fired power plants are minimised in the energy transformation technology fleet in these test cases.
### Table 9.1: Total discounted costs of energy system

<table>
<thead>
<tr>
<th>Component</th>
<th>Base Case</th>
<th>High Oil Price</th>
<th>Low Oil Price</th>
<th>Emissions Limit</th>
<th>No Nuclear Gas</th>
<th>No Nuclear</th>
<th>RE Target</th>
<th>Carbon Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage, Transmission, Transportation and Distribution</td>
<td>35</td>
<td>1.4%</td>
<td>35</td>
<td>1.2%</td>
<td>35</td>
<td>1.3%</td>
<td>35</td>
<td>1.3%</td>
</tr>
<tr>
<td>Import</td>
<td>1922</td>
<td>77.4%</td>
<td>2363</td>
<td>79.4%</td>
<td>1209</td>
<td>68.0%</td>
<td>2187</td>
<td>81.0%</td>
</tr>
<tr>
<td>Extraction/Production</td>
<td>208</td>
<td>8.4%</td>
<td>207</td>
<td>7.0%</td>
<td>207</td>
<td>11.6%</td>
<td>188</td>
<td>7.0%</td>
</tr>
<tr>
<td>Electricity generation infrastructure</td>
<td>189</td>
<td>7.6%</td>
<td>189</td>
<td>6.3%</td>
<td>189</td>
<td>10.6%</td>
<td>199</td>
<td>7.4%</td>
</tr>
<tr>
<td>Liquid fuels production infrastructure</td>
<td>129</td>
<td>5.2%</td>
<td>183</td>
<td>6.2%</td>
<td>138</td>
<td>7.8%</td>
<td>92</td>
<td>3.4%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>2484</td>
<td>100.0%</td>
<td>2977</td>
<td>100.0%</td>
<td>1779</td>
<td>100.0%</td>
<td>2701</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
9.4 CO₂ Emissions
Carbon dioxide emissions for the test cases are presented in Figure 9.3. These emissions are primarily driven by the use of coal for transformation but considerable amounts of coal are also used in other parts of the economy. Placing limits on refineries and electricity generation only, results in greater use of imported energy. Without demand side emissions limits being imposed, these emissions continue growing unconstrained. There were no options available to switch between final energy carriers except for cars which are able to switch from fuels to electricity.

National emissions limits cannot be met without addressing final demand for energy carriers.

![Figure 9.3: CO₂ emissions for all test cases](image)

The reduction in the use of coal also has a significant impact on carbon emissions. The emissions constrains resulted in a 5.3 billion tonnes (or 24%) reduction in carbon dioxide emissions over the 40 year period.

From the modelling results, emissions from transport and final energy use are substantial in the future and considerably larger than the transformation sector. Emission constraints should rather be placed on the total emissions allowing technologies choices anywhere within the energy value chain to contribute towards emissions mitigation.
Table 9.2: Emissions comparison and abatement costs

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>High Oil Price</th>
<th>Low Oil Price</th>
<th>Emissions Limit</th>
<th>No Nuclear</th>
<th>No Nuclear Gas</th>
<th>RE Target</th>
<th>Carbon Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Discounted Cost</td>
<td>2484</td>
<td>2977</td>
<td>1779</td>
<td>2701</td>
<td>2705</td>
<td>2707</td>
<td>2570</td>
<td>2644</td>
</tr>
<tr>
<td>Difference in cost from Base Case (Rb)</td>
<td>0</td>
<td>494</td>
<td>-705</td>
<td>218</td>
<td>222</td>
<td>223</td>
<td>87</td>
<td>160</td>
</tr>
<tr>
<td>Difference in cost from Base Case (%)</td>
<td>0.0%</td>
<td>19.9%</td>
<td>-28.4%</td>
<td>8.8%</td>
<td>8.9%</td>
<td>9.0%</td>
<td>3.5%</td>
<td>6.4%</td>
</tr>
<tr>
<td>Model Period Emissions 2010-2050 (Mt)</td>
<td>22101</td>
<td>22425</td>
<td>22393</td>
<td>16811</td>
<td>16808</td>
<td>16808</td>
<td>20419</td>
<td>19833</td>
</tr>
<tr>
<td>Difference in emissions from Base Case (Mt)</td>
<td>0</td>
<td>324</td>
<td>292</td>
<td>-5290</td>
<td>-5293</td>
<td>-5293</td>
<td>-1682</td>
<td>-2268</td>
</tr>
<tr>
<td>Average cost difference of CO2 from Base Case (R/t)</td>
<td>0</td>
<td>1525</td>
<td>-2411</td>
<td>-41</td>
<td>-42</td>
<td>-42</td>
<td>-52</td>
<td>-71</td>
</tr>
</tbody>
</table>
9.5 Water Use

Water used in the various test cases is shown in Figure 9.4. CTL plants use large qualities of water as can be seen in a comparison of the Base Case and the Emissions Limit case. There is very little difference in water consumption for the Emissions Limit case and the No Nuclear case. The small difference is because nuclear is assumed to use sea water whereas the CSP technologies require fresh water. In general the test cases which limit coal to liquid activities reduce the demand for water. Water demand is also reduced by using dry cooling in electricity generation and the renewable energy technologies use less water.

![Water use for Test Cases](Figure 9.4)

9.6 Energy Intensity

Energy intensity (Total Primary Energy Supplied divided by GDP) for all the test cases for each year in the modelled period is shown in Figure 9.5. All the test cases with emissions limits have very similar energy intensities starting at about 2.25 TJ/Rm in 2010 decreasing almost linearly around 1 TJ/Rm in 2050. In the case studies which are not limited by emissions limits there is a slight increase in energy intensity in about 2020 and decrease again in the 2040s' due to the use of CTL technologies which are energy intensive.
Figure 9.5: Energy intensity for all test cases