Quantifying Uncertainty in Baseline Projections of CO_2 Emissions for South Africa

Activity 2 Report: Development and Testing of Alternative Model Implementations

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Introduction

Two different model formulations are considered for the project:

- SATIM without and with Elastic Demand Response
- SATIM with Perfect Foresight vs Myopic

Elastic Demand Response

Pye et. al () have shown that the demand response to price increases for commodities will play an increasingly important role in energy modelling and planning, but are at the time being unaccounted for due to the lack of evidence base and research. Table 1 to 3 give the elastic demand parameters that Pye (2014) et. al. used for their research based on literature findings.

Table 1: Estimates of price elasticities of demand for private road vehicles (Goodwin et al. 2004, Graham and Glaister 2004)

Dependent variable	Short term	Long term	
Goodwin et al (2004)	Mean	Mean	Range
Fuel consumption Vehicle-km Vehicle stock	-0.25 -0.1 -0.08	-0.64 -0.29 -0.25	0,-1.81 -0.63, -0.1 -0.63, -0.1
Graham and Glaister (2004)			
Fuel consumption Car-km Car trips	-0.25 -0.16 -0.16	-0.77 -0.26 -0.19	

Table 2: Estimates of the Rebound effect for different household energy services (Sorrell 2007, Sorrell et al. 2009)

Energy service	Range from evidence base	'Best guess'	No. of studies	Degree of confidence
Space heating	1.4-60%%	10-30%	9	Medium
Space cooling	1-26%	1-26%	2	Low
Other services	0-49%	<20%	3	Low

Table 3: Elasticity input parameters by energy service demand.

ESD Name	Sector	Low	Central	High
Aviation Domestic Passenger	Transport	-0.50	-0.70	-1.50
Aviation International Passenger	Transport	-0.40	-0.60	-1.00
Rail Passenger (electric and diesel)	Transport	-0.60	-0.80	-1.10
Rail Freight	Transport	-0.01	-0.03	-0.05
Road Passenger Car (2 size classes)	Transport	-0.15	-0.30	-0.50
Road Passenger Bus	Transport	-0.50	-0.70	-1.00
Road Freight Goods Vehicle (heavy and medium))	Transport	-0.05	-0.20	-0.30
Road Freight Light Goods Vehicle	Transport	-0.10	-0.25	-0.35

Maritime International Freight	Transport	-0.01	-0.03	-0.05
Maritime Domestic Freight	Transport	-0.01	-0.03	-0.05
Dwellings (3 density types - high, medium, low)	Residential	-0.10	-0.25	-0.40
Appliances	Residential	-0.05	-0.15	-0.30
Cooking	Residential	-0.05	-0.15	-0.30
Air Conditioning	Residential	-0.05	-0.15	-0.30
Commercial Floorspace	Comm. / Public sector	-0.01	-0.10	-0.15
Public Floorspace	Comm. / Public sector	-0.01	-0.10	-0.15
Industry (8 subsectors)	Industry	-0.01	-0.03	-0.05

Table 3 central values were used as elasticities for each relevant sector in this study. There is detail for transport subsectors and the elasticities for these were used accordingly, but where SATIM has transport modes not listed by Pye then the assumption of -0.03 is used. The table below shows the assignment of elasticities to each end use demand.

Table 4: The elasticities used in SATIM for end use demands

Transport subsectors	**Elasticity used**	**Comment**
Transport Passenger SUV Priv.Veh.	-0.3	
Transport Passenger Car Priv.Veh.	-0.3	
Transport Passenger Moto Priv.Veh.	-0.3	
Transport Passenger Bus	-0.7	
Transport Passenger Minibus	-0.03	Assumed not to respond as 'bus'
Transport Passenger BRT	-0.7	
Transport Passenger Metro Rail	-0.8	
Transport Passenger Gautrain	-0.8	
Transport Freight - LCV	-0.25	
Transport Freight - MCV	-0.2	
Transport Freight - HCV	-0.2	
Transport Freight - Rail Corridor	-0.03	
Transport Freight - Rail Other	-0.03	
Transport Freight - Rail Export (bulk mining)	-0.03	
Transport Other - Pipeline	-0.03	
Transport Other - Aviation Jet Fuel	-0.7	
Transport Other - Aviation Gasoline	-0.7	
Transport Other - HFO	-0.03	
Commercial sector – all end use demands	-0.1	
Residential sector – all end use demands	-0.15	

Industrial sector – all subsectors and demands	-0.03	
Agriculture –all end uses	none	No data available.

Carbon tax scenario run

To perform an elastic demand run in TIMES, a run of the model needs to be done where the prices of commodities are saved to a file. Once this is done, the model may then be run in the elastic demand mode where the model is run with an added scenario which would affect the price of commodities such as a carbon tax. The two model scenarios (one without a carbon tax and the elastic demand run with the carbon tax) are compared and the change in demand for an end use due to a price increase can be gauged.

The model used was the short timeslice version of SATIM as the regular timeslice length version of the model would require about 40minutes to compute whereas the shortened timeslice version would require less than a minute.

The carbon tax used was R100/ton by 2020 – the model would ramp up to this number starting in 2015.

Comparing the reference case (REF) with the case of a carbon tax and where elasticities are included (REF + R100/ton) the end use demand is compared in Figure 1.

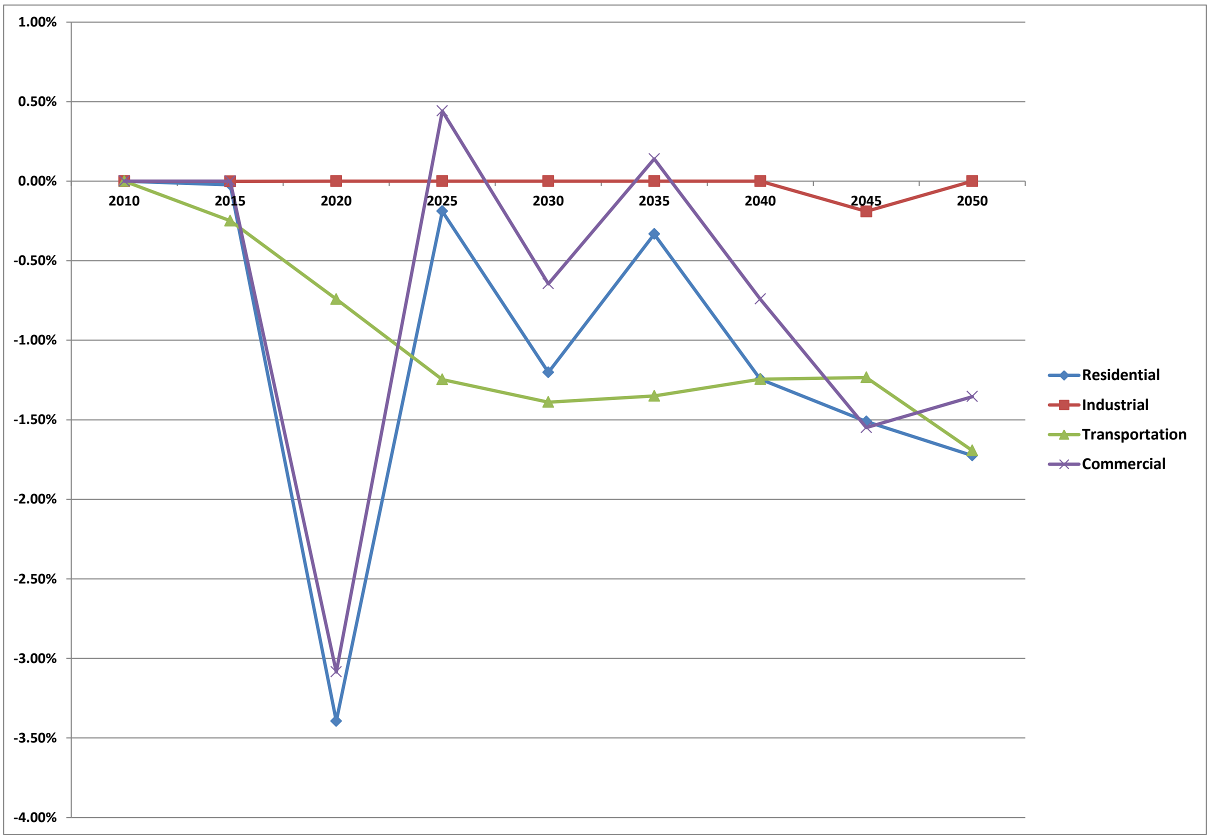

Figure 1: The total demand for end use change in the model with elasticities included.

The price shock of the carbon tax of R100 by 2020 is clearly seen in the demand responses. The demand response is seen starting in 2015 as the model starts to implement a carbon price tax.

The total electricity production for South Africa is given in Table 5.

Table 5: Electricity production demand change in the scenario for R100/ton carbon tax by 2020 onwards.

	2010	2015	2020	2025	2030	2035	2040	2045	2050
REF	945	1023	1236	1395	1662	1903	2161	2378	2659
REF + R100/ton	945	1021	1187	1349	1603	1837	2071	2270	2553
% difference	0.0%	-0.1%	-4.0%	-3.3%	-3.6%	-3.5%	-4.2%	-4.5%	-4.0%

The electricity prices for both scenarios are given Figure 2, and the

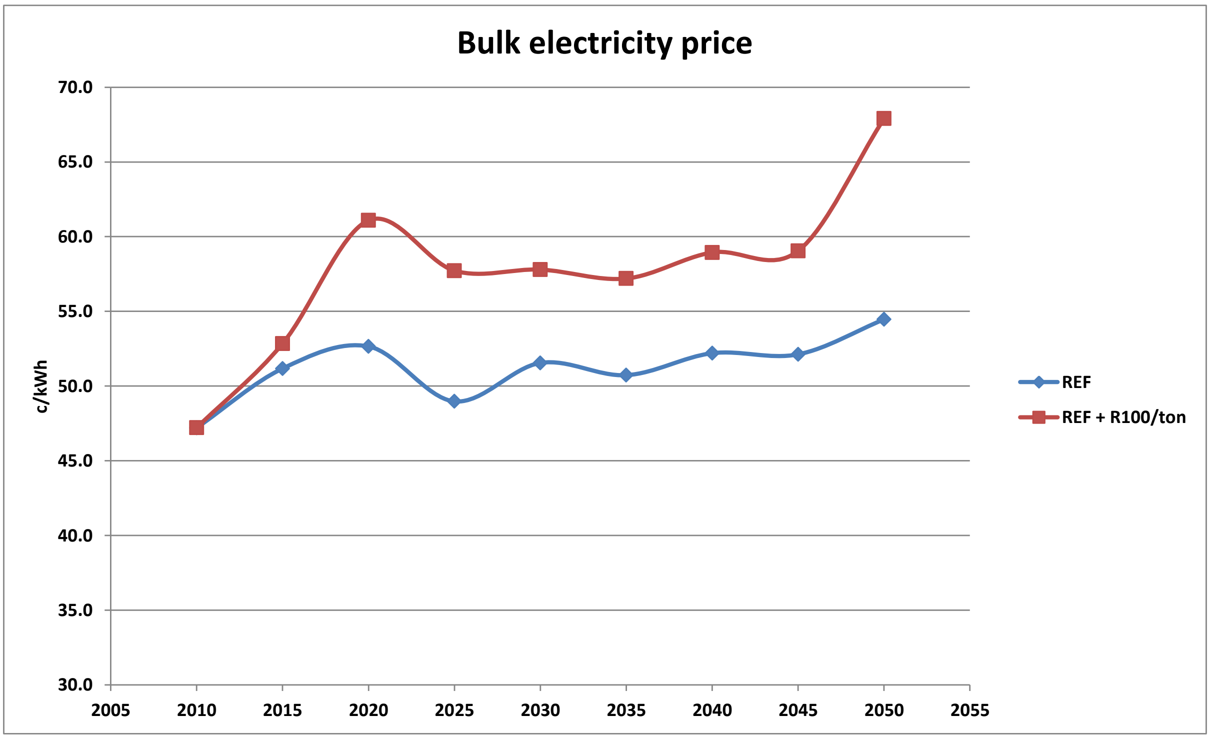

Figure 2: Bulk electricity price for the model using a carbon tax compared to the reference scenario.

The electricity production (demand) closely follows the price increase for electricity as shown in Figure 2. Demand starts to reduce as a carbon tax is implemented and coal powered stations have increased operating costs this results in an 11.8% increase for coal power by 2015 which rises to 50% increase by 2020 and stays about 50% more relative to the reference case through to 2050, this will force demand side sectors to fuel switch in conjunction with reducing demand (in the elastic demand scenario)

Fuel switching in the sub sectors in the model

This section compares the final energy demands by fuel for each sub sector in the model and shows the change relative to the non-elastic model run (REF). Only consumption which has more than a 1% change are shown in the following tables.

Transportation

Transportation demands are largely met with fossil fuels (save for hydrogen and clean electricity in the future) and due to this, transportation has the least ability to fuel switch. This would explain the sustained decline of demand shown in Figure 1 for the end use reductions.

Table 6: transportation final energy consumption comparison between elastic model and reference model runs.

	2010	2015	2020	2030	2040	2050
Coal						
Natural Gas			-10%	29%	12%	7%
Diesel						-2%
Gasoline			1%	-11%	-17%	-11%
Kerosens/Paraffin				-5%	-5%	-5%
LPG						
HFO		-30%				
Hydrogen				55%	65%	3%
Electricity		-1%	-3%	-1%	-1%	-1%

Industry

Table 7: The total final energy consumption change relative to the REF scenario.

	2010	2015	2020	2030	2040	2050
Coal						
Natural Gas						
Diesel						
Gasoline						
Kerosens/Paraffin						
LPG						
HFO	-2%	8%				
Biomass&Waste	1%	-7%				
Electricity						

The change in industry for consumption of Heavy Fuel Oil (HFO) in 2010 occurs in the brick and cement industry where biomass fuel replaces the HFO consumption and this reverses again and in a larger quantity in 2015. Apart from this difference, industry shows very little change overall, but this is evident since the elasticities for industry used in this study are lower than the other end use sectors.

Commerce

Table 8: The change in final energy consumption for the commercial sector.

	2010	2015	2020	2030	2040	2050
Coal			5%			
Natural Gas		-1%	17%	77%	100%	-19%
Diesel			-2%	-15%	-11%	
Gasoline				58%		-37%
Kerosens/Paraffin		-3%	-3%		12%	
LPG			-12%	1%	-4%	-23%
HFO					-1%	
Electricity			-6%	-1%	-1%	-2%

The commercial sector shows a variety of fuel changes. Notably is natural gas – this comes from an increased use of distributed cogeneration using gas turbines and providing electricity and heat to the commercial sector demands. This is more a result of the carbon tax than of demand reduction.

Residential

Table 9: The residential sector final energy consumption change for the case of elastic demands.

	2010	**2015**	**2020**	**2030**	**2040**	**2050**
Coal	-3%		-31%	-7%	-4%	-2%
Natural Gas				1%	40%	56%
Diesel						
Gasoline						
Kerosene/Paraffin			19%	14%	2%	2%
LPG			3%	-27%	-30%	-61%
HFO						
Biomass & Waste		1%	5%	3%	9%	8%
Electricity			-6%		-6%	-5%

The residential sector shows a trend of reducing electricity consumption and a shift to kerosene for cooking, space heating and water heating.

Shale gas scenario

In this section shale gas becoming available to the model will be used as the base scenario (Shale) and then the shale gas prices becoming lower will be used as an elastic demand model run (Low Gas).

In this case, shale gas drops from R54/PJ to R41/PJ throughout the model timeframe. And of course, shale gas is assumed to become available in South Africa. Figure 3 shows the impact this has on the end use consumption for each subsector.

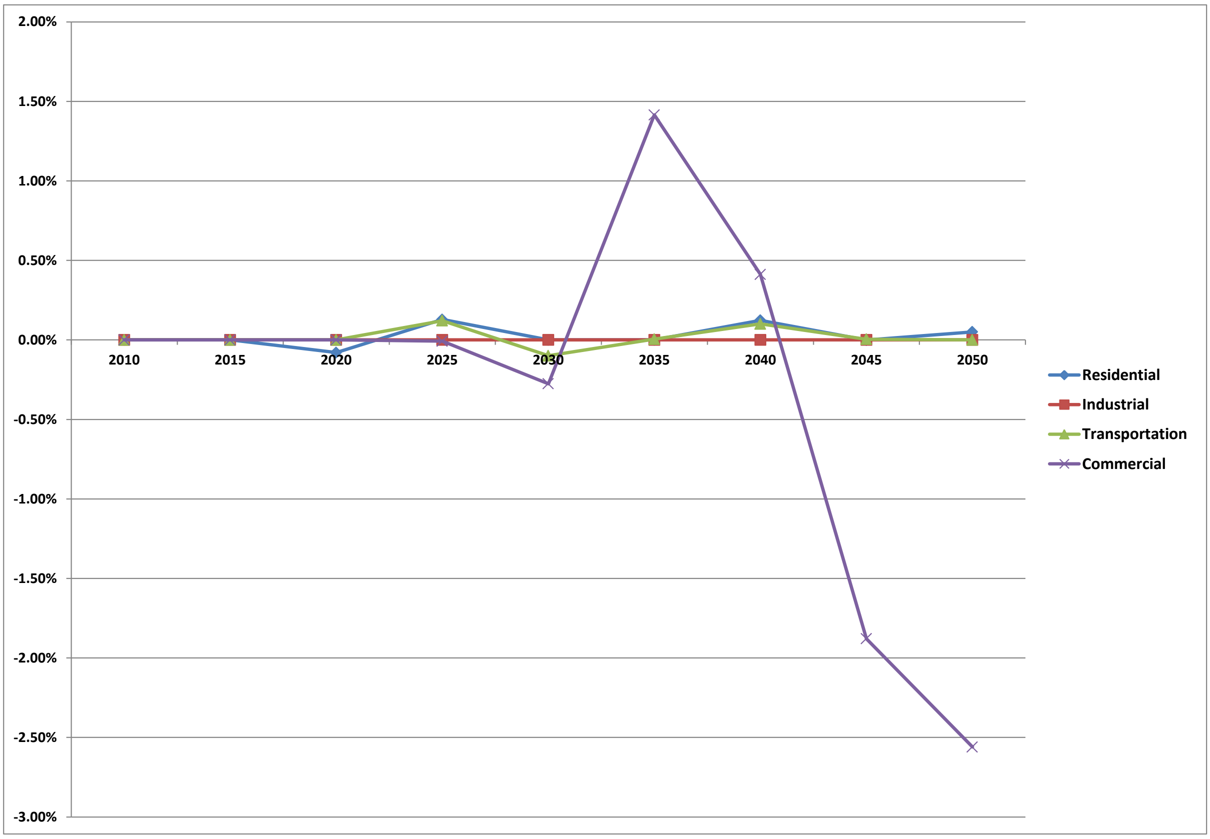

Figure 3: The change in end use demands for each sub sector for the case where shale gas is made cheaper.

The large change in the commercial sector is attributed to the extensive use of embedded generation in the commercial sector which uses gas and supplies electricity and heat – space heating being the end use which increases any significant amount in this scenario.

Electricity produced (and consumed) where gas is made cheaper to the model is given in Table 10 and shows a back and forth growth and reduction in electricity consumed in the model up to 2035 and then a general increase in electricity consumption from there to 2050.

Table 10: the electricity produced (in PJ) and consumed within the model with elastic demand response and cheaper shale gas prices.

	2010	2015	2020	2025	2030	2035	2040	2045	2050
REF + Shale	945	1023	1238	1403	1645	1865	2091	2255	2524
Low shale price	945	1023	1235	1409	1643	1857	2103	2287	2566

% difference	0.0%	0.0%	-0.2%	0.5%	-0.1%	-0.4%	0.6%	1.4%	1.7%

Cheaper crude oil prices scenario

A scenario where crude oil prices remain flat from 2015 onwards at R120/GJ compared with the model where the price rises to R150/GJ by 2050 is considered here to study the impact that crude oil prices have (given that it becomes cheaper)- since crude oil is a vital commodity in many economies (and since transport is usually a large portion of energy consumption within countries).

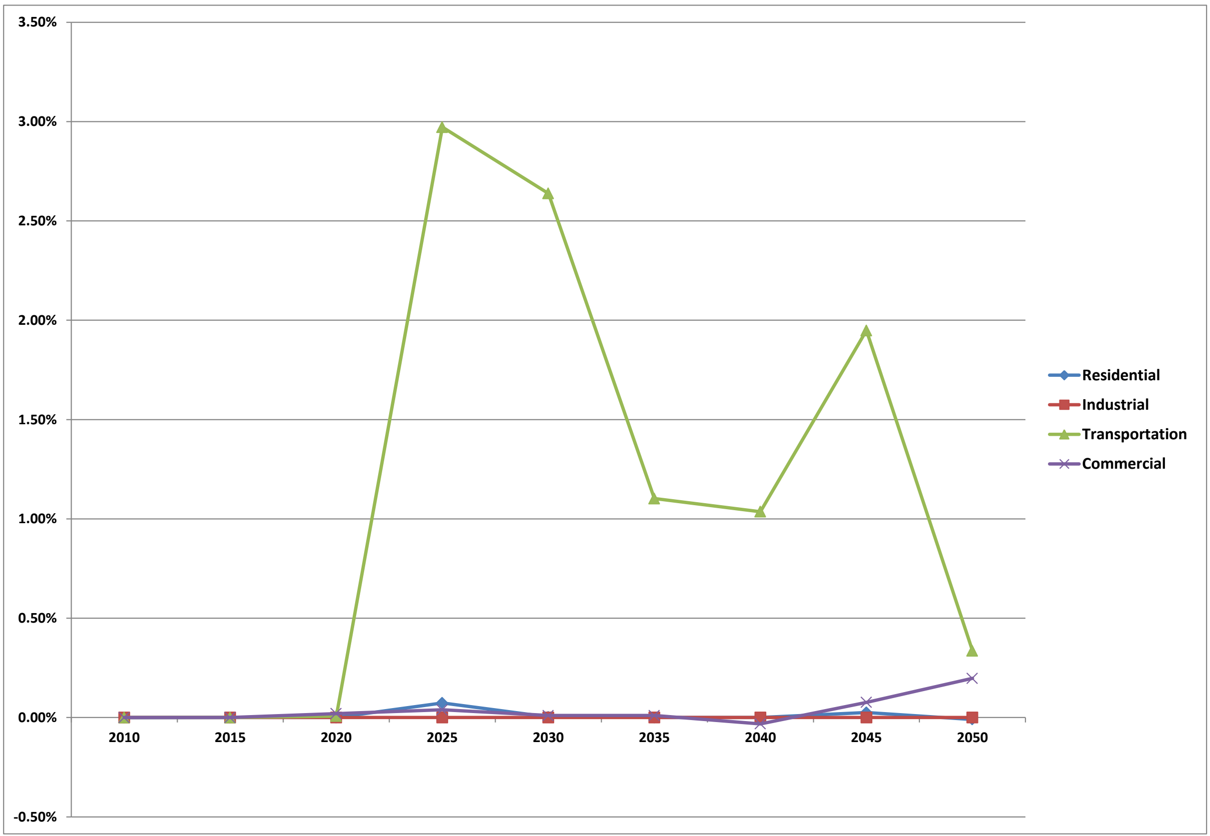

Figure 4: End use consumption for the scenario of cheaper crude oil.

Transportation is dominantly oil product dependant and the large increase in transport demand reflects this.

References

S. Pye, W. Usher and N. Strachan, *The uncertain but critical role of demand reduction in meeting long-term energy decarbonisation targets*, University of College London, IEW presentation 2014.

Myopic vs Perfect Foresight

The various results within the models for both the myopic and perfect foresight (normal run) SATIM model are compared in this report.

The process of a myopic run in an optimisation model is where short periods (shorter than the full model period) are run in subsequent steps of each other and the results from each of these steps compiled together. This is termed 'myopic' for 'short sightedness' and has the advantage in that price shocks in commodities such as oil or coal can be studied as they would occur in real world situations where price shocks are unexpected.

This myopic run in TIMES is processed as shown in Figure 5 how the model is optimised in blocks and incremented or subtended together to form a complete model optimisation.

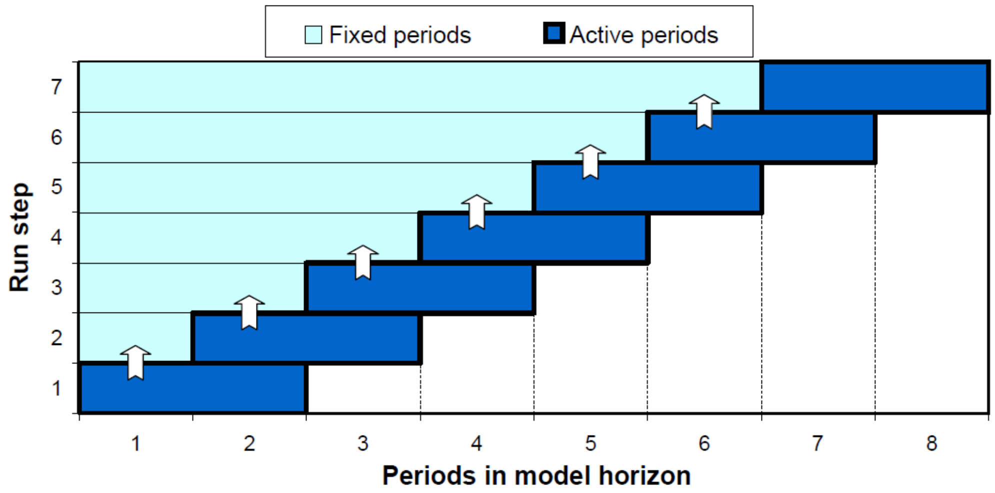

Figure 5: Overview of myopic process in TIMES and MARKAL. Taken from the TIMES user manual.

Myopic – 10 year blocks and 5 year overlaps

Here, the SATIM model in TIMES was run as a myopic run and uses 10 year timesteps with a 5 year overlaps, various aspects of the model were compared to check for similarity and deviations.

Power sector

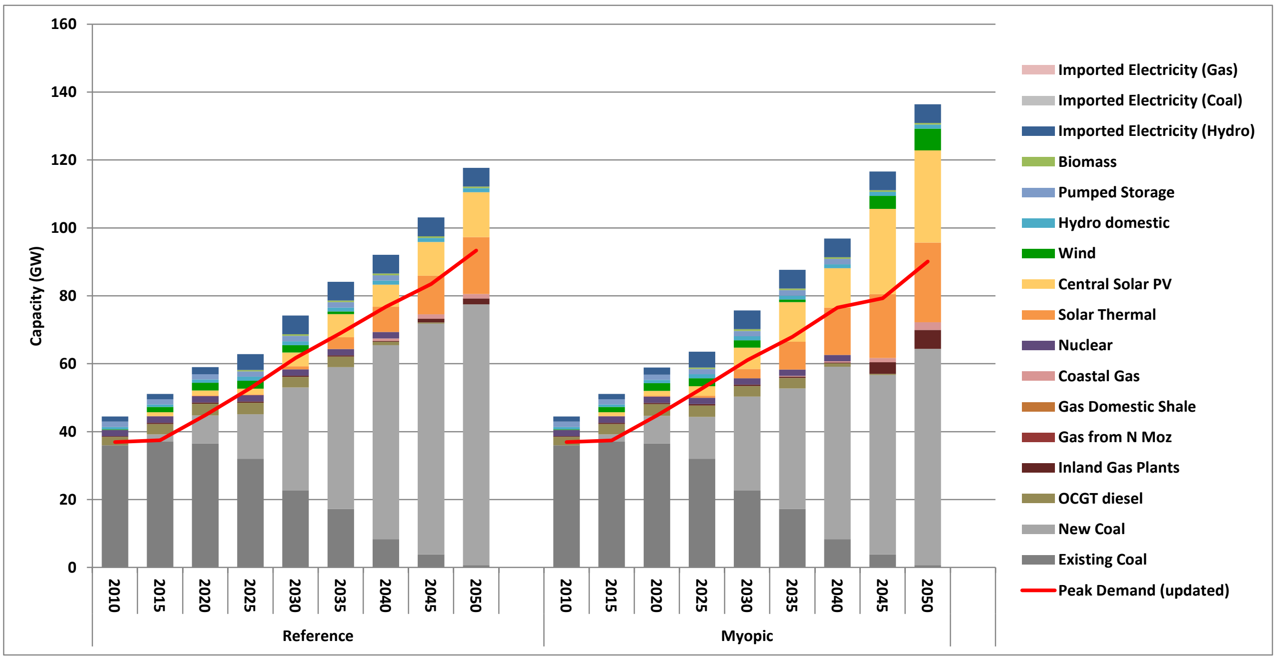

Figure 6: The comparison of the power sector builds for the regular model perfect forsight (reference scenario) and the myopic model (myopic).

A large deviation is observed in the power sector build in the myopic version. There is also a reduced electricity demand in in the model.

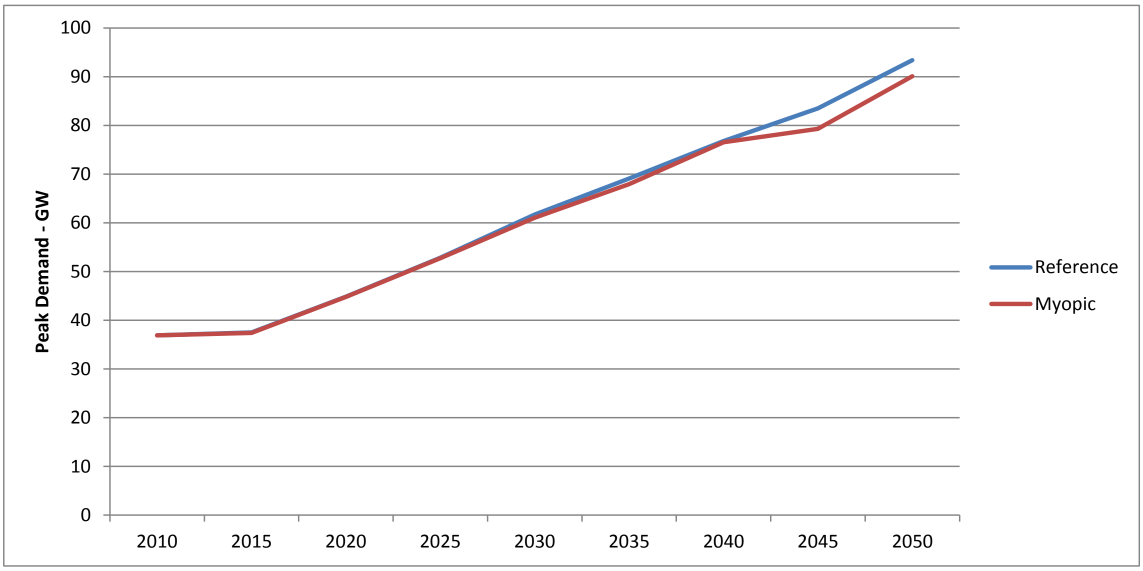

Table 11: the total power sector capacity (GW)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Reference .	44.5	51.1	59.0	62.8	74.2	84.1	92.1	103.1	117.7
Myopic	44.5	51.1	58.9	63.6	75.7	87.7	96.9	116.6	136.4

Table 12: the total power sector difference in GW between the two models (positive is more capacity in myopic model)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Coal	0.0	0.0	-0.1	-0.8	-2.7	-6.3	-6.3	-15.1	-13.1
OCGT diesel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inland Gas Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	3.8
Gas from N Moz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Domestic Shale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coastal Gas	0.0	0.0	0.0	0.0	0.0	0.2	-0.4	0.0	0.9
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar Thermal	0.0	0.0	0.0	0.4	1.9	4.8	6.5	7.4	6.7
Central Solar PV	0.0	0.0	0.0	1.1	2.2	4.8	5.1	15.1	13.9
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	6.4
Hydro domestic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pumped Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imported Electricity (Hydro)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electricity prices

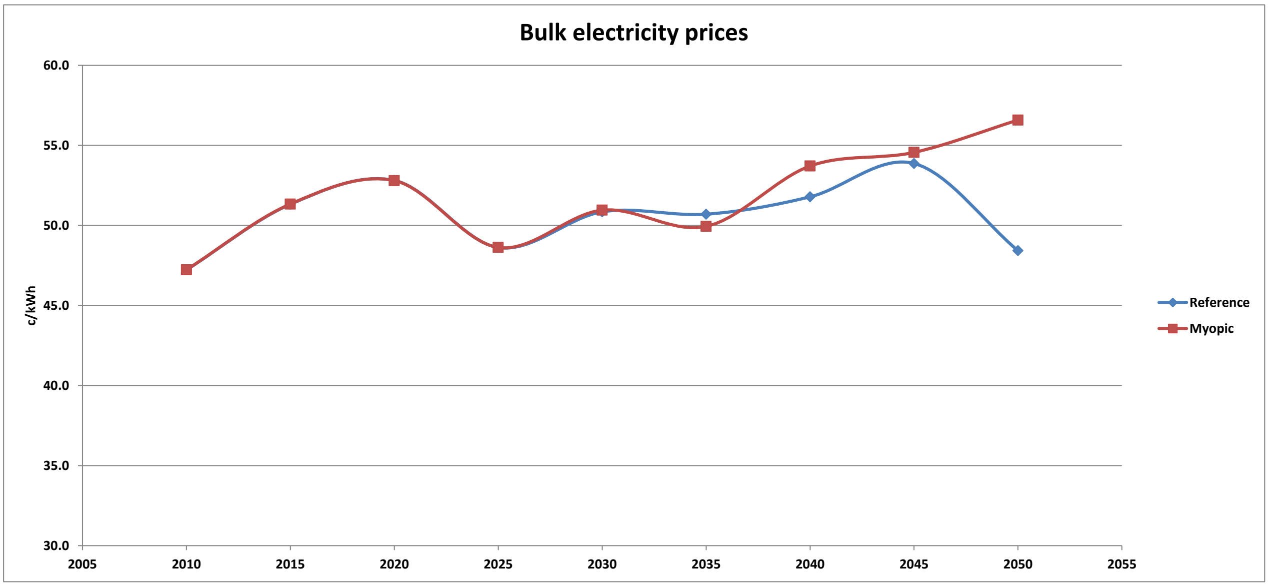

Figure 7: The electricity price for the two models.

Emissions

The total sector emissions are shown in Figure 8 below. There is a large deviation in model emissions for the myopic model. These differences are highlighted in Table 13. There is a large emissions difference between the two models - at around 10% less in the myopic model.

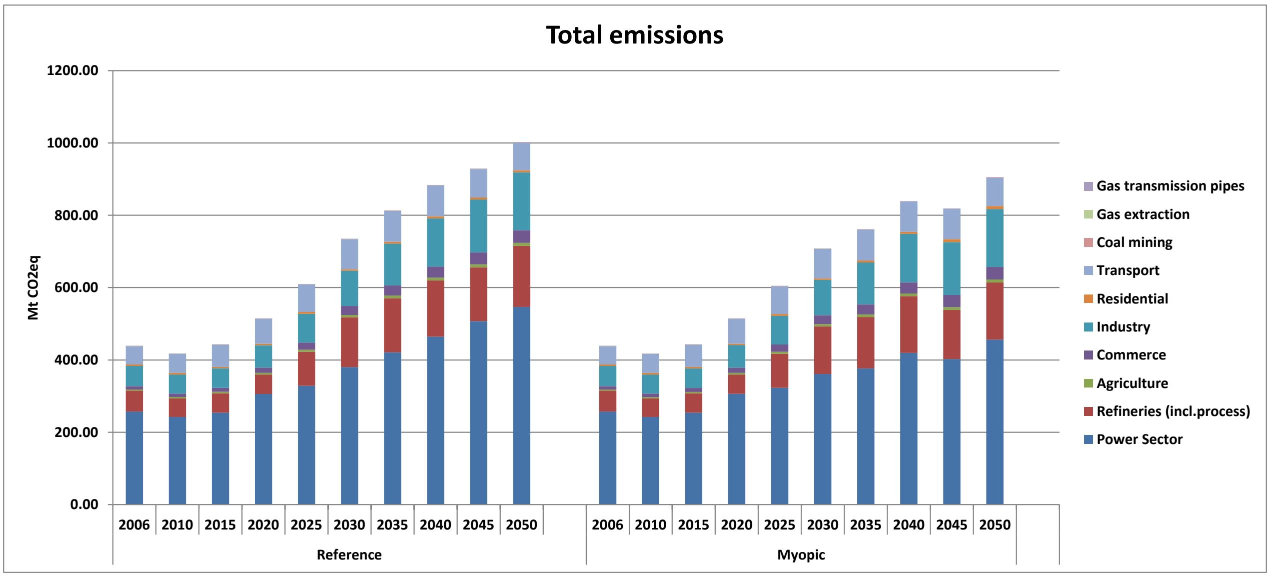

Figure 8: the total model emissions by sector.

Table 13: Emissions differences (in Mt CO2eq) of all the sectors in the model.

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Power Sector	-0.2	-0.2	0.2	-5.7	-18.8	-44.1	-44.7	-105.1	-90.7
Refineries (incl.process)	0.0	0.0	0.0	0.0	-6.5	-8.0	0.9	-13.0	-10.6
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commerce	0.0	-0.1	-0.1	0.2	0.0	0.0	0.1	0.5	-0.4
Industry	0.1	0.1	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Residential	0.1	0.0	0.0	0.1	0.0	0.9	-0.2	2.6	2.2
Transport	0.0	0.0	0.0	0.0	-1.2	-0.4	-1.2	5.0	3.0
Coal mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1
Gas extraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas transmission pipes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Total	-0.1	-0.1	0.2	-5.3	-26.6	-51.7	-44.4	-110.0	-96.3
% difference to reference	0.0	0.0	0.0	-0.9	-3.6	-6.4	-5.0	-11.8	-9.6

Results discussion

The observed differences between the myopic model and the perfect foresight model are large enough to consider the two models as very different (10% in emissions and 18% in the total power sector capacity). What is observed in the power sector is the large amount of extra solar power and extra gas turbines. The model milestone years (years in which the model optimises and gives results) were set to be in 5 year intervals with 2006, 2010,2015,2020 and so on to 2050. The model was then run as a regular optimisation model to 2050 and then compared to the same model with myopic format set to 10 year blocks and 5 year overlays.

The large deviation in the power sector capacity (and technologies) is suspected to be a result of how the model is able to build new capacity to meet demand in short periods (the myopic periods).

In the reference model, the model builds a lot of super critical coal power throughout the model period, but this is not the case in the myopic model where solar PV and thermal (with gas and wind as well) making up a large majority of capacity toward the end period. The coal technology requires 4 years lead time to build, whereas the solar and wind technologies require 1 year and gas turbines 2 (3 for some gas technologies).

Mini model

Further investigation was done with the use of a short mini model in TIMES with both the supercritical coal and solar power from SATIM added to the model (with their associated costs and parameters). A myopic run was done on the mini model for 10 year blocks an 5 year intervals, but this was done for both a version of the model where every milestone year is included and one where there is only 5 year interval milestone years (as in the case for SATIM).

The results showed that the model with every milestone year included, both the myopic and the regular run where almost identical to each other. The same model with 5 year milestone gaps run for a regular optimisation (standard) and for a myopic (10 year block and 5 year overlap) showed different capacity builds (both capacity and timings) for coal and solar power.

The model was then run in myopic for 5 year blocks and 2 year intervals using every milestone year. The results showed only solar power being built and *no* coal power being built. This further highlighted the effects of compounding build lead times with optimisation over short periods.

Discussion

The SATIM model is too large to run every milestone year (every year) to 2050, it is not impossible but the computation time required is exponentially large as the number of years increases, but for a myopic model run to be used in SATIM this would become impractical in the context of using these in a Monte Carlo algorithm.

This investigation showed that with TIMES, the SATIM model run in a myopic mode (time stepping) produces large differences to the model results when compared to the reference model. This difference would be expected normally in the situations where commodity prices (such as coal price projections) change throughout the model years. In SATIM the coal price plateus after 2025. However, the difference observed in this investigation is a result of the model unable to meet demand with the same technologies as in the reference run due to build lead times. This comes about as a combination of running the model with 5 year milestone intervals coupled with the 10 year timesteps and 5 year overlaps – the model will run a block (say 2030 to 2040) to optimise and would be unable to meet the demand in the first milestone of that block due to 'short notice' and would thus turn to more expensive solar power which is able to be built within a short time. In the very least, this investigation showed the extent to which energy planning is sensitive to the period over which the planning is intended for.