Development of the "Water Smart" South Africa TIMES model: SATIM-W

Development of a National Water-Energy System Model with Emphasis on the Power Sector

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MAPS

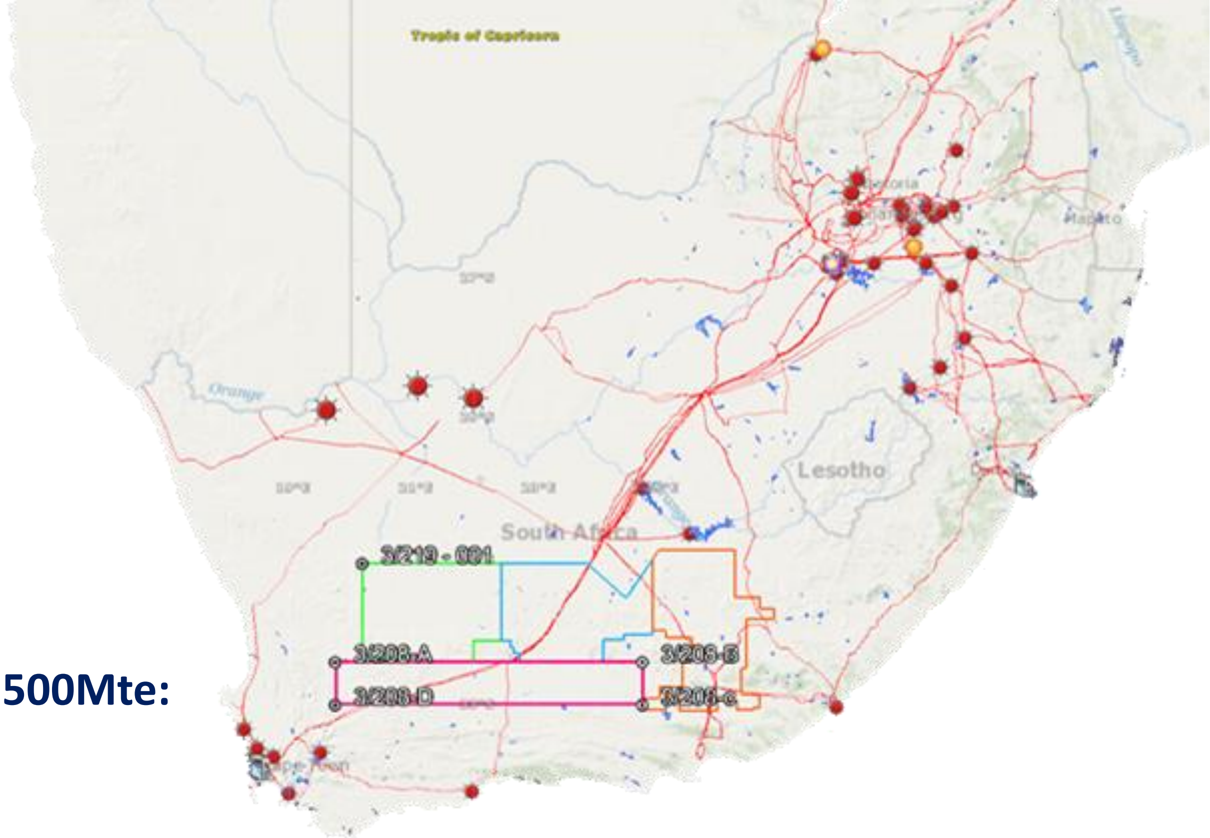
thirsty energy

DecisionWare Group
Policy Analysis for
Energy, Economy and Environment

The methodology is part of the Thirsty Energy Initiative of the World Bank. It cannot be quoted or used for now the info belongs to the Bank and the activity has not been finalized. Financing is from ESMAP and also from the WPP, part of the Water Global Practice.

Presence at IEW made possible with the help of MAPS

South African energy economy
at a glance…



Economy is coal-based:

- 80% of primary energy supply
- 90% of electricity supply
- 30% of liquid fuels supply

National CO2e emissions (2010) ~ 500Mte:

- Power Sector responsible for 60%
- Coal-synfuel facility responsible for 10%
  - Largest point source emitter in southern hemisphere

Energy Security concerns and Climate Change policy leading to INDC deliberations looking at:

- Increasing interest in expanding the nuclear fleet from the existing 1.9 GW
- A shift towards Renewable Energy alternatives with emphasis on Solar-PV, Solar-thermal and Wind
- Potential for local shale-gas supply

Water-Energy Planning in South Africa

Department of Energy

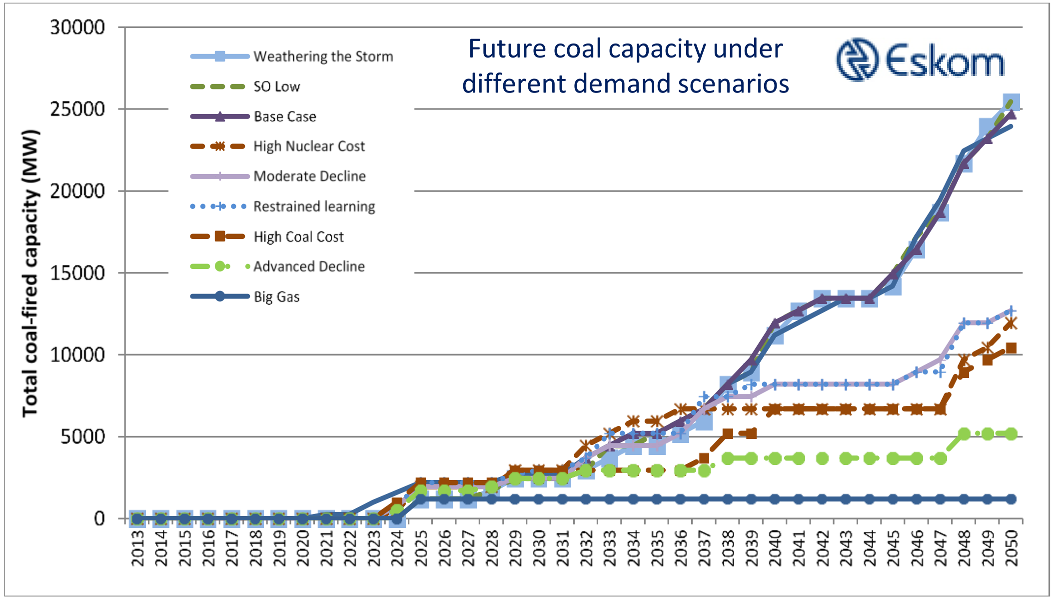
- Energy planning conducted at the national level
- *Integrated Energy Plan*
- *Integrated Resource Plan* (Eskom)

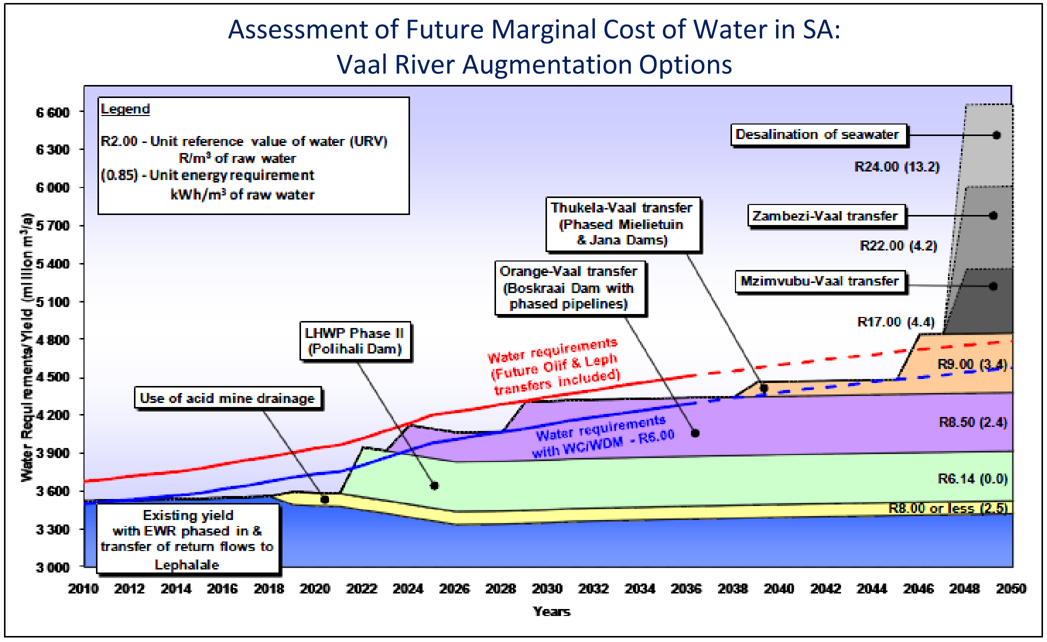
Department of Water and Sanitation

- Water planning conducted regionally with different scenarios of future water demands
- *Assessment of Future Marginal Cost of Water in SA*

Separate studies may not capture the full water-energy linkage.

SATIM-W is addressing this shortcoming by integrating the water and energy supply chains from source to end-use.

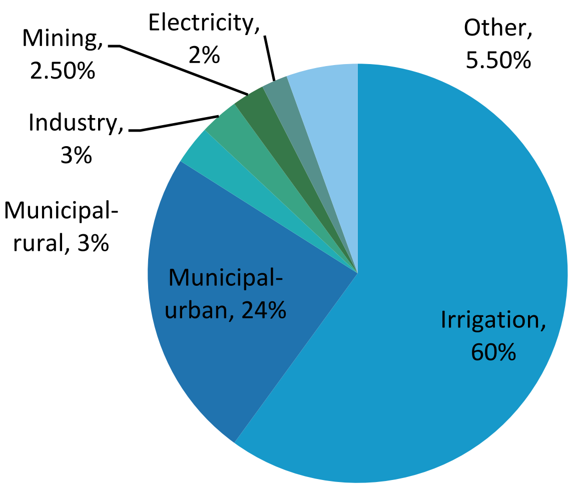




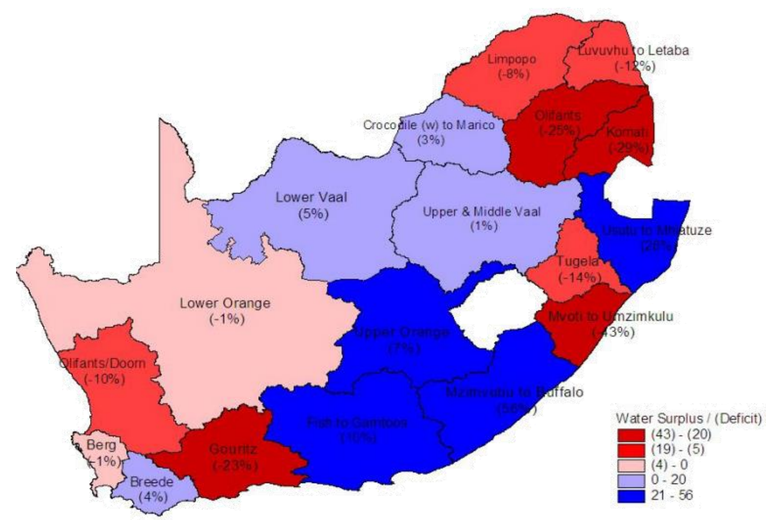
South African Water-Energy Context

South Africa is an energy constrained country facing the double dilemma of aging infrastructure for both power and water supply

- ~90% of population with access to electricity
- Operating dry-cooled plants since the late 1960s
- Zero Liquid Effluent Discharge policy at existing coal power plants
- Existing net capacity of dry-cooled units is approximately 9,700 MW (ca. 30% of total capacity)
- Existing water supply systems at or approaching capacity: 97% of existing supply allocated

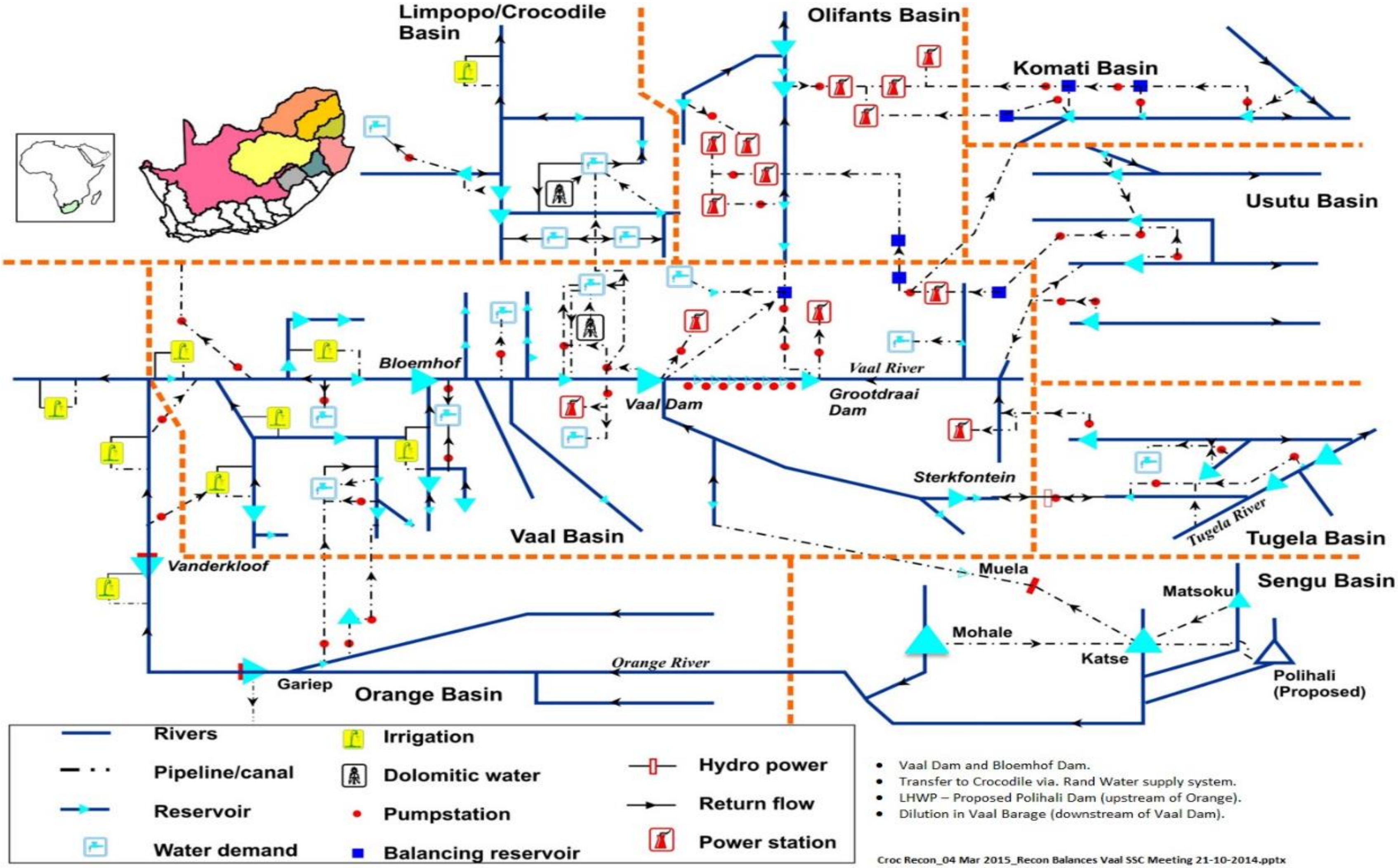


Estimate of sectorial water use



Water Management Areas percentage surplus/deficit for the year 2000 (Source: NWRS)

South African Water-Energy Network

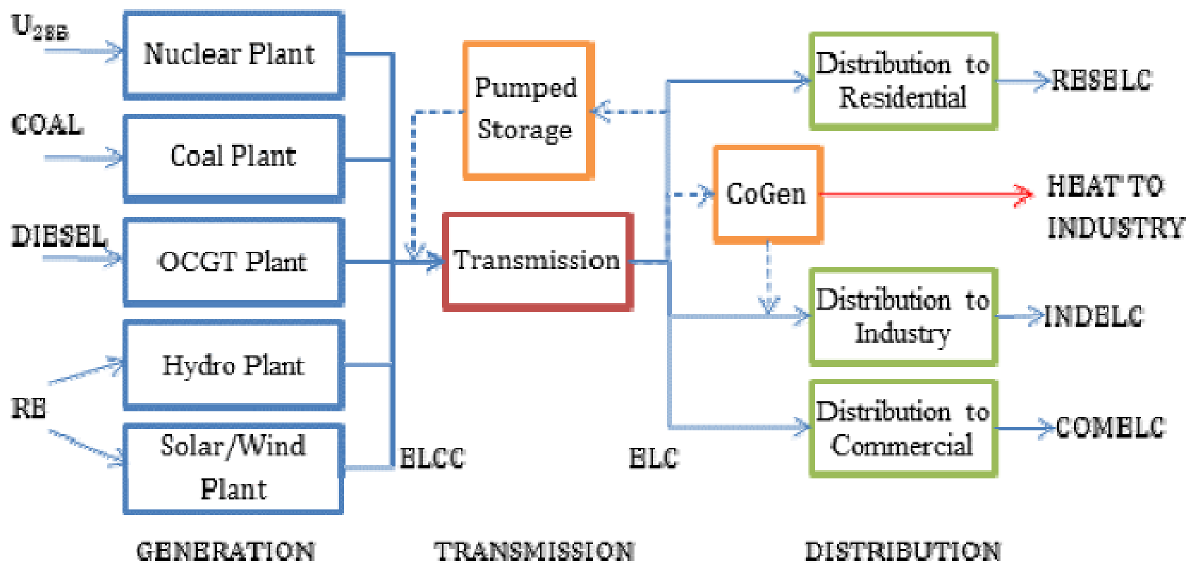


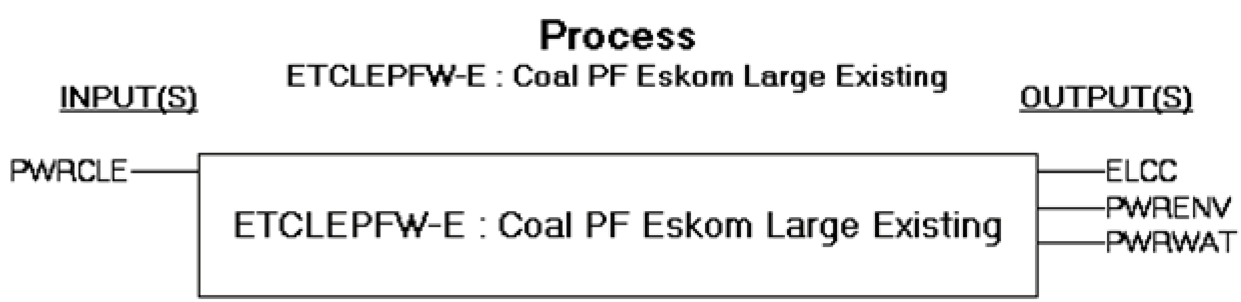
- Water for power supported by major inter-basin transfers
- The transfer and treatment of water is very sensitive to energy costs

South African TIMES model (SATIM) Simplified Representation of Water

In its previous form, SATIM was a single region national representation of energy commodity flows, energy transformation technologies and the incurred costs.

In SATIM only water consumption by the Power Sector is represented by including the water use intensity of power plants. The implementation did not consider regional disparities in water supply and costs and did not include auxiliary water usage by non-electricity generation technologies such as coal mining.





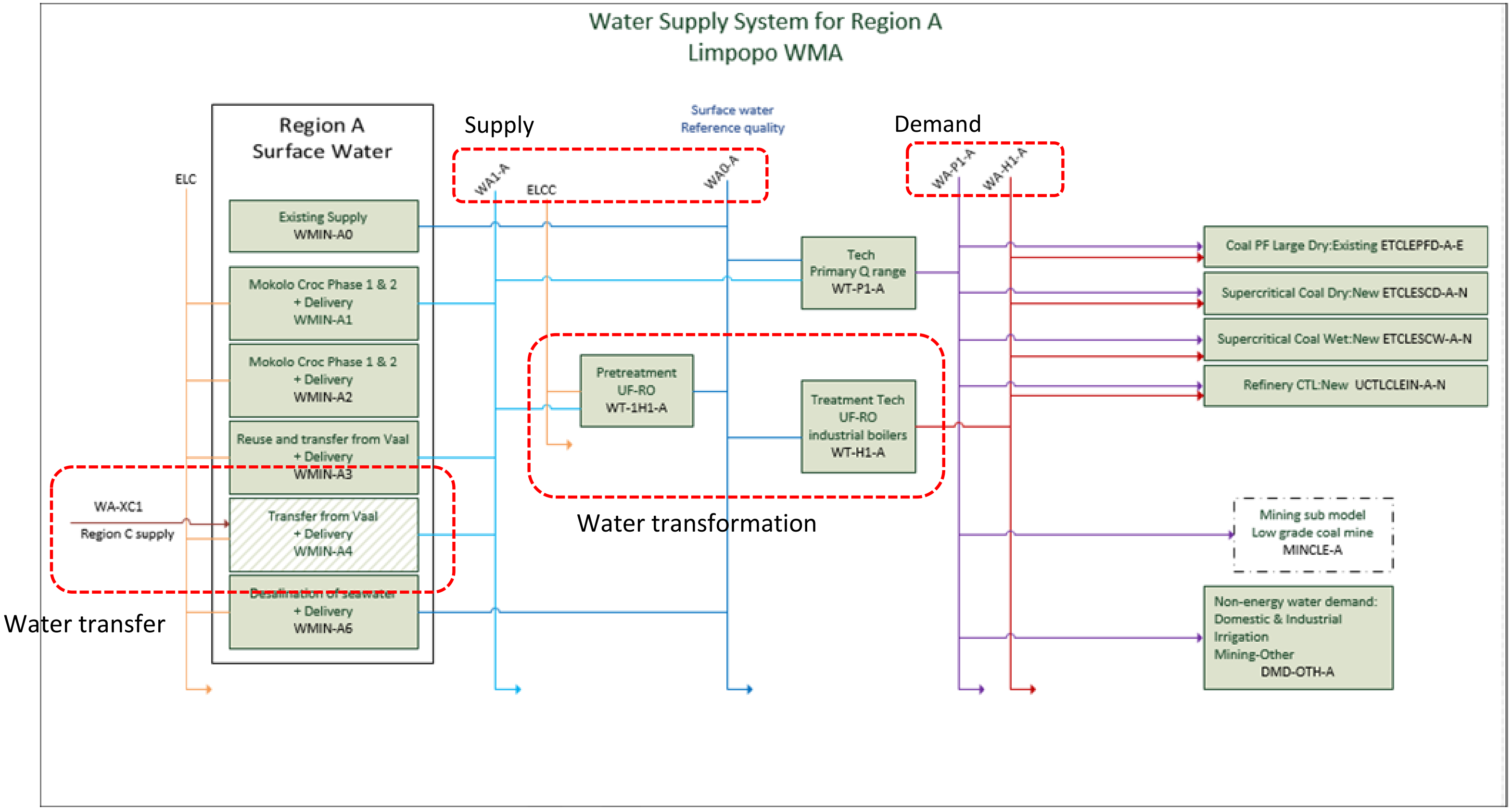
Incorporating Water Supply Infrastructure in SATIM-W

- Introduce water commodities that represent water quality types or levels.
- The two distinct water treatment types refer to two water commodities that are required by consumers:
  - Basic quality or Primary treated water, and
  - High Quality (HQ) demineralised water for boiler feed water make-up

- Split single region model using naming conventions to align with the Water Supply Regions (WSR)
- Technologies are designated by region and end-use water type
- Higher quality end-use water requirements can be transformed via treatment technologies, lower water quality demand such as agriculture can be supplied via "mixing" technologies that are less discriminate (costly)
- Cost components of the water supply options determine the Marginal Water Supply Cost Curve (MWSCC):

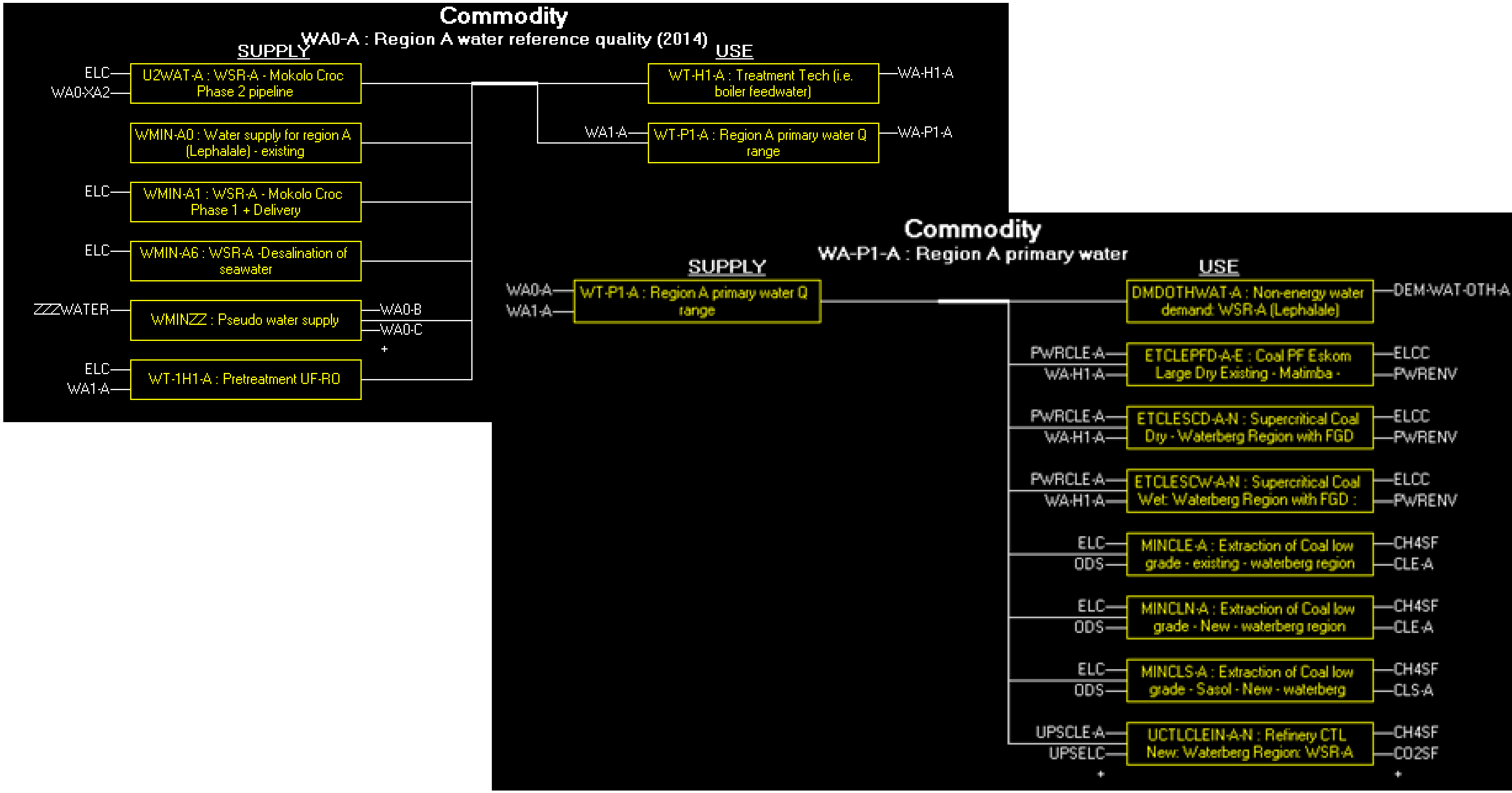
Scheme Costs = Capital + Fixed_OM1 + Var_OM (Energy cost of conveyance (endogenous)) + Fixed_OM2 (Administrative charges)

Incorporating Water Supply Infrastructure in SATIM-W

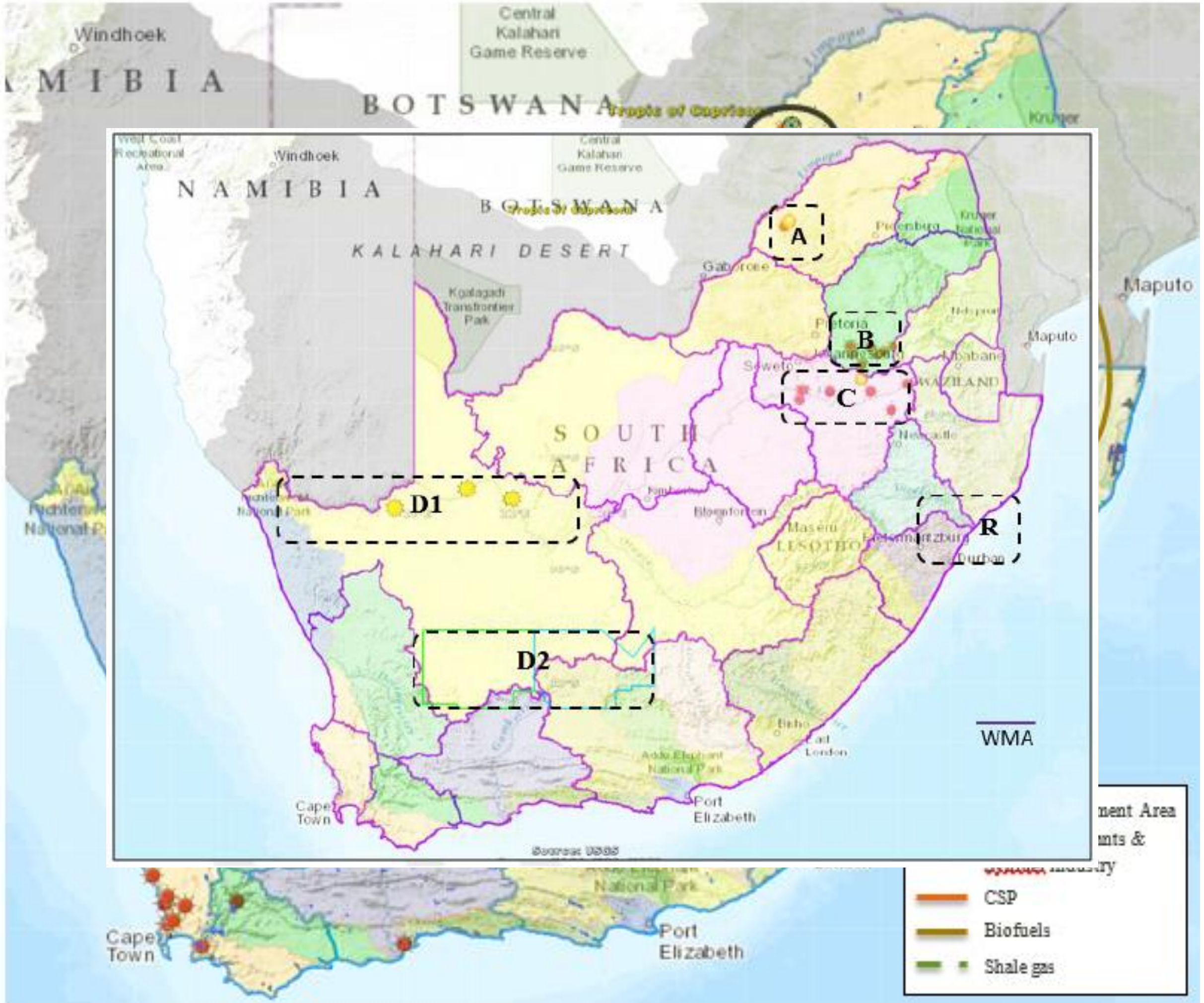


- A TIMES model can be readily adapted to track water requirements for energy (and vise versa), either by representing exogenously prepared (MWSCC) or depicting to full infrastructure build-out options available
- The water subsystem is introduced into SATIM-W by means of explicit water supply and infrastructure options for each of the (WSR) where major energy facilities are found, and their associated energy consumption (e.g. electricity for pump-stations or diesel for truck transport)

Reference Energy-Water System (REWS) as depicted in SATIM-W

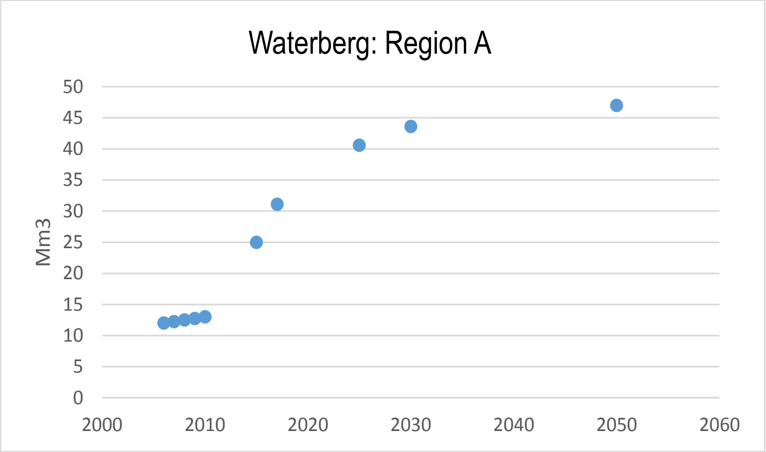


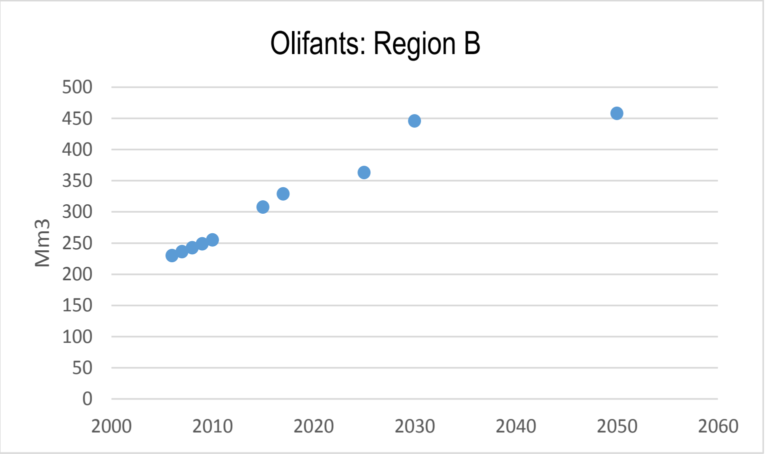
Regions of Expected Energy Sector Growth

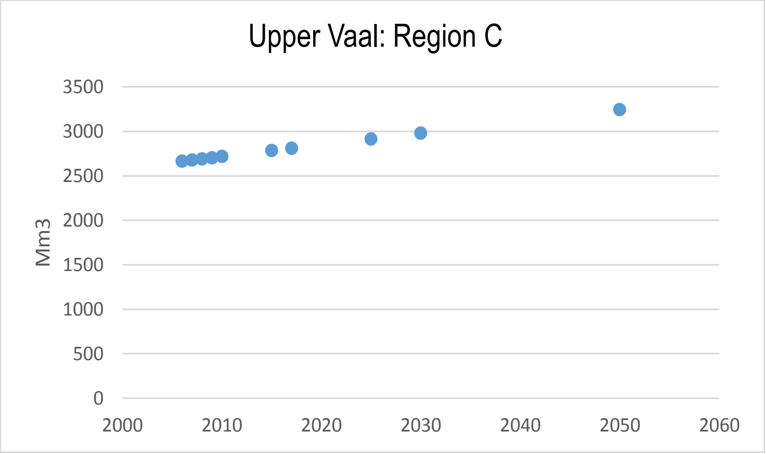


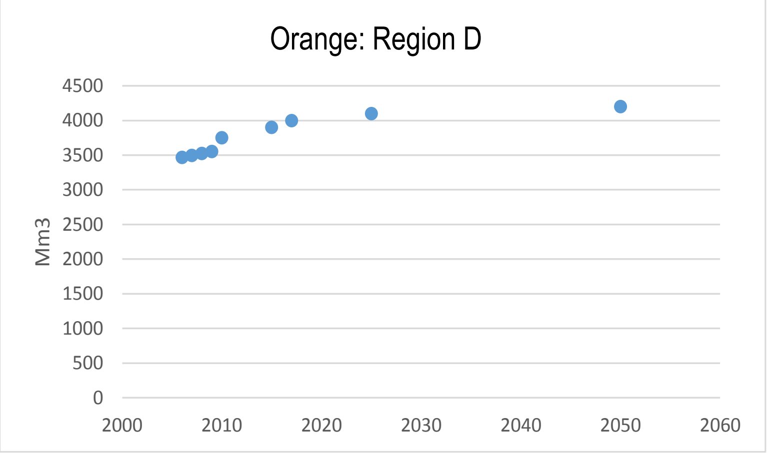
- Location of power generation plants in the country along with the regions of interest for the water-energy dimension of the power sector
- Colour-shaded areas depict the country’s primary surface water drainage basins or catchments

Demand Growth Assumptions



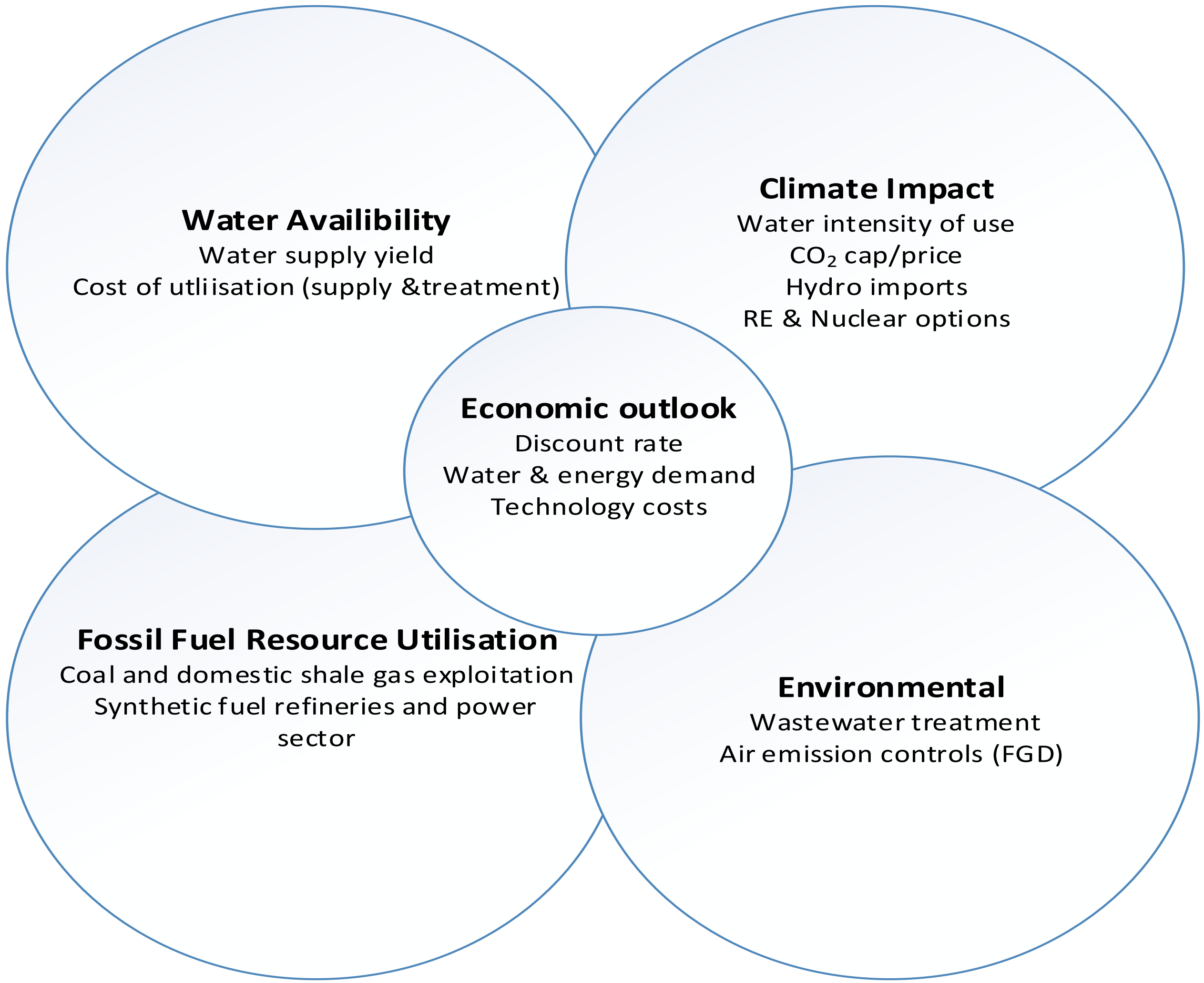






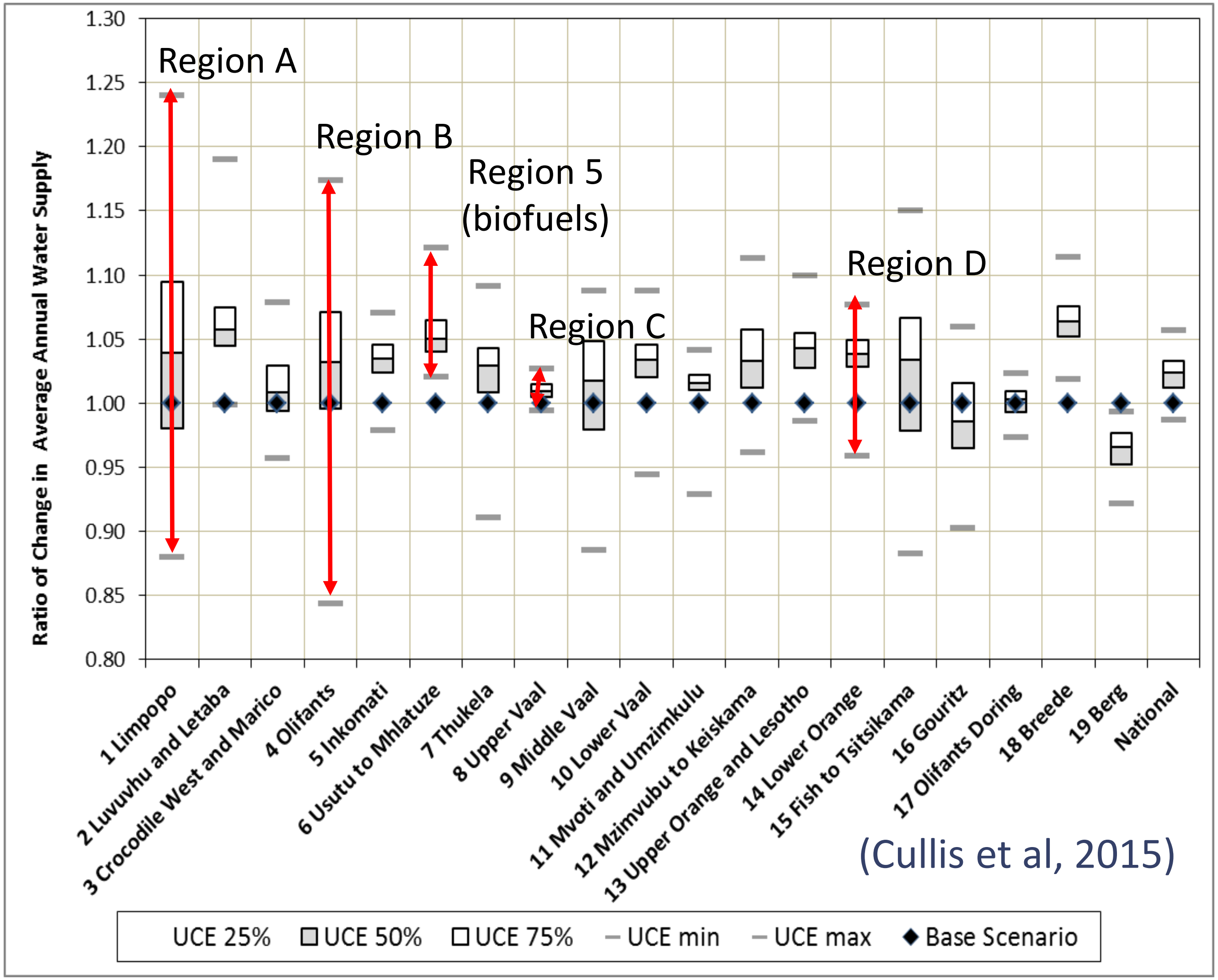
- Water demand is at present exogenous, with explicit allocations for non-energy consumption
- Average 3% per year GDP growth is the main driver for the demand for energy services which must be met by SATIM-W

Modelling the Future: Scenario Factors



Themes explore the interaction of the various factors that would influence planning decisions in the energy supply sector from a water and energy perspective

The Spatial Variation of Water Supply (and Demand) is an Important Driver of Regional Water Supply Planning



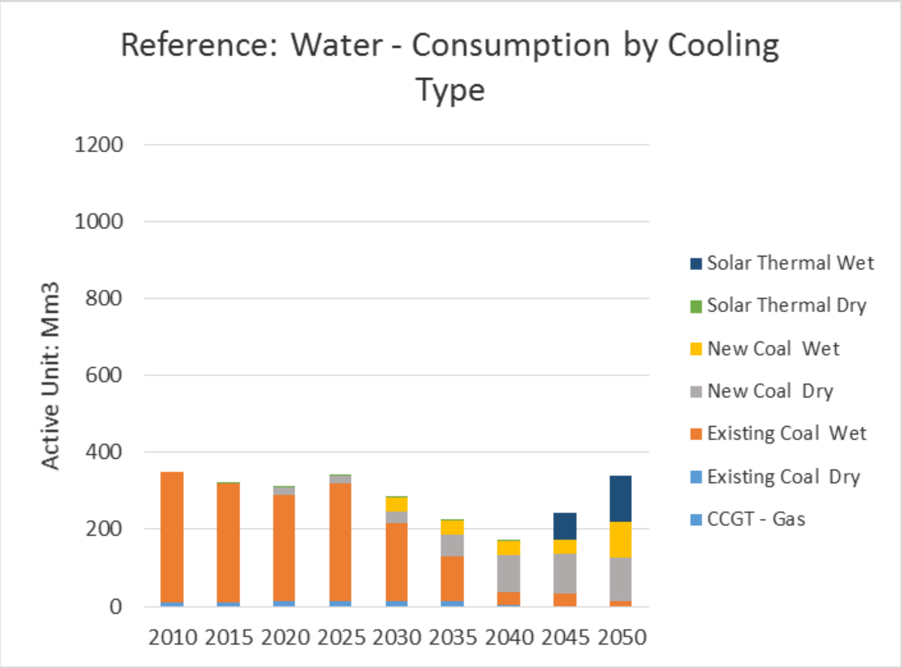
Uncertainty of regional average annual bulk water supply due to Climate Change by 2050

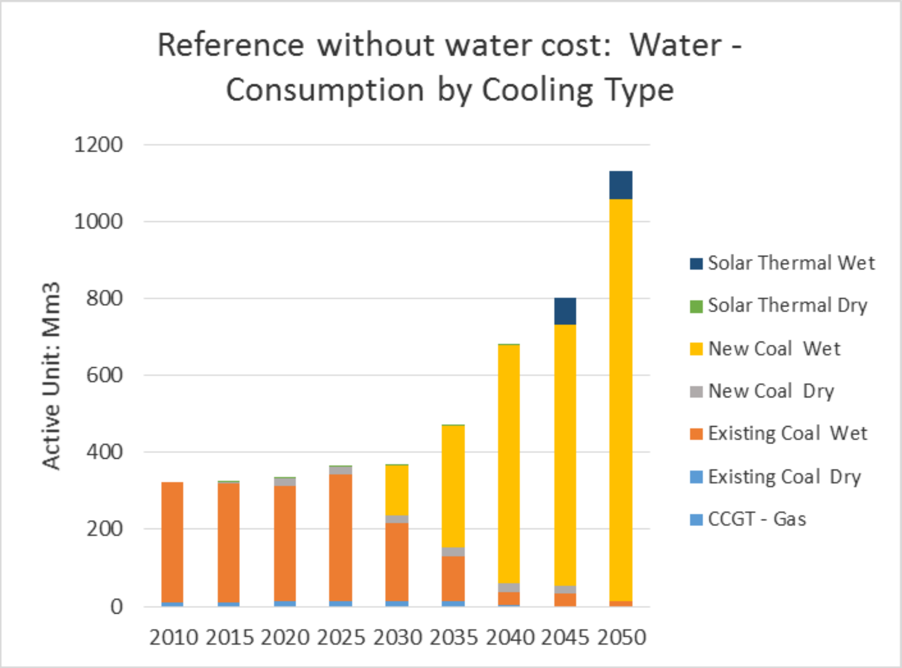
Scenario Matrix for Cases

Preliminary Analysis

SATIM-W Scenario Matrix					
	Scenario Area	Shale gas	Drier Climate / Water Stress	Environmental compliance	CO_2 cap / limit / tax
	Scenario Description	Shale gas extraction limited to 40 tcf otherwise	Drier climate: increasing non-energy water demand and reduction in water supply	FGD retrofit to older coal power plants. New build plants are assumed to be built with Wet-type FGD.	A cumulative CO2 cap set at 10/14Gt by 2050
	Scenario Indicator	S	D	E	C/L/T#
Case Description	**Case Name**				
Reference (no shale)	BAU	SOOO	ODOO	OOEO	S_OOOC#
No Water Cost (no shale) Add: SUP_WAT-NIL	BNW				S_NWC#
Shale					S_SOOC#
Drier Climate		SDOO		ODEO	S_ODOC#
Environ. Compl.		SOEO			S_OOEC#
Drier Climate and Environ.Comp.		SDEO			S_ODEC#
Shale, Drier Climate and Environ.Comp.					S_SDEC#

Why Cost Water for Energy Supply?

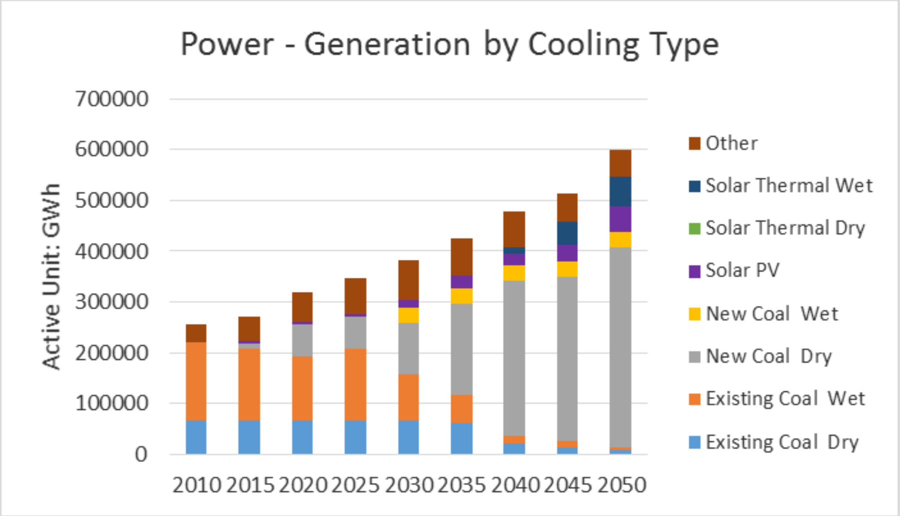


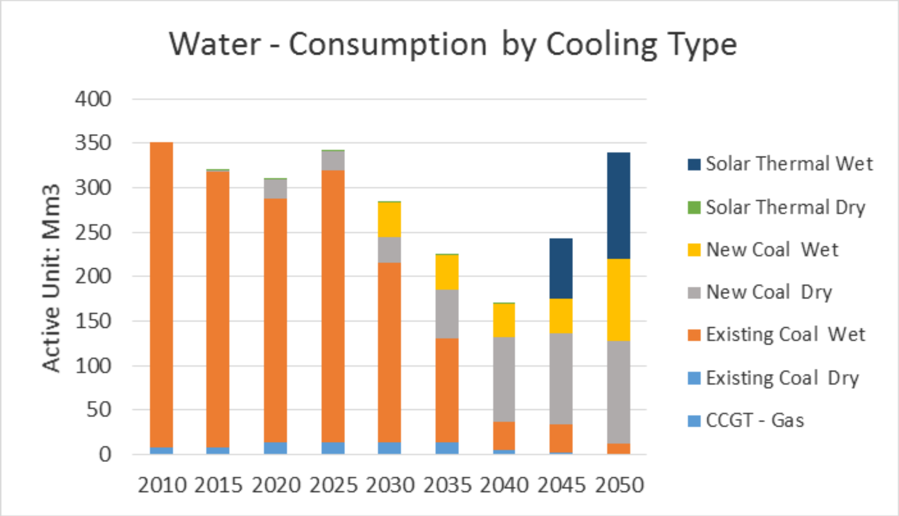


- Without a cost for water, new coal power plants employ Wet Cooling, but when water costs are applied there is a shift towards Dry Cooling and Solar Thermal
- Not including a cost for water lowers total system cost by building more coal-fired power plants instead of renewables, but results in an 80% increase in water consumption for power generation while producing 2% more CO_2

Scenario	System Cost		Water to Power		Power Plant Builds		CO2 Emissions	
	2010MZAR	%	Mm3	%	GW	%	kT	%
Reference (BAU)	6,855,224		14,000		117.06		17,449,206	
Reference (BAU) no cost water	-76,099	-1.11%	11,054	78.96%	-7.89	-6.74%	350,419	2.01%

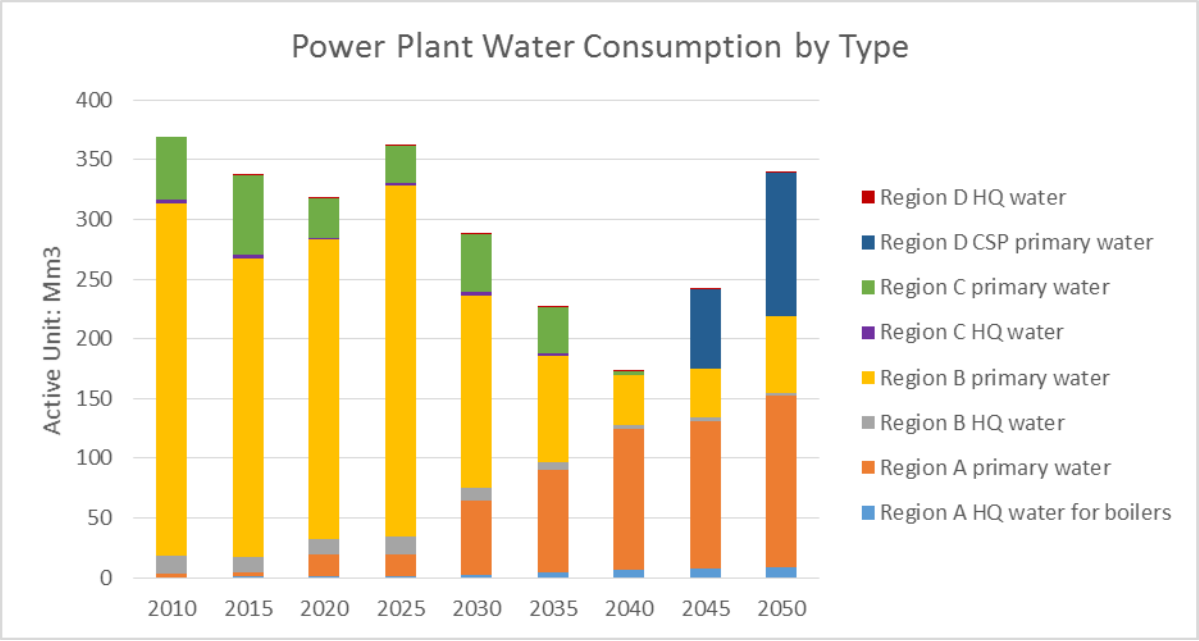
Reference case: Energy Generation and Water Consumption





In the later planning periods wet-cooled solar thermal plants are preferred with ~4 GW of new wet-cooled coal due to a basic economic benefit of allocating available water to power generation.

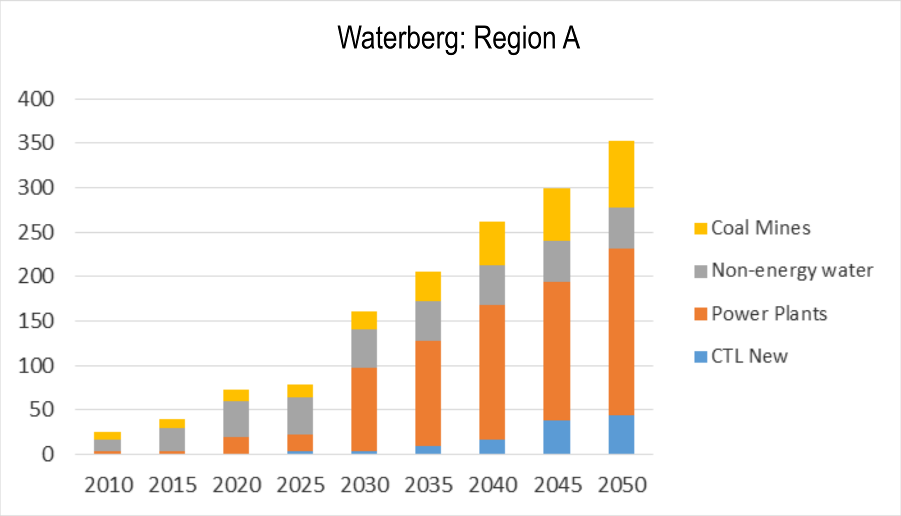
Reference case: Power Plants Water Consumption by Type

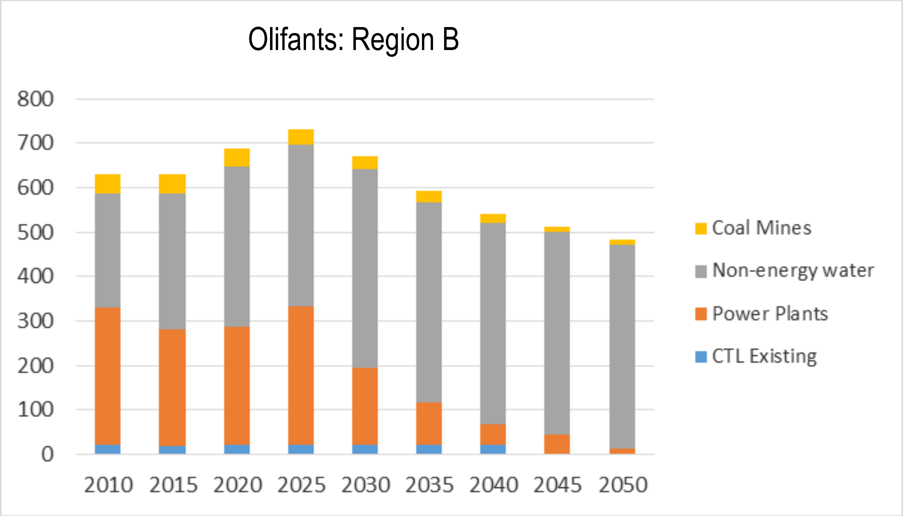


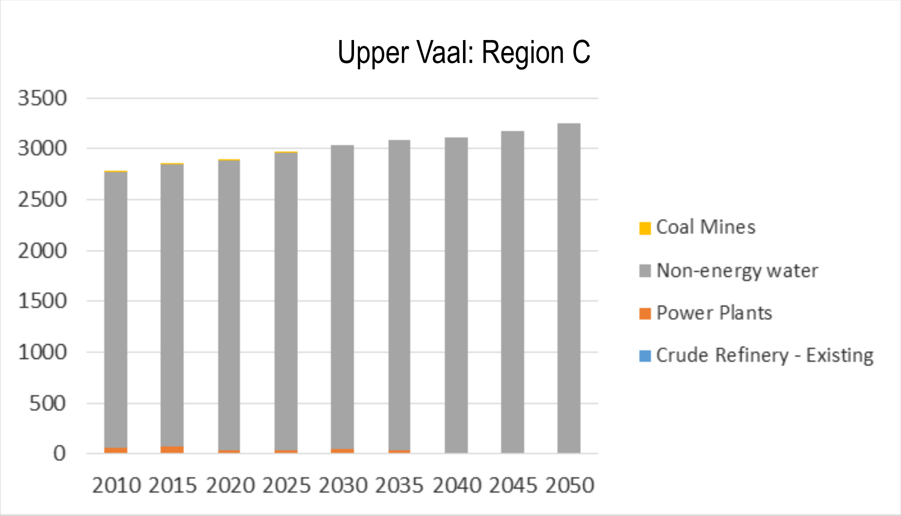
Coal	1.606	1.481	1.227	1.319	1.088	0.776	0.537	0.527	0.456
Gas	0.996	0.572	1.384	1.384	0.890	1.082	1.082	0.000	0.000
Solar	0.000	0.331	0.331	0.331	0.331	0.331	2.041	2.068	2.035
Total	1.404	1.196	0.996	1.056	0.822	0.598	0.469	0.571	0.529

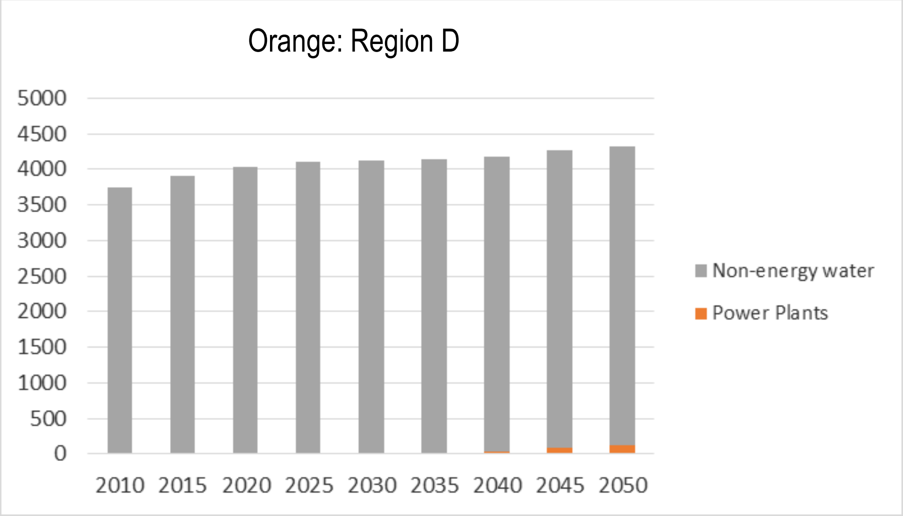
- Water intensity of coal plants decrease over time while solar thermal increases ten fold due to wet cooling
- Gas generation remains relatively flat over the planning horizon

Reference Case: Regional Water Consumption





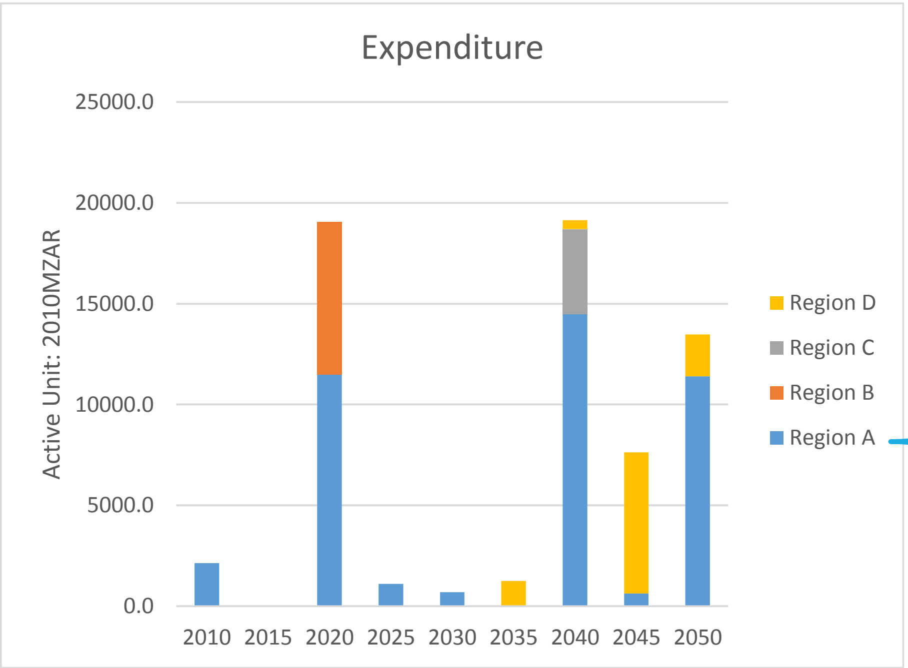


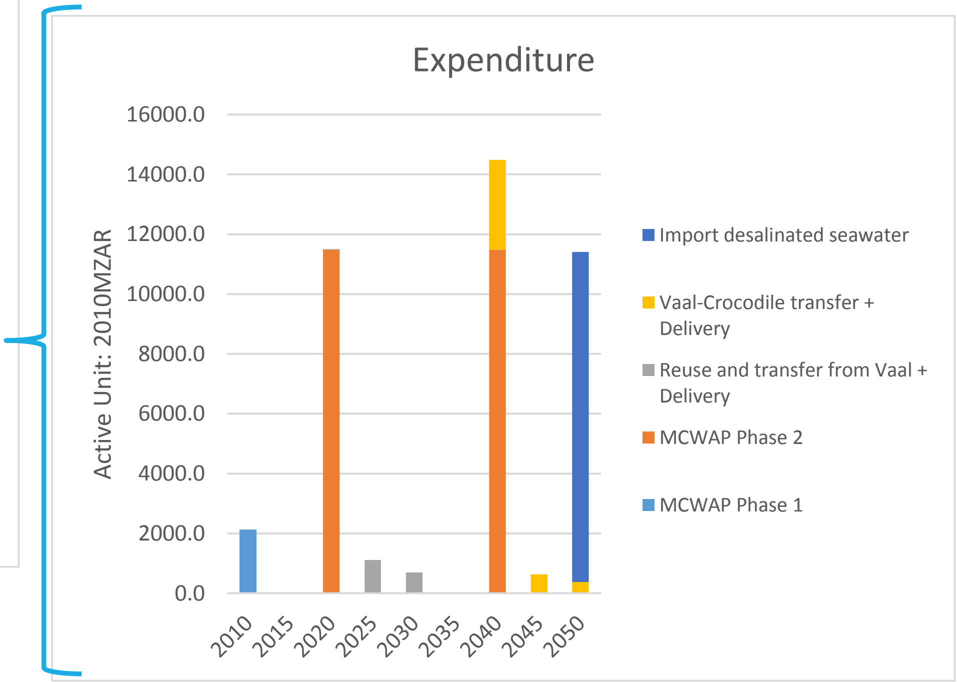


- Waterberg is the key water-energy region. Non-energy water demands dominate the other regions
- In the Olifants energy water needs shrink substantially as existing power plants retire

Water Infrastructure Investments: Lumpsum Payments

Reference Case

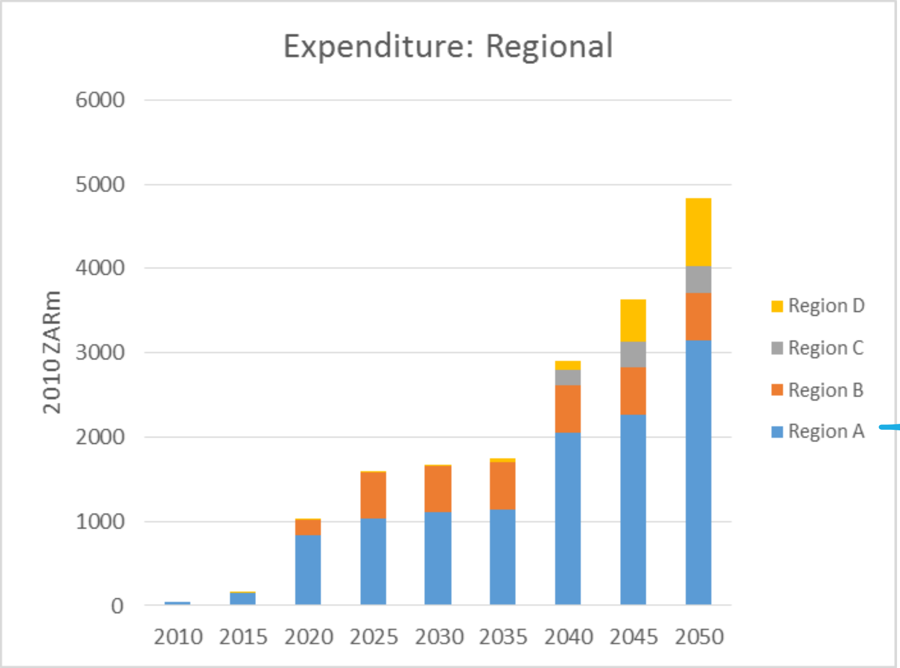


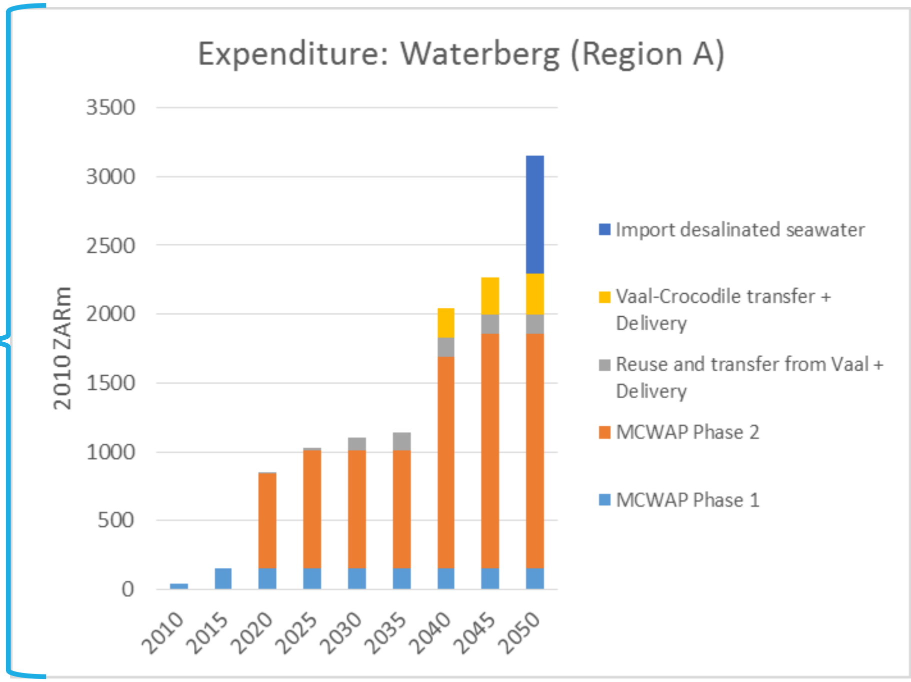


- Bulk of water for energy expenditure occurs in Waterberg, where MCWAP Phase 2 is the main expense
- Potential water shortage in 2050 (as backstop desalination kicks in)

Water Infrastructure Investments: Annual Payments

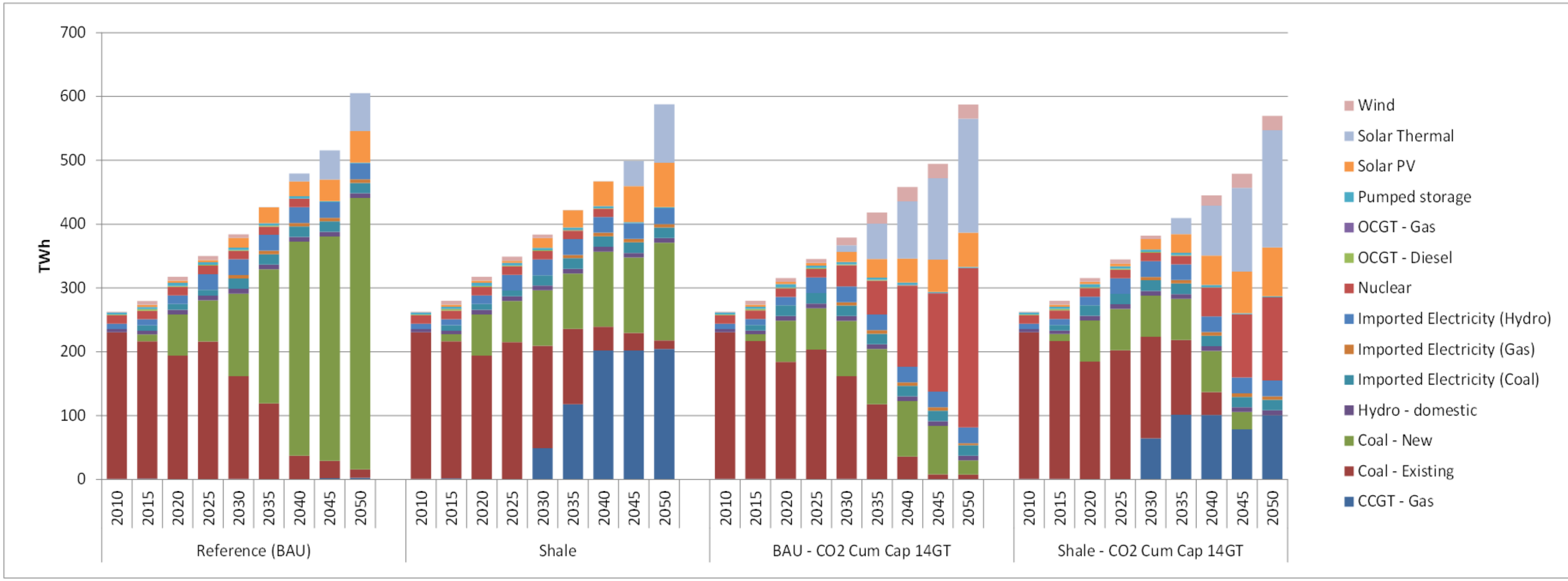
Reference Case





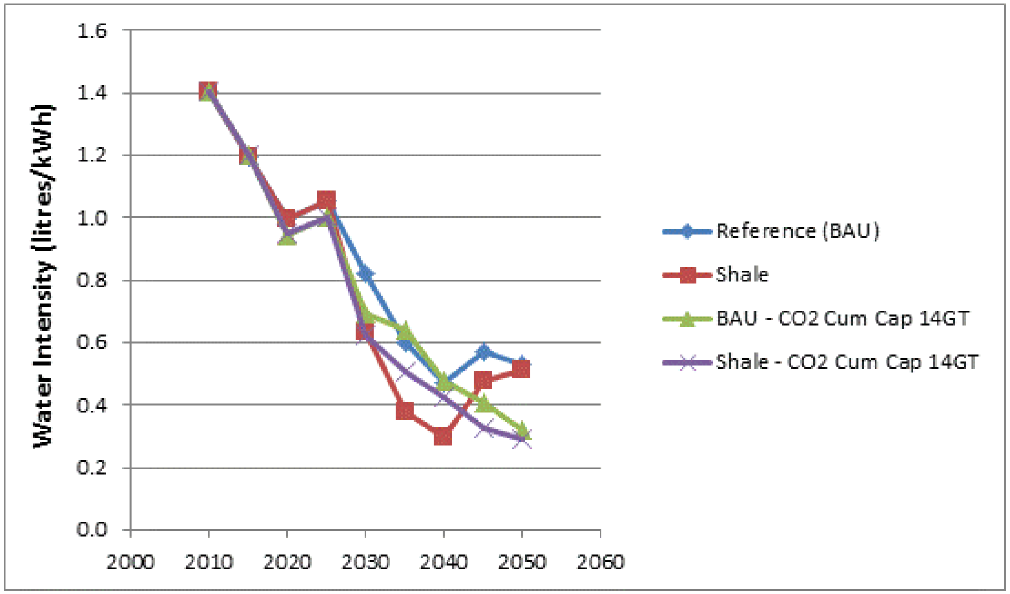
Future expenditure in energy related water infrastructure escalates with growth in the Waterberg (Region A)

Power Generation by Scenario



- Reference continues the country's reliance on coal-fired generation
- Shale allows a bit more variable renewables into the generation mix
- Nuclear and renewables are turned to heavily to meet the CO_2 cap without Shale
- 3GW of existing coal capacity is almost "stranded" in the later years under the CO_2 cap
- Shale delays nuclear to 2040 and eliminates almost all coal generation with the CO_2 cap

Water Intensity of Power Generation by Scenario

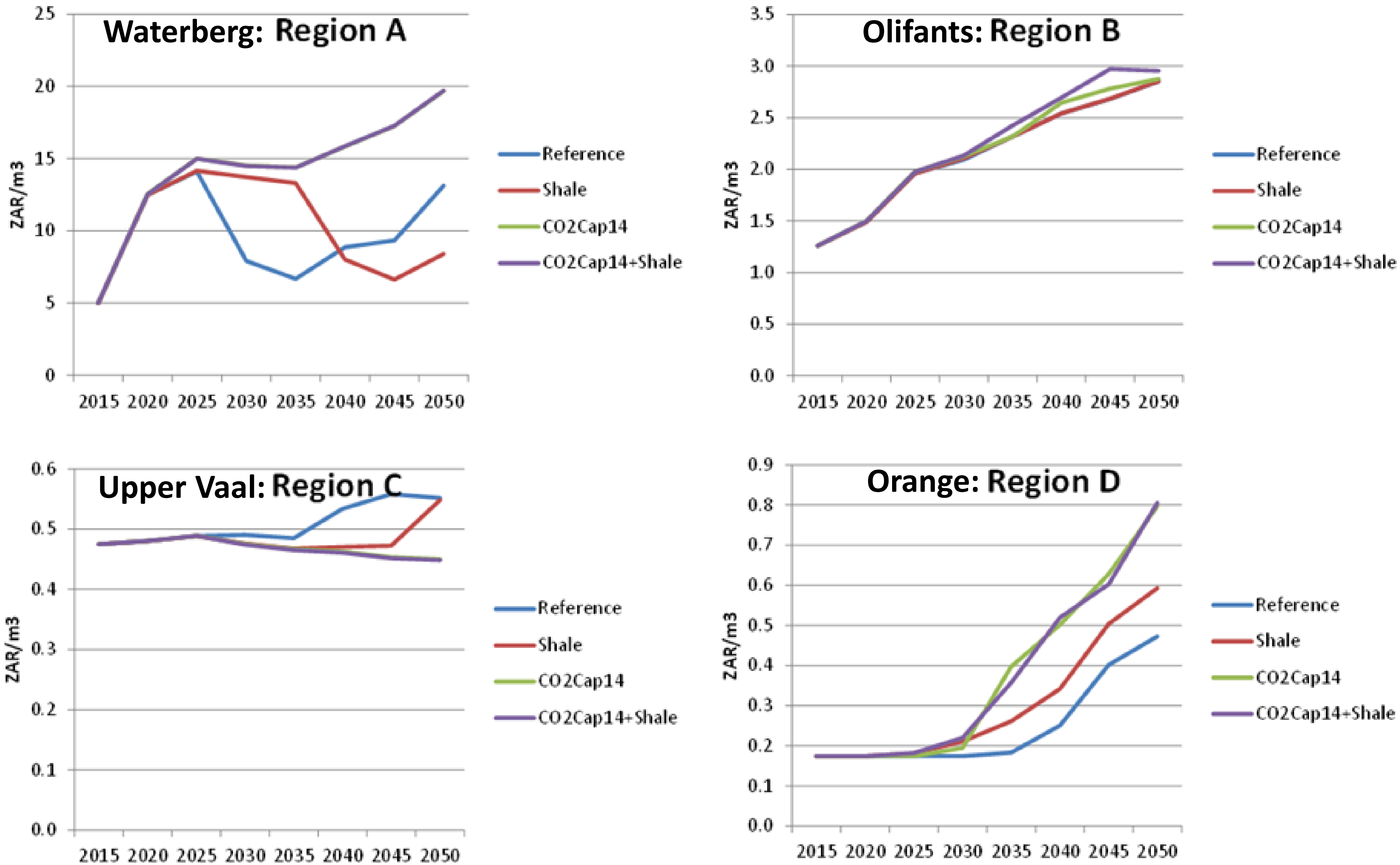


Water intensity of electricity generation exhibits a decreasing trend.

Overcapacity from committed builds in the near term results in an increase in water intensity in the mid-term due to the increased utilisation of older (less efficient) wet-cooled plants.

A more stringent cumulative CO_2 cap favours less water intensive technologies bringing down water intensity of generation earlier, steeper and deeper, leveling off at about 0.2 litres/kWh.

Average Cost of Regional Water Supply by Scenario



In the Waterberg, water supply costs drop in the Reference as more energy projects take up capacity of water infrastructure. The drop is delayed with Shale and doesn't happen with the CO2 cap.

Conclusions

- A TIMES model can be readily adapted to track water requirements for energy (and vise versa), either by representing exogenously prepared marginal water supply cost curves (MWSCC) or by depicting the full infrastructure build-out options available as is the case with SATIM-W and determining the MWSCC endogenously.

- Both water & energy as part of the national planning process allows for optimal investments decisions in both sectors by identifying potential risks to either water or energy infrastructure planning. For example the potential for abandoned or stranded capital under certain scenarios (e.g. Climate Change induced regional shifts in investment).

- While this first foray into a comprehensive approach examining the energy-water nexus in South Africa needs further refinement to be ready to advise policy formulation and investment, it is clear that important insights may be overlooked without taking a fully integrated approach to coordinating water and energy planning.

Planned Model Refinements and Possible Next Steps

Water

- Disaggregate the non-energy water sectors to enable water reallocation to be examine
- Water-energy cost for other energy supply sectors: hydrogen, uranium mining and processing
- Impact of water treatment for coal and shale gas mining effluent
- Impact of regional water quality
- Incorporate the temporal (intra annual) variation in water supply and demand

Energy

- Add costs for expansion of the transmission lines from remote solar sites
- Re-examine characterisation of wind options
- Introduce load balancing requirements as the share of renewables grows

Next Steps

- Breakout non-energy water demands to explore reallocation schemes
- Link to an economy-wide (CGE) model to realize a comprehensive national energy-water-economy-environment planning framework