Water and Energy: Beyond the Nexus

Quantifying the Tradeoffs of the Water-Energy Nexus

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Why is this issue important?

90% of global POWER GENERATION is WATER-INTENSE.

By 2035, GLOBAL ENERGY consumption will INCREASE 50%.

... increasing WATER CONSUMPTION by 85%.

2.8 billion PEOPLE live in areas of HIGH WATER SCARCITY.

And 2.5 billion PEOPLE have UNRELIABLE or NO access to ELECTRICITY.

CLIMATE CHANGE will impact both the ENERGY and WATER sectors.

Sources: IEA, 2012 and UN, 2012
Outline

- Water Risks for the Energy Sector
- Water Needs of the Energy Sector
- Quantifying the Tradeoffs of the Water and Energy Nexus – a World Bank Initiative
- South Africa as a First Case Study
WATER RISKS OF THE ENERGY SECTOR
Rapid growth in energy demand in developing countries will drive a doubling of water demand for energy by 2035

- Africa’s electricity generation will be 7 times as high as nowadays by 2050
- Asia’s primary energy production will almost double, and electricity generation will more than triple by 2050
- In Latin America, the amount of electricity generated is expected to increase fivefold in the next 40 years and the amount of water needed will triple
The energy-water nexus is already present and very real problem.
Impacts in the Energy Sector in the US

The US Department of Energy recently issued a report looking at water impacts on their energy sector.
The Energy sector is starting to recognize the magnitude of the issue.

The first time that the IEA World Energy Outlook report has included a special section on the water needs and the possible future water constraints of the energy sector.

* Word cloud (count) infographic of the IEA report
Energy Sector is vulnerable to Water Issues

**MAIN WATER RISKS***

- **INCREASED WATER TEMPERATURE FOR COOLING** – for thermal power plants

- **DECREASE IN WATER AVAILABILITY** – for hydro, thermal power plants, fuel extraction and processing

* Besides floods and other extreme events

[Sources: Worldwatch.org, Washington Post]
Pressure on water resources is growing:
Key drivers include more people, growing economies, and climate change

![Map showing increasing pressure on water resources globally. Regions are color-coded to indicate decreasing and increasing pressure levels: blue for decreasing large, cyan for decreasing moderate, gray for small change, and red for increasing large and moderate.](image-url)
Hot Spots – where “low flows” and “water temperature increase” meet

Source: Vulnerability of US and European electricity supply to climate change. Michelle T. H. van Vliet1, John R. Yearsley2, Fulco Ludwig1, Stefan Vögele3, Dennis P. Lettenmaier2 and Pavel Kabat.
So the challenge is how do we plan and how do we design our investments.

The baselines water stress is defined as the ratio of total annual freshwater withdrawals for the year 2000, relative to expected annual renewable freshwater supply based on 1950–1990 climatic norms.

Source: World Resources Institute
But we must acknowledge the complexities of the energy sector.
WATER NEEDS OF THE ENERGY SECTOR
Almost all forms of electricity generation require water.

**HYDROPOWER**

Water is required mainly for cooling purposes.

**THERMAL POWER PLANTS**

Geothermal

Pulverized Coal

CSP (Tower)

**Geothermal**

**Pulverized Coal**

**CSP (Tower)**

Thermoelectric power plants account for 40% of the freshwater withdrawn every year in the US and for 43% in Europe*.

*Source: Vulnerability of US and European electricity supply to climate change. Michelle T. H. van Vliet1, John R. Yearsley2, Fulco Ludwig1, Stefan Vögele3, Dennis P. Lettenmaier2 and Pavel Kabat*
Water is also needed to extract and process fuels

- Water consumption for fuels such as oil, coal or gas can seem minor compared to other sectors, however, its development can be very water intensive locally and temporally.

- Biofuels is the single largest renewable energy source in use today, and will increase in the future, increasing also water consumption

Source: IEA 2012

Moreover…water quality can be an issue if not regulated/managed properly.

- Thermal Pollution
- Drainage from Abandoned coal mines
- Fracking waste water
QUANTIFYING THE TRADEOFFS OF THE WATER-ENERGY NEXUS
A WORLD BANK INITIATIVE
The World Bank Initiative

Objective: The main objective of the initiative is 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.

1. Rapid assessments in priority basins/countries

2. Implementation of case studies using existing tools when possible

3. Knowledge dissemination, advocacy and capacity building
Methodological Approach 1/2

- **Entry point is Energy Sector**: we acknowledge that it is very difficult to change energy planning from water organizations.

- **Engagement** with relevant **stakeholders** from day 1, involving local partners from energy and water sectors work to identify and assess possible case studies based on their current energy and water sector situation and trends and constraints.

- **Flexible modeling framework** to facilitate tailored analyses over different geographical regions and challenges.

- Build on **existing** country knowledge and modeling tools whenever possible to ensure continuity and sustainability of initiative and **lower costs**.

  **Client ownership** and **capacity building** are crucial to ensure the success of the initiative.

- Robust treatment of **risk** and **uncertainty**

- Incorporate the long-term effects of climate change.
Methodological Approach 2/2

- **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:
  - Water scarce country
  - Country with abundant water but with seasonal variability - tropical
  - Country with in-house capacity and good data
  - Country with lack of data (small-poor)

- Forming **stronger alliances** is also priority of this initiative. The challenge presented by the nexus is too large for any country, region, development finance institution or implementing agency to tackle alone.

- It will also **collaborate** with partners to leverage efforts of other countries, the international community, and partners in the nonprofit and private sectors for more success in moving the nexus agenda forward both at the global policy level and at the country level.
Methodological approach: Building 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
SOUTH AFRICA AS A CASE STUDY
South Africa: the case of A Water Scarce Country

- Water scarce country with very stressed basins in terms of water allocation
- 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

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

Sources - Top: CSIR, Bottom: ESKOM and Department of Energy of South Africa
Using what already exist and is currently used: Improvement of existing TIMES model

South Africa TIMES (SATIM) used by the Energy Research Center:

- Partial equilibrium linear optimization model capable of representing the whole energy system, including its economic costs and its emissions
- Five demand sectors – industry, agriculture, residential commercial and transport - and two supply sectors - electricity and liquid fuels
- The model is capable of solving for a variety of constraints

PHASE 1 of CASE STUDY:

1. Develop marginal water supply cost schedules
2. Develop the “water smart” SATIM
3. Energy-Water Model Simulations: run different scenarios to assess how energy sector development strategies change relative to the reference scenario depending if water is constraint, if water has a price, etc.
Overview of SATIM

Energy Resources/Import and Exports
- Import/export (elc, oil, gas)
- Renewable energy resource potential
- Fossil fuel reserves

Supply Technology
- Future coal/gas supply technologies
- Future liquid fuel supply technologies
- Future power generation technologies
- Existing coal/gas supply system
- Existing liquid fuel supply system
- Existing power system

Base Year Energy Balance

MARKAL/TIMES optimization energy model (GAMS with CPLEX solver)

Demand Sectors (commercial and agriculture omitted from diagram)
- Residential sector future technologies
- Industrial sector future technologies
- Transport sector future technologies

Demand Sectors base-year calibration
- Residential sector base-year calibration
- Industrial sector base-year calibration
- Transport sector base-year calibration

Residential sector Demand projections
- Industrial sector Demand projections
- Transport sector Demand projections

Policy objectives/constraints
- Energy security objectives
- Environmental objectives, taxes
- Socio-economic growth objectives

Economic Analysis
- Socio-Economic Variables (GDP, Population)

Results Analysis
- Investment Schedule/Plan
- Imports, exports, consumption, production, Emissions
- System costs, energy costs

Source: ERC - UCT
Example: the Power Sector

SATIM PARAMETERISATION OF POWER PLANT TECHNOLOGIES

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>ADDITIONAL PARAMETERS FOR CHP PLANTS</th>
<th>ADDITIONAL PARAMETERS FOR NEW PLANT TECHNOLOGIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy input commodity or fuel</td>
<td>Industrial process heat</td>
<td>Limits on capacity</td>
</tr>
<tr>
<td>WATER CONSUMPTION</td>
<td>Operation in back pressure</td>
<td>Investment cost</td>
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<tr>
<td>Efficiency</td>
<td>Additional input fuel</td>
<td>Technology life</td>
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<tr>
<td>Output commodity</td>
<td></td>
<td>Technology lead-time</td>
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<tr>
<td>Energy availability</td>
<td></td>
<td>Upper bound on new capacity</td>
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<tr>
<td>Capacity availability</td>
<td></td>
<td>Upper bound on capacity factor</td>
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<td>Capacity credit</td>
<td></td>
<td>Winds on wind classes</td>
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<tr>
<td>Fixed operating and maintenance cost</td>
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<td>Wind intermittency</td>
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<tr>
<td>Variable operating and maintenance cost</td>
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<td>Capacity credit of wind</td>
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<td>Refurbishment/retirement profile</td>
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<td>Diurnal production of solar with and without storage by timeslice</td>
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<tr>
<td>&quot;Season&quot; &amp; &quot;Daylite&quot; operating categories</td>
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...but as of now there is no constraint on it, the model assumes that it is an infinite resource and with no price or regional constraint
Links to CGE model (E-SAGE)

E-SAGE: Energy-extended South African General Equilibrium model

**PHASE 2 of CASE STUDY:**

- Run the CGE model to establish reference scenario demand projections for energy.
- Run SATIM with these given demand projections to produce a new Reference case, and then run a new EW-Nexus case that allows for reduced energy demands from economy-wide adjustments when energy prices rise to reflect water scarcity.
- Pass SATIM findings on increased energy production costs back into the CGE model in order to evaluate the economy-wide impact of accounting for water scarcity in energy sector development.
- Compare these reference and EW-Nexus scenarios.
- Compare the incremental water supply costs for energy expansion across the different water management areas in the model to other figures for water shadow prices by water management area. Using such comparisons, highlight where increased demands on water sources from energy sector expansion may particularly pose challenges to efficient water management across sectors and water management areas.
E-SAGE Model

Economywide framework

Source: Thurlow, UNU-WIDER
First publication:

“Thirsty Energy”

is available at the World Bank Booth and online at: www.worldbank.org/water

It introduces the energy-water nexus, examines the water requirements of power generation and outlines some potential technical and institutional solutions for improving the management of the nexus.
THANK YOU

Questions?

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