The Challenge of Addressing the Water-Energy "Nexus" with Climate Change: An Example of Opportunities for Expanding Integrated Assessment Modeling

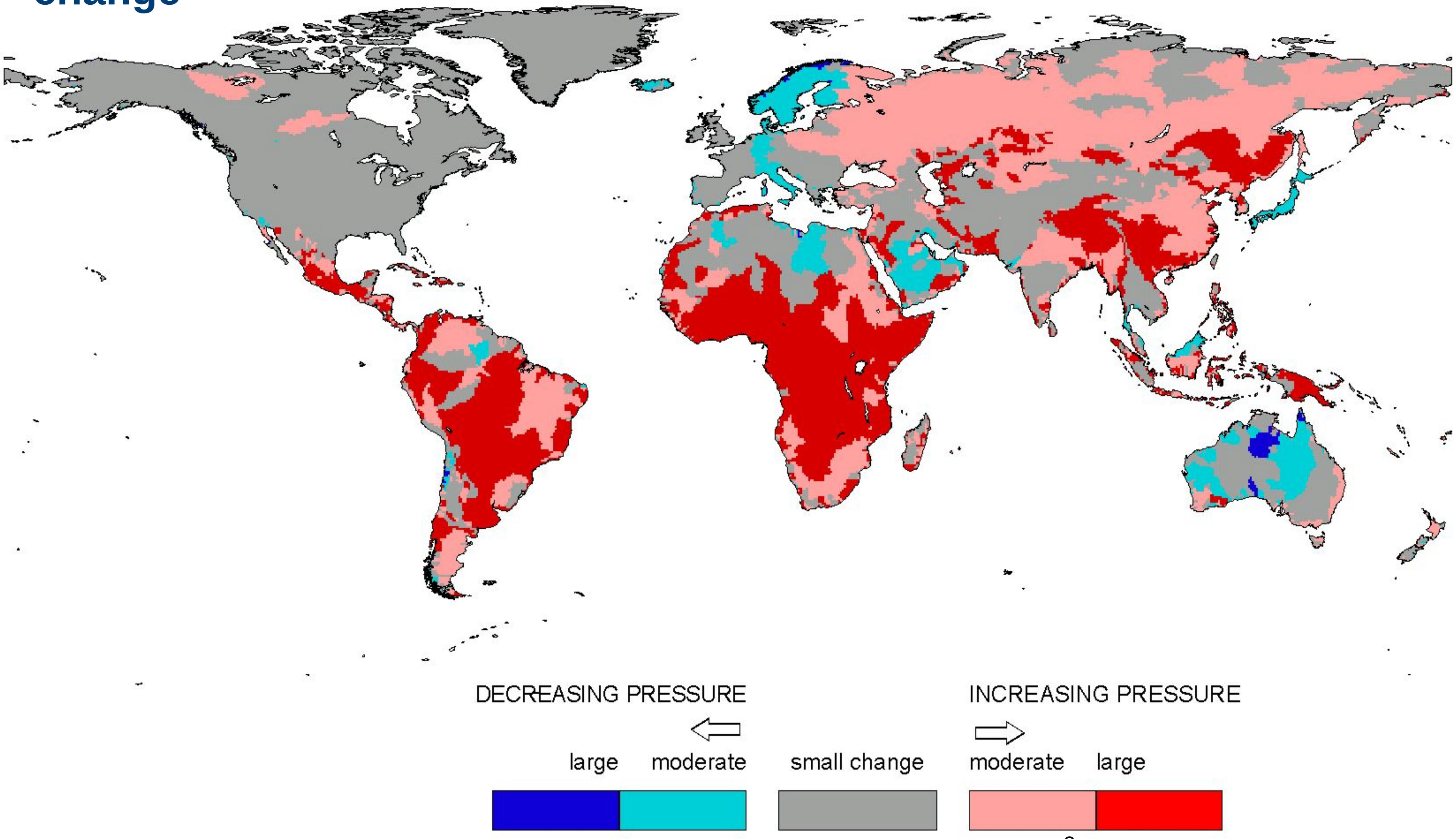
Michael Toman
World Bank Research Department
19th Annual Conference on Global Economic Analysis
Washington DC, June 17, 2016

OUTLINE

- Overview of the water-energy nexus
- Example of nexus analysis – South Africa
- Implications for broadening the scope of integrated assessment

Water pressure is growing:

Key drivers include more people, growing economies, and climate change

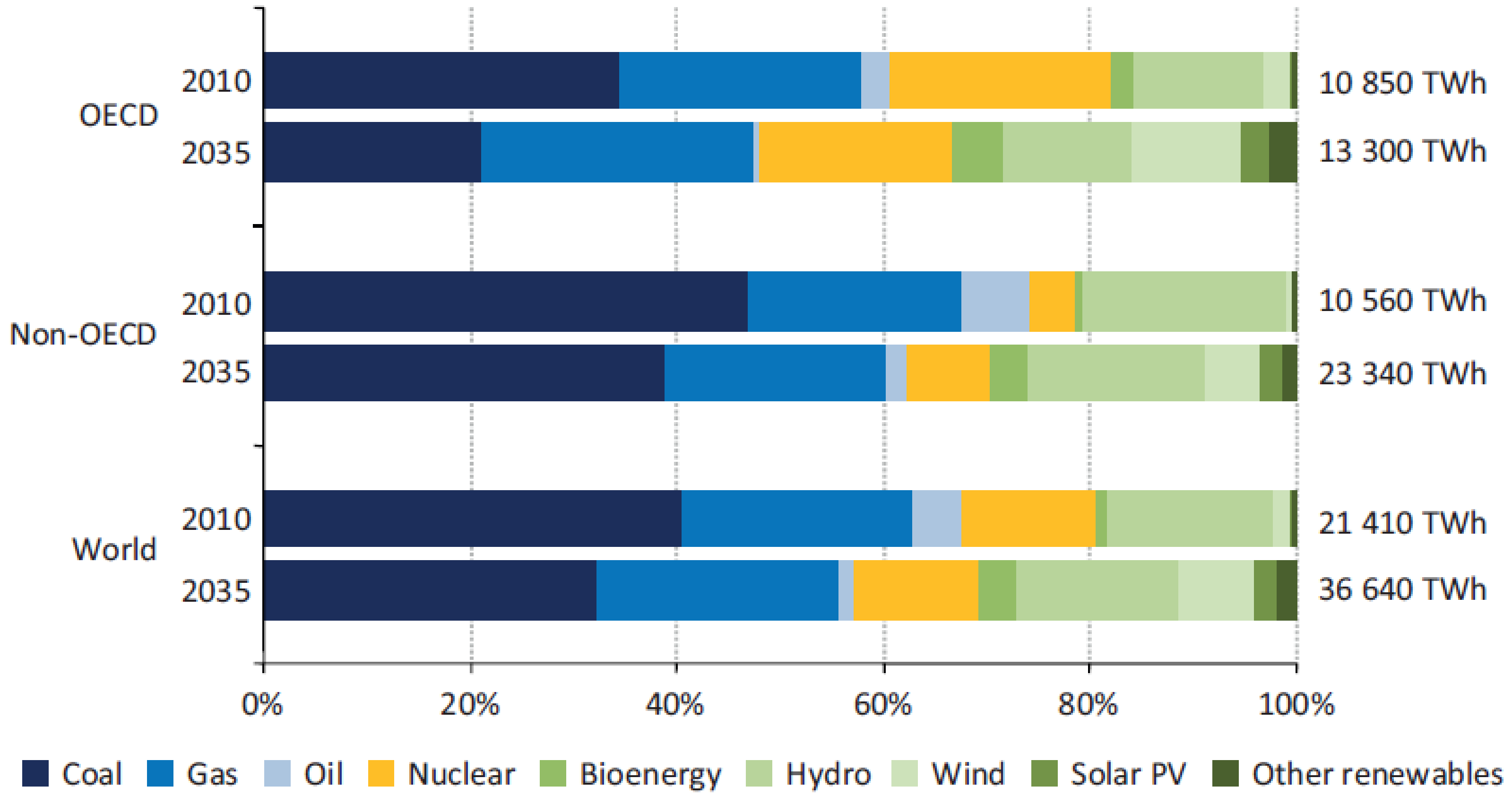


Increasing impacts of global warming on energy supply and demand

- Increasing surface and lower troposphere temperatures
- Increasing frequency of weather extremes
- Loss of glacier cover in mountain areas
- Changing precipitation patterns – more intense rainfall, longer periods of drought
- Changes in river stream flows
- Decreasing mean mid-latitude wind speeds

SOURCE: ESMAP PRESENTATION ON CLIMATE IMPACTS ON ENERGY SYSTEMS. NOVEMBER 16, 2010

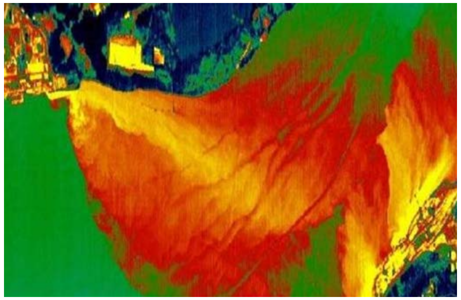
Thermal Power Plants and Hydropower account for about 90% of Electricity Generation (and will continue to do so in 2035)



Power Sector Vulnerability to Climate Change Impacts on Water Resources

MAIN WATER RISKS*

INCREASED WATER TEMPERATURE FOR COOLING



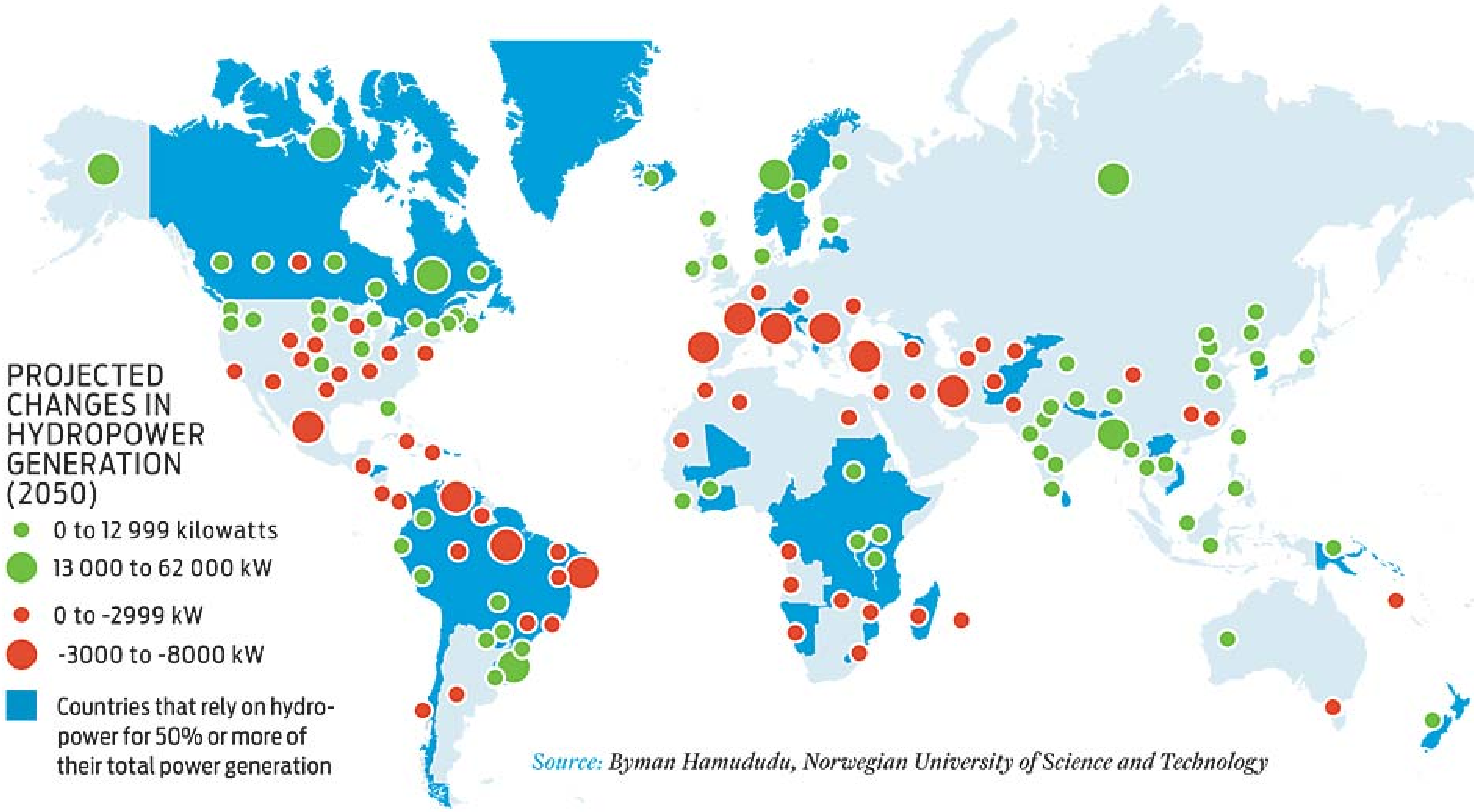
DECREASE IN WATER AVAILABILITY

WORLDWATCH.ORG

WASHINGTON POST

* Besides floods and other extreme events

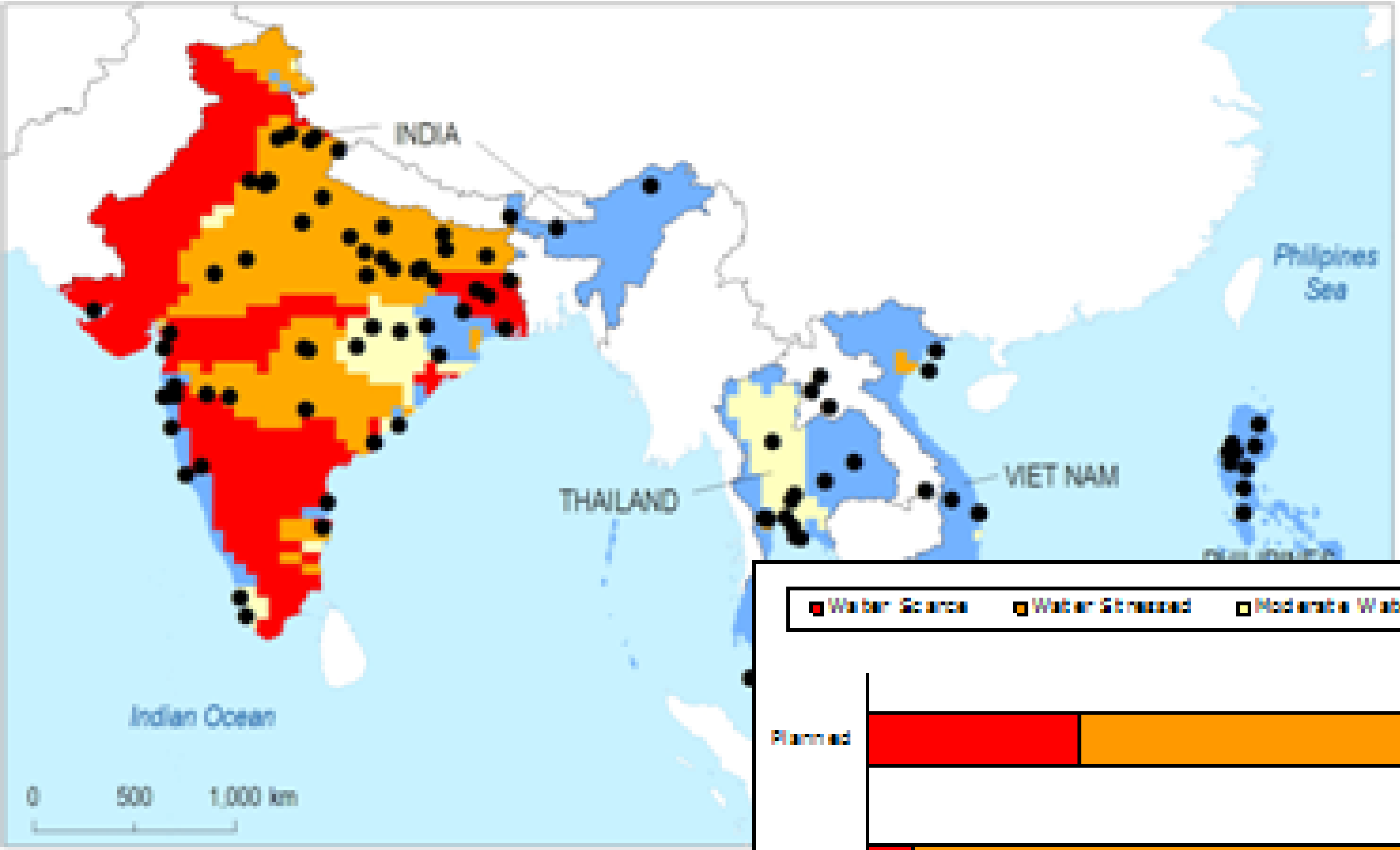
Hydropower may be affected by changing precipitation & water regulation in mountainous regions

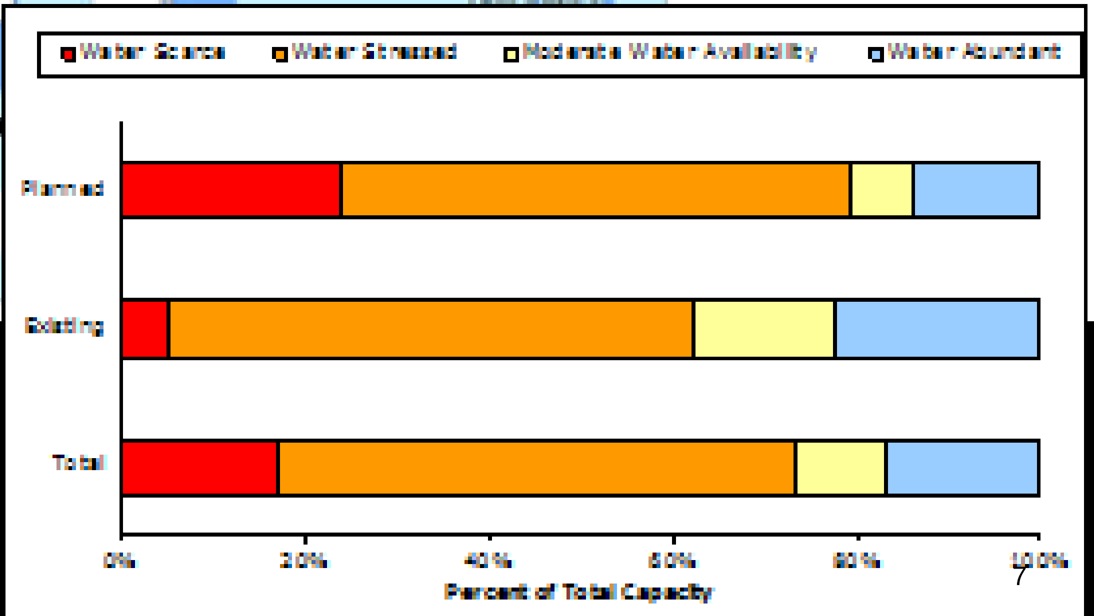


Source: http://spectrum.ieee.org/energy/renewables/future-of-hydropower

Informing portfolio decisions

Example: Power plant locations and water stress levels

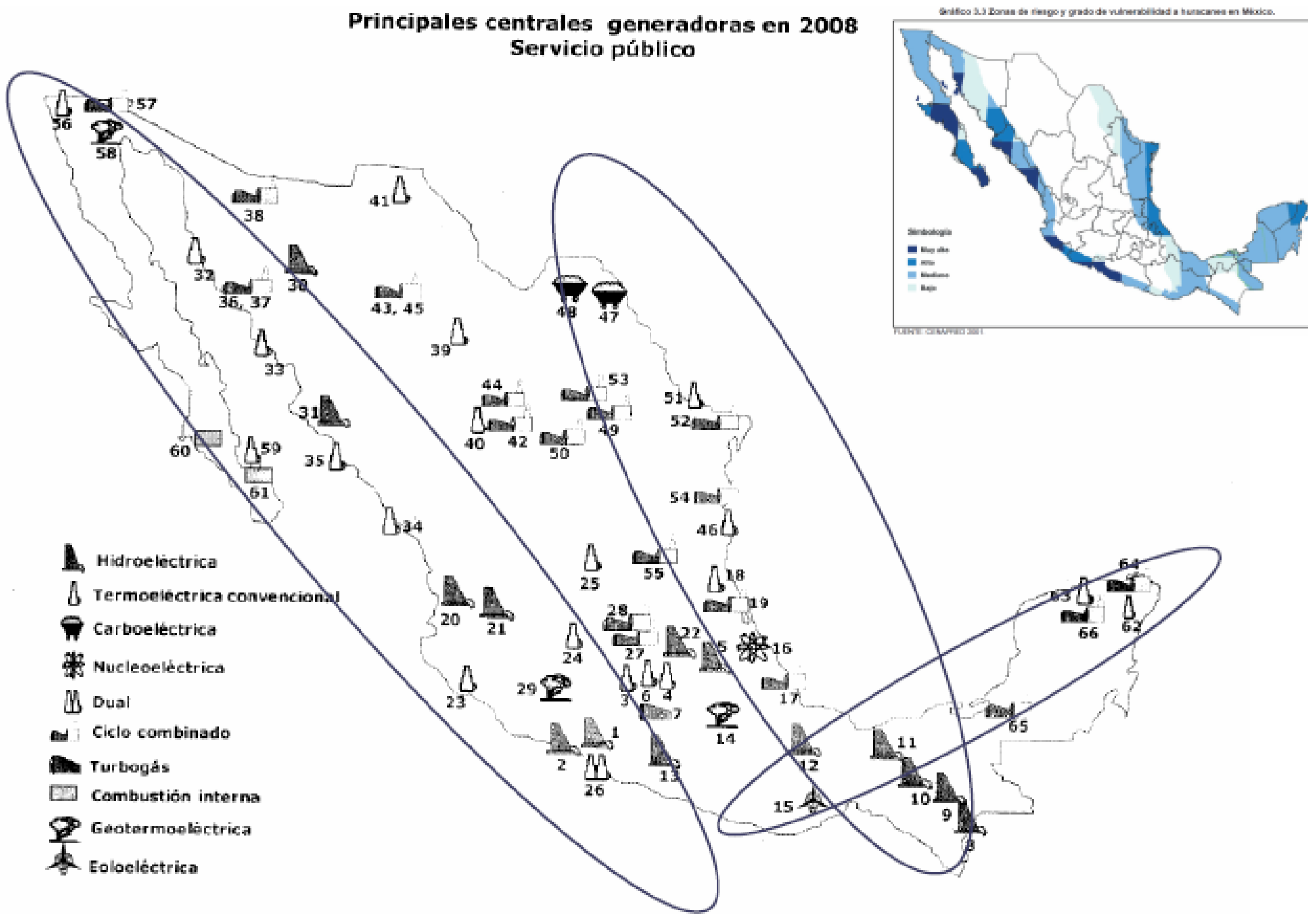




Source: WRI and HSBC, *Over Heating: Financial Risks from Water Constraints on Power Generation in Asia* (2010).

Changes in extreme weather events will affect energy infrastructure vulnerability

Relative location of power plants vs. hurricane/typhoon zoning areas in Mexico



Water for Energy in the Context of Climate Change

First Time IEA World Energy Outlook (2012) looks at Water needs for the Energy Sector

- **Global energy consumption will increase by nearly 50% in 2035**
- **Water Consumption by the Energy Sector will increase by 100% in 2035 (from 66bcm to 120 bcm), putting additional pressure on already constrained water resources**

"Constraints on water can challenge the reliability of existing operations and the viability of proposed projects, imposing additional costs for necessary adaptive measures", the report concludes.

The World Bank "Thirsty Energy" Initiative

Objective: The main objective of the flagship is to contribute to a sustainable management and development of the water and energy sectors by increasing capacity on *integrated planning* of energy and water investments identifying and evaluating trade-offs and synergies between water and energy planning.

1. **Rapid assessments in priority basins/countries**
2. **Implementation of case studies**
3. **Knowledge dissemination, advocacy and capacity building**

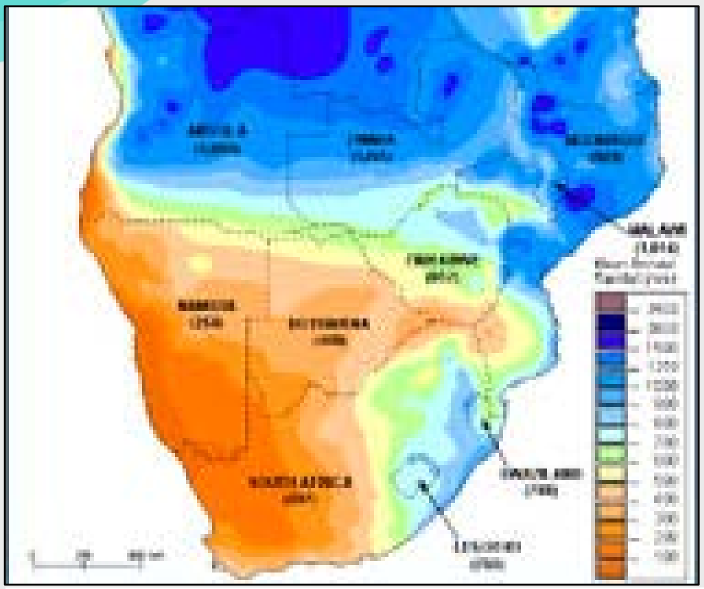
Thirsty Energy Methodology and Case Study

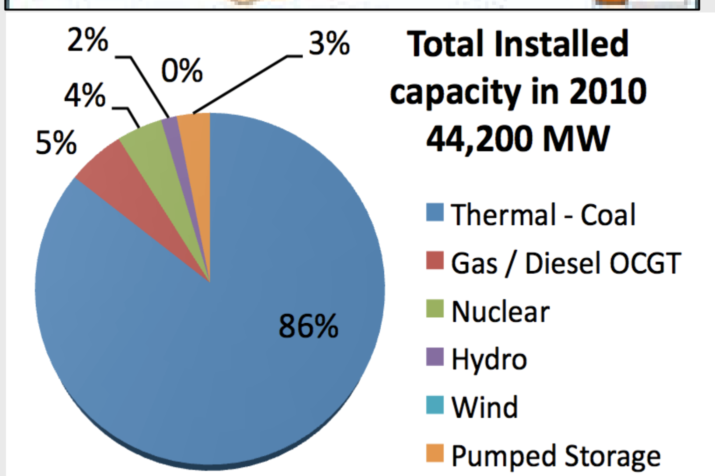
- In South Africa, TE is working with Energy Research Center of the University of Cape Town and Aurecon
- Using TIMES-based energy systems analysis model to examine the energy-water planning nexus, incorporating a representation of water supply, consumption and treatment requirements for the energy sector

Key Aspects of TIMES

- Encompasses an *entire energy system* from resource extraction through to end-use demands
- Employs least-cost *optimization*
- Identifies the most *cost-effective* pattern of resource use and technology deployment over time
- Provides a framework for the evaluation of mid-to-long-term *policies and programs* that can impact the evolution of the energy system
- Quantifies the *costs and technology choices, and associated emissions,* that result from imposition of policies and programs
- Is a *widely used international standard* under the auspice of the IEA-ETSAP (www.iea-etsap.org) Implementing Agreement

South Africa: The Case of a Water Scarce Country



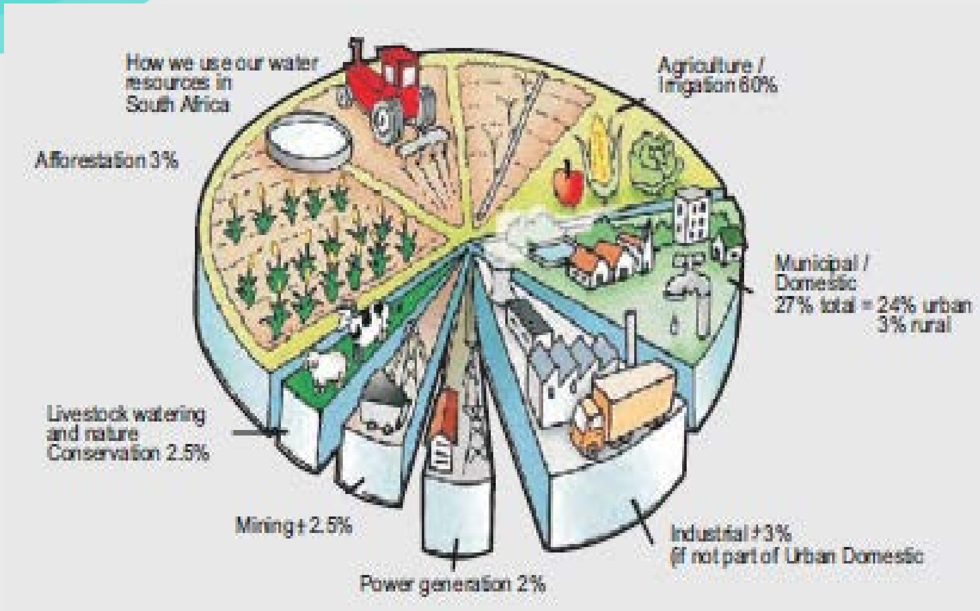


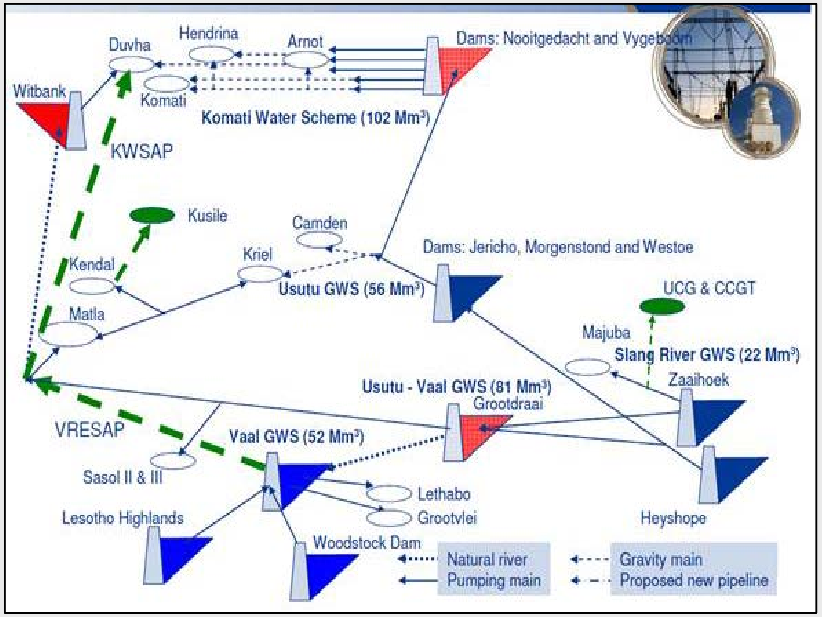
Sources - Top: CSIR, Bottom: ESKOM and Department of Energy of South Africa

- **Water scarce country with very stressed basins in terms of water allocation**
- **Coal Thermal Power plants account for almost 90% of the installed capacity**
- **Competition for water across sectors will increase – power plants have priority, which could negatively affect other sectors such as agriculture**
- **Fracking for Shale Gas is being explored, which will put additional pressure on water resources**

Need integrated Water and Energy planning to achieve a sustainable future and avoid water scarcity problems in the next years

Water Use in South Africa



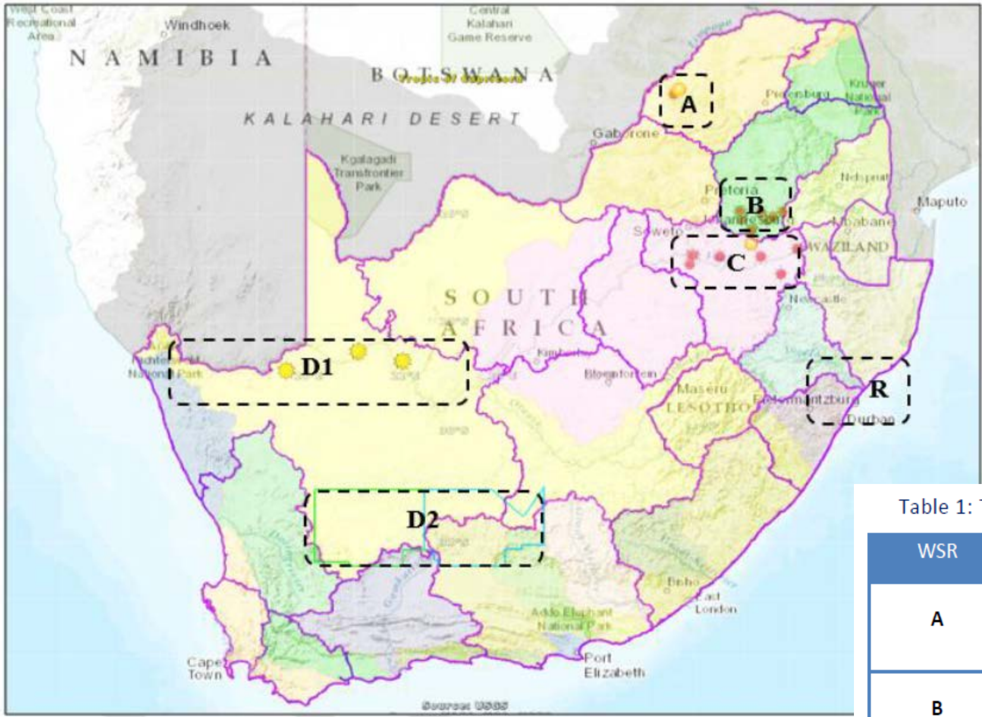


- Direct use for power generation is small (2%) at national level but is significant at a regional level (e.g. 37% in the Upper Olifants)
- Requires a high level of assurance
- Water for power supported by major inter-basin transfers
- Transfer and treatment of water is very sensitive to energy costs

Methodology: Incorporate Water into an existing TIMES Energy Systems Model

South Africa TIMES (SATIM)

- Five demand sectors – industry, agriculture, residential commercial and transport - and two supply sectors - electricity and liquid fuels
- The model is capable of assessing a wide variety of policies and constraints
- Incorporating water supply infrastructure options and constraints into SATIM:
  1. Develop water consumption demands for all power plant types and cooling options, coal mining, shale gas production, coal-to-liquids/coal-to-gas processing facilities, and solar
  2. Track water quality and incorporate water treatment options and costs
  3. Run different Energy-Water model simulations to assess how energy sector development strategies change – when water has a price and supply limits
  4. Scenarios include expansion of coal use, shale gas fracking, GHG limits, etc.



Developing the SATIM-Water Model:

1. Matching energy producing regions with

Need to “geo-reference” somehow the power plants and energy facilities in order to regionally constraint the amount of water available by assigning the different power plants and energy extraction locations to their basin

Table 1: Technologies represented in SATIM-W for Phase 1 implementation by water supply system.

WSR	WMA	Region	Activity
A	Limpopo	Lephalale	• Open-cast coal mining • Coal thermal power plants with FGD option • Coal-to-Liquids refineries
B	Olifants	Mpumalanga, Witbank	• Open-cast & underground coal mining • Coal thermal power plants with FGD option. • Coal-to-Liquids refineries
C	Upper Vaal	Mpumalanga, Secunda	• Open-cast & underground coal mining • Coal thermal power plants with FDG option • Inland gas thermal power plants • Inland Gas-to-Liquids refineries
D1	Lower Orange	Northern Cape, Upington	• Concentrated Solar Thermal Power Plants (CSP)
D2	Lower/Upper Orange	Northern Cape, Karoo	• Shale gas mining • Gas thermal power plants • Inland gas-to-liquids refineries
R	n/a	Richards Bay Coal Export Terminal	• Coastal open-cycle coal power plants with seawater cooling and seawater FGD option

In SATIM-W the cooling systems for thermal power plants may be either closed-cycle wet-cooled or direct dry-cooled. The model is free to choose the cooling type, except for open-cycle wet-cooled plants which are restricted to the coastal region, as part of determining the least-cost energy-water integrated system.

Developing the SATIM-Water Model:
2. Including water costs into the energy model

Marginal Cost Curves for Water Supply were calculated for each area (A, B, C, D) except for R (coastal area where power plants use seawater for cooling). Those cost components (and the corresponding water yields) were added to the model to represent the cost of supplying water to the energy facilities.

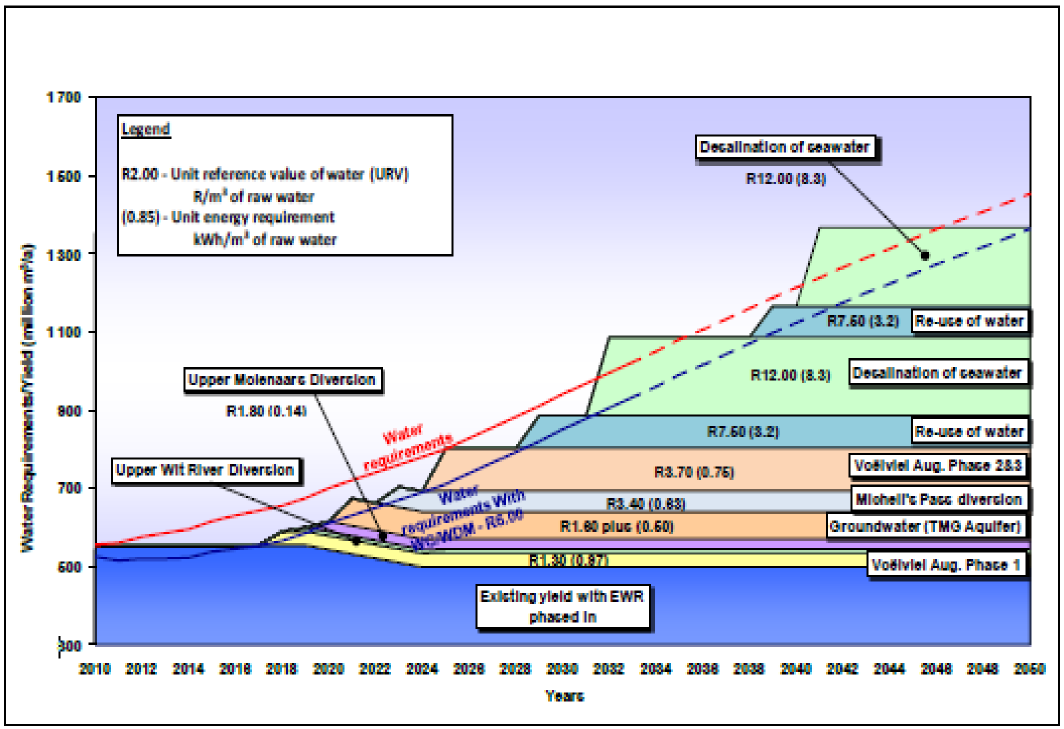
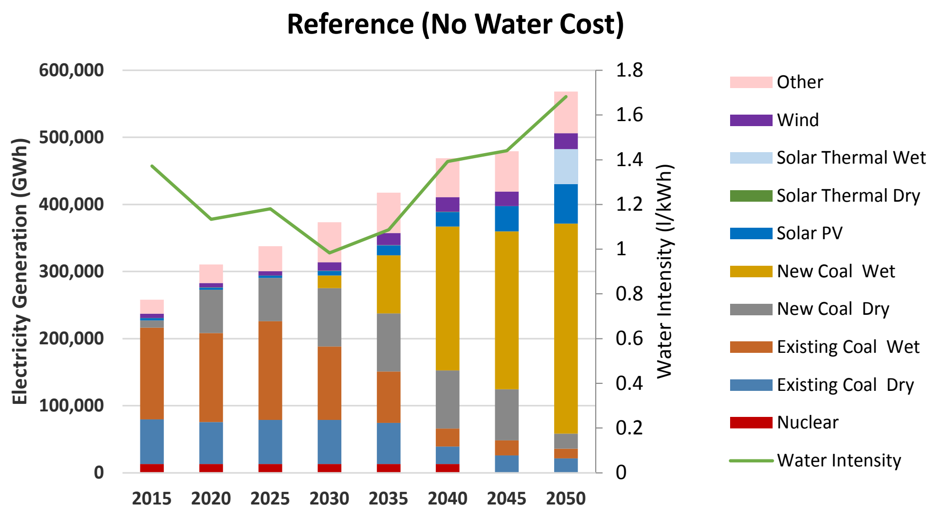
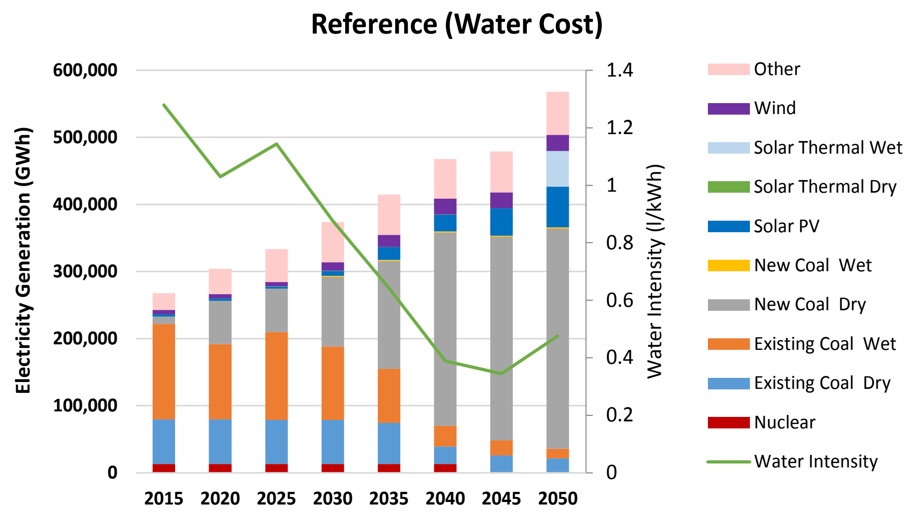


Figure 4.10 (a) Western Cape Augmentation Options (without climate change)

Water costs matter

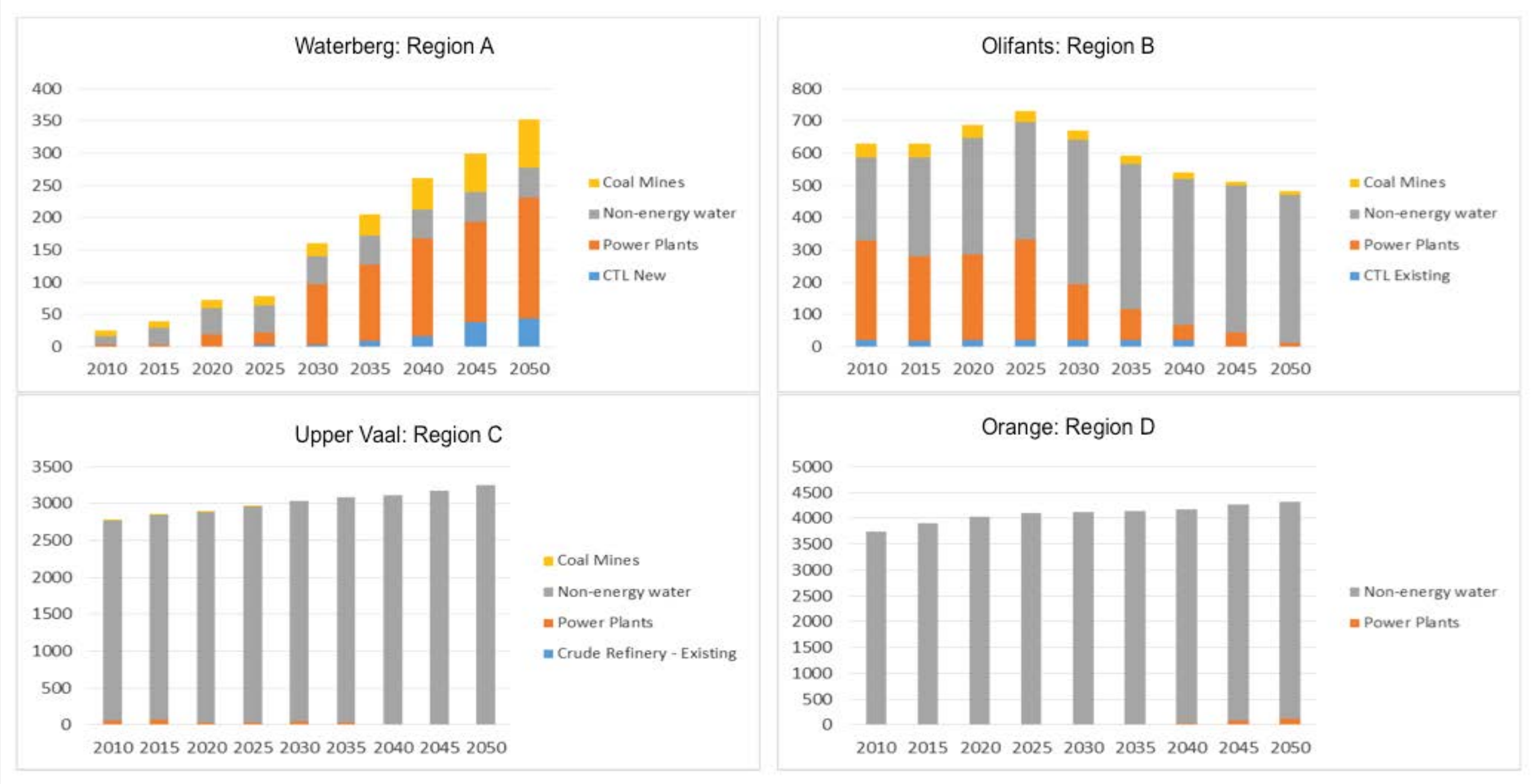




- **With water costs, shift to dry cooling and solar, decrease in water consumption**
- **Reference (Water Cost) scenario produces slightly more CO2 emissions in spite of generating 1.3% less electricity with coal and 2% more with RE technologies -- higher unit emissions with dry-cooled coal plants.**
- **Reference (water cost) scenario cuts cumulative (2010-2050) water consumption for the power sector by 9,338 Mm3 (77.34%), with just a modest increase (0.84%) in the system cost.**
- **With CO2 Cap scenarios, reduction in coal consumption and increases in renewables from wind, solar PV and concentrating solar (CSP) with storage using wet cooling. Water use for power generation increases by 15 %, due to the use of wet-cooled CSP**
- **With CO2 Cap and a dry climate, CSP capacity shifts to dry cooling, and water use for power decreases by 10%.**

Regional Differences Matter

Water consumption (Mm3) by region



- The Waterberg (Region A) is the region more exposed to water-energy tradeoffs.
- Non-energy water demands dominate the other regions.
- In the Olifants region (Region B), water needs for the energy sector shrink substantially as existing power plants retire.

What about economy-wide implications of the energy-water nexus (for the power sector)?

- In general it is fairly easy to link TIMES with CGE frameworks
- But to capture water-energy interactions, it is vital that the spatial referencing used in the partial equilibrium nexus analysis carry over, given differences in:
  - Locations of power plants and water resources
  - Technical costs of water provision by location
  - Opportunity costs of competing water uses
  - Potential impacts of climate change

Some preliminary work on building water into a SA CGE has been done, but more is needed

- A recent CGE paper* parametrized economic activity by WMA and accounted for different water availabilities – looked at cases with and without spatial transfers based on marginal economic values of water
- Could add on spatial differences in electricity generation capacities in various parts of the country, look at how both water cost and water availability affect electricity cost and trade within SA
- Technical challenges in how water services, including in situ values, are represented in SAM (difficulty in getting disaggregated water valuations and demands in many sectors, including in situ values)

***Rashid Hassan and James Thurlow, "Macro–micro feedback links of water management in South Africa: CGE analyses of selected policy regimes," *Agricultural Economics* 42 (2011) 235–247.**

Key challenges for expanding integrated assessment analysis

- Geographic differences in water availability
- More emphasis on how water dynamics, and effects on production and consumption possibilities
- Consideration of the variety of water uses
- Integrating physical resource availability with cross-sector economic values and tradeoffs, beyond what a standard social accounting system may reveal

Key challenges for expanding integrated assessment analysis

- Better understanding of infrastructure costs for different water services, including water reallocation as well as provision
- More fine-grained understanding of the potential impacts of climate change on water and energy services

THANK YOU

mtoman@worldbank.org

A World Bank
Initiative

thirsty energy

Thank You

Diego Rodriguez , Senior Economist, Water Practice
drodriguez1@worldbank.org

www.worldbank.org/thirstyenergy

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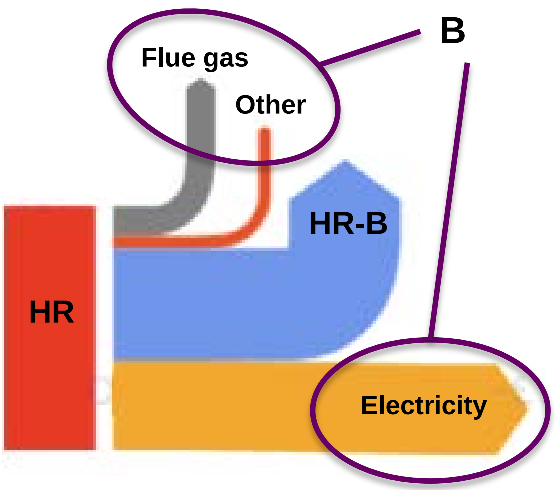
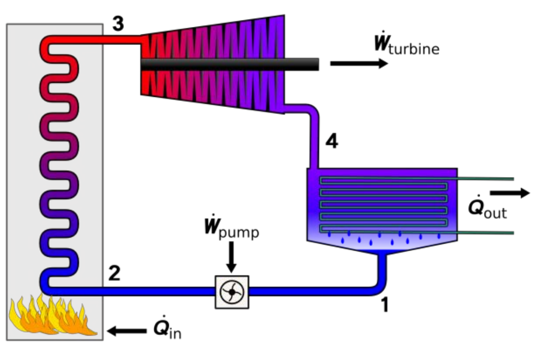
Thermal Power plant main water use: cooling

Power plant heat balance





The more efficient → the less heat losses → Less cooling needs

All the waste heat ("loss") has to be rejected somehow to the environment. The vast majority of this heat is rejected to the environment through cooling systems.

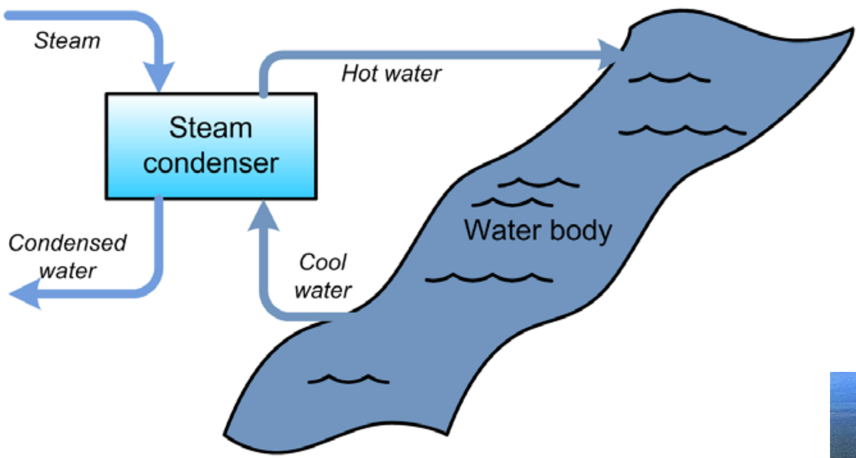
Example of Efficiencies:

- Natural Gas Combined Cycle: 50%
- Super Critical Pulverized Coal: 39%
- Subcritical Pulverized Coal: 36%
- Nuclear: 33%
- Solar Thermal (Rankine Cycle) : 32%

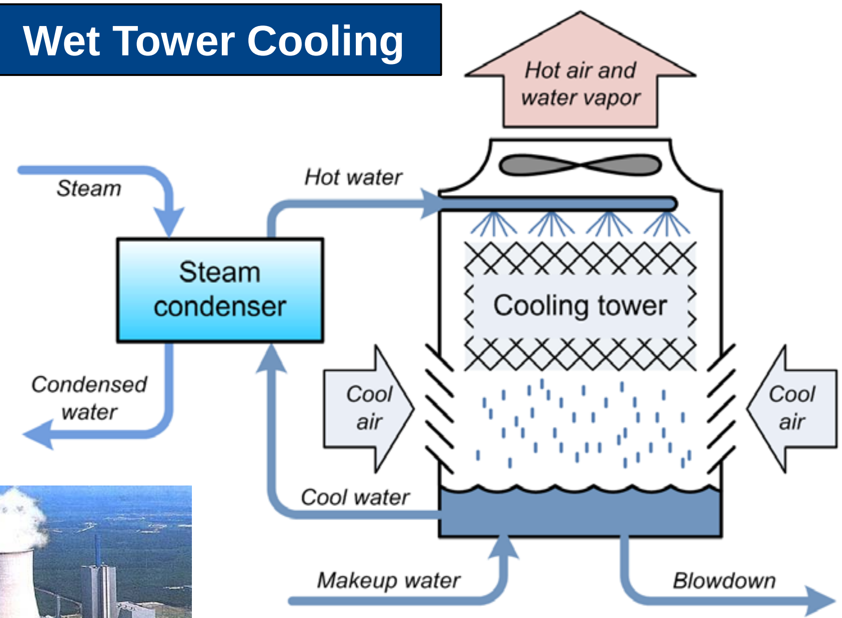
SOURCE: WATER FOOTPRINT OF ELECTRIC POWER GENERATION: MODELING ITS USE AND ANALYZING OPTIONS FOR A WATER-SCARCE FUTURE. DELGADO, 2012.

Types of cooling systems

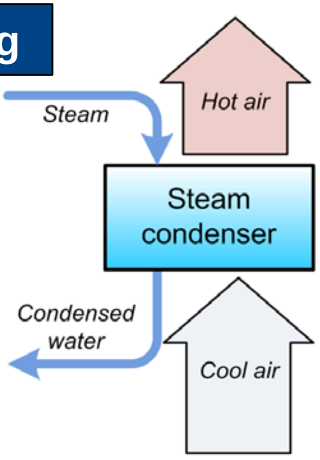
Once-through cooling



Wet Tower Cooling



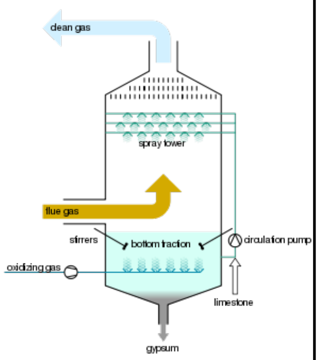
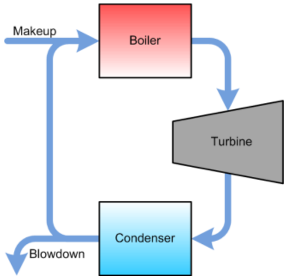
Dry cooling



	H2O withdrawal	H2O consumption	Capital cost	Plant efficiency	Ecological impact
Once-through cooling:	bad	ok	good	good	bad
Evaporative cooling:	ok	bad	ok	good	ok
Dry or hybrid cooling:	good	good	bad	bad	good

SOURCE: WATER FOOTPRINT OF ELECTRIC POWER GENERATION: MODELING ITS USE AND ANALYZING OPTIONS FOR A WATER-SCARCE FUTURE. DELGADO, 2012.

Non-cooling process water uses

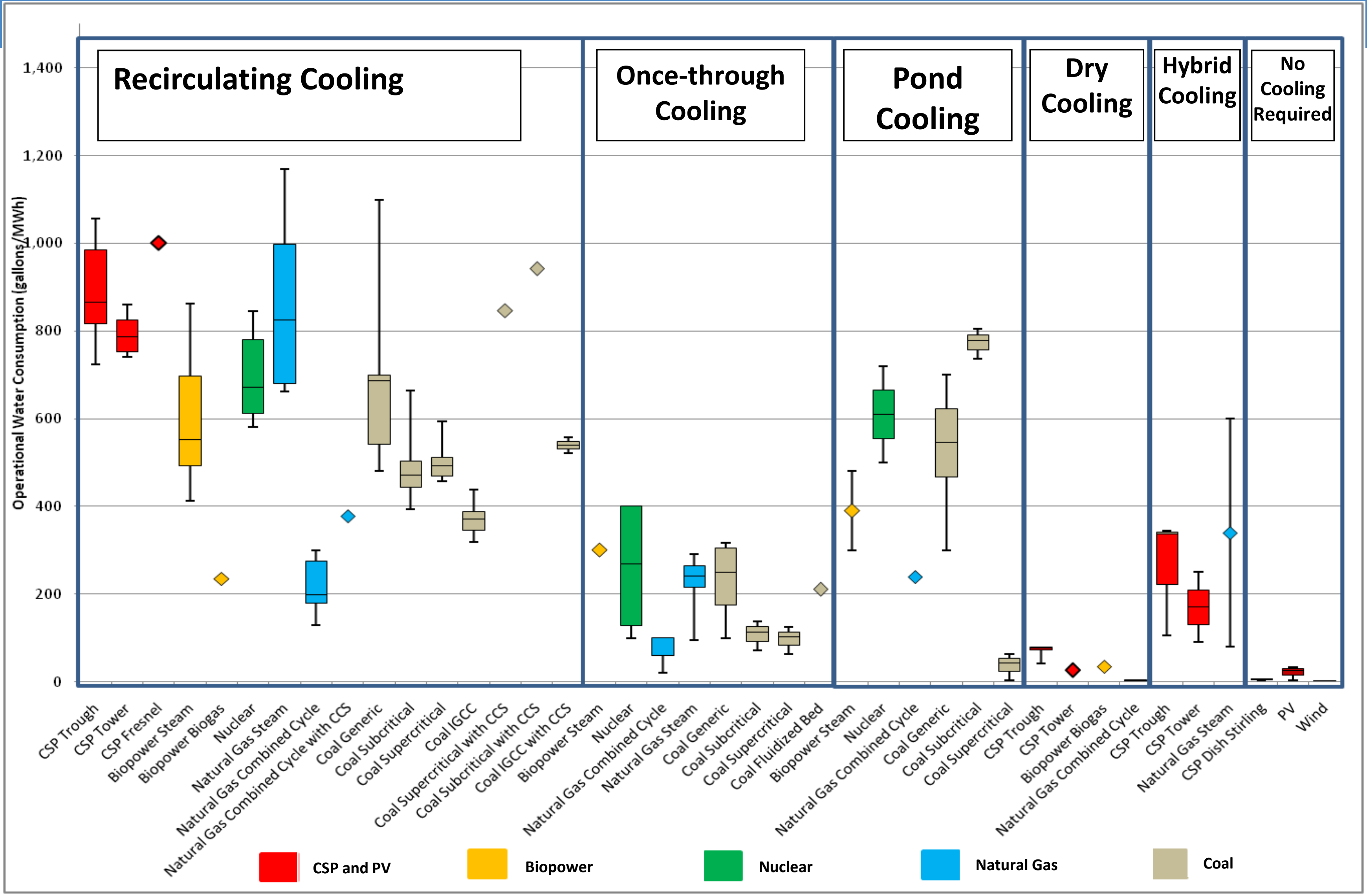
Flue gas desulfurization	Bottom ash handling	Gasification / Water Gas Shift	Mirror / PV surface washing	Boiler feedwater makeup
		$C + H_2O \rightarrow CO + H_2$ $CO + H_2O \rightarrow CO_2 + H_2$		
Coal	Coal	IGCC (Coal or biomass)	Solar	All steam-cycle
~200 L/MWh (consumed)	~100 L/MWh (reusable)	~200 L/MWh (consumed)	~20 L/MWh (consumed)	~20 L/MWh (reusable)

Compare to ~2000 L/MWh consumed in typical cooling tower!

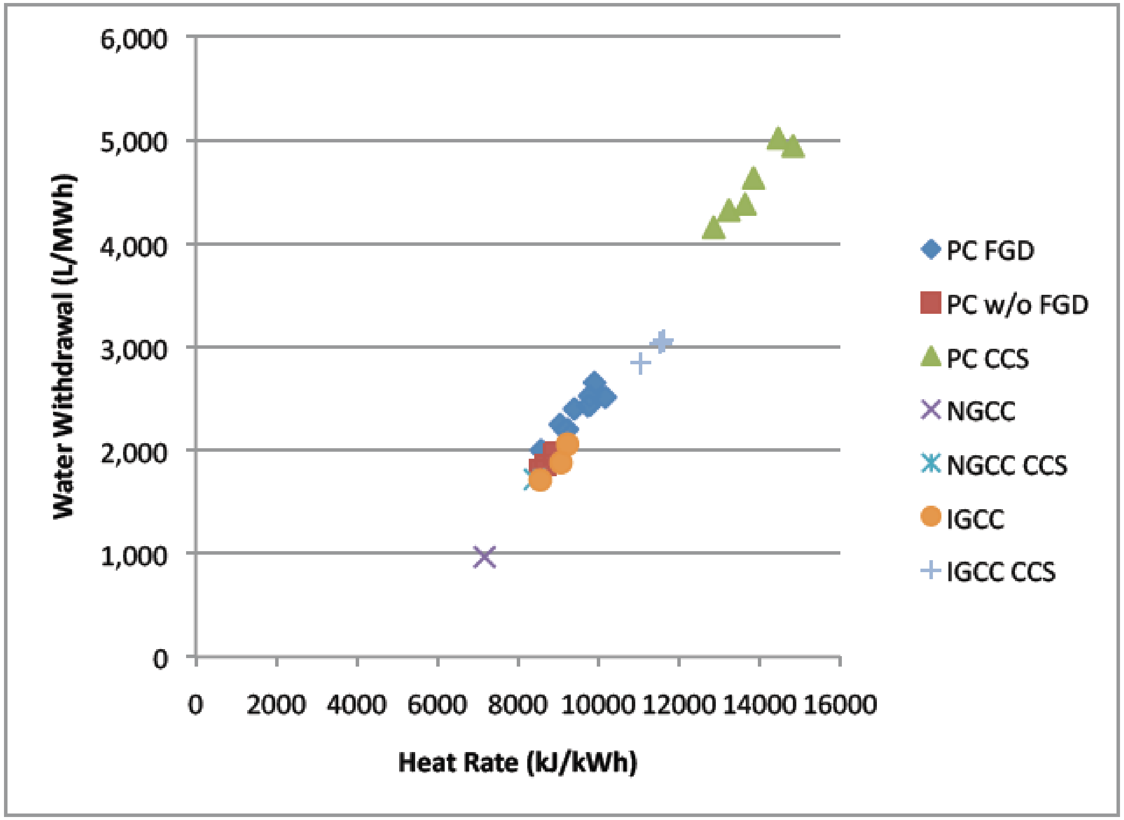
But even small water streams can incur large economic costs, e.g. Hg removal for discharge…

SOURCE: WATER FOOTPRINT OF ELECTRIC POWER GENERATION: MODELING ITS USE AND ANALYZING OPTIONS FOR A WATER-SCARCE FUTURE. DELGADO, 2012.

Water consumption for electricity generation



Water consumption for electricity generation



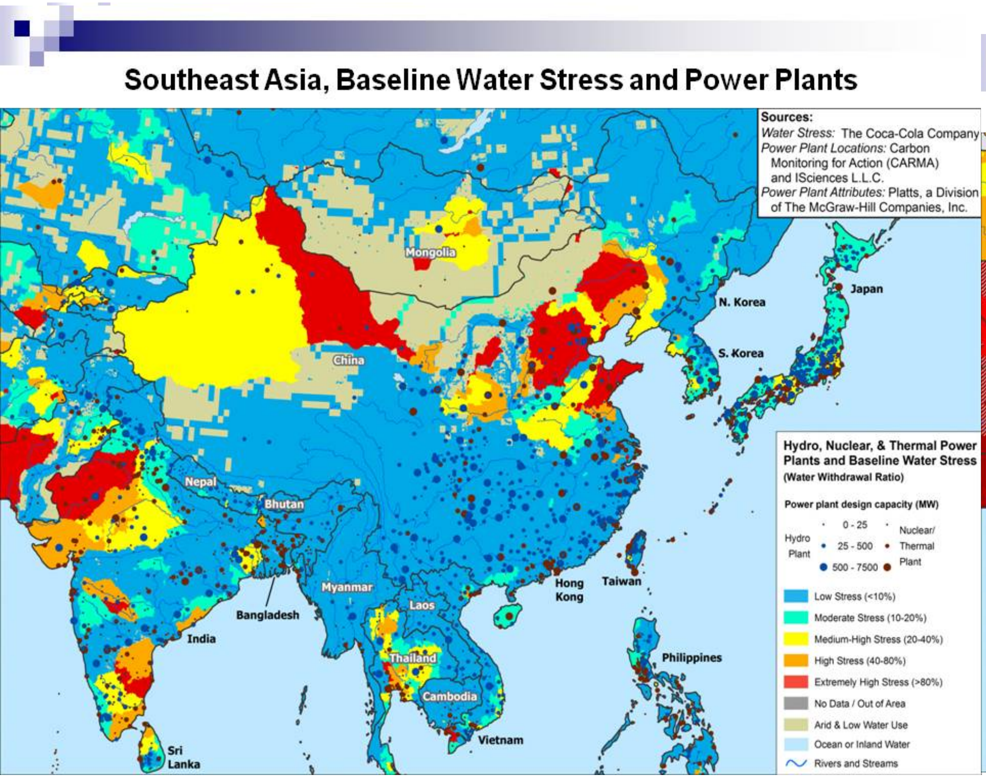
For a given cooling system:

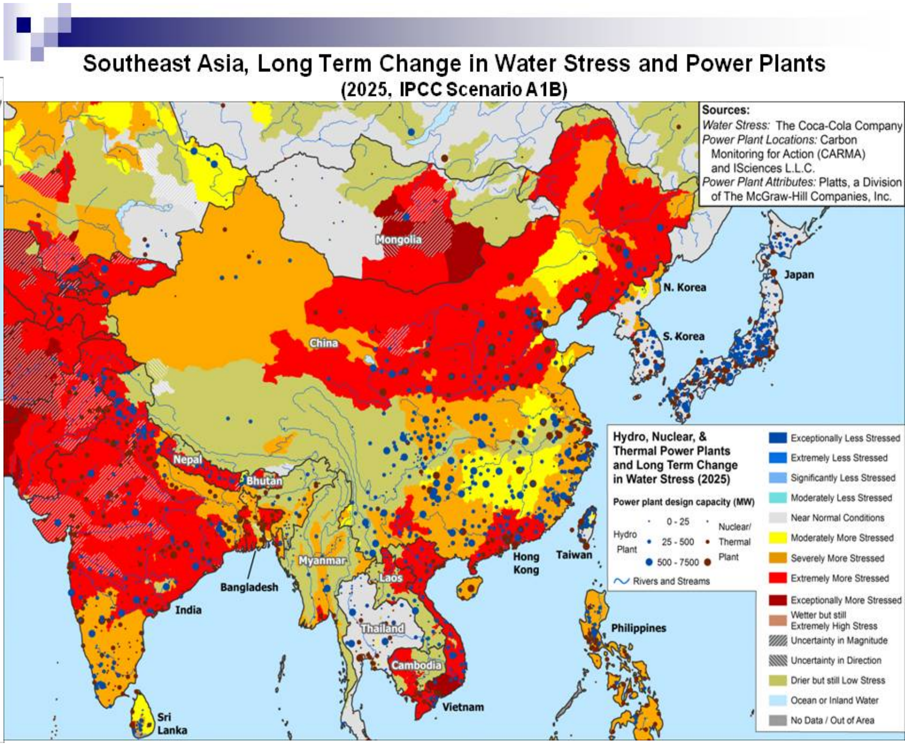
Heat Rate explains most of the variation between Cases

Most of the water is used for cooling purposes (85% to 95%)

SOURCE: WATER FOOTPRINT OF ELECTRIC POWER GENERATION: MODELING ITS USE AND ANALYZING OPTIONS FOR A WATER-SCARCE FUTURE. DELGADO, 2012.

Water Footprint in Asia





Methodological approach

- Flexible modeling framework to facilitate tailored analyses over different geographical regions and challenges
- Build on existing country knowledge and modeling tools
- Robust treatment of risk and uncertainty
- Incorporate the long-term effects of climate change
- Economic tools to assess the tradeoffs between competing sectors and to provide policy recommendations to mitigate potential effects
- Case studies or pilots to illustrate different types of situations in that are most relevant for client countries

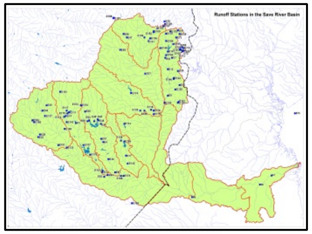
Methodological approach – build on existing energy tools – start small

MARKAL / TIMES

- Application on regional or country level for long-term energy planning
- Improved integration of water dynamics and economy of water

LEAP - WEAP

- Improved LEAP optimization
- Application of LEAP-WEAP on country or national river basin level for joint energy and water master planning
- Improved integration of economics for water

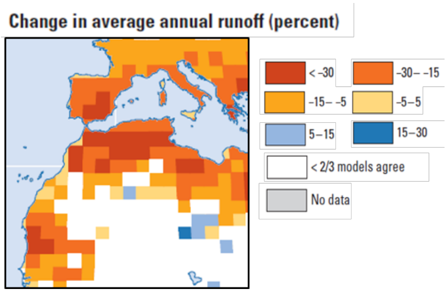


Partnerships

- World Business Council for Sustainable Development
- Stockholm Environment Institute
- Inter-American Development Bank
- World Resources Institute
- Water Partnership Program
- Korea Trust Fund for Green Growth
- ESMAP

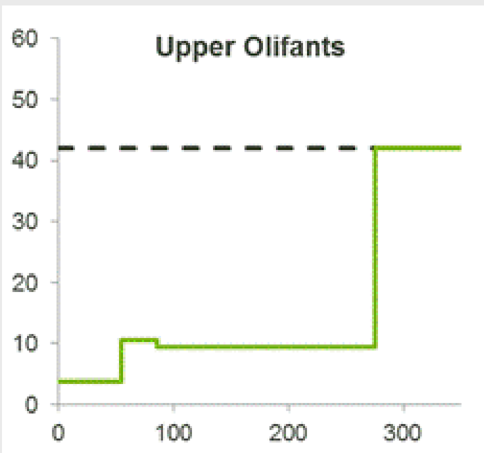
Potential Case Studies

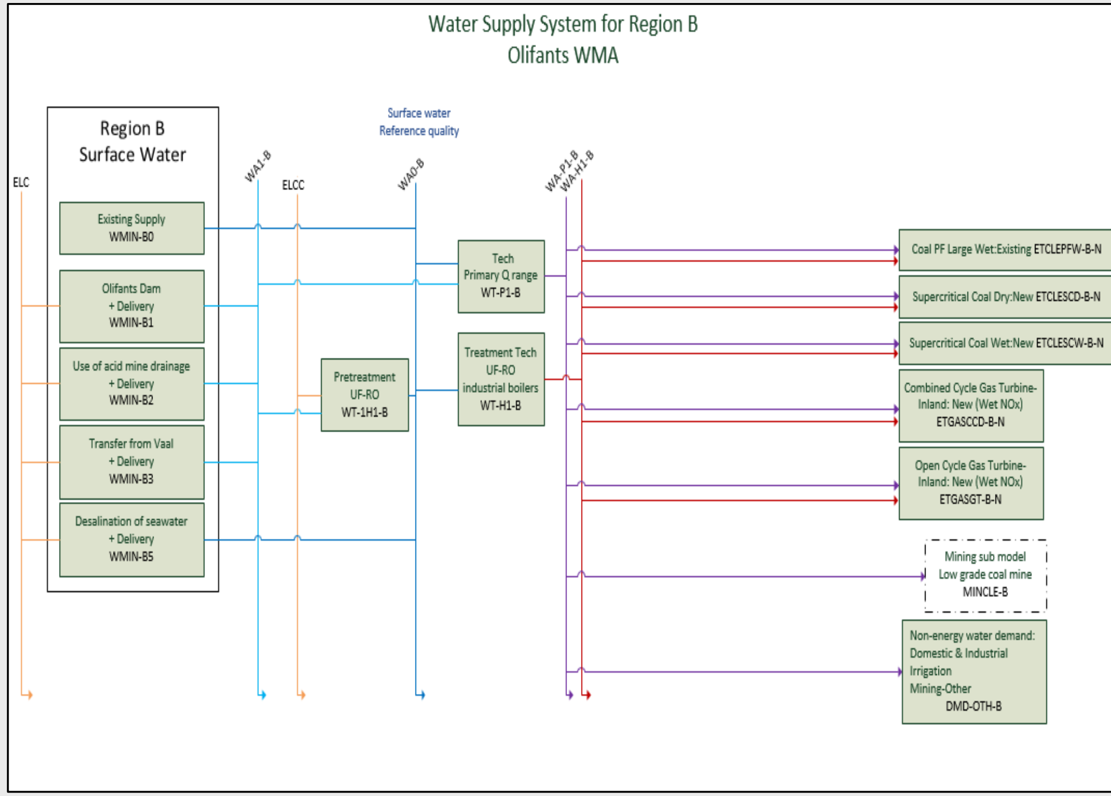
- **Morocco**
- **Southern Africa**
- **Equatorial Lakes**



Depicting Water in SATIM-W

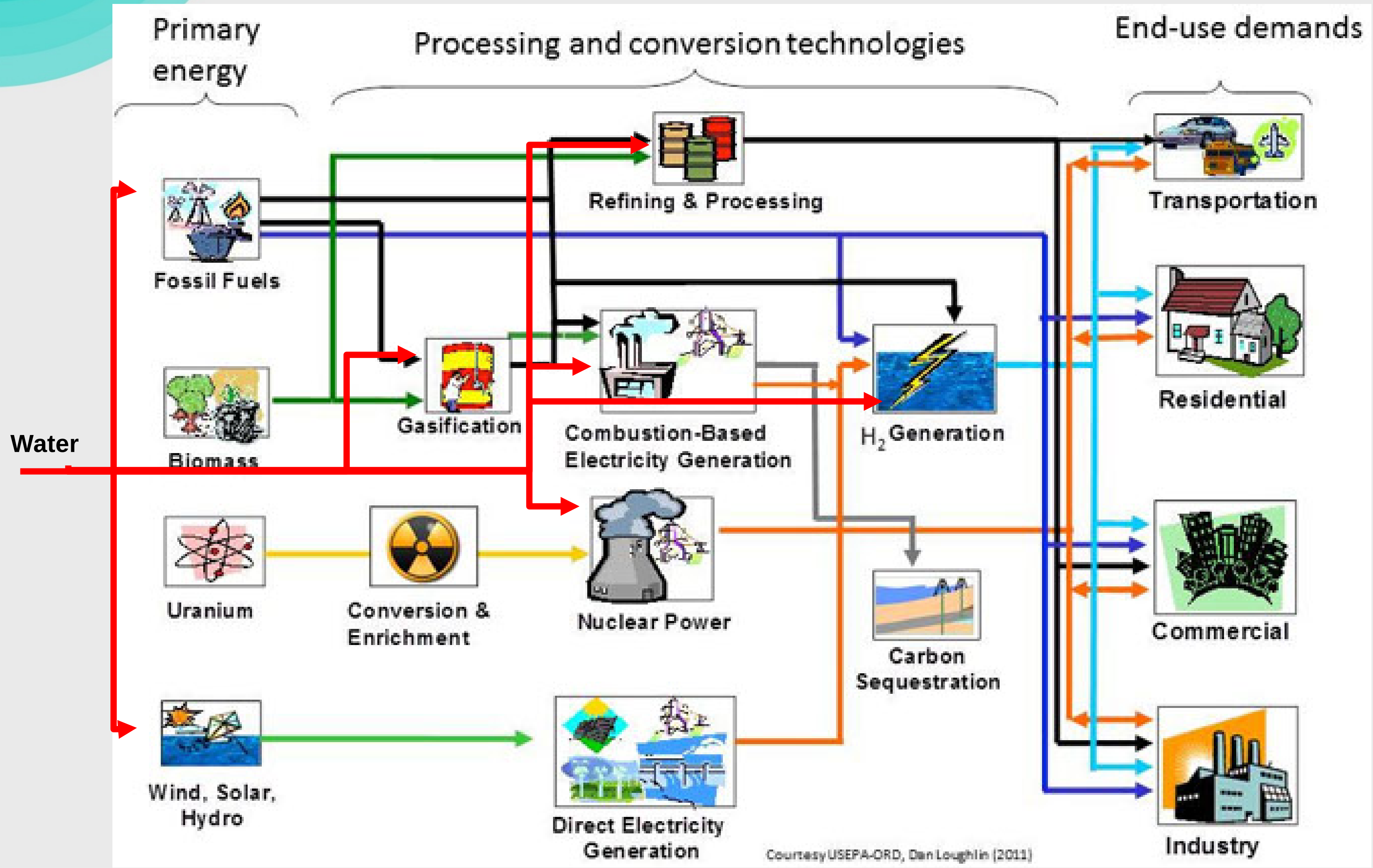
Water Supply Region B



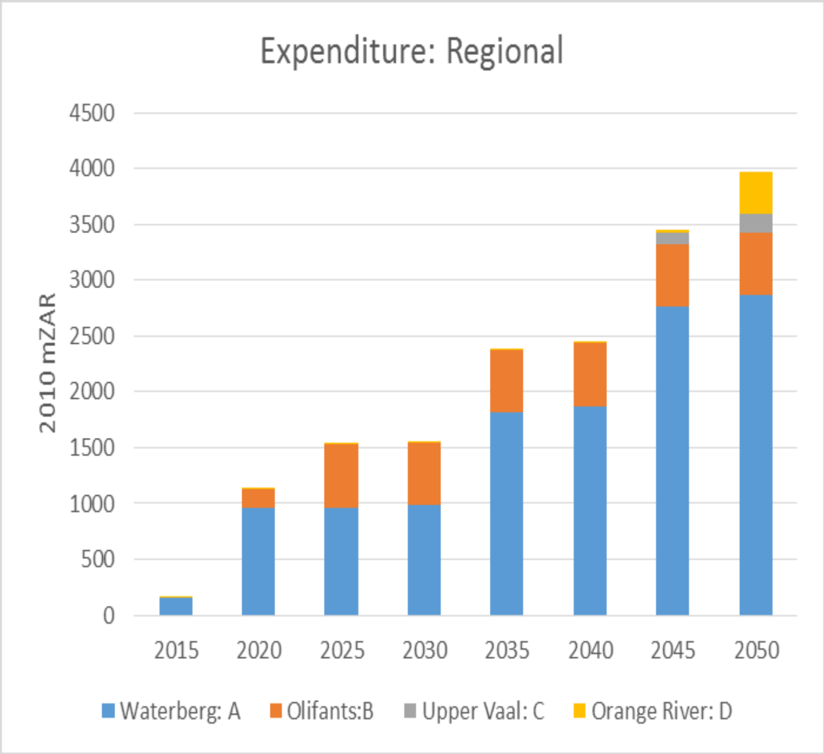


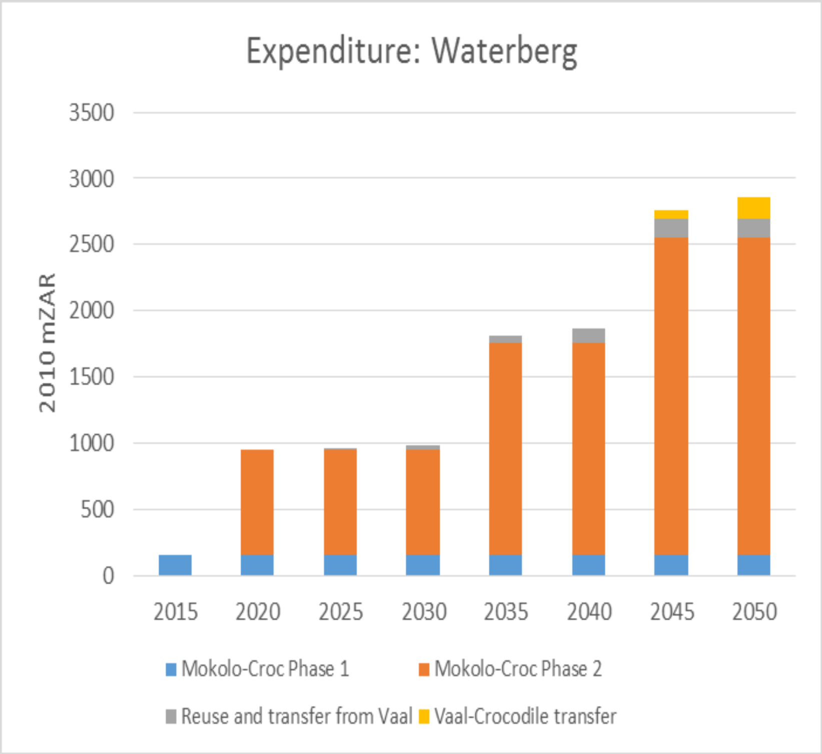
- Water flows are introduced to the RES **from supply sources to treatment processes to consuming processes thru the infrastructure**
- **Special techniques employed to sequence dependent, less expensive schemes, that require a more expensive option be put in place first**

Simplified
Reference Energy-Water System



Water Infrastructure Annual Investments





- Bulk of water **expenditures for** energy occur in the Waterberg
- Mokolo-Croc Phase 2 is the most expensive investment

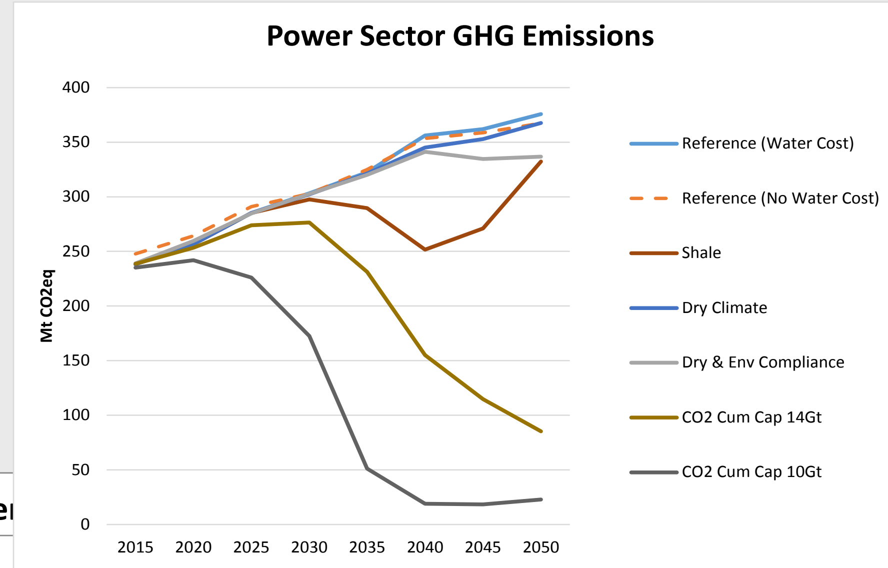
Scenarios Investigated

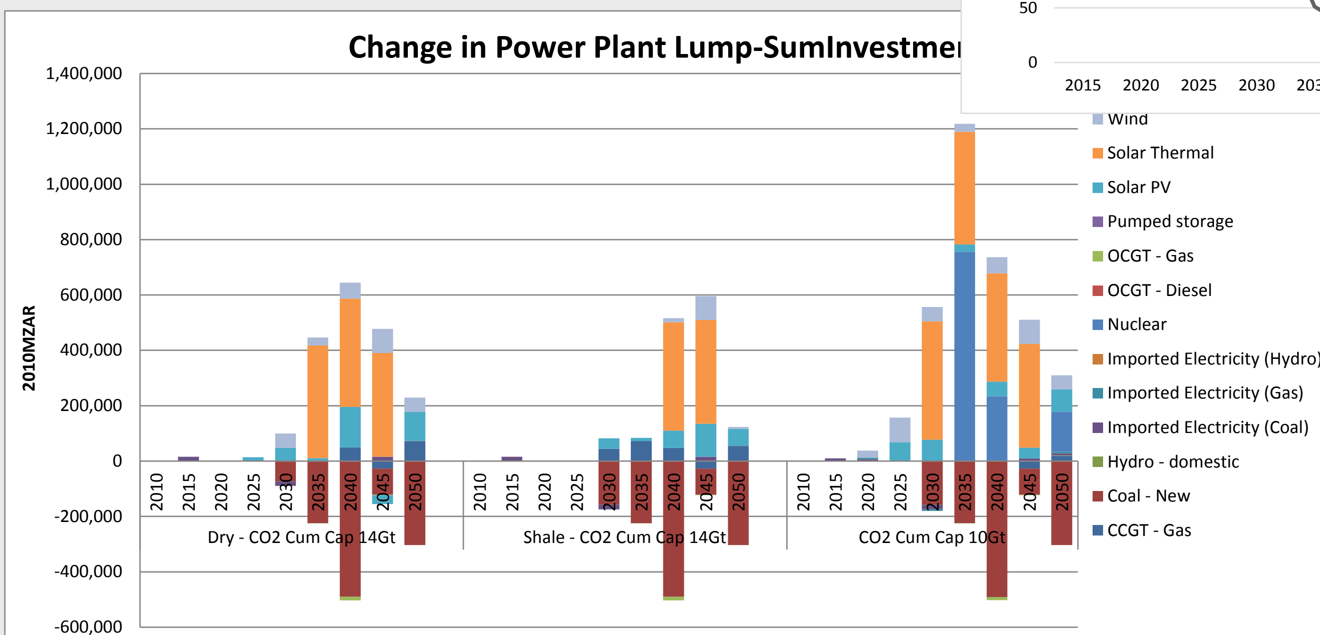
Scenario Name	Description
Reference (BAU)	The Reference SATIM-W scenario, which assumes a continuation of status quo planning, but includes the cost of water supply.
Shale	Shale-gas extraction occurs in the Orange River region. At total of 40 Tcf of gas is estimated to be recoverable.
Dry Climate	Regional water supplies and the non-energy water demands in the reference scenario are adjusted to reflect the possible effects of future climate change, affecting the unit water supply cost of regional schemes. As noted in Table 13.
Env. Compliance	This scenario entails: • Retrofitting existing coal power plants with wet-FGD. • Fitting existing and new CTL refineries with semi-dry CFB-FGD technology. • Operating all CCGTs with wet NOx control in accordance with EPRI data submitted to Eskom. • Including the increased costs to coal mines associated with the treatment of water discharged to the environment. • Assuming the water quality of transfers from Regions B and C to Region A is lower than local supplies, requiring additional treatment for demineralised application (e.g. make-up water for boilers).
Dry & Environmental Compliance	A dry climate with environmental compliance scenario. The scenario represents a water stress case with elevated water demands across sectors and increased costs associated with water usage.
CO_2 Cum Cap 14GT	The imposition of a carbon budget limiting cumulative national GHG emissions to 14Gt by 2050.
CO_2 Cum Cap 10GT	The imposition of a carbon budget limiting cumulative national GHG emissions to 10Gt by 2050.

constraint

GHG Emissions & Power Plant Investment Impacts

- **Two GHG reduction policies were examined in combination with other scenarios**
- **Power sector investment requirements vary significantly in type of timing**





WB-TE SA Main Conclusions (1/2)

- **SATIM-W has demonstrated the ability to represent the water needs of the energy sector by region, along with the ability to understand which water infrastructure will be needed for the energy sector.**

- **Dry cooling makes economic sense in South Africa and confirms the decisions by ESKOM to use dry cooling**

- **Requirements for flue gas desulphurization systems at new coal facilities**
  - **Increases total system cost around 0.8%**
  - **Reduces the investment in Coal-to-Liquid (CTL) plants by 75% in 2050**
  - **Leads to early retirement of 2 GW of wet-cooled coal power plant capacity by 2030**
  - **Reduces investment in new coal plants by 3 to 4 GW in the 2045 and 2050 periods**

- **Development of shale gas resources**
  - **Lowers total system cost around -0.65%**
  - **Significantly increases power generation from natural gas except with the CO_2 cap scenarios**
  - **Eliminates wind and CSP, except with the CO_2 cap scenarios**
  - **Requires investment in a water supply pipeline, but following that the cost of water as currently incorporated does not alter the decision to invest in shale gas**

WB-TE SA Main Conclusions (2/2)

- **CO_2 Cap scenarios reduce coal consumption, increases wind, solar PV and concentrating solar with storage, and defer any new investment in CTL plants**
- **CO_2 Cap scenarios may also lead to stranded coal assets**
  - **Existing CTL plant is decommissioned 5 years early in the 14Gt case and 20 years early In the 10 Gt CO2 case**
  - **The 10 Gt CO2 Cap scenario leads to the early retirement of all existing coal plants and shifts electricity production from the Waterberg to the Orange River region**
- **CO_2 Cap scenarios impact the cost of water supply differently in each region**
  - **Existing coal power plants in the Olifants are retired earlier so the cost of water decreases**
  - **New coal plants are built in the Waterberg to replace retiring plants so the cost of water increases**
- **The impact of a Dry Climate (due to Climate Change) is to move forward investments in solar PV and new coal capacity while retiring existing coal capacity**