DEPARTMENT OF ENERGY

DRAFT 2012 INTEGRATED ENERGY PLANNING REPORT

ANNEXURE B – MODEL INPUT AND ASSUMPTIONS (OPTIMISATION MODEL)

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1. Introduction

This document summarises the optimisation modelling methodology and presents the relevant inputs and assumptions for the optimisation model based on information known at the time of modelling.

The key assumptions that inform the optimisation modelling include, projected future energy demand, assumptions about current and future energy technologies; commodity prices and policy constraints. While demand is a key input into the optimisation model, other assumptions, such as macroeconomic and demographic assumptions inform the projected demand - the demand modelling approaches for the various sectors together with the demand projections are provided in a separate document.

As far as demand, this document therefore focuses only on assumptions made regarding demand technologies (more specifically transport technologies). It also includes assumptions on transformation technologies (electricity generation and liquid fuel production); costs of sourcing primary energy carriers. Changes to these assumptions based on policy constraints are provided for the Base Case and the various test cases.

1.1 Procedure

The purpose of the optimisation modelling is to find the least cost development path of the South African energy system to the year 2050. Such a path is required to meet the predetermined demands for energy services and energy carriers within given policy, environment, economic and social constraints. The same procedures and tools are used to evaluate the impacts of various policy options available to government.

The modelling procedure used to optimise the energy sector includes:

1. Determining the types of existing energy technologies and their properties from available literature and reports;
2. Determining the current stock as well as possible future options of transformation technologies used to provide for the country's energy needs (i.e. electricity generation technologies, oil refineries and synthetic fuel plants). This includes determining the properties (i.e. costs, efficiencies, water consumption factors, emissions factors, capacity factors, operational life, etc.) of all transformation technologies. For liquid fuel plants this further includes determining the slate of products;
3. Considering the availability and where relevant the extraction or import costs of primary energy resources such as coal, nuclear fuel, natural gas and crude oil. This includes considering the costs of importing of final liquid fuel products;
4. Populating the optimisation model with the above datasets and executing the model runs for the base case and various test cases; and
5. Analysing the results and summarising conclusions from the model runs.

1.2 Scope of optimisation modelling

The scope of the optimisation modelling is limited to the supply of electricity, coal, natural gas and petroleum products (i.e. liquid petroleum gas, diesel, petrol, aviation fuel and residual fuel oil) for final energy consumption. It also includes road transport services i.e. passenger kilometres and tonne kilometres (where petrol and diesel demand is derived from transport services).

- Primary energy supply includes extraction of coal and natural gas (from conventional means, shale and coal bed methane) and imports of crude oil and natural gas. Renewable. energy technical potentials (wind and solar) are also included.
- The transformation sector includes conventional crude oil refineries, coal to liquid (CTL) plants and gas to liquid (GTL) plants. A variety of electricity generation technologies (i.e. coal, nuclear, wind, solar, hydro, OCGT, CCGT) are considered.

This document is not intended to provide a detailed description of the functioning of the various mathematical procedures, but rather a high-level description of the basic principles to facilitate the understanding of the optimisation process. The principles of operation behind the mathematical models and linear programming solver are discussed in detail in their respective documentation [Howells et al (2011) for the optimisation model and Makhorin (2008) for the linear programming solver].

1.3 Structure of this Document

Section 2 provides a description of the methodology used in the optimisation process. Section 3 presents the model input parameter values for technologies considered and describes assumptions made for optimisation modelling for the Base Case. Selected key technology parameters are provided in the text in the form of charts and tables, more detailed information is provided in data sheets in the appendices for all other parameter values. Section 4 provides the key differences in assumptions for the various Test Cases. Since most of the assumptions of the Base Case are the same as for the various Test Cases, section 4 only describes the deviations from the Base Case assumptions.

2. Modelling Methodology

This section provides an overview of the process which was used to formulate the problem for optimising the energy system for Integrated Energy Planning. The nature and scope of the problem, energy systems and their parameterisation and linear optimisation are briefly described.

2.1 Nature and Scope of the Problem

Energy systems must operate in the context of social, economic and environmental factors. Drivers of demand for energy services, constraints on the costs, natural resource availability and ecological vulnerability, are shown in Figure 2.1. The modeller's activities primarily involve the quantification of boundary conditions and the energy system attributes within the rectangle in the centre of the diagram.

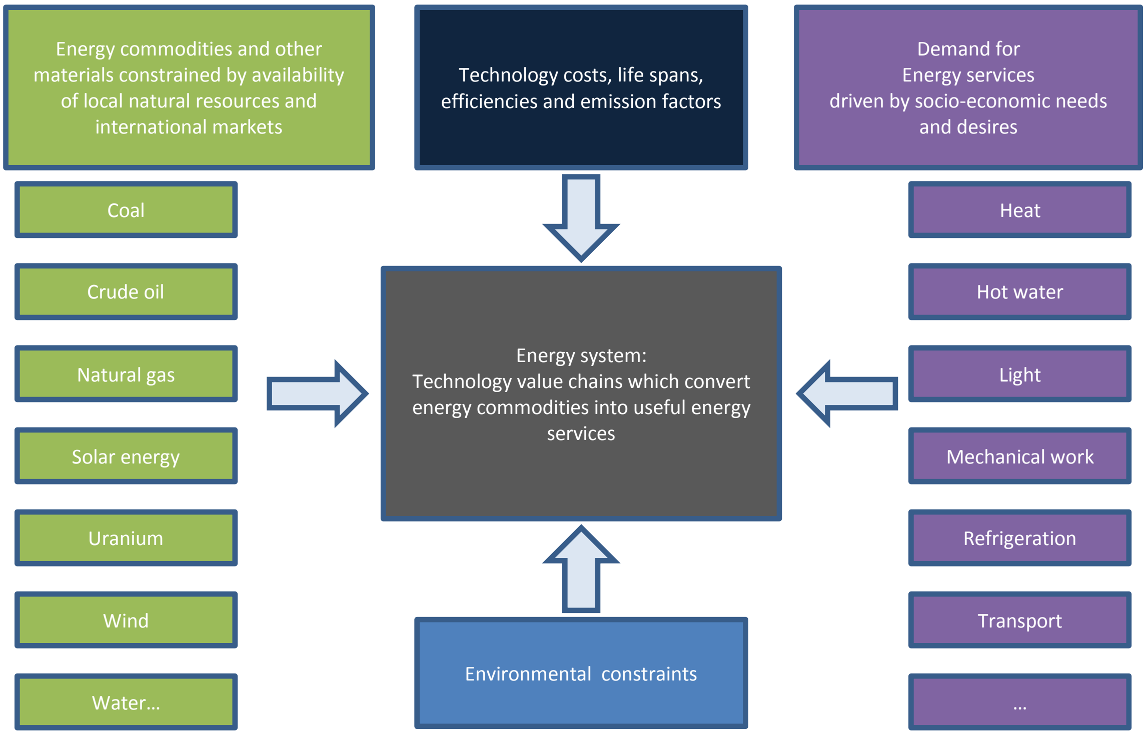

Figure 2.1: Context in which an energy system must operate

There are various ways to consider the interaction between energy systems and their environment. The following subsection considers the energy system optimisation as the main tool used within Integrated Energy Planning to consider the possible development of the South African energy system.

2.2 Energy System Optimisation

Energy system optimisation tools such as TIMES (The Integrated MARKAL-EFOM System) used by the International Energy Agency and MESSAGE (Model for Energy Supply System Alternatives and their General Environmental Impacts) used by the International Atomic Energy Agency have been used over the last few decades for national and regional energy planning and policy development.

These tools generally determine the least costs energy system development for given demands and social and environmental constraints, determined externally to the optimisation model.

The Open Source Energy Modelling System (OSeMOSYS) (Howells et al, 2011) has been adopted, modified and incorporated into the South African Energy Modelling System (SAEMS) by the Department of Energy (DoE) for energy system optimisation. It uses the same mathematical principles as the above mentioned models and together with other tools (backend database and user interface) developed within the department provides the department with greater flexibility in data management, future modifications and adaptation to specific requirements due to its open source nature and support from an international community of energy modellers.

Linear optimisation (or linear programming) is the mathematical technique used within the OSeMOSYS to determine the least cost energy system development path. This technique defines a large set of equations that mathematically describe complex energy technology systems and solves the equations for a known set of parameter values. Often there are too many unknowns (or variables) within complex systems to determine a single solution to a problem with the given set of equations and parameter values. In relation to energy systems, this means there may be many ways to provide for the country’s energy needs within given constraints; typically, however, one would like to know solution is the most optimal given within a given set of constraints and objectives. This is achieved by defining which variable should be optimised as well as defining ranges of values within which the other variables should be constrained. Allowable emissions, availability of primary energy resources, renewable energy targets or capacity constraints are examples of variable ranges which are often used.

The equations defining complex systems are formulated using combinations of simpler components each with a set of defining characteristics (quantified as parameters). For energy systems, these components are technologies and commodities (more generally, these components could be expressed as processes and materials). Technologies convert input commodities into output commodities, such as power stations converting coal to electricity or refineries converting crude oil to petroleum products, while simultaneously emitting emissions and accruing costs. The commodities provide a means to connect technologies together and allow one to define demands for energy carriers or place constraints on their availability.

2.3 Reference Energy Systems

Energy systems are constructed by building energy value chains which consist of alternating technology and commodity components. An example of an energy value chain is provided in Figure 2.2 (vertical lines represent commodities, rectangles represent technologies and horizontal lines represent commodity flows).

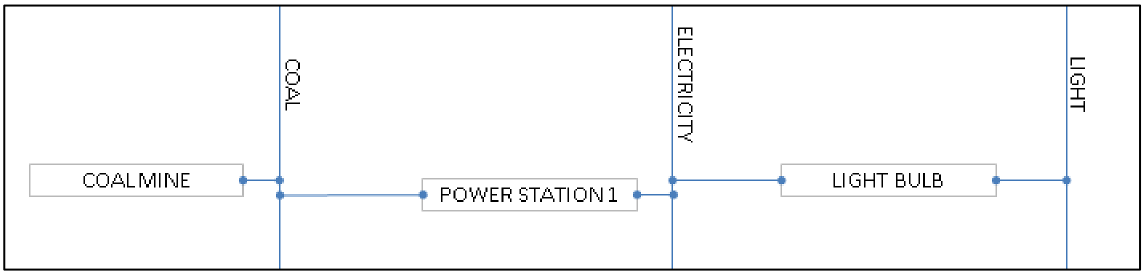

Figure 2.2: Energy value chain

The cost of providing an energy service or energy carrier (such as light or electricity respectively in Figure 2.2) is determined by summing the costs associated with all the technologies in the preceding parts of the energy value chain. Similarly, total emissions may be determined by adding the emissions emitted by each of the technologies.

Within larger energy systems there are connections between values chains, as different value chains may use the same commodities. A more detailed representation of interconnected value chains is provided in Figure 2.3 in the form of a simple energy system.

The diagram presents some important features of energy systems. The process starts with primary forms of energy which are converted into secondary forms of energy (e.g. in power stations to generate electricity and in refineries to produce liquid fuels). Certain secondary energy carriers, such as petrol or diesel, may be imported directly into the energy system. The final processes in the energy value chains are performed by demand technologies which transform energy carriers into services such as light, heat, refrigeration and transportation. The primary purpose of the energy system is to ensure that all the demands for energy services are met.

Determining all the possible combinations of value chains available to the energy system and defining the parameter values of these components is referred as constructing a reference energy system.

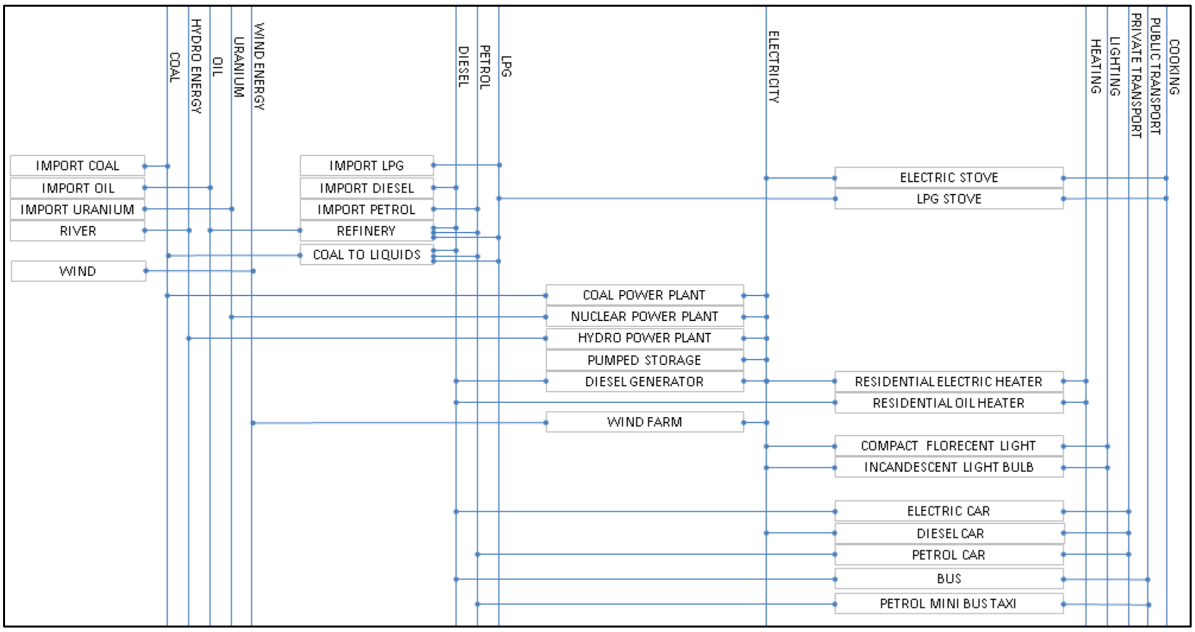

Figure 2.3: Energy system diagram

The cost of the whole energy system is determined by summing of the costs related to the investments and activity of all technologies. Using this approach, commodities do not have prices as these are represented by the cost of using the technologies, for example the price of imported crude is accounted for by allocating a cost per unit energy to run the “import oil” technology. The linear optimisation model determines all combinations of energy carrier usage and technology activity, which minimise the total cost of the system within given constraints.

The interaction between value chains requires special attention when analysing the results from the energy system optimisation model as changing costs, demands and any other parameters of technologies in one part of the system may influence costs and level of use of other technologies in other parts of the system due to the interactions between the value chains.

The list of technologies together with their inputs and outputs which form of the reference energy system are provided in Appendix C: List of Technologies and Appendix E: Parameter Data Sheets for Base Case.

2.4 Parameterisation of the Problem

Energy systems and their operating environments are characterised using parameters which are relevant to the equations built into the energy models. The model parameters are discussed in the following subsections.

2.4.1 Model Parameters

The parameters defining the model can be grouped according to commodity and technology characteristics and are further categorised into demands, costs, storage, activity, capacity, emissions and tags (tags mark special technologies or commodities depending on their qualitative characteristics e.g. renewable or non-renewable energy or a peak or non-peak power technology). Input parameters for the South African Modelling System are included in Table 2.1. Descriptions of these parameters are provided in the OSeMOSYS documentation (Howells et al, 2011).

Table 2.1: Parameters defining energy systems

Component of energy system	Category	Parameter
Technologies	Capacity	Capacity Factor
		Lead Time
		Residual (existing) Capacity
		Tech With Capacity Needed To Meet Peak Time Slice
		Total Annual Max Capacity
		Total Annual Max Capacity Investment
		Total Annual Min Capacity
		Total Annual Min Capacity Investment
	Activity	Total Technology Annual Activity Lower Limit
		Total Technology Annual Activity Upper Limit
		Total Technology Model Period Activity Lower Limit
		Total Technology Model Period Activity Upper Limit
		Input Activity Ratio
		Output Activity Ratio
		Emission Activity Ratio
		Capacity To Activity Unit
	Storage	Storage Lower Limit
		Storage Upper Limit
		Technology From Storage
		Technology To Storage
		Storage Inflection Times
	Costs	Operational Life
		Discount Rate
		Capital Cost
		Fixed Cost
		Variable Cost
		Availability Factor
		Emissions Penalty
		Salvage Factor
	Tags	Reserve Margin Technology Tag
		Renewable Energy Technology Tag
Commodities	Emission	Annual Emission Limit
		Annual Exogenous Emission
		Model Period Emission Limit
		Model Period Exogenous Emission
	Demands	Specified Annual Demand
		Specified Demand Profile
		Accumulated Annual Demand
		Year Split
		Reserve Margin
	Tags	Reserve Margin Fuel Tag
		Renewable Energy Fuel Tag
		Renewable Energy Min Production Target

2.4.2 Dimensions of the Problem

A number of dimensions define each parameter used to describe an attribute of an energy system component. Dimensions provide information about the situation being considered and influence the value of a parameter. The technology, mode of operation, commodity being used, region, year and time slice are all dimensions typically considered within energy systems. Dimension sets defined for the modelling system are included in Table 2.2.

Table 2.2: Dimension sets defined for the modelling system

Dimension sets
Mode of operation
Storage Technology
Technology
Emission
Fuel
Region
Time slice
Year

The items in each dimension set are defined during the application of the modelling system.

2.4.3 Parameters and Their Dimensions

Each parameter, listed in Table 2.1, is only valid for a certain number of dimensions depending on what it represents. The parameters from Table 2.1 are grouped according to combinations of valid dimensions and are listed in Table 2.3. Dimensions are important for providing information about constraints or demands e.g. when specifying an emissions limit one would want to indicate the emissions specie and the year the limit is set for or a demand for a specific fuel may be set for a certain year.

Table 2.3: Parameters and their dimensions

Parameter	Dimensions
Model Period Emission Limit	Emission, Region
Model Period Exogenous Emission	Emission, Region
Storage Lower Limit	Storage, Region
Storage Upper Limit	Storage, Region
Technology From Storage	Technology, Mode of operation, Storage, Region
Technology To Storage	Technology, Mode of operation, Storage, Region
Discount Rate	Technology, Region
Capacity To Activity Unit	Technology, Region
Total Technology Model Period Activity Upper Limit	Technology, Region
Total Technology Model Period Activity Lower Limit	Technology, Region
Operational Life	Technology, Region
Tech With Capacity Needed To Meet Peak TS	Technology, Region
Annual Emission Limit	Year, Emission, Region
Emissions Penalty	Year, Emission, Region
Annual Exogenous Emission	Year, Emission, Region
Specified Annual Demand	Year, Fuel, Region
Reserve Margin Tag Fuel	Year, Fuel, Region
RE Tag Fuel	Year, Fuel, Region
Accumulated Annual Demand	Year, Fuel, Region
RE Min Production Target	Year, Region
Reserve Margin	Year, Region
Emission Activity Ratio	Year, Technology, Emission, Mode of operation, Region
Output Activity Ratio	Year, Technology, Fuel, Mode of operation, Region
Input Activity Ratio	Year, Technology, Fuel, Mode of operation, Region
Variable Cost	Year, Technology, Mode of operation, Region
Total Annual Min Capacity Investment	Year, Technology, Region
Capital Cost	Year, Technology, Region
Fixed Cost	Year, Technology, Region
Availability Factor	Year, Technology, Region
Salvage Factor	Year, Technology, Region
Capacity Factor	Year, Technology, Region
RE Tag Technology	Year, Technology, Region
Total Technology Annual Activity Lower Limit	Year, Technology, Region
Total Annual Min Capacity	Year, Technology, Region
Total Annual Max Capacity Investment	Year, Technology, Region
Total Annual Max Capacity	Year, Technology, Region
Residual Capacity	Year, Technology, Region
Reserve Margin Tag Technology	Year, Technology, Region
Capacity Factor	Year, Technology, Region
Total Technology Annual Activity Upper Limit	Year, Technology, Region
Year Split	Year, Time slice
Specified Demand Profile	Year, Time slice, Fuel, Region

3. Base Case Inputs and Assumptions

This section provides information about the parameters and the related assumptions/values which informed input into the optimisation model for the base case. Some of these values are determined by known technical attributes (i.e. costs and efficiencies). Others are based on best estimates given known information (e.g. assumptions on the number of vehicles or potential for wind energy. Dimensions, default parameter values and demands for energy carriers and energy services are summarised and detailed parameter values are presented for different parts of the energy system.

The Base Case is the starting point for all of the other test cases. Most of the information used in the model is provided in the definition of the Base Case. Additional information specific to the other test cases is provided in section 4.

3.1 Dimensions Considered

The technologies, commodities, years, regions and time slices have been defined for the IEP reference energy system. There are 70 commodities (including fuels, emissions and services) and 179 technologies considered in the modelling. Commodities and technologies considered are listed in Appendix B: List of Energy Carriers and Services and Appendix C: List of Technologies respectively. The model period is from 2010 to 2050 with 2010 taken as the base year i.e. all input and result values are discounted to the year 2010. Only one region representing the whole country is considered in the model. Time slices are discussed under the electricity generation section.

3.2 Demand Technologies

This subsection provides details about demand technologies. A brief description of how proxy technologies are setup to represent overall consumption of energy carriers is provided. The focus of the subsection is on transport technologies as transport is the only sector considered to the service level. Parameter values related to costs, fuel consumption, CO_2 emissions and penetration rates for transport technologies are provided.

3.2.1 Aggregate demand technologies

In order to maintain the energy systems approach described in Section 2.3, placeholder/dummy technologies were setup for each of the energy carriers considered in the demand projections and consumed in significant amounts within the agricultural, commercial, industrial and residential sectors. The function of these dummy technologies is, therefore, to connect the production of energy carriers by the energy sector to the point of final consumption and act as a means to aggregate emissions from the use of the particular energy carrier within the model. Although there are no costs associated with these dummy technologies, *it should be noted that taking the costs of individual end-use technologies into consideration may influence the overall mix of energy carriers in the energy system as costs for end-use technologies may represent a larger proportion of the total cost of providing the energy services. This is an area of further refinement in the integrated energy planning process.*

The emissions factors assumed for the dummy technologies in the final consumption of various energy carriers are shown in Table 3.1. These emission factors were obtained from the Intergovernmental Panel on Climate Change emissions factors database IPCC, 2011).

Table 3.1: Emission factors used for energy carriers used in final demand

Energy Technology	Mt CO2/PJ
Coal using technology all sectors	0.095
Diesel using technology all sectors	0.073
LPG using technology all sectors	0.063
Natural Gas using technology all sectors	0.056
Residual fuel oil using technology all sectors	0.077
Other kerosene using technology all sectors	0.072

3.2.2 Transport technologies

The most significant vehicle technology types in the current South Africa vehicle fleet are listed in Table 3.2. (HI, MI, and LI indicate high, middle and low income groups respectively, i.e. High Income, Medium Income and Low Income respectively.) The technologies marked HI, MI and LI are the same in all respects except for their names and capacity requirements. Given that household income is a key factor in determining demand for different transport modes and vehicle types, these technologies are given different names so that demands for transport services in different income groups can be differentiated from each other if required. This methodology is used as average vehicle costs are used with the assumption that there will be greater vehicle ownership in higher income groups.

Table 3.2: Vehicle technologies considered in existing vehicle fleet

Technology
Bus Public – Diesel
Car Private HI – Diesel
Car Private HI – Petrol
Car Private LI – Diesel
Car Private LI – Petrol
Car Private MI – Diesel
Car Private MI – Petrol
Minibus taxis - Diesel
Minibus taxis - Petrol
SUV Private HI – Diesel
SUV Private HI – Petrol
SUV Private LI – Diesel
SUV Private LI – Petrol
SUV Private MI – Diesel
SUV Private MI – Petrol
Truck Diesel Heavy
Truck Diesel Light
Truck Diesel Medium
Truck Petrol Light

In addition to the technologies listed in Table 3.2 new vehicle types for which data could be found and considered available in the future are listed in Table 3.3. Only two additional technologies are made available for future private passenger transport - electric and hybrid motorcars.

Only competition between petrol, diesel, hybrid (petrol) or electric vehicles is assumed i.e. there is no competition between vehicles of different types (e.g. Sports Utility Vehicles - SUVs and cars) in the private passenger vehicle sector. (Competition in this context refers to the ability of one technology to replace another technology in providing the same service.) In the public transport subsector, busses and taxis are assumed to compete. In the freight subsector, only light commercial vehicle (LCV) technologies of different fuel types are assumed to compete. In the case that the replacing technology uses a different energy carrier or fuel type from the original technology, fuel switching occurs.

It is assumed that there is no technology learning (i.e. a decrease in the cost of a particular vehicle type which results as a consequence of its maturity and increased penetration in the market). The vehicle efficiencies are also assumed to remain constant throughout the planning period. It is therefore assumed that any improvement in average fleet efficiency is due switching vehicle technologies but not due to changes within individual technologies. (It is often assumed that average new car efficiencies improve at a rate of 1% a year due to historical trends (IEA, 2000).

Table 3.3: Vehicle technologies considered for new vehicle investments

Technology
Car Private HI – Electric
Car Private HI – Hybrid
Car Private LI – Electric
Car Private LI – Hybrid
Car Private MI – Electric
Car Private MI – Hybrid

3.2.2.1 Vehicle costs

Fixed, capital and variable costs for all the vehicle types considered in the modelling are shown in Table 3.4. Fixed and variable costs (excluding fuel costs) were calculated from the capital costs using tables and calculations available from (AA, 2012).

Table 3.4: Vehicle costs used in model

Vehicle Classification			Capital Cost	Fixed Cost	Variable Cost
			Rand per 1000 tkm per year or Rand per 1000 person km per year		Rand per 1000 tkm or Rand per 1000 person km
New vehicles	Private passenger vehicles	Car Diesel	5660	421	463
		Car Electric	6398	475	175
		Car Hybrid	5808	432	335
		Car Petrol	4922	366	350
		SUV Diesel	16266	763	659
		SUV Petrol	15694	736	674
	Public transport vehicles	Bus - Diesel	765	66	142
		minibus taxis diesel	391	29	409
		minibus taxis petrol	397	29	318
	Road freight vehicles	Truck Diesel Heavy	657	31	422
		Truck Diesel Light	7310	871	6971
		Truck Diesel Medium	3329	176	2136
		Truck Petrol Light	7053	841	6971
Existing vehicles	Private passenger vehicles	Car Diesel	Capital costs for existing vehicles were paid outside of modelling period	363	463
		Car Petrol		316	350
		SUV Diesel		679	659
		SUV Petrol		655	674
	Public transport vehicles	Bus - Diesel		66	142
		minibus taxis diesel		29	409
		minibus taxis petrol		29	318
	Road freight vehicles	Truck Diesel Heavy		31	422
		Truck Diesel Light		871	6971
		Truck Diesel Medium		176	2136
		Truck Petrol Light		841	6971

All costs account for vehicle occupancy rates of 1.4, 14 and 25 people for cars, mini bus taxis and busses respectively and loading rates of 0.5, 2.5 and 15 tonnes for light, medium and heavy duty vehicles respectively (ERC, 2012).

For new vehicles capital costs were determined by finding the top selling manufactures for each vehicle type, fuel type and engine capacity class for a sample of the 2009 NATIS database. Sales weighted average new car prices for different vehicle types and fuels were then calculated from the 2009 sales and the current vehicle prices (as published in popular motoring magazines) discounted to 2010 Rand values. Fixed and maintenance costs were calculated as with the existing vehicle fleet from AA data as described above.

Vehicle usage varies by vehicle type and age. Average vehicle kilometres for various vehicle types were obtained from ERC (2012). These are listed in Table 3.5 for existing and new vehicles. Vehicle use by age is not considered in the modelling.

Table 3.5: Average annual distances travelled by vehicle type and class (ERC, 2012)

		Existing vehicles	New vehicles
Vehicle class	**Fuel type**	**Ave km/a**	**km/a**
Motorcars	Diesel	21254	24000
Motorcars	Petrol	16169	24000
Motorcars	Petrol hybrid	23678	24000
SUV	Diesel	20314	24000
SUV	Petrol hybrid	24000	24000
SUV	Petrol	19128	24000
Minibuses (taxis)	Diesel	43474	50000
Minibuses (taxis)	Petrol	30927	50000
Buses	Diesel	22072	40000
Motorcycle	Petrol	8340	10000
Light Commercial Vehicles (LCV - LDV)	Diesel	19202	25000
Light Commercial Vehicles (LCV - LDV)	Petrol	16662	25000
Medium Commercial Vehicles (MCV - trucks)	Diesel	33417	45000
Medium Commercial Vehicles (MCV - trucks)	Petrol	13575	25000
Heavy Commercial Vehicles (HCV - trucks)	Diesel	48403	70500

The existing fleet consists of a variety of vehicles of various technologies, ages and types. New vehicle technologies such as hybrids and electric vehicles are typically aimed at specific vehicle segments while the price of new conventional vehicle are taken to be the average new price of vehicles weighted by their sales volumes. The prices of new technologies cannot, therefore, be fairly compared with the average price of the existing fleet without adjustment. To provide a comparative pricing of new vehicles of new technologies the size and perceived value of the vehicles are used to find a relative price difference between conventional and new technologies. For example, the Honda Jazz hybrid and Honda Jazz conventional petrol vehicle of similar specifications are used to find a percentage premium on hybrid vehicles in the small vehicle segment. Similarly the same is done for the Toyota Auris hybrid and conventional and BMW hybrid and conventional petrol vehicles. An average percentage price premium of 18% was determined between hybrid and conventional petrol cars. This was used to find an average capital cost premium of hybrid vehicles over the average cost of new conventional vehicles.

For electric vehicles a 30% premium is placed on the capital and fixed costs of electric vehicles over conventional petrol vehicles of similar size and performance based on expected costs of the Joule and Nissan Leaf. Variable costs where assumed to be half those of conventional vehicles due to the lower service costs. The equivalence between conventional and new technologies is obscured by brand value and the wide range of prices for vehicles of the same make and model but different specifications such as safety features and engine capacity. For example the retail price of a Toyota Corolla varies between R186000 and R294000 and a VW Golf between R236000 and R451000 (in 2012 prices). No attempt has been made to account for detailed vehicle specifications or brand value in the modelling.

3.2.2.2 Fuel consumption and CO_2 emission factors

Fuel/energy consumption and CO_2 emission factors used for vehicles are provided in Table 3.6. Energy consumption factors were derived from the fuel economy (litres per 100km), occupancy and loading rates, and fuel energy content published in ERC (2012). Carbon dioxide emission factors were derived directly from the energy consumption factors and the carbon content of the energy consumed by the respective vehicles.

Table 3.6: Vehicle emissions and fuel consumption factors

Vehicle Classification			Emissions	Fuel consumption
			kg CO2 per person km (passenger) kg CO2 per ton km (freight)	MJ per person km (passenger) MJ per ton km (freight)
New vehicles	Private passenger vehicles	Car Diesel	0.148	2.09
		Car Electric	0.000	0.49
		Car Hybrid	0.120	1.55
		Car Petrol	0.156	2.21
		SUV Diesel	0.231	3.26
		SUV Petrol	0.235	3.33
	Public transport vehicles	Bus - Diesel	0.038	0.54
		minibus taxis diesel	0.023	0.32
		minibus taxis petrol	0.026	0.37
	Road freight vehicles	Truck Diesel Heavy	0.073	1.16
		Truck Diesel Light	0.659	9.27
		Truck Diesel Medium	0.324	4.56
		Truck Petrol Light	0.682	9.66
Existing vehicles	Private passenger vehicles	Car Diesel	0.148	2.09
		Car Petrol	0.156	2.21
		SUV Diesel	0.231	3.26
		SUV Petrol	0.235	3.33
	Public transport vehicles	Bus - Diesel	0.038	0.54
		minibus taxis diesel	0.023	0.32
		minibus taxis petrol	0.026	0.37
	Road freight vehicles	Truck Diesel Heavy	0.073	1.04
		Truck Diesel Light	0.659	9.27
		Truck Diesel Medium	0.324	4.56
		Truck Petrol Light	0.682	9.66

3.2.2.3 Transport technology penetration rates

In preliminary model runs the model selected busses and electric vehicles exclusively for private and public transport vehicles respectively due to their assumed low total discounted cost. In reality, market conditions need to be considered such as the acceptability of using busses instead of taxis or for consumers and the motor industry to adapt to producing electric vehicles. A maximum penetration rate of 15% increase per annum was imposed on busses. This was determined by the maximum annual increase within the period 2000 to 2010 for busses in Gauteng. A 40% maximum annual increase for electric vehicles starting from 200 electric vehicles in 2013 was assumed.

3.3 Transformation Technologies

The parameter values related to electricity generation and liquid fuels production are presented in this section. Conventional crude oil refineries, coal to liquids and gas to liquids transformation are considered as means to transform available energy carriers into liquid fuels. Costs, primary sources of energy, slates (shares of products produced by refineries), efficiency factors and emissions for transformation are provided.

3.3.1 Electricity generation

For the purposes of this IEP, the generation technologies modelled can be split between two type of technologies – *existing* and *new or future* technologies.

For electricity generation, all assumptions about existing plants (i.e. costs, capacity factors, operational life, availability factors, efficiencies, emissions, etc) were obtained from the IRP2010 (DOE, 2010). More details on each of the technologies can be obtained therein.

3.3.1.1 Eskom plants

For the purposes of this model, the Eskom system contributes a significant amount of generation currently over 90% of installed capacity with the rest being supplied by municipal and Independent Power Producers (IPPs).

Below is a table of current existing Eskom plants, dominated by coal plants, with one nuclear plant, some pumped storage, run of river hydro and gas turbines.

Table 3.7: Eskom Existing Plant

Eskom Existing	Capacity (GW)	Plant Type	Remaining Life	Year of Decommissioning
Arnot	2.28	Coal	13	2023
Camden	1.52	Coal	15	2025
Duvha	3.45	Coal	22	2032
Grootvlei	0.75	Coal	19	2029
Hendrina	1.87	Coal	12	2022
Kendal	3.84	Coal	30	2040
Komati	0.20	Coal	14	2024
Kriel	2.85	Coal	18	2028
Lethabo	3.56	Coal	27	2037
Majuba	3.84	Coal	41	2051
Matimba	3.69	Coal	29	2039
Matla	3.45	Coal	21	2031
Tutuka	3.51	Coal	27	2037
Gariep	0.36	Hydro	15	2025
Van der Kloof	0.24	Hydro	17	2027
Acacia	0.34	Diesel	21	2031
Ankerlig	1.32	Diesel	22	2032
Gourikwa	0.74	Diesel	22	2032
Koeberg	1.80	Nuclear	37	2047
Drakensberg	1.00	Pumped Storage	21	2031
Palmiet	0.40	Pumped Storage	28	2038
Total	**41.02**			

Save for Majuba, the table above shows that nearly all of the Eskom plants get decommissioned by 2040 while the modelling period ends in 2050. The committed greenfield Eskom plants currently under construction are shown in Table 3.8.

Table 3.8: Eskom committed greenfield projects

Eskom Committed Plant (GW)	Type	Commercial Operation Date	Projected Life	Year of Decommissioning
Medupi (4.332)	Coal	2012*	40	2052
Kusile (4.338)	Coal	2014	40	2054
Ingula (1.332)	Pumped Storage	2013	60	2073
Sere (0.1)	Wind	2012	20	2032

The assumptions on the performance of these plants are the same as that assumed in the IRP2010.

3.3.1.2 Non-Eskom existing plant

The assumptions made in the IRP 2010 for non-Eskom plant still hold, Table 3.9 below refers.

Table 3.9: non-Eskom plant

non-Eskom Existing Plant	Capacity (GW)	Plant Type	Remaining Life	Year of Decommissioning
Coal	1.08	Coal	30	2040
Cahora Bassa	1.50	Hydro	23	2033
Other	0.50	Co-generation	30	2040
Steenbras	0.18	Pumped Storage	-	-
Total	**3.26**			

Cahora Bassa is a hydro plant located in Mozambique with known generation capacity and energy parameters; and Steenbras is a pumped storage scheme, with known capacity and energy parameters. The rest of the non-Eskom plants have been modelled as limited energy options, see Table 3.10 below.

Table 3.10: Load Factors for non-Eskom plant

non-Eskom Existing Plant	Load Factor (%)	Variable Cost (R/MWh)	Fixed Cost (R/kW)
Coal	62.40	-	-
Cahora Bassa	85.83	-	-
			-
Other	62.40	-	-
Steenbrass	34.31	-	-

Current commitments as defined in the IRP2010 are included in the IEP. These include the pre-IRP determinations as well as the 2011 and 2012 determinations as listed in Table 3.11 below.

Table 3.11: Department of Energy determinations in MW

	New build options								Committed					Non IRP	
	Coal imports	Nuclear	Import hydro	Gas – CCGT	Peak – OCGT[1]	Wind	CSP	Solar PV	Coal	Other	DoE Peaker	Wind[2]	Other Renew.	Co-generation	TOTAL
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
2010	-	-	-	-	-	-	-	-	380	260	-	-	-	-	640
2011	-	-	-	-	-	-	-	-	679	130	-	-	-	-	809
2012	-	-	-	-	-	-	-	300	303	-	-	400	100	-	1,103
2013	-	-	-	-	-	-	-	300	823	333	1,020	400	25	-	2,901
2014	500	-	-	-	-	400	-	300	722	999			100	-	3,021
2015	500	-	-	-	-	400	-	300	1,444				100	200	2,944
2016	-	-	-	-	-	400	100	300	722					200	1,722
2017	-	-	-	-	-	400	100	300	2,168					200	3,168
2018	-	-	-	-	-	400	100	300	723					200	1,723
2019	250	-	-	237	-	400	100	300	1,446						2,733
2020	250	-	-	237	-	400	100	300	723						2,010
2021	250		-	237	-										487
2022	250		1,143		805										2,198
2023	250		1,183		805										2,238
2024	250		283		-										533
2025					805										805
2026															-
2027															-
2028															-
2029															-
2030															-
Total	2,500	-	2,609	711	2,415	2,800	500	2,700	10,133	1,722	1,020	800	325	800	29,035

🟦 **Eskom Commitments (Pre IRP)**
■ **2011 determinations**
🟩 **2012 determinations**

3.3.1.3 Modelling existing capacity

Currently existing and committed plans were modelled as Residual Capacity, and all plant variable costs collected in R/MWh are converted to R/GJ through the relationship,

$${}^{R}/_{MWh} = {}^{R}/_{3.6GJ}$$

This is equivalent to Rm/PJ, which is the required model number. This is also applies to fuel costs.

Capital costs for new plant, and fixed costs for existing plants, collected as R/kW were used, and are equivalent to Rm/GW.

The data for new plant options, that is costs and performance characteristics, were obtained from the EPRI report compiled for IRP 2010, as listed in Table 3.12.

Table 3.12: EPRI Data for new options, used in the IEP model

Technology	Open Cycle Gas Turbine	Combined Cycle Gas Turbine	Pulverized Coal with FGD 6x750 MW	FBC with FGD	Six 2x2x1 Shell IGCC
Rated Capacity, MW gross	115.9	732.4	4856	534	1578
Rated Capacity, MW net	114.7	711.3	4500	500	1288
Plant Cost Estimates (Jan 2011)					
Total Plant Costs, Overnight, ZAR/kW	4,240	6,396	21,248	18,267	27,246
Lead Times and Project Schedule, years	2	3	9	5	5
Fuel Cost Estimates					
First Year, ZAR/GJ	42.10	42.10	15	7.5	15
Fuel Energy Content, MJ/SCM	39.3	39.3	19.22	19,220	19,200
Operation and Maintenance Cost Estimates					
Fixed O&M, ZAR/kW-yr	70	148	455	404	830
Variable O&M, ZAR/MWh	-		44.4	99.1	14.4
Availability Estimates					
Equivalent Availability	87.0	88.8	91.7	90.4	85.7
Maintanance	6.9	6.9	4.5	5.7	4.7
Unplanned Outages	4.6	4.6	3.7	4.1	10.1
Performance Estimates					
Economic Life, years	30	30	30		30
Heat Rate, kJ/kWh					
Average Annual	11,926	7,486	9,769	10,081	9,758
Plant Load Factor					
Typical Capacity Factor	10%	50%	85%	85%	85%
Water Usage					
per Unit of Energy, L/MWh	19.80	12.80	229.1	33.3	256.8
Air Emissions, kg/MWh					
CO_2	622.00	376.00	936.2	976.9	857.1

3.3.1.4 New plant costs

For options where there is still further scope for decreasing capital costs going into the future, the IRP suggested the curves below, for selected technologies (coal and nuclear costs are added for reference.)

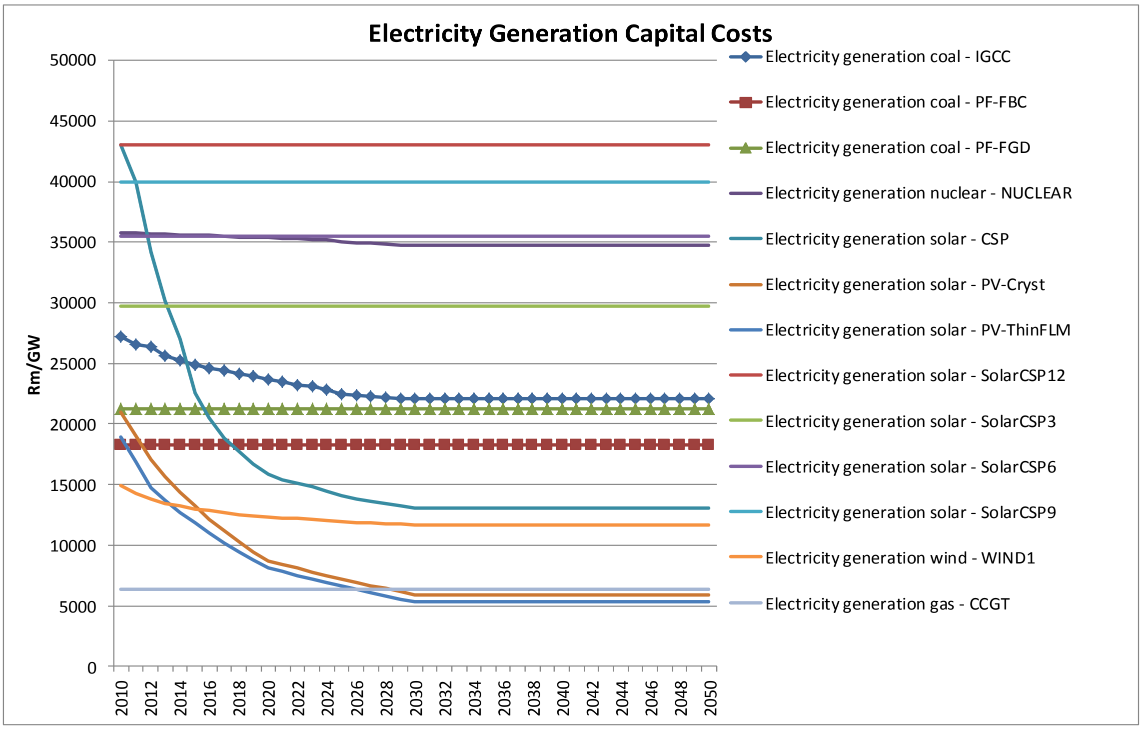

Figure 3.1: Capital costs showing learning rates for new electricity generation technologies (Rm/GW)

3.3.1.5 Reserve margin and time slices

A constant electricity reserve margin of 19% was used for the entire modelling period. The rationale for the chosen reserve margin is captured in annexure A.3.1. Six time slices were used to simulate the electricity demand profile. These are provided in Table 3.13. Day time is taken to be 07:00-17:59, night time is taken to be 21:00-06:59 and a peak is taken to be 18:00-20:59.

Table 3.13: Time slices used to model the electricity demand profile

Time slice name	Season	Day type	Time bracket	Demand profile	Share of Time
Whole year Week days Day	Whole year	Week days	Day, 07:00-17:59	38%	31%
Whole year Week days Night	Whole year	Week days	Night, 21:00-06:59	25%	28%
Whole year Week days Peak	Whole year	Week days	Peak, 18:00-20:59	10%	8%
Whole year Weekends Day	Whole year	Weekends	Day, 07:00-17:59	14%	15%
Whole year Weekends Night	Whole year	Weekends	Night, 21:00-06:59	9%	14%
Whole year Weekends Peak	Whole year	Weekends	Peak, 18:00-20:59	4%	4%

3.3.1.6 Transmission and distribution losses

The electrical system in South Africa is characterized by coal plants located in the Mpumalanga province. These plants form the bulk of base-load generation. The demand, however, is spread throughout the country and as a result leads to annual aggregate transmission losses of about 3.5%. Distribution losses additional to that are an aggregate annual amount of about 6.5%. At distribution level, there are additional non-technical losses. A 10% total system loss is assumed for the modelling. No transmission and distribution costs are included in the model.

3.3.2 Liquid fuels production

This section covers crude oil refineries, gas to liquids (GTL) and coal to liquid (CTL) plant technical parameters and costs.

3.3.2.1 Existing capacity

The existing liquid fuels production capacity is provided in Table 3.14. Sapref, Enref, Calref and Natref are conventional crude oil refineries whereas Secunda is a CTL plant and PetroSA is a GTL plant.

Table 3.14: Existing refinery capacity (Sapia, 2010)

Refinery	Refinery Type	Nameplate Capacity (bpsd[1])	Ownership	Location
Chevref	Conventional (Crude Oil)	100 000	Chevron South Africa	Cape Town
Enref	Conventional	125 000	Engen Petroleum	Durban
Natref	Conventional	92 000	Sasol/Total South Africa (64/36%)	Gauteng
Sapref	Conventional	180 000	Shell South Africa/BP Southern Africa (50/50%)	Durban
Sasol (Secunda)	Coal-to-Liquid	150 000 (crude equivalent @ average yield)	Sasol	Gauteng
PetroSA	Gas-to-Liquid	45 000 (crude equivalent @ average yield)	PetroSA	Western Cape

3.3.2.2 Capacity constraints

No capacity constraints were placed on new conventional refineries but any future coal to liquid capacity increases have been limited to 80 000 barrels per day based on historical discussions of new CTL plant.

3.3.2.3 Remaining life of plant

The remaining life of refineries is unclear due to the routine maintenance and occasional upgrades which tend to extend the plant life. From the modelling perspective operational life does not have a significant influence on the overall cost of providing liquid fuels and hence has a negligible impact on the model results. The main reason for this is the relative cost of the crude oil throughput to the capital costs of refineries. For example, using indicative numbers, a 400 000 barrels per day refinery costing R40 billion and with a life of 40 years, the total cost crude oil over its operational life would be R4,300 billion (assuming $100 per barrel and R8/US$). The cost of the refinery would be 1% the cost of the crude oil. For this reason the existing refineries were assumed to remain operational beyond the end of the modelling period.

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[1] bpsd – barrels per stream day

3.3.2.4 Costs

Capital and fixed costs for conventional crude oil refineries, CTL and GTL used in the modelling are provided in Figure 3.2. Costs are given per unit of energy output from transformations. While the capital and fixed costs for the coal and gas to liquids are higher than conventional refineries the cost for coal is considerably lower than that of crude oil (see figure 3.1). There are no variable costs associated with these transformation technologies as the fuel costs are accounted for in the cost of the technologies providing the fuels i.e. the import or extraction technologies.

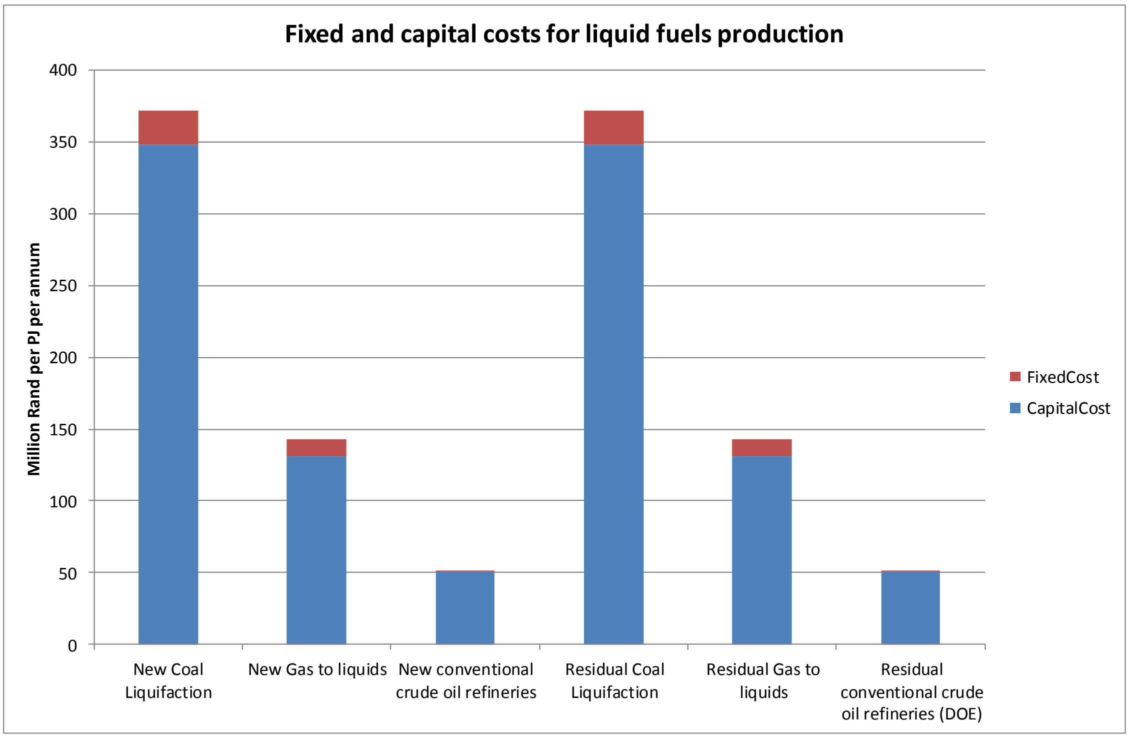

Figure 3.2: Fixed and capital costs for new and existing liquid fuels production technologies

3.3.2.5 Refinery slates

The input and output fuels from the liquid fuels production technologies are presented in Figure 3.3 and the ratio of energy input to energy output of these technologies is shown in Figure 3.4. The main inputs into CTL plants are coal and gas but electricity is also used in the process. The GTL plant uses natural gas and natural gas liquids, crude oil and electricity and the conventional refineries use crude oil, natural gas and electricity. The outputs from the liquid fuels refining process include petrol, diesel, jet fuel, aviation gas, paraffin, liquid petroleum gas, residual fuel and small amounts of other non-energy products.

A key assumption to note is that the share of final products from refineries is based on the current average refinery slate which is kept constant throughout the modelling period. However it is acknowledged that there is a trend towards greater diesel demand in the future. The future demand for diesel, paraffin and LPG together with future sources of crude oil and its properties are required to determine a more likely refining slate and associated costs.

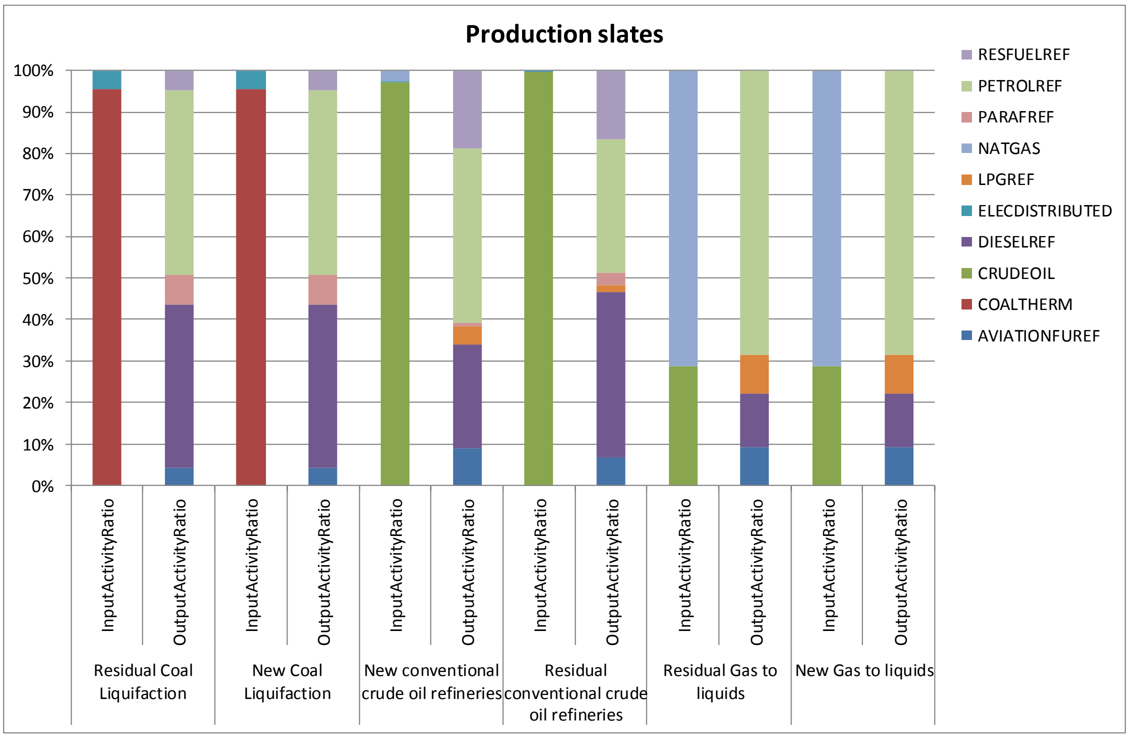

Figure 3.3: Input and output energy carriers for liquid fuels production technologies

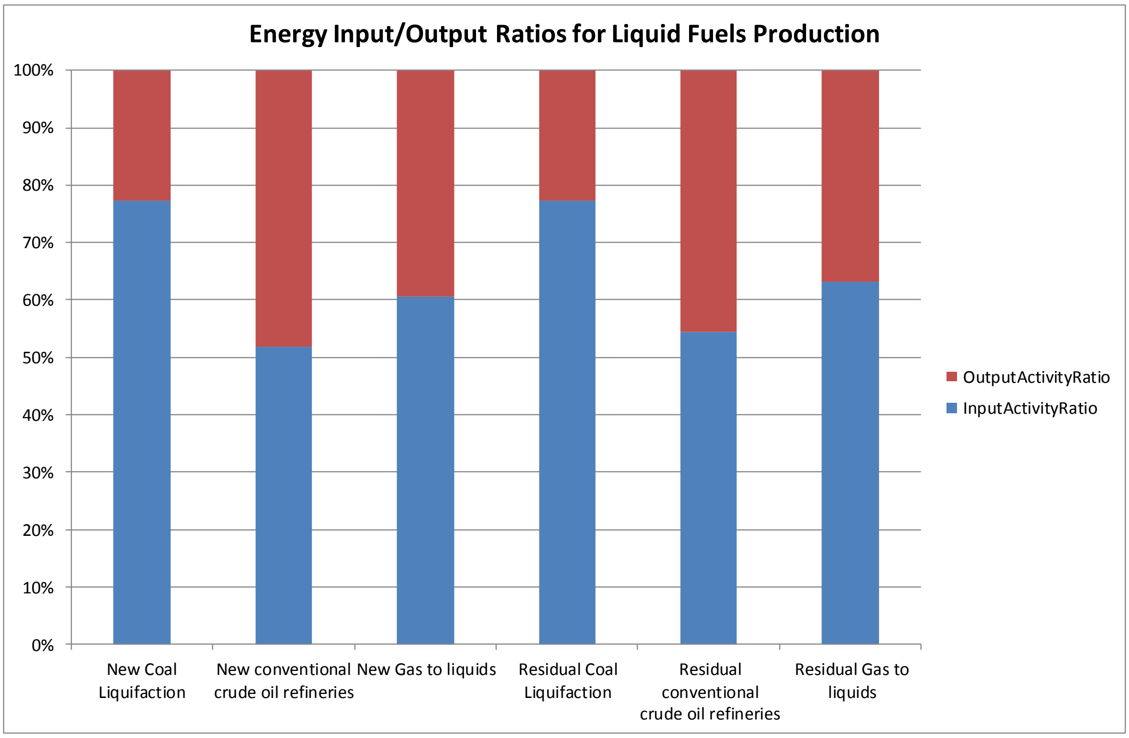

Figure 3.4: Ratio of input to output energy for liquid fuels production technologies

3.3.2.6 CO_2 Emissions factors

Carbon dioxide emission factors per unit of energy output for the liquid fuels production technologies are shown in Figure 3.5. CTL plants have a carbon intensity of about one order of magnitude greater than conventional refineries whereas GTL plants are within the same order of magnitude. The emissions factors for refineries and CTL plants were calculated from the national energy balances as the difference between the carbon content of the input commodities and output commodities. New CTL plants were assumed to have the same technical properties as the existing CTL plants. It is however acknowledged that this may not be an accurate assumption for new plants due to further development that has since taken place on these technologies. The IPCC emissions factors were used for the individual commodities (IPCC, 2011). The emission factors for new and existing (residual) GTL plants are different as they use different processes (high and low temperature Fischer-Tropsch). These numbers were obtained from (Shaw (2012)

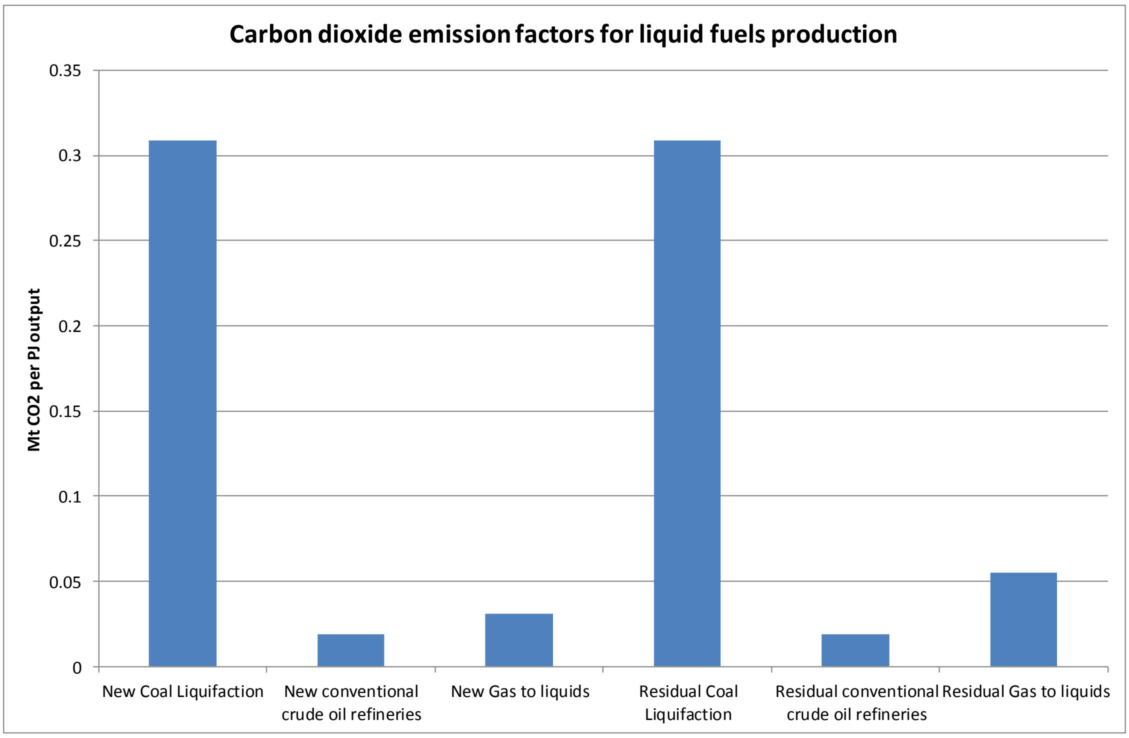

Figure 3.5: CO_2 emission factors for liquid fuels production technologies

3.3.2.7 Water consumption

Water consumption by refineries, CTL and GTL plants are presented in Figure 3.6. New GTL plants are expected to use sea water and should therefore have negligible fresh water consumption. Water consumption for CTL plants is higher than that of other liquid fuels production technologies as water (or steam) is used as part of the chemical process as well as for cooling and other auxiliary processes.

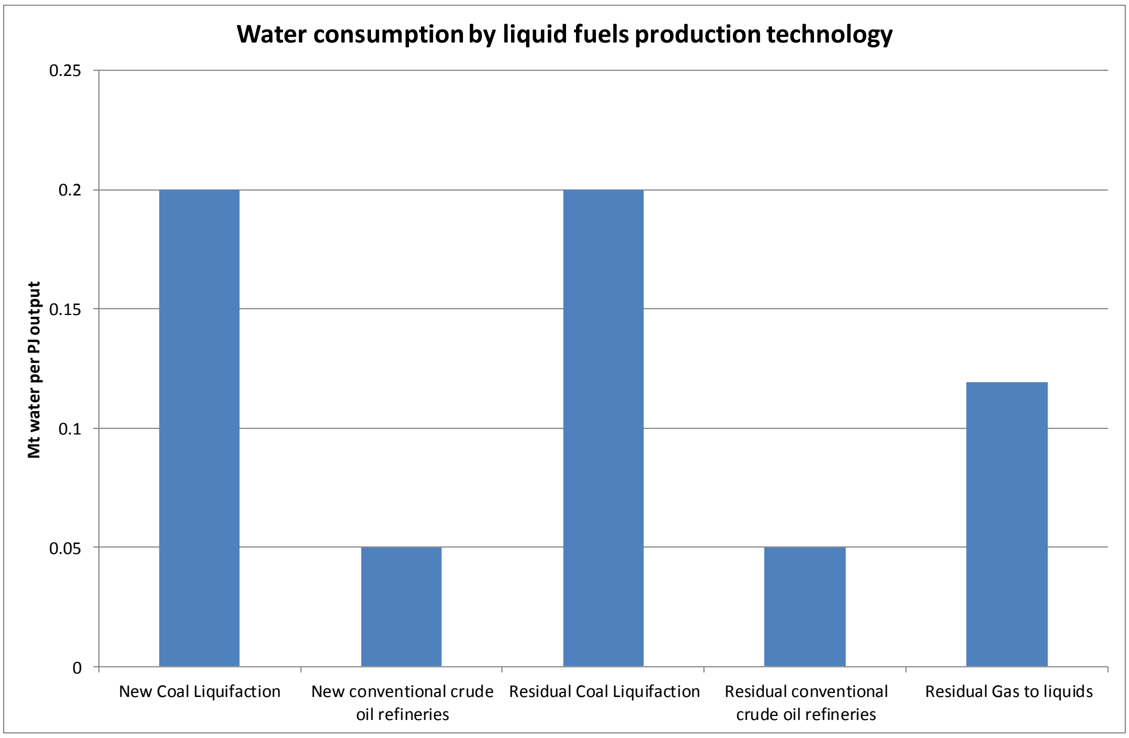

Figure 3.6: Water consumption factors for liquid fuels production technologies

3.3.3 Liquid fuel transportation and distribution

Transport, distribution and storage costs from the retail margin for petrol from 2010 (10.8 cents per litre) from the South African Energy Price Report 2011 (DOE, 2011) is used as a variable costs to "distribution" technologies for liquid fuels. These costs were adjusted to the density of the fuel and represented in R/GJ. Density and energy content were used from Digest of South African Energy Statistics 2009 (DOE, 2009).

3.4 Sources of Primary Energy

The primary energy considered for the modelling includes local extraction of coal and natural gas (conventional natural gas, coal bed methane and shale gas) as well as imports of crude oil and natural gas. For the sake of completeness, import of final product is also considered.

Two types of coal mining were considered for the provision of coal: opencast and underground. Natural gas and its derivatives are available from a number of sources including conventional natural gas extraction, hydraulic fracturing for shale gas and underground coal gasification for coal bed methane.

Fixed and capital costs for the extraction of energy resources are shown in Figure 3.7. It should be noted that fixed costs are almost negligible compared to capital costs.

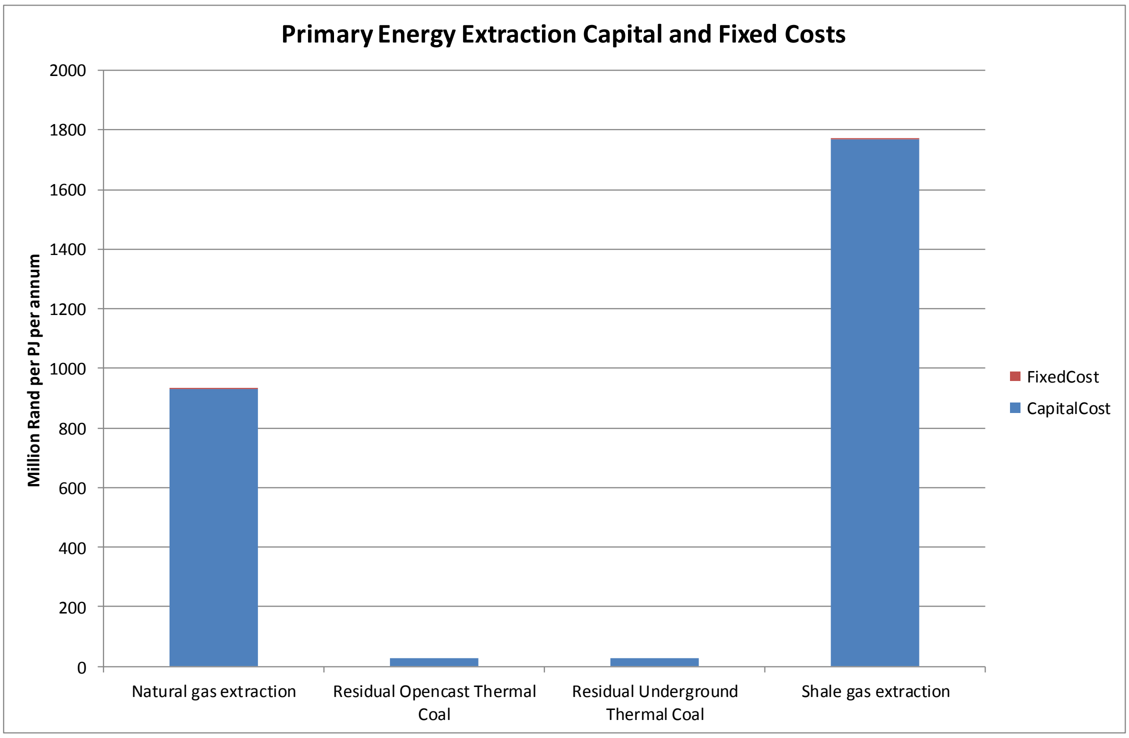

Figure 3.7: Fixed and capital costs for extraction of natural resources

Variable costs associated with the extraction of natural resources are dependent on the prices of the energy carriers consumed during the extraction. Both electricity and diesel are inputs into the extraction of primary energy in terms of the reference energy system.

Import prices of various energy carriers are included in Figure 3.8. The petrol and diesel prices are calculated based on the basic fuel price which is correlated to crude oil prices.

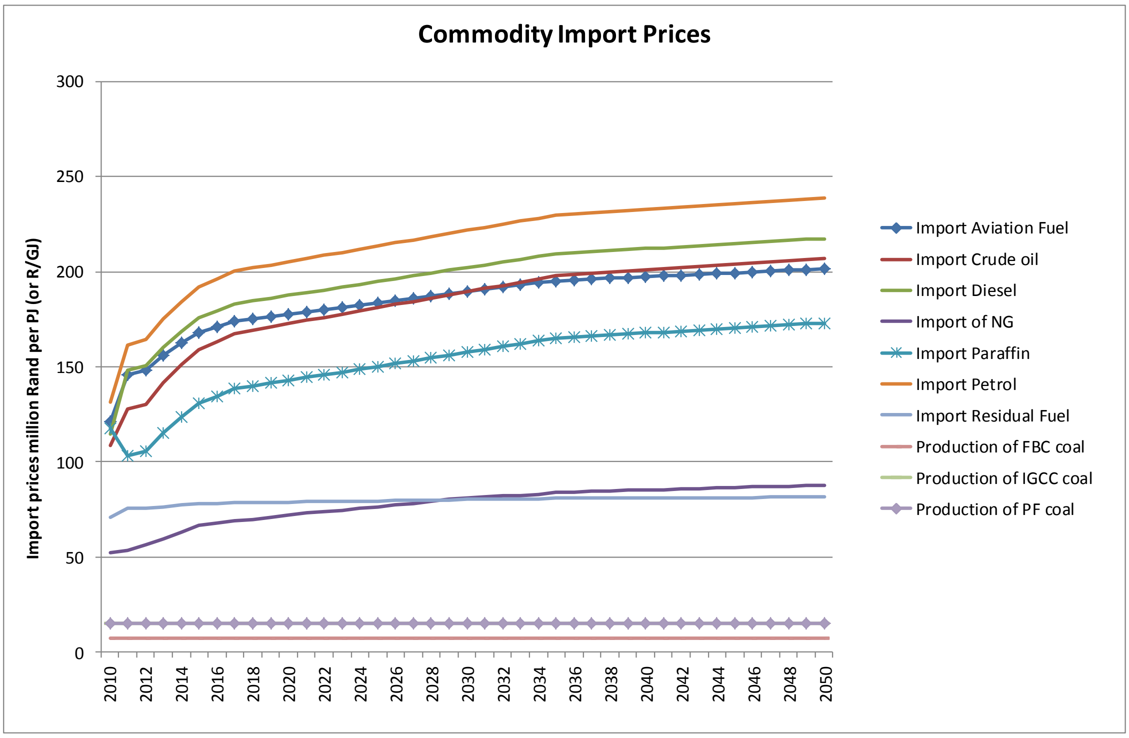

Figure 3.8: Prices of imports and costs of energy extraction

The Reference Case crude oil price projections estimated by the US Energy Information Agency in their Annual Energy Outlook 2012 (EIA, 2012) were used to price crude to the year 2030 and continued trends were then assumed up to 2050. Correlations between residual basic fuel prices and crude oil were used together with the EIA crude oil price projections to estimate the prices of imported petrol and diesel to 2050. Imports of natural gas were also considered. Natural gas price projections were based on the projections for average gas import prices in Europe in the International Energy Agency 2011 World Energy Outlook (IEA, 2011) for the ‘New Policies’ scenario. The figures for projected crude oil prices and natural gas prices are provided in the main Draft Integrated Energy Planning Report in the section “Summary of Key Macroeconomic Assumptions”.

3.5 Default Parameter Values

Each parameter used in the model has a default value. These values are mostly used for convenience so that a value can be set once and then assumed to be the same for most circumstances. The default parameter value of particular importance is the capacity to activity unit which is set to 31.536 PJ/GW/a (this defines the amount of energy that will be transformed if a technology is run at capacity for a whole year non-stop). In general, all the other defaults are set to be least constraining on the energy system i.e. maximum limits are set very high and minimum limits are set very low. Any parameter values explicitly provided during the modelling process override default values. Default parameter values are provided in Appendix D: Default Parameter Values.

4. Test Case Assumptions

This section provides information about the parameters and the related assumptions/values which informed input into the optimisation model for the various test cases.

As mentioned in section 3, the Base Case is the starting point for all of the other test cases. This section only provides those assumptions for the respective test cases which deviate from the Base Case.

4.1 Emissions Limit Case

The Emissions Limit Case uses all the technology assumptions used in the Base Case. The purpose of this test case is to provide insight into the impact of the Peak-Plateau-Decline emissions limits with all other input parameters remaining the same.

The national emissions limits for energy use and transformation are presented in Figure 4.1. ***These emission limits were applied to electricity generation and liquid fuels production in proportion to their current share of CO_2 emissions***.

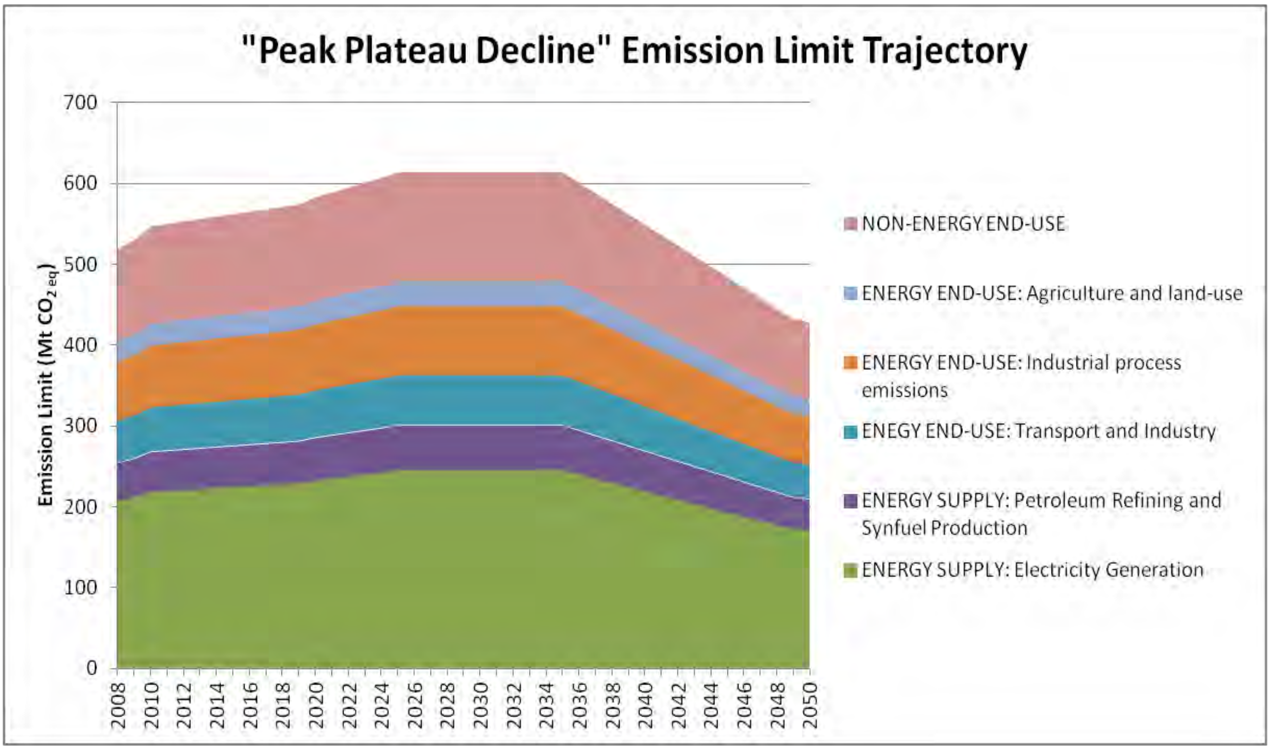

Figure 4.1: Peak-Plateau-Decline CO_2 emissions limits

4.2 No New Nuclear Case

The No Nuclear Case uses all the technology assumptions used in the Base Case. The purpose of this test case is to provide insight into the impact of the Peak-Plateau-Decline emissions limits with the additional condition that ***no new nuclear technologies are included as available technologies to the energy system***. All other input parameters remain the same as the Emissions Case.

4.3 No New Nuclear Gas Case

The purpose of this test case is to provide insight into the impact of using as much gas as possible to displace nuclear energy. ***The maximum natural gas capacity used in the IRP2010 was used as the upper limit to the amount of electricity produced from natural gas (4.2 GW) and a maximum annual capacity increase of 948 MW/a was assumed***. All other input parameters remain the same as those for the No New Nuclear Case.

4.4 Renewable Energy Target Case

The Renewable Energy Target Case uses all the technology assumptions used in the Base Case. The purpose of this test case is to provide insight into the impact of specifying a renewable energy target as an alternative to an emissions limit with the objective of determining whether these options have the same impact. All the assumptions for the Base Case are assumed for this case with the ***addition of the requirement that renewable energy increases linearly from zero at the start of the modelling period to 10% of the total primary energy by 2030. A target is not specified after 2030 but the share of renewable energy is not allowed to drop below 10% of the primary energy input***.

4.5 High Oil Price Case

The High Oil Price test case is used to test the sensitivity of the energy system to high crude oil prices. The import crude and petroleum product prices for this case are provided in Figure 4.2.

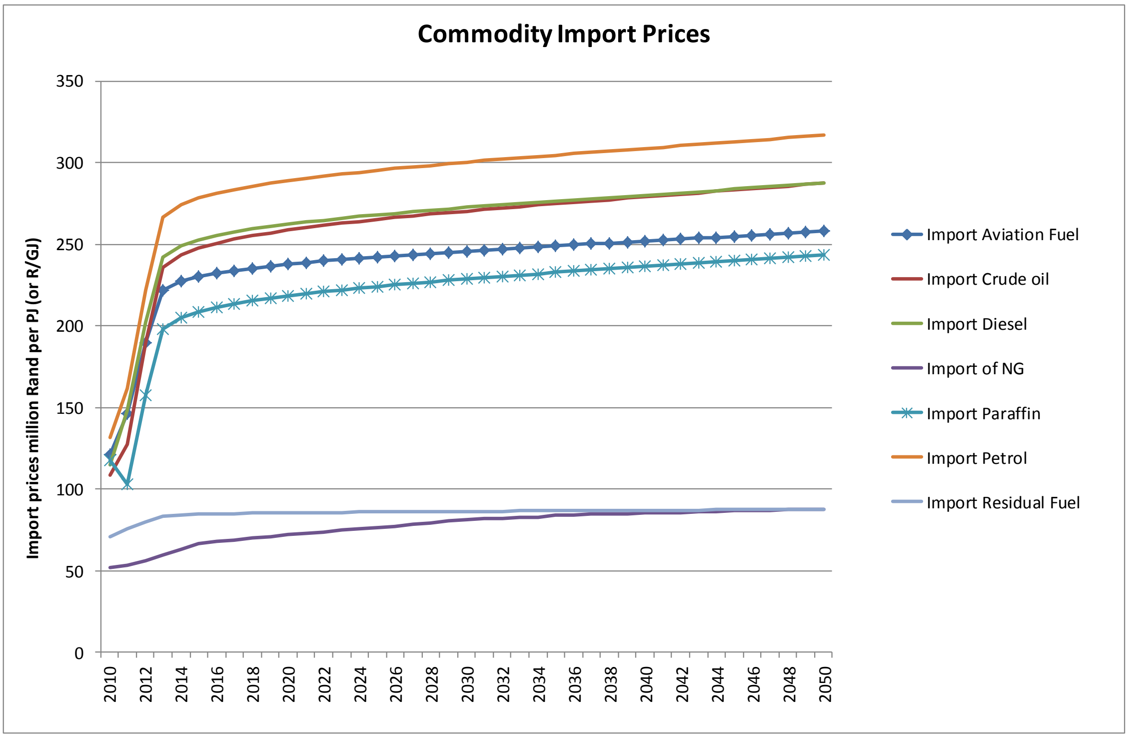

Figure 4.2: Import prices based on high oil price projection (EIA, 2012)

4.6 Low Oil Price Case

The Low Oil Price test case is used to test the sensitivity of the energy system to low crude oil prices. The import crude and petroleum product prices for this case are provided in **Figure 4.3**.

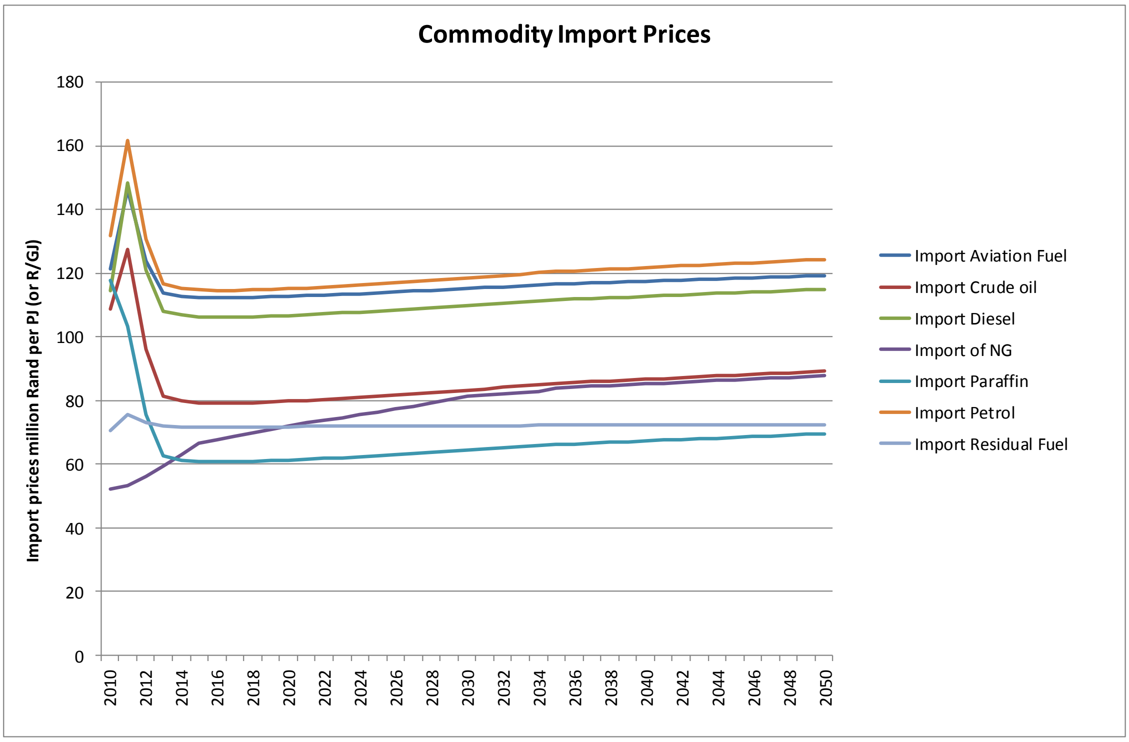

Figure 4.3: Import prices based on low oil price projection (EIA, 2012)

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Appendix A: Energy Carrier Properties

Table A.1: Energy carrier properties (DOE, 2010)

Energy Carrier	Energy Content	Unit	Density kg/l	MJ/kg
LPG	26.7	MJ/l	0.54	49.4
Paraffin Power	37.5	MJ/l	0.81	46.1
Gas SASOL	18.0	MJ/m^3		
Diesel	38.1	MJ/l	0.84	45.4
Electricity	3.6	MJ/kWh		
Natural Gas	41.0	MJ/m^3		
Heavy Fuel Oil	41.6	MJ/l	0.98	42.3
Petrol	34.2	MJ/l	0.72	47.3
Paraffin Illuminating CSS (StatsSA) Data	37.0	MJ/l	0.79	47.0
Aviation Gas	33.9	MJ/l	0.73	46.4
Jet Fuel	34.3	MJ/l	0.79	43.3
Coal Eskom Average	20.1	MJ/kg		
Coal (General purpose)	24.3	MJ/kg		
Coal (Coking)	30.1	MJ/kg		
Coke	27.9	MJ/kg		
Coke oven gas	17.3	MJ/m^3		
Blast furnace gas	3.1	MJ/m^3		
Bagasse (wet)	7.0	MJ/kg		
Bagasse fibre (dry)	14.0	MJ/kg		
Biomass (wood dry typical)	17.0	MJ/kg		
Gas Sasol - methane rich	35.0	MJ/m^3		

Appendix B: List of Energy Carriers and Services

Table B.1: Commodities (carriers, services and emissions) considered in the IEP

Commodity code	Commodity name	Commodity type	Commodity group	Sector
CO2	Carbon dioxide	Emission	Emission	
CO2ELECGEN	CO2 from elec generation	Emission	Emission	
CO2REFINING	CO2 from refining	Emission	Emission	
BIO	Biomass	Fuel	Biomass	
HCOARN	Hard Coal Arnot	Fuel	Coal	
HCOCAM	Hard Coal Camden	Fuel	Coal	
HCODUV	Hard Coal Duvha	Fuel	Coal	
HCOFBC	Hard coal for fluidised bed combustion PS	Fuel	Coal	
HCO	Hard Coal for IGCC PS	Fuel	Coal	
HCOPF	Hard coal for pulverised fuel PS	Fuel	Coal	
HCOGRO	Hard Coal Grootvlei	Fuel	Coal	
HCOHEN	Hard Coal Hendrina	Fuel	Coal	
HCOKEN	Hard Coal Kendal	Fuel	Coal	
HCOKOM	Hard Coal Komati	Fuel	Coal	
HCOKRI	Hard Coal Kriel	Fuel	Coal	
HCOKUS	Hard Coal Kusile	Fuel	Coal	
HCOLET	Hard Coal Lethabo	Fuel	Coal	
HCOMAJ	Hard Coal Majuba average	Fuel	Coal	
HCOMATi	Hard Coal Matimba	Fuel	Coal	
HCOMATL	Hard Coal Matla	Fuel	Coal	
HCOMED	Hard Coal Medupi	Fuel	Coal	
HCOTUT	Hard Coal Tutuka	Fuel	Coal	
COALTHERM	Thermal Coal	Fuel	Coal	
CRUDEOIL	Crude Oil	Fuel	Crude	
ELECDISTRIBUTED	Electricity at consumption	Fuel	Electricity	
ELECTRANSMITTED	Electricity at end of transmission	Fuel	Electricity	
ELECGENERATED	Electricity at point of generation	Fuel	Electricity	
ELC	Grid Electricity	Fuel	Electricity	
H2O	fresh water	Fuel	Fresh water	
NATGAS	(Pipeline) NG	Fuel	Gas	
CNG	CNG	Fuel	Gas	
GAS	Natural Gas for CCGT	Fuel	Gas	
NATGASREF	Pre-transported NG	Fuel	Gas	
HYD	Hydro power	Fuel	Hydro	
NUC	Nuclear Fuel	Fuel	Nuclear	
AVIATIONFU	Aircraft fuels	Fuel	Petroleum product	
DIESEL	Diesel	Fuel	Petroleum product	
RESFUELIMP	imported residual fuel oil	Fuel	Petroleum product	
LPG	LPG	Fuel	Petroleum product	
PARAFFIN	Paraffin	Fuel	Petroleum product	
PETROL	Petrol	Fuel	Petroleum product	
AVIATIONFUREF	Refined Aircraft fuels	Fuel	Petroleum product	
DIESELREF	Refined Diesel	Fuel	Petroleum product	
LPGREF	Refined LPG	Fuel	Petroleum product	
PARAFREF	Refined Paraffin	Fuel	Petroleum product	
PETROLREF	Refined Petrol	Fuel	Petroleum product	
RESFUELREF	Refined Residual Fuel Oil	Fuel	Petroleum product	
RESFUEL	Residual fuel oil	Fuel	Petroleum product	
SECPETRPROD	Secondary petroleum products	Fuel	Petroleum product	

SECPETRPRODREF	Secondary petroleum products from ref	Fuel	Petroleum product	
SOL	Solar Resource	Fuel	Solar	
WND	Wind Resource	Fuel	Wind	
DALLCOAL	Demand for Coal all final use	Service	Coal	Total final demand
DMD01	Demand for Electricity	Service	Electricity	Total final demand
DALLNATGAS	Demand for Natural Gas all final use	Service	Gas	Total final demand
PKMAIR	Demand for Aviation Fuel in Passenger Transport	Service	Mobility	Transport
PKMHICAR	Pass-km HI Car demand	Service	Mobility	Transport
PKMHISUV	Pass-km HI SUV	Service	Mobility	Transport
PKMLICAR	Pass-km LI Car demand	Service	Mobility	Transport
PKMLISUV	Pass-km LI SUV	Service	Mobility	Transport
PKMMICAR	Pass-km MI Car demand	Service	Mobility	Transport
PKMMISUV	Pass-km MI SUV	Service	Mobility	Transport
PKMPUBLICROAD	Pass-km road public trans	Service	Mobility	Transport
TKMLRGTR	Ton-km demand large truck	Service	Mobility	Transport
TKMMEDTR	Ton-km demand medium truck	Service	Mobility	Transport
TKMSMLTR	Ton-km demand small truck	Service	Mobility	Transport
DALLDIES	Demand for Diesel all final use	Service	Petroleum product	Total final demand
DALLKERO	Demand for kerosene all final use	Service	Petroleum product	Total final demand
DALLLPG	Demand for LPG all final use	Service	Petroleum product	Total final demand
DALLRESFUEL	Demand for Residual Fuel all final use	Service	Petroleum product	Total final demand

Appendix C: List of Technologies

Table C.1: Technologies considered in the IEP

Technology code	Technology name	Technology type	Sector
DISTRIBUTEELEC	Distribution of electricity to final demand	Distribution	Energy
GXNEWBIO	Bagasse PS	Electricity generation biomass	Energy
GXRESBIOREFIT	LANDGAS	Electricity generation biomass	Energy
GXNEWHCOIGCC	IGCC	Electricity generation coal	Energy
GXRESNONESKHCO	Non Eskom Coal	Electricity generation coal	Energy
GXNEWHCOFBC	PF-FBC	Electricity generation coal	Energy
GXNEWHCOGENPF	PF-FGD	Electricity generation coal	Energy
DSMCOMAIR	CompressedAir	Electricity generation DSM	Energy
DSMHEATPUM	HeatPumps	Electricity generation DSM	Energy
DSMLTHVAC	Lighting and HVAC	Electricity generation DSM	Energy
DSMNEWINIT	New Initiatives	Electricity generation DSM	Energy
DSMPROCOPT	Process Optimisation	Electricity generation DSM	Energy
DSMSHOWHDS	Shower Heads	Electricity generation DSM	Energy
DSMSOLWATHEAT	Solar Water Heaters	Electricity generation DSM	Energy
GXNEWHYDBOR	BOROMA	Electricity generation hydro	Energy
GXRESNONESKHYDCAH	Cahora Bassa	Electricity generation hydro	Energy
GXNEWHYDHCBNOR	CHB North	Electricity generation hydro	Energy
GXRESESKHYDGAR	Gariep	Electricity generation hydro	Energy
GXNEWHYDITEZH	ITEZHI	Electricity generation hydro	Energy
GXNEWHYDKAFU	KAFUE	Electricity generation hydro	Energy
GXNEWHYDKARI	KARIBA Ext	Electricity generation hydro	Energy
GXNEWHYDMPAND	MPANDA	Electricity generation hydro	Energy
GXRESHYDREFIT	REFITHYDRO	Electricity generation hydro	Energy
GXRESESKHYDVAN	Van De Kloof	Electricity generation hydro	Energy
GXRESESKNUCKOEU1	Koeberg Unit 1	Electricity generation nuclear	Energy
GXRESESKNUCKOEU2	Koeberg Unit 2	Electricity generation nuclear	Energy
GXNEWNUCPWR	NUCLEAR	Electricity generation nuclear	Energy
GXRESMTPPP1	MTPPP1	Electricity generation other	Energy
GXRESNONESKOTH	NONESKOTH	Electricity generation other	Energy
GXRESESKKERACA	Acacia	Electricity generation petroleum	Energy
GXRESESKKERANK	Ankerlig	Electricity generation petroleum	Energy
GXNEWGASCC	CCGT	Electricity generation petroleum	Energy
GXRESNONESKKERDOE	DOE-IPP	Electricity generation petroleum	Energy
GXRESESKKERGOU	Gourikwa	Electricity generation petroleum	Energy
GXNEWGASOC	OCGT	Electricity generation petroleum	Energy
GXRESESKPSDRA	Drakensberg	Electricity generation pumped storage	Energy
GXRESESKPSING	Ingula	Electricity generation pumped storage	Energy
GXRESESKPSPAL	Palmiet	Electricity generation pumped storage	Energy
GXRESNONESKPSSTE	Steenbras	Electricity generation pumped storage	Energy
GXNEWSOLCSPTOW12HR	CSP	Electricity generation solar	Energy
GXNEWSOLPVCRYST	PV-Cryst	Electricity generation solar	Energy
GXNEWSOLPVTHNFLM	PV-ThinFLM	Electricity generation solar	Energy
GXRESSOLCSPREFIT	REFITSOLAR	Electricity generation solar	Energy
GXNEWSOLCSP12HR	SolarCSP12	Electricity generation solar	Energy
GXNEWSOLCSP3HR	SolarCSP3	Electricity generation solar	Energy
GXNEWSOLCSP6HR	SolarCSP6	Electricity generation solar	Energy
GXNEWSOLCSP9HR	SolarCSP9	Electricity generation solar	Energy
GXNEWSOLPARTRO9HR	TROUGH	Electricity generation solar	Energy
GXRESWND1REFIT	REFITWIND1	Electricity generation wind	Energy
GXRESWND2REFIT	REFITWIND2	Electricity generation wind	Energy
GXRESESKWNDSERE	Sere	Electricity generation wind	Energy
GXNEWWNDGEN1	WIND1	Electricity generation wind	Energy
GXNEWWNDGEN2	WIND2	Electricity generation wind	Energy
GXNEWWNDGEN3	WIND3	Electricity generation wind	Energy
GXNEWWNDGEN4	WIND4	Electricity generation wind	Energy
TRANSELEC	Electricity transmission	Energy Transportation	Energy
TRANSPET	Transport of Petrol	Energy Transportation	Energy
TRANSSECPETRPROD	Transport of Secondary Petroleum Products	Energy Transportation	Energy

TRANSAIRFUEL	Transportation of Aircraft Fuels	Energy Transportation	Energy
TRANSDIESEL	Transportation of Diesel	Energy Transportation	Energy
TRANSLPG	Transportation of LPG	Energy Transportation	Energy
TRANSNG	Transportation of of Natural gas	Energy Transportation	Energy
TRANSPARA	Transportation of Paraffin	Energy Transportation	Energy
TRANSFUELOIL	Transportation of Residual Fuel Oil	Energy Transportation	Energy
RSCEXPELC	Export Electricity	Export	Energy
RSCBIO	Biomass harvesting	Extraction/Production	Energy
EXTRACTOTHERNG	Natural gas extraction (coal bed methane)	Extraction/Production	Energy
EXTRACTNATG	Natural gas extraction (conventional)	Extraction/Production	Energy
RSCMINHCOFBC	Production of FBC coal	Extraction/Production	Energy
RSCMINHCO	Production of IGCC coal	Extraction/Production	Energy
RSCMINHCOPF	Production of PF coal	Extraction/Production	Energy
RESMINTHCOALOC	Residual Opencast Thermal Coal	Extraction/Production	Energy
RESMINTHCOALUG	Residual Underground Thermal Coal	Extraction/Production	Energy
RSCHYD	River	Extraction/Production	Energy
EXTRACTSHALEG	Shale gas extraction	Extraction/Production	Energy
RSCSUN	The sun	Extraction/Production	Energy
RSCWIND	The wind	Extraction/Production	Energy
RSCNUC	Uranium extraction and fuel prod	Extraction/Production	Energy
RSCH2O	water supply for transformation	Extraction/Production	Energy
IMPAVIATIONFU	Import Aviation Fuel	Import	Energy
IMPCRUDESEA	Import Crude oil	Import	Energy
IMPDIESEL	Import Diesel	Import	Energy
RSCIMPELC	Import Electricity	Import	Energy
RSCIMPGAS	Import Gas	Import	Energy
IMPLPG	Import LPG	Import	Energy
IMPNATGPIPE	Import of NG	Import	Energy
IMPPARA	Import Paraffin	Import	Energy
IMPPET	Import Petrol	Import	Energy
IMPFUELOIL	Import Residual Fuel	Import	Energy
IMPSECPETRPROD	Import Secondary Petroleum Products	Import	Energy
DAM	Storage	Storage	Energy
NEWCTL	New Coal Liquifaction	Transformation	Energy
NEWREFINERY	New conventional crude oil refineries	Transformation	Energy
NEWGTL	New Gas to liquids	Transformation	Energy
RESCTL	Residual Coal Liquifaction	Transformation	Energy
RESREFINERY	Residual conventional crude oil refineries (DOE)	Transformation	Energy
RESGTL	Residual Gas to liquids	Transformation	Energy
ALLCOALTECH	Coal using technology all sectors	Demand	Total final demand
ALLDIESTECH	Diesel using technology all sectors	Demand	Total final demand
ALLELECTECH	Electricity using technology all sectors	Demand	Total final demand
ALLLPGTECH	LPG using technology all sectors	Demand	Total final demand
ALLNATGASTECH	Natural Gas using technology all sectors	Demand	Total final demand
ALLKEROTECH	Other kerosene using technology all sectors	Demand	Total final demand
ALLRESFUELTECH	Residual fuel oil using technology all sectors	Demand	Total final demand
AIRCRAFTPASS	Aircraft passenger IEP	Demand	Transport
NEWBUSDIESEL	New Bus Public - Diesel	Demand	Transport
NEWCARDIESELHI	New Car Private HI - Diesel	Demand	Transport
NEWCARELECHI	New Car Private HI - Electric	Demand	Transport
NEWCARHYBRIDPETHI	New Car Private HI - Hybrid	Demand	Transport
NEWCARPETHI	New Car Private HI - Petrol	Demand	Transport
NEWCARDIESELLI	New Car Private LI - Diesel	Demand	Transport
NEWCARELECLI	New Car Private LI - Electric	Demand	Transport
NEWCARHYBRIDPETLI	New Car Private LI - Hybrid	Demand	Transport
NEWCARPETLI	New Car Private LI - Petrol	Demand	Transport
NEWCARDIESELMI	New Car Private MI - Diesel	Demand	Transport
NEWCARELECMI	New Car Private MI - Electric	Demand	Transport
NEWCARHYBRIDPETMI	New Car Private MI - Hybrid	Demand	Transport
NEWCARPETMI	New Car Private MI - Petrol	Demand	Transport
NEWMBTDIESEL	New minibus taxis diesel	Demand	Transport

NEWMBTPETROL	New minibus taxis petrol	Demand	Transport
NEWSUVDIESELHI	New SUV Private HI - Diesel	Demand	Transport
NEWSUVPETROLHI	New SUV Private HI - Petrol	Demand	Transport
NEWSUVDIESELLI	New SUV Private LI - Diesel	Demand	Transport
NEWSUVPETROLLI	New SUV Private LI - Petrol	Demand	Transport
NEWSUVDIESELMI	New SUV Private MI - Diesel	Demand	Transport
NEWSUVPETROLMI	New SUV Private MI - Petrol	Demand	Transport
NEWTRUCKDIESELHD	New Truck Diesel Heavy	Demand	Transport
NEWTRUCKDIESELLD	New Truck Diesel Light	Demand	Transport
NEWTRUCKDIESELMD	New Truck Diesel Medium	Demand	Transport
NEWTRUCKPETROLLD	New Truck Petrol Light	Demand	Transport
RESBUSDIESEL	Residual Bus Public - Diesel	Demand	Transport
RESCARDIESELHI	Residual Car Private HI - Diesel	Demand	Transport
RESCARPETHI	Residual Car Private HI - Petrol	Demand	Transport
RESCARDIESELLI	Residual Car Private LI - Diesel	Demand	Transport
RESCARPETLI	Residual Car Private LI - Petrol	Demand	Transport
RESCARDIESELMI	Residual Car Private MI - Diesel	Demand	Transport
RESCARPETMI	Residual Car Private MI - Petrol	Demand	Transport
RESMBTDIESEL	Residual minibus taxis diesel	Demand	Transport
RESMBTPETROL	Residual minibus taxis petrol	Demand	Transport
RESSUVDIESELHI	Residual SUV Private HI - Diesel	Demand	Transport
RESSUVPETROLHI	Residual SUV Private HI - Petrol	Demand	Transport
RESSUVDIESELLI	Residual SUV Private LI - Diesel	Demand	Transport
RESSUVPETROLLI	Residual SUV Private LI - Petrol	Demand	Transport
RESSUVDIESELMI	Residual SUV Private MI - Diesel	Demand	Transport
RESSUVPETROLMI	Residual SUV Private MI - Petrol	Demand	Transport
RESTRUCKDIESELHD	Residual Truck Diesel Heavy	Demand	Transport
RESTRUCKDIESELLD	Residual Truck Diesel Light	Demand	Transport
RESTRUCKDIESELMD	Residual Truck Diesel Medium	Demand	Transport
RESTRUCKPETROLLD	Residual Truck Petrol Light	Demand	Transport

Appendix D: Default Parameter Values

Table D.1: Default Parameter Values

Parameter	Default Value
AccumulatedAnnualDemand	0
AnnualEmissionLimit	99999999999
AnnualExogenousEmission	0
AvailabilityFactor	1
CapacityFactor	1
CapacityOfOneTechnologyUnit	0
CapacityToActivityUnit	31.536
CapitalCost	0
DaySplit	0.00137
DiscountRate	0.113
EmissionActivityRatio	0
FixedCost	0
InputActivityRatio	0
MinStorageCharge	0
ModelPeriodEmissionLimit	1E+13
ModelPeriodExogenousEmission	0
OperationalLife	1
OperationalLifeStorage	99
OutputActivityRatio	0
REMinProductionTarget	0
ReserveMarginTagFuel	0
ReserveMarginTagTechnology	0
ResidualCapacity	0
ResidualStorageCapacity	999999
RETagFuel	0
RETagTechnology	0
SalvageFactor	0
SpecifiedAnnualDemand	0
SpecifiedDemandProfile	0
StorageInflectionTimes	0
StorageLevelStart	999999
StorageLowerLimit	0
StorageMaxChargeRate	999
StorageMaxDischargeRate	999
StorageUpperLimit	999999
TechnologyFromStorage	0
TechnologyToStorage	0
TechWithCapacityNeededToMeetPeakTS	0
TotalAnnualMaxCapacity	9999999
TotalAnnualMaxCapacityInvestment	9999999
TotalAnnualMinCapacity	0
TotalAnnualMinCapacityInvestment	0
TotalTechnologyAnnualActivityLowerLimit	0
TotalTechnologyAnnualActivityUpperLimit	9999999
TotalTechnologyModelPeriodActivityLowerLimit	0
TotalTechnologyModelPeriodActivityUpperLimit	9999999
TradeRoute	0
VariableCost	0.000001

Appendix E: Parameter Data Sheets for Base Case

Final Energy Demand

Table E.1: Capital and fixed costs for transport technologies

Fixed and capital costs in Rm per billion km (passenger or freight tonnes) per year capacity		
Equivalent to R/1000 km/year		
Costs are in real terms and assumed to remain constant for the modelling period		
Sector	Transport	
Year	2010	
Active	TRUE	
Sum of Value		
	Capital Cost	**Fixed Cost**
Residual Truck Petrol Light	7053	841
Residual Truck Diesel Medium	3329	176
Residual Truck Diesel Light	7310	871
Residual Truck Diesel Heavy	657	31
Residual SUV Private MI - Petrol	13959	655
Residual SUV Private MI - Diesel	14468	679
Residual SUV Private LI - Petrol	13959	655
Residual SUV Private LI - Diesel	14468	679
Residual SUV Private HI - Petrol	13959	655
Residual SUV Private HI - Diesel	14468	679
Residual minibus taxis petrol	397	29
Residual minibus taxis diesel	391	29
Residual Car Private MI - Petrol	4251	316
Residual Car Private MI - Diesel	4888	363
Residual Car Private LI - Petrol	4251	316
Residual Car Private LI - Diesel	4888	363
Residual Car Private HI - Petrol	4251	316
Residual Car Private HI - Diesel	4888	363
Residual Bus Public - Diesel	765	66
New Truck Petrol Light	7053	841
New Truck Diesel Medium	3329	176
New Truck Diesel Light	7310	871
New Truck Diesel Heavy	657	31
New SUV Private MI - Petrol	15694	736
New SUV Private MI - Diesel	16266	763
New SUV Private LI - Petrol	15694	736
New SUV Private LI - Diesel	16266	763
New SUV Private HI - Petrol	15694	736
New SUV Private HI - Diesel	16266	763
New minibus taxis petrol	397	29
New minibus taxis diesel	391	29
New Car Private MI - Petrol	4922	366
New Car Private MI - Hybrid	5808	432
New Car Private MI - Electric	6398	475
New Car Private MI - Diesel	5660	421
New Car Private LI - Petrol	4922	366
New Car Private LI - Hybrid	5808	432
New Car Private LI - Electric	6398	475
New Car Private LI - Diesel	5660	421
New Car Private HI - Petrol	4922	366
New Car Private HI - Hybrid	5808	432
New Car Private HI - Electric	6398	475
New Car Private HI - Diesel	5660	421
New Bus Public - Diesel	765	66
Aircraft passenger IEP	16013	

Table E.2: Transport technologies operational life

Years of operational life	
CaseStudyCode	IEPEmissionsv8
Sector	Transport
Active	TRUE
	Parameter
Technology Name	**OperationalLife**
New Bus Public - Diesel	15
New Car Private HI - Diesel	12
New Car Private HI - Electric	12
New Car Private HI - Hybrid	12
New Car Private HI - Petrol	12
New Car Private LI - Diesel	12
New Car Private LI - Electric	12
New Car Private LI - Hybrid	12
New Car Private LI - Petrol	12
New Car Private MI - Diesel	12
New Car Private MI - Electric	12
New Car Private MI - Hybrid	12
New Car Private MI - Petrol	12
New minibus taxis diesel	12
New minibus taxis petrol	12
New SUV Private HI - Diesel	12
New SUV Private HI - Petrol	12
New SUV Private LI - Diesel	12
New SUV Private LI - Petrol	12
New SUV Private MI - Diesel	12
New SUV Private MI - Petrol	12
New Truck Diesel Heavy	10
New Truck Diesel Light	10
New Truck Diesel Medium	10
New Truck Petrol Light	10
Residual Bus Public - Diesel	15
Residual Car Private HI - Diesel	12
Residual Car Private HI - Petrol	12
Residual Car Private LI - Diesel	12
Residual Car Private LI - Petrol	12
Residual Car Private MI - Diesel	12
Residual Car Private MI - Petrol	12
Residual minibus taxis diesel	12
Residual minibus taxis petrol	12
Residual SUV Private HI - Diesel	12
Residual SUV Private HI - Petrol	12
Residual SUV Private LI - Diesel	12
Residual SUV Private LI - Petrol	12
Residual SUV Private MI - Diesel	12
Residual SUV Private MI - Petrol	12
Residual Truck Diesel Heavy	10
Residual Truck Diesel Light	10
Residual Truck Diesel Medium	10
Residual Truck Petrol Light	10
Aircraft passenger IEP	30

Table E.3: Transport technologies emission factors

Unit: Mt CO_2 per billion passenger or tonne kilometres	
or kg CO_2 per passenger or tonne km	
Sector	Transport
Year	2010
Active	TRUE
Sum of Value	**Parameter**
TechnologyName	**EmissionActivityRatio**
Residual Truck Petrol Light	0.682
Residual Truck Diesel Medium	0.324
Residual Truck Diesel Light	0.659
Residual Truck Diesel Heavy	0.073
Residual SUV Private MI - Petrol	0.235
Residual SUV Private MI - Diesel	0.231
Residual SUV Private LI - Petrol	0.235
Residual SUV Private LI - Diesel	0.231
Residual SUV Private HI - Petrol	0.235
Residual SUV Private HI - Diesel	0.231
Residual minibus taxis petrol	0.026
Residual minibus taxis diesel	0.023
Residual Car Private MI - Petrol	0.156
Residual Car Private MI - Diesel	0.148
Residual Car Private LI - Petrol	0.156
Residual Car Private LI - Diesel	0.148
Residual Car Private HI - Petrol	0.156
Residual Car Private HI - Diesel	0.148
Residual Bus Public - Diesel	0.038
New Truck Petrol Light	0.682
New Truck Diesel Medium	0.324
New Truck Diesel Light	0.659
New Truck Diesel Heavy	0.073
New SUV Private MI - Petrol	0.235
New SUV Private MI - Diesel	0.231
New SUV Private LI - Petrol	0.235
New SUV Private LI - Diesel	0.231
New SUV Private HI - Petrol	0.235
New SUV Private HI - Diesel	0.231
New minibus taxis petrol	0.026
New minibus taxis diesel	0.023
New Car Private MI - Petrol	0.156
New Car Private MI - Hybrid	0.120
New Car Private MI - Diesel	0.148
New Car Private LI - Petrol	0.156
New Car Private LI - Hybrid	0.120
New Car Private LI - Diesel	0.148
New Car Private HI - Petrol	0.156
New Car Private HI - Hybrid	0.120
New Car Private HI - Diesel	0.148
New Bus Public - Diesel	0.038
Aircraft passenger IEP	0.072

Table E.4: Transport technologies activity ratios (fuel consumption) factors

Unit: PJ/billion passenger or tonne kilometres	
or MJ/km	
Unit for Air craft is PJ/PJ	
Sector	Transport
Active	TRUE
	Parameter
Technology Name	**Input Activity Ratio**
New Bus Public - Diesel	0.540
New Car Private HI - Diesel	2.090
New Car Private MI - Diesel	2.090
New Car Private LI - Diesel	2.090
New Car Private HI - Electric	0.493
New Car Private MI - Electric	0.493
New Car Private LI - Electric	0.493
New Car Private HI - Hybrid	1.554
New Car Private MI - Hybrid	1.554
New Car Private LI - Hybrid	1.554
New Car Private HI - Petrol	2.210
New Car Private MI - Petrol	2.210
New Car Private LI - Petrol	2.210
New minibus taxis diesel	0.320
New minibus taxis petrol	0.367
New SUV Private HI - Diesel	3.257
New SUV Private HI - Petrol	3.327
New SUV Private LI - Diesel	3.257
New SUV Private LI - Petrol	3.327
New SUV Private MI - Diesel	3.257
New SUV Private MI - Petrol	3.327
New Truck Diesel Heavy	1.156
New Truck Diesel Light	9.272
New Truck Diesel Medium	4.560
New Truck Petrol Light	9.656
Residual Bus Public - Diesel	0.540
Residual Car Private HI - Diesel	2.090
Residual Car Private MI - Diesel	2.090
Residual Car Private LI - Diesel	2.090
Residual Car Private HI - Petrol	2.210
Residual Car Private MI - Petrol	2.210
Residual Car Private LI - Petrol	2.210
Residual minibus taxis diesel	0.320
Residual minibus taxis petrol	0.367
Residual SUV Private HI - Diesel	3.257
Residual SUV Private HI - Petrol	3.327
Residual SUV Private LI - Diesel	3.257
Residual SUV Private LI - Petrol	3.327
Residual SUV Private MI - Diesel	3.257
Residual SUV Private MI - Petrol	3.327
Residual Truck Diesel Heavy	1.040
Residual Truck Diesel Light	9.272
Residual Truck Diesel Medium	4.560
Residual Truck Petrol Light	9.656
Aircraft passenger IEP	1.000

Table E.5: Transport technologies variable costs

Unit: Rm/bpkm passenger and Rm/btkm freight (R/1000 km)	
Note: variable costs exclude costs of fuel, fuel costs depend on the energy value chains	
HI - high income group, MI - middle income group, LI - low income group	
Sector	Transport
Year	2010
Active	TRUE
Sum of Value	**Parameter**
Technology Name	**Variable Cost**
Residual Truck Petrol Light	6971
Residual Truck Diesel Medium	2136
Residual Truck Diesel Light	6971
Residual Truck Diesel Heavy	422
Residual SUV Private MI - Petrol	674
Residual SUV Private MI - Diesel	659
Residual SUV Private LI - Petrol	674
Residual SUV Private LI - Diesel	659
Residual SUV Private HI - Petrol	674
Residual SUV Private HI - Diesel	659
Residual minibus taxis petrol	318
Residual minibus taxis diesel	409
Residual Car Private MI - Petrol	350
Residual Car Private MI - Diesel	463
Residual Car Private LI - Petrol	350
Residual Car Private LI - Diesel	463
Residual Car Private HI - Petrol	350
Residual Car Private HI - Diesel	463
Residual Bus Public - Diesel	142
New Truck Petrol Light	6971
New Truck Diesel Medium	2136
New Truck Diesel Light	6971
New Truck Diesel Heavy	422
New SUV Private MI - Petrol	674
New SUV Private MI - Diesel	659
New SUV Private LI - Petrol	674
New SUV Private LI - Diesel	659
New SUV Private HI - Petrol	674
New SUV Private HI - Diesel	659
New minibus taxis petrol	318
New minibus taxis diesel	409
New Car Private MI - Petrol	350
New Car Private MI - Hybrid	335
New Car Private MI - Electric	175
New Car Private MI - Diesel	463
New Car Private LI - Petrol	350
New Car Private LI - Hybrid	335
New Car Private LI - Electric	175
New Car Private LI - Diesel	463
New Car Private HI - Petrol	350
New Car Private HI - Hybrid	335
New Car Private HI - Electric	175
New Car Private HI - Diesel	463
New Bus Public - Diesel	142
Aircraft passenger IEP	170

Liquid fuels production

Table E.6: Capital and fixed costs for liquid fuel production technologies

Unit: Rm/PJ out/annum		
Sector	Energy	
Technology Type	Transformation	
	Parameter	
Technology Name	**Capital Cost**	**Fixed Cost**
New Coal Liquifaction	348.47	23.19
New Gas to liquids	130.67	12.41
New conventional crude oil refineries	50.46	0.57
Residual Coal Liquifaction	348.47	23.19
Residual Gas to liquids	130.67	12.41
Residual conventional crude oil refineries	50.46	0.57

Table E.7: Operation life of liquid fuels production technologies

Unit: Years	
Sector	Energy
Technology Type	Transformation
	Parameter
Technology Name	**Operational Life**
New Coal Liquifaction	30
New conventional crude oil refineries	25
New Gas to liquids	20
Residual Coal Liquifaction	30
Residual conventional crude oil refineries	25
Residual Gas to liquids	20

Note: operational life is used to discount the capital costs of the plant. Refeneries generally have longer lives. In the model the “real” life is controlled by the available capacity

Table E.8: Emissions factors for liquid fuels production technologies

Unit: Mt CO2/PJ output	
Sector	Energy
Technology Type	Transformation
	Parameter
Technology Name	**Emission Activity Ratio**
New Coal Liquifaction	0.309
New conventional crude oil refineries	0.019
New Gas to liquids	0.031
Residual Coal Liquifaction	0.309
Residual conventional crude oil refineries	0.019
Residual Gas to liquids	0.055

Table E.9: Emissions factors for liquid fuels production technologies

Unit: energy commodities are unit less – ratios (i.e. PJ/PJ)			
Water ratios are in Mt water/PJ output			
Sector	Energy		
Technology Type	Transformation		
Year	2010		
Active	TRUE		
		Parameter	
Technology Name	**Commodity Code**	**Input Activity Ratio**	**Output Activity Ratio**
New Coal Liquifaction	COALTHERM	3.000	
	H2O	0.200	
	ELECDISTRIBUTED	0.137	
	PETROLREF		0.428
	DIESELREF		0.379
	RESFUELREF		0.045
	SECPETRPRODREF		0.016
	AVIATIONFUREF		0.041
	PARAFREF		0.069
New conventional crude oil refineries	CRUDEOIL	1.000	
	H2O	0.050	
	NATGAS	0.025	
	ELECDISTRIBUTED	0.003	
	RESFUELREF		0.189
	PARAFREF		0.009
	PETROLREF		0.420
	AVIATIONFUREF		0.090
	DIESELREF		0.250
	LPGREF		0.045
New Gas to liquids	NATGAS	0.714	
	CRUDEOIL	0.286	
	AVIATIONFUREF		0.046
	PETROLREF		0.340
	SECPETRPRODREF		0.156
	DIESELREF		0.064
	LPGREF		0.046
Residual Coal Liquifaction	COALTHERM	3.000	
	H2O	0.200	
	ELECDISTRIBUTED	0.137	
	PETROLREF		0.428
	DIESELREF		0.379
	RESFUELREF		0.045
	SECPETRPRODREF		0.016
	AVIATIONFUREF		0.041
	PARAFREF		0.069
Residual conventional crude oil refineries	CRUDEOIL	1.000	
	H2O	0.050	
	ELECDISTRIBUTED	0.003	
	PARAFREF		0.027
	DIESELREF		0.351
	PETROLREF		0.283
	RESFUELREF		0.147
	AVIATIONFUREF		0.061
	LPGREF		0.014
Residual Gas to liquids	NATGAS	0.714	
	CRUDEOIL	0.286	
	H2O	0.119	
	PETROLREF		0.340
	AVIATIONFUREF		0.046
	SECPETRPRODREF		0.156
	LPGREF		0.046
	DIESELREF		0.064

Primary Supply

Table E.10: Capital and fixed costs for primary energy production

Unit: Rm/PJ/annum		
Sector	Energy	
Technology Type	Extraction/Production	
	Parameter	
Technology Name	**Capital Cost**	**Fixed Cost**
Natural gas extraction	931.96	0.015
Other Natural gas extraction (coal bed methane)	526.08	0.007
Residual Opencast Thermal Coal	28.78	
Residual Underground Thermal Coal	28.78	
Shale gas extraction	1768.94	0.009

Table E.11: Capital and fixed costs for primary energy production

Unit: ratio for energy commodities (i.e. PJ/PJ)			
water use is in Mt water/PJ energy output			
Sector	Energy		
Technology Type	Extraction/Production		
		Parameter	
Technology Name	**Commodity Code**	**Input Activity Ratio**	**Output Activity Ratio**
Natural gas extraction	NATGAS	0.041666668	1
Other Natural gas extraction (coal bed methane)	NATGAS		1
Production of IGCC coal	HCO		1
Residual Opencast Thermal Coal	H2O	0.016860001	
	DIESEL	0.00324	
	ELECDISTRIBUTED	0.0019	
	COALTHERM		1
Residual Underground Thermal Coal	H2O	0.01009	
	ELECDISTRIBUTED	0.0027	
	DIESEL	0.001	
	COALTHERM		1
River	HYD		1
Shale gas extraction	H2O	4.485000134	
	DIESEL	0.0095	
	NATGAS		1
The sun	SOL		1
The wind	WND		1
Uranium extraction and fuel prod	NUC		1
water supply for transformation	H2O		1
Production of FBC coal	HCOFBC		1
Production of PF coal	HCOPF		1

Table E.12: Import prices for various commodities

Unit: R/GJ							
Sector	Energy						
Technology Type	Import						
	Technology Name						
Year	**Import Aviation Fuel**	**Import Crude oil**	**Import Diesel**	**Import of NG**	**Import Paraffin**	**Import Petrol**	**Import Residual Fuel**
2010	121.21	79.40	114.55	76.33	117.70	131.62	70.55
2011	150.44	93.22	164.50	77.97	90.90	161.49	75.43
2012	152.53	95.34	167.81	79.65	93.15	164.32	75.65
2013	160.41	103.34	180.31	81.36	101.67	174.96	76.48
2014	167.31	110.34	191.25	83.11	109.12	184.27	77.20
2015	173.22	116.34	200.63	84.66	115.50	192.25	77.83
2016	176.17	119.34	205.31	85.59	118.69	196.24	78.14
2017	179.25	122.47	210.20	86.53	122.02	200.40	78.46
2018	180.47	123.70	212.13	87.49	123.33	202.04	78.59
2019	181.68	124.93	214.05	88.45	124.64	203.68	78.72
2020	182.90	126.16	215.98	89.52	125.95	205.31	78.84
2021	184.11	127.40	217.90	90.19	127.27	206.95	78.97
2022	185.32	128.63	219.83	90.87	128.58	208.59	79.10
2023	186.54	129.86	221.76	91.55	129.89	210.23	79.23
2024	187.75	131.10	223.68	92.23	131.20	211.87	79.36
2025	188.97	132.33	225.61	92.99	132.51	213.51	79.48
2026	190.18	133.56	227.54	93.66	133.82	215.15	79.61
2027	191.40	134.79	229.46	94.33	135.14	216.79	79.74
2028	192.61	136.03	231.39	95.01	136.45	218.43	79.87
2029	193.83	137.26	233.31	95.70	137.76	220.07	79.99
2030	195.04	138.49	235.24	96.46	139.07	221.71	80.12
2031	196.26	139.72	237.17	97.04	140.38	223.35	80.25
2032	197.47	140.96	239.09	97.62	141.70	224.99	80.38
2033	198.68	142.19	241.02	98.20	143.01	226.63	80.51
2034	199.90	143.42	242.95	98.79	144.32	228.27	80.63
2035	201.11	144.66	244.87	99.23	145.63	229.91	80.76
2036	201.54	145.09	245.55	99.53	146.09	230.49	80.81
2037	201.97	145.53	246.23	99.83	146.56	231.07	80.85
2038	202.40	145.96	246.91	100.13	147.02	231.65	80.90
2039	202.83	146.40	247.60	100.43	147.49	232.23	80.94
2040	203.26	146.84	248.28	100.73	147.95	232.81	80.99
2041	203.70	147.28	248.97	101.03	148.42	233.40	81.03
2042	204.13	147.72	249.66	101.34	148.89	233.99	81.08
2043	204.57	148.16	250.36	101.64	149.36	234.58	81.12
2044	205.01	148.61	251.05	101.95	149.84	235.17	81.17
2045	205.45	149.05	251.75	102.25	150.31	235.76	81.22
2046	205.89	149.50	252.45	102.56	150.79	236.36	81.26
2047	206.33	149.95	253.15	102.87	151.27	236.95	81.31
2048	206.77	150.40	253.85	103.17	151.74	237.55	81.36
2049	207.22	150.85	254.55	103.48	152.22	238.15	81.40
2050	207.66	151.30	255.26	103.79	152.71	238.75	81.45