Modeling the energy-water-land nexus: A review of opportunities and challenges for integrated assessment modeling

Nils Johnson, Peter Burek, Simon Parkinson, Petr Havlik, Nebojsa Nakicenovic, Keywan Riahi, and David Wiberg

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The Nexus Challenge

Underlying socioeconomic trends
- Population growth
- Rising middle class
- Urbanization

Increasing resource demands
- Water
- Energy
- Land

Solutions for human welfare
- Clean Water
- Reliable Energy
- Food, Feed, and Fiber

Avoiding Environmental Degradation
- Aquatic Ecosystems
- Climate Change
- Terrestrial Ecosystems
Scoping Study/Literature Review

Annotated Bibliography: ~400 papers, reports, and books

Scoping study: Synthesis of over 120 papers
Implications of Water for Energy

Impacts of water availability and quality on the power sector

Water supply solutions can use substantial energy

- 19% of California’s electricity is used for water-related services
- ~99% of Dubai’s water supply comes from desalination
- Desalination consumes 10-12x more energy than standard treatment

van Vliet et al., Water constraints on global electricity supply: adaptation options for sustainable water-energy security, Nature Climate Change, Accepted/Embargoed (do not cite or quote).
Implications of Energy for Water
Range of 2°C Scenarios

Water Withdrawal

Range of 2°C Scenarios

No climate policy

2 °C Energy Transformation Pathways (Cost % Ref.)

- Full mitigation portfolio (122 %)
- Limited wind / solar (133 %)
- No carbon capture and storage (143 %)
- No new nuclear (138 %)

Uncertainty Range

- GEA-Efficiency
- GEA-Mix
- GEA-Supply
- Total Uncertainty

Range in 2100

- GEA-Efficiency
- GEA-Mix
- GEA-Supply
- Adaptation Scenarios

Fricko et al., Energy sector water use implications of a 2 °C climate policy, In Review (do not cite or quote).
Implications of Energy for Water Efficiency + Adaptation

Water Withdrawal

Range of 2ºC Scenarios

Fricko et al., Energy sector water use implications of a 2 ºC climate policy, In Review (do not cite or quote).
Land, water, and (bio)energy trade-offs

Water implications

BE_RF = Bioenergy_Rainfed

Bonsch et al., Trade-offs between land and water requirements for large-scale bioenergy production, GCB Bioenergy (2014).
Land, water, and (bio)energy trade-offs
Land and emissions implications

Bonsch et al., Trade-offs between land and water requirements for large-scale bioenergy production, GCB Bioenergy (2014).
Water availability varies through space and time
Higher resolution tools are needed to better reflect resource constraints

Connectivity is key
Distribution infrastructure and trade are important solutions to resource scarcity

- Water Conveyance
- Proportion of cities water-stressed
  - Without conveyance infrastructure
  - With conveyance infrastructure
  - -36%

- Socioeconomic Heterogeneity
- Income class
  - High
  - Upper mid.
  - Lower mid.
  - Low
- Average distance of water transport (km)
  - < $1035 per capita
  - > $12616 per capita

McDonald et al., Water on an urban planet: Urbanization and the reach of urban water infrastructure, Global Environmental Change, 27 (2014) 96-105.
Financial and Institutional Capacity

Human water security (HWS)

Figure 4 | Shifts in spatial patterns of relative human water security threat after accounting for water technology benefits. Inset maps illustrate the analytical approach and net impact of investment over a north–south transect (top). Incident human water security (HWS) threat is converted to reduced threat (inset maps), which is then globally re-scaled into adjusted human water security threat. The final map shows relative units: areas with substantial technology investments have effectively limited exposure to threat whereas regions with little or no investment become the most vulnerable in a global context. Colour spectra depict three measures of threat (increasing, blue to red) and investment benefits (increasing, light to dark).

Importance of environmental quality, not just quantity
Water quality risk associated with nitrogen pollution

2000-2005 Base Period

Importance of environmental quality, not just quantity
Water quality risk associated with nitrogen pollution

Climate Change Scenarios
Representative Concentration Pathways (RCPs)
SRES Emission Pathways

Socioeconomic Scenarios
Shared Socioeconomic Pathways (SSPs)
SRES Socioeconomic Pathways

Climate Inputs
(e.g., temperature, precipitation)

Population
GDP
Storyline

Hydrological Models

Agro-Ecosystem Models
EPIC
AEZ
LPJmL
WaterGAP
PCR-GLOBWB
H08

Crop Yields,
Irrigation Water
Requirements

Agro-Economic Models
GLOBIOM
MAgPIE

Energy-Economic Models
GCAM
IMAGE
REMINDE
MESSAGE

Hydro-Economic Models

Spatial & Temporal Resolution

Emulator
Opportunities/Challenges for the IAM Community

• Consistent and scalable platforms

• Increased temporal and spatial resolution

• Tracking energy and land requirements

• Infrastructure - distribution and trade

• Income heterogeneity and financial/institutional capacity

• Ecosystem security – quality matters too