Modeling the Water-Energy Nexus

How Do Water Constraints Affect Energy Planning in South Africa?
the challenge: how do we plan & design our investments in a sustainable way?

Political-level challenges impede effective planning:

- The two sectors have been regulated separately
- Current energy planning is often made without considering changes in water availability and quality, competing uses or the impacts of climate change

Challenges in securing enough water for energy and energy for water will increase with population and economic growth and climate change

Stronger integrated planning will be necessary to evaluate tradeoffs, find synergies, and ensure sustainable development
**Thirsty Energy initiative**

**GOAL:** to contribute to a **sustainable management and development** of the water and energy sectors by **increasing awareness and capacity** on **integrated planning** of energy and water investments **identifying and evaluating trade-offs and synergies** between water and energy planning.

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<th>1</th>
<th>Rapid assessments in priority basins/countries</th>
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<td>2</td>
<td>Implementation of case studies using existing tools when possible</td>
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<td>3</td>
<td>Knowledge dissemination, advocacy and capacity building</td>
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</table>
South Africa: the case of A Water Scarce Country

- Water scarce country with very stressed basins in terms of water allocation. Existing water supply systems at or approaching capacity: 97% of existing supply allocated.
- Coal Thermal Power plants account for almost 90% of the power capacity installed.
- 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.

**Total Installed capacity in 2010**

- Thermal - Coal: 86%
- Gas / Diesel OCGT: 5%
- Nuclear: 4%
- Hydro: 0%
- Wind: 0%
- Pumped Storage: 3%

Sources: ESKOM and Department of Energy of South Africa
Water Use in South Africa

- Direct use for power generation is small (2%) at national level but can be significant at a regional level (e.g. 37% in the Upper Olifants)
- Water for power requires a high level of assurance
- Water for energy is supported by major inter-basin transfers
- Transfer and treatment of water is very sensitive to energy costs
South Africa: Energy benefits from strong water infrastructure interconnectness

Water availability and demand, with major interbasin transfers

Power Sector reliance on water

Note: Blue bars = resource availability in each water management area; Green bars = total demand; Red bars = resource development potential; Blue arrows = major interbasin transfer schemes, including transfers for power generation and international exports.
South Africa: the case of A Water Scarce Country

- Partnered with the Energy Research Center (ERC) of the University of Cape Town to incorporate water constraints in their energy planning tools.
- ERC has developed and maintained now for many years an energy optimization model for South Africa (SATIM).
- At the start, this model did not contain water as a constraining factor, nor did it include any water-related costs.

Case Study Approach

1. Develop marginal water supply cost schedules
2. Develop the “water smart” SATIM energy model
3. Run different Energy-Water model simulations to assess how energy sector development strategies change – depending if water is constrained, if water has a price, etc.
4. Scenarios include expansion of coal use, shale gas fracking, GHG limits, etc.
Overview of South Africa TIMES (SATIM)

- Partial equilibrium linear optimization model: least-cost optimization
- Encompasses an entire energy system from resource extraction through to end-use demands
- Identifies the most cost-effective pattern of resource use and technology deployment over time
- The model is capable of solving with a variety of constraints
- 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
Water already represented in the existing model but...
South Africa water-energy nexus modeling framework: SATIM-W

SATIM
Full-sector energy systems model

Regional characterization of water supply schemes and energy production bases

Water resources
Hydrological models for each water basin

Investment and operating costs and water supply increment from water basins

SATIM-W
(Water infrastructure and marginal cost of water supply is endogenized)

Policy analysis examples using SATIM-W
Developing the SATIM-Water Model

STEP 1 → Spatially Aligning the Water-Energy Systems

In order to regionally constraint the amount of water available:
Need to “geo-reference” the power plants and energy facilities by assigning the different power plants and energy extraction locations to a water supply region.
Developing the SATIM-Water Model:
STEP 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.

Source: Adapted from Aurocon 2011; Coleman et al. 2007; Cullis et al. 2014; DWA, 2010a, 2010b, 2010c; DWAF 2013.
Note: UWC – unit water cost; WSC – water supply cost.
Water flows are introduced to the RES from supply sources to treatment processes to consuming processes thru the infrastructure.

Multiple water qualities are individually tracked.
How does accounting for regional variability in water availability and the associated infrastructure costs of water supply in different regions affect future energy planning?

Is the current policy of dry cooling for new coal-fired power plants economically justified?

How do stricter environmental controls affect coal investments in the Waterberg region?

How does a dry climate affect coal investments in the Waterberg region?

How does the cost of water affect shale gas production?

In a carbon-constrained world, what is the likelihood of stranded assets?

Why does SATIM-W select concentrating solar power (CSP) with wet cooling in the Orange River Basin?
A broad set of scenarios were run to look at uncertainties associated with the role of shale gas, implications of more stress on the water system, and stricter environmental requirements, with each of these examined under a CO$_2$ constraint.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Description</th>
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<tbody>
<tr>
<td>Reference (BAU)</td>
<td>The Reference SATIM-W scenario, which assumes a continuation of status quo planning, but includes the cost of water supply.</td>
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<tr>
<td>Shale</td>
<td>Shale-gas extraction occurs in the Orange River region. At total of 40 Tcf of gas is estimated to be recoverable.</td>
</tr>
<tr>
<td>Dry Climate</td>
<td>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.</td>
</tr>
<tr>
<td>Env. Compliance</td>
<td>This scenario entails:</td>
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<tr>
<td></td>
<td>• Retrofitting existing coal power plants with wet-FGD.</td>
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<tr>
<td></td>
<td>• Fitting existing and new CTL refineries with semi-dry CFB-FGD technology.</td>
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<tr>
<td></td>
<td>• Operating all CCGTs with wet NOx control in accordance with EPRI data submitted to Eskom.</td>
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<tr>
<td></td>
<td>• Including the increased costs to coal mines associated with the treatment of water discharged to the environment.</td>
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<tr>
<td></td>
<td>• 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).</td>
</tr>
<tr>
<td>Dry &amp; Environmental Compliance</td>
<td>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.</td>
</tr>
<tr>
<td>CO$_2$ Cum Cap 14GT</td>
<td>The imposition of a carbon budget limiting cumulative national GHG emissions to 14Gt by 2050.</td>
</tr>
<tr>
<td>CO$_2$ Cum Cap 10GT</td>
<td>The imposition of a carbon budget limiting cumulative national GHG emissions to 10Gt by 2050.</td>
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</table>
Water Costs matter

- In absolute terms, not including water costs in the energy model increases the cumulative (2010-2050) water consumption for the power sector by 77% and for the whole energy system by 58%
- Including the costs of water, increases total system cost by 1%. Investment for water supply infrastructure accounts for 40% of this increase, while water-system supply and operating costs account for the remaining 60%
Eskom’s Current Dry-Cooling Coal Generation Policy Is Economically Justified

- Once the true costs of water supply are incorporated into the energy model, dry cooling replaces wet cooling for coal power. This means that dry cooling makes economic sense in South Africa even if dry cooling decreases the efficiency of the power plant.
- Water intensity of the power sector drops to a quarter of the ‘no water cost’ 2050 level.
Including the cost of water primarily impacts the cooling choices. There is a shift to dry cooling for coal.

Reliance on coal-fired generation remains strong over the planning horizon in both cases.

Interestingly, the 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. This is caused by the higher emissions associated with the dry-cooled coal plants compared to wet-cooled.

Not including a cost for water lowers slightly total system cost by building more coal-fired power plants instead of renewables, but results in an 77% increase in water consumption for power generation.
Regional differences matter

- Nationally, water consumed by the energy sector is a small percentage
- **The Waterberg region is the region where the water-energy nexus is most evident and critical:** energy already accounts for 40% of water demand and will increase in the future
- Non-energy water demands dominate the other regions
- In the Olifants region, water needs for the energy sector shrink substantially as existing power plants retire
Even with dry-cooling coal generation expansion in the Waterberg requires high expenditure and drives up the regional cost of water.
The CO2 Cap scenarios have the potential to strand energy and water supply assets

Water supply infrastructure for the Waterberg at risk of being underutilized if a CO2 mitigation policy is implemented

The early closure of coal-fired capacity increases costs of water for the remaining users, as the supply system is being underutilized

If water and energy resources are planned in a more integrated manner, this issue could be foreseen and the water could be redirected to other users
The water intensity of the power sector under other scenarios is close to the intensity level generated by the Reference scenario with water costs.

In the case of the scenarios based on targets for reducing greenhouse gas (GHG) emissions, water intensity increases given that the model favors CSP plants using wet cooling.

However, with CO2 Cap and a dry climate, CSP capacity shifts to dry cooling, and water use for power decreases by 10%.
Main Conclusions

- Water for power in South Africa is supported by major interbasin transfers. Water and energy planning must therefore take into account the significant regional variability in water availability and the associated cost of water supply infrastructure.
- 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 and when.
- Dry cooling makes economic sense in South Africa and confirms the decisions by ESKOM to use dry cooling.
- Stricter environmental controls on coal technologies can have various effects on energy and water infrastructure investments, depending on region.
- Policies limiting carbon emissions can both lower GHGs and water needs of the energy sector if designed properly.
- Policies limiting carbon emissions may strand some water-energy infrastructure but could make water available (at higher cost) for other users if planned accordingly.
Take Away Messages

- The **cost and availability of water supply** matters in energy planning as demonstrated in the case study. Regional impacts are very important.

- Decision makers must consider the **interconnected nature of resources**, and how decisions ripple across sectors in order to simultaneously achieve all SDGs in a sustainable manner.

- We need **cross-sectoral solutions**. We need practical tools to address complex challenges, focusing on minimizing tradeoffs and fostering synergies. Otherwise gains in one goal (SDGs, INDCs) may have negative impacts on another.

- A forgotten aspect: planning, design and implementation of water needs **coordination** with energy. Planning is more effective that addressing synergies downstream after infrastructure is in place.

- Specific energy sector policies can have significant implications for new investment in water supply infrastructure and, in some cases, can strand water supply investments (and vice versa), reinforcing the importance of planning in an integrated manner.
The development of the water-smart energy model and the main conclusions have been documented in the report *Modeling the Water-Energy Nexus: How Do Water Constraints Affect Energy Planning in South Africa?*
EXTRA SLIDES
why does the energy sector need water?

Water is used throughout energy generation processes. Constraints on water availability influence the choice of technology, siting, energy facility selection, and energy resource development.

today 15% of global water withdrawals are for energy production.

Source: IEA/IEE 2012

By 2035, energy consumption will increase by 35%, water consumption by 85%, and water withdrawal by 20%.

Source: UN 2014

www.worldbank.org/thirstyenergy
**energy extraction**

Water use in energy development not only varies by fuel type, but also can vary a lot within fuel types, depending on the development method and the site conditions.

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**legend**

- water withdrawal (in litres)
- water consumption (in litres)

\[= 1 \text{ toe (tonne of oil equivalent)}^*\]

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Energy production can adversely impact water resources and the environment if not managed properly.

Biofuels’ water needs and environmental impact depend on the crop, and whether it is rain-fed or irrigated.

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[Source: IEA World Energy Outlook 2012]

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[Source: IEA/CEA]

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Almost all forms of electricity generation require water.

**HYDROPOWER**

Wind and Solar PV have a negligible impact on water resources.

**THERMAL POWER PLANTS**

But they are intermittent.
thermal power plants

Once the energy resources are refined and processed, some are used as fuel in thermal power plants to generate electricity.

1. The water is heated with different energy sources (coal, oil, natural gas, uranium, solar energy, biomass, geothermal energy) depending on the sub-type of power plant, but the principle is the same.

2. The steam spins the turbine, which is connected to a generator that produces electricity.

3. After passing through the turbine, the steam is cooled down and condensed to start the cycle again.

4. Thus, most thermal power plants require a cooling system to convert the steam back to water and close the cycle.
The type of cooling system used will determine the amount of water required by the thermal power plant.

<table>
<thead>
<tr>
<th>main types of cooling systems</th>
<th>use</th>
<th>water withdrawal</th>
<th>water consumption</th>
<th>efficiency</th>
<th>cost</th>
<th>environmental impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>once through</td>
<td>water</td>
<td></td>
<td></td>
<td></td>
<td>$</td>
<td>small</td>
</tr>
<tr>
<td>cooling towers</td>
<td>water</td>
<td></td>
<td></td>
<td></td>
<td>$$</td>
<td>medium</td>
</tr>
<tr>
<td>dry cooling</td>
<td>air</td>
<td>0</td>
<td>0</td>
<td></td>
<td>$$$</td>
<td>high</td>
</tr>
</tbody>
</table>

Note on water withdrawal and consumption: this is an approximate representation to show the difference in magnitude for types of cooling systems. The exact amount of water will vary depending on the efficiency of the power plant, but the ratios will remain constant. This table shows an approximate calculation for a power plant with an efficiency of ~35%, and each drop = 1000 liters/MWh.
Thank You

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