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Hydro-economic modeling of integrated solutions for the water-energy-land nexus in Africa

Simon Parkinson

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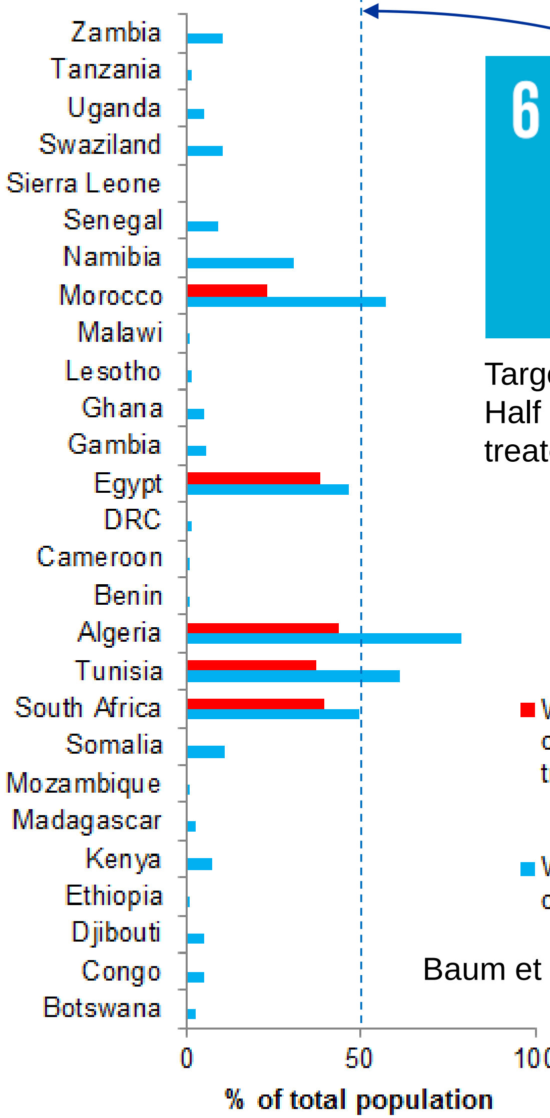
2017 AGU Fall Meeting

Infrastructure gaps in Africa

What technologies to use? **How much will it cost?**

Access to wastewater treatment in 2010



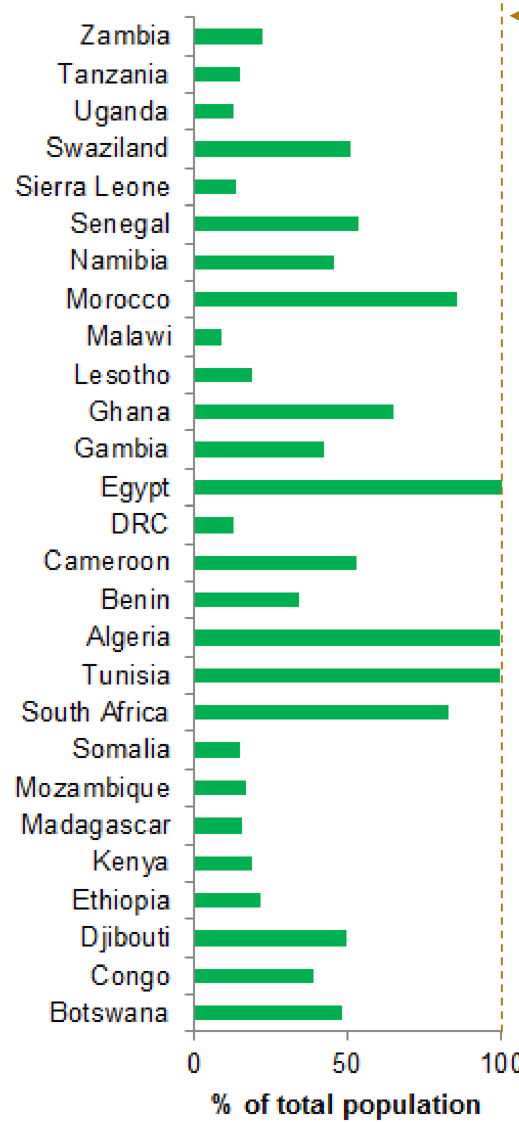
Target 6.3
Half of all wastewater treated by 2030

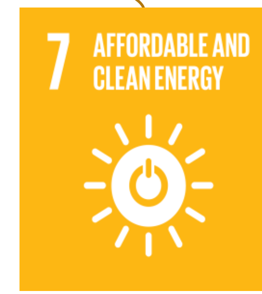
■ Wastewater collection and treatment

■ Wastewater collection

Baum et al. (2013)

Access to electricity in 2010





Target 7.1
Universal access by 2030

World Bank Indicators (2016)

Climate change and Africa’s water-energy-land nexus

Made for minds.

GERMANY WORLD BUSINESS SCIENCE ENVIRONMENT CULTURE SPORTS

TOP STORIES / WORLD / AFRICA

AFRICA

Zambia turns to charcoal as hydroelectricity sources drain

Zambia has long relied on rainfall to generate electricity. But with climate change rapidly depleting water sources, people are turning to charcoal for their power needs, prompting calls to ban the black fuel.

Sikombe, 2017

In 2016 (from Zambia Energy Regulation Board, 2016)

- Blackouts averaging eight (8) hours a day
- Power imports increased to 2,184 GWh, from 785 GWh, in 2015 (180% increase)

Integration of regional electricity markets couples basin adaptation planning across the African continent

Conway et al. (2017)

ARTICLES
https://doi.org/10.1038/s41560-017-0037-4
nature energy

Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption

Declan Conway[1*], Carole Dalin[1,2], Willem A. Landman[3] and Timothy J. Osborn[4]

Linking of regional electricity sharing mechanisms could mitigate intraregional risk

Wu et al. (2017)

PNAS

Strategic siting and regional grid interconnections key to low-carbon futures in African countries

Grace C. Wu[a,b,1,2], Ranjit Deshmukh[a,b,1,2], Kudakwashe Ndhlukula[c], Tijana Radojicic[d], Jessica Reilly-Moman[a,b], Amol Phadke[b], Daniel M. Kammen[a], and Duncan S. Callaway[a]

[a]Energy and Resources Group, University of California, Berkeley, CA 94720; [b]International Energy Studies Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720; [c]Southern Africa Development Community (SADC) Centre for Renewable Energy and Energy Efficiency, Namibia University of Science and Technology, Windhoek, Namibia; and [d]Country Support and Partnerships, International Renewable Energy Agency, Masdar City, Abu Dhabi, United Arab Emirates

Edited by M. Granger Morgan, Carnegie Mellon University, Pittsburgh, PA, and approved February 23, 2017 (received for review July 18, 2016)

Regional interconnections are crucial for realizing no-regrets wind and solar energy development

Research Challenge

How to balance regional opportunities with localized resource constraints?

Hydro-economic modeling

"Hydro-economic models represent spatially distributed water resource systems, infrastructure, management options and economic values in an integrated manner," Harou et al. (2009).

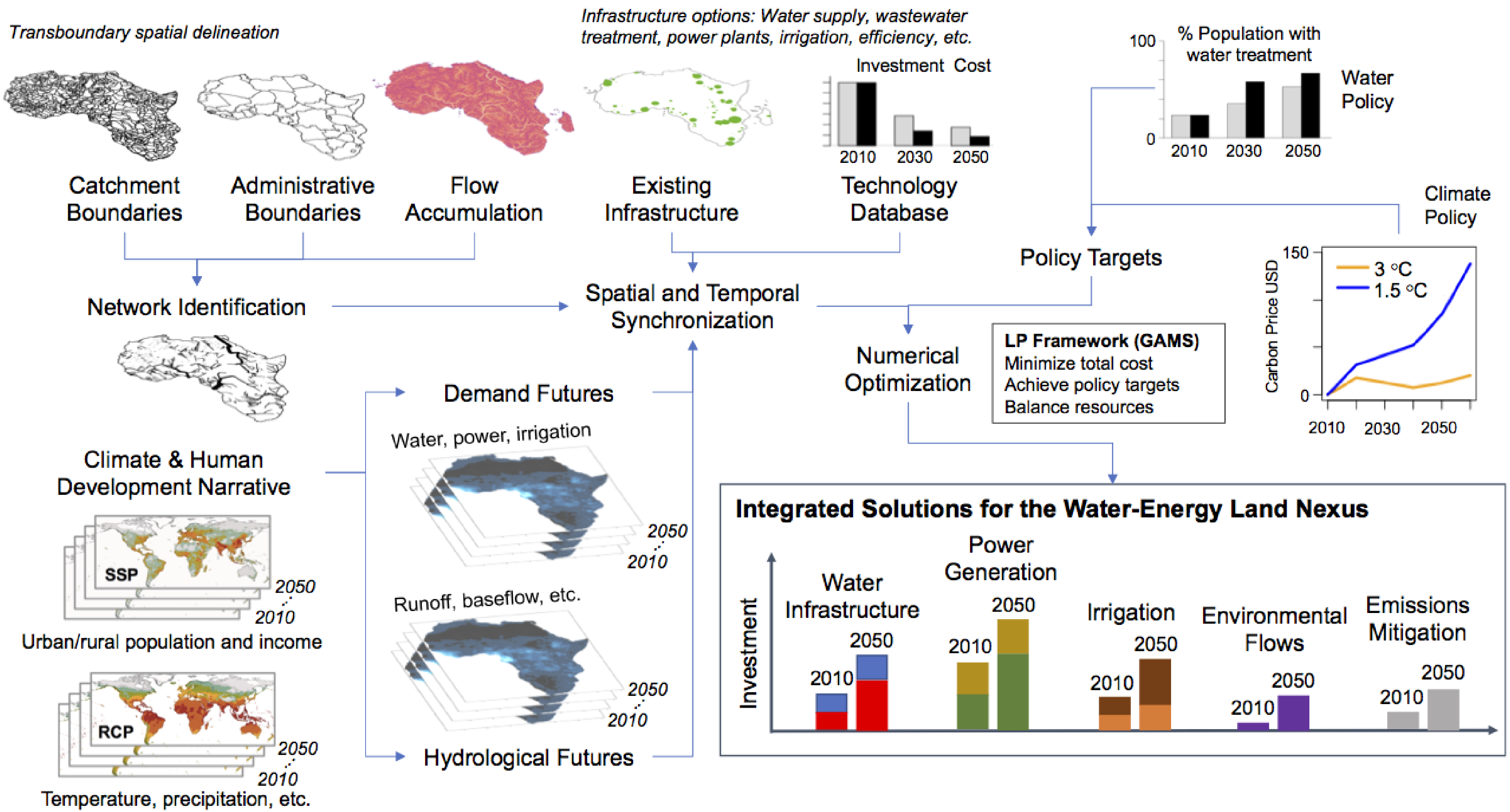
- Most hydro-economic models focus on existing infrastructure
  - Limited ability to look at long-term transformations.
- Most hyrdro-economic models focus on a single basin

Research Objectives

- Develop a new **integrated hydro-economic modeling tool** for water and electricity sector **expansion planning** in Africa
  - Spatially-distributed water and energy resources
  - Long-term planning horizons (pathways to 2050)
  - Flexible implementation for application in other regions

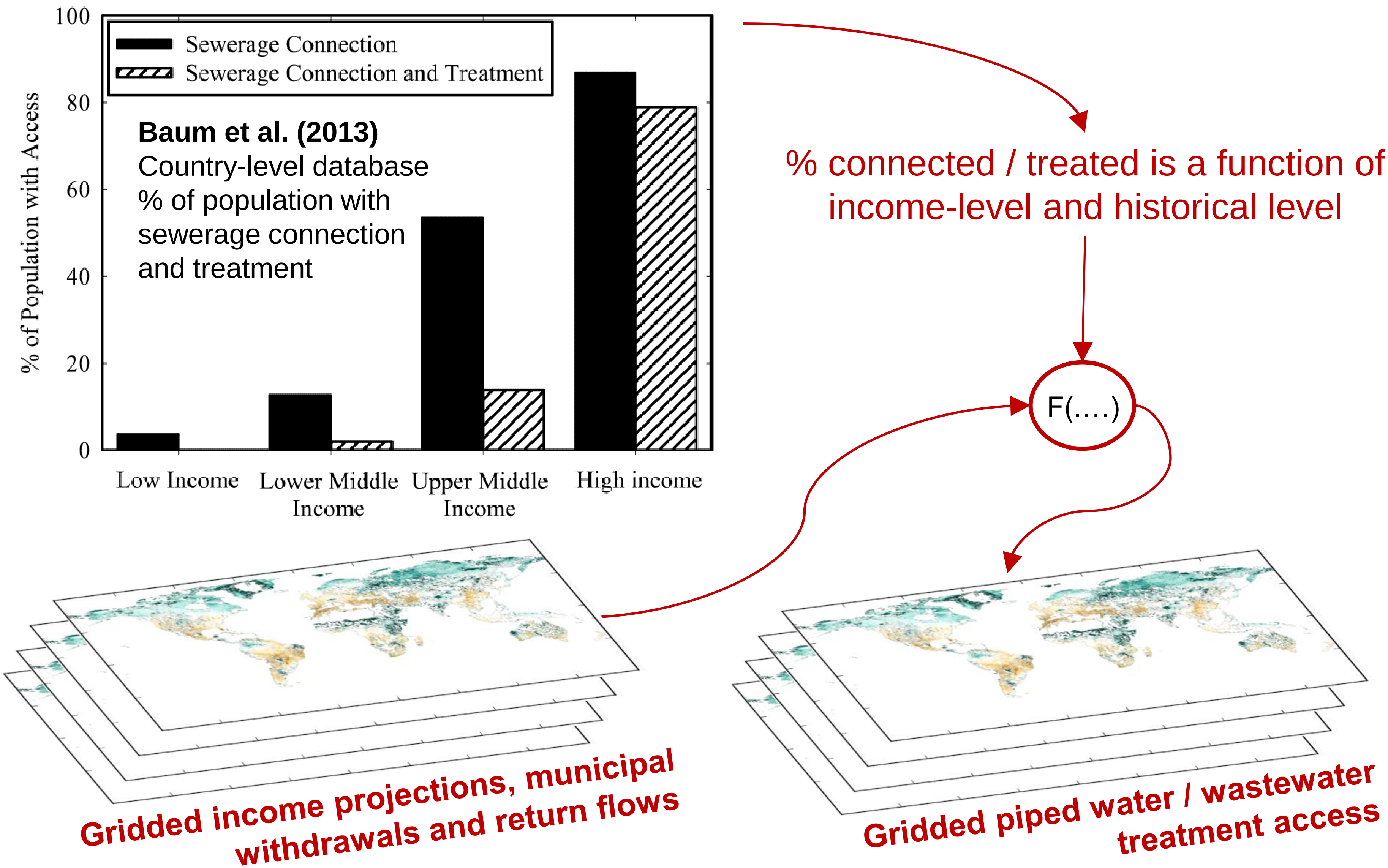
ECHO

Extended Continental-scale Hydro-economic Optimization



Kahil et al. (forthcoming)

Projecting water infrastructure demand under clean water goals



Preliminary scenario analysis: Focus on water infrastructure pathways to 2050

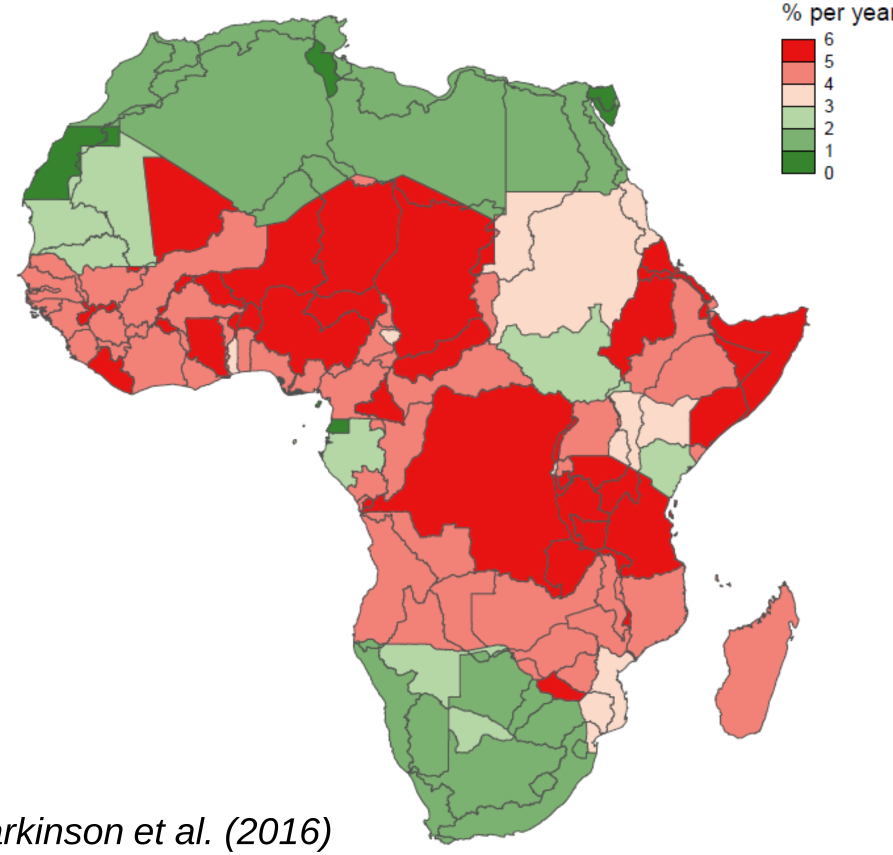
Three socio-economic and climatic scenarios:

1/ Middle of the Road (***MoR***): SSP2-RCP6.0

2/ Regional Rivalry **(*RR*)**: Water demand increases over time in all water sectors and water availability decreases, compared to *MoR.*

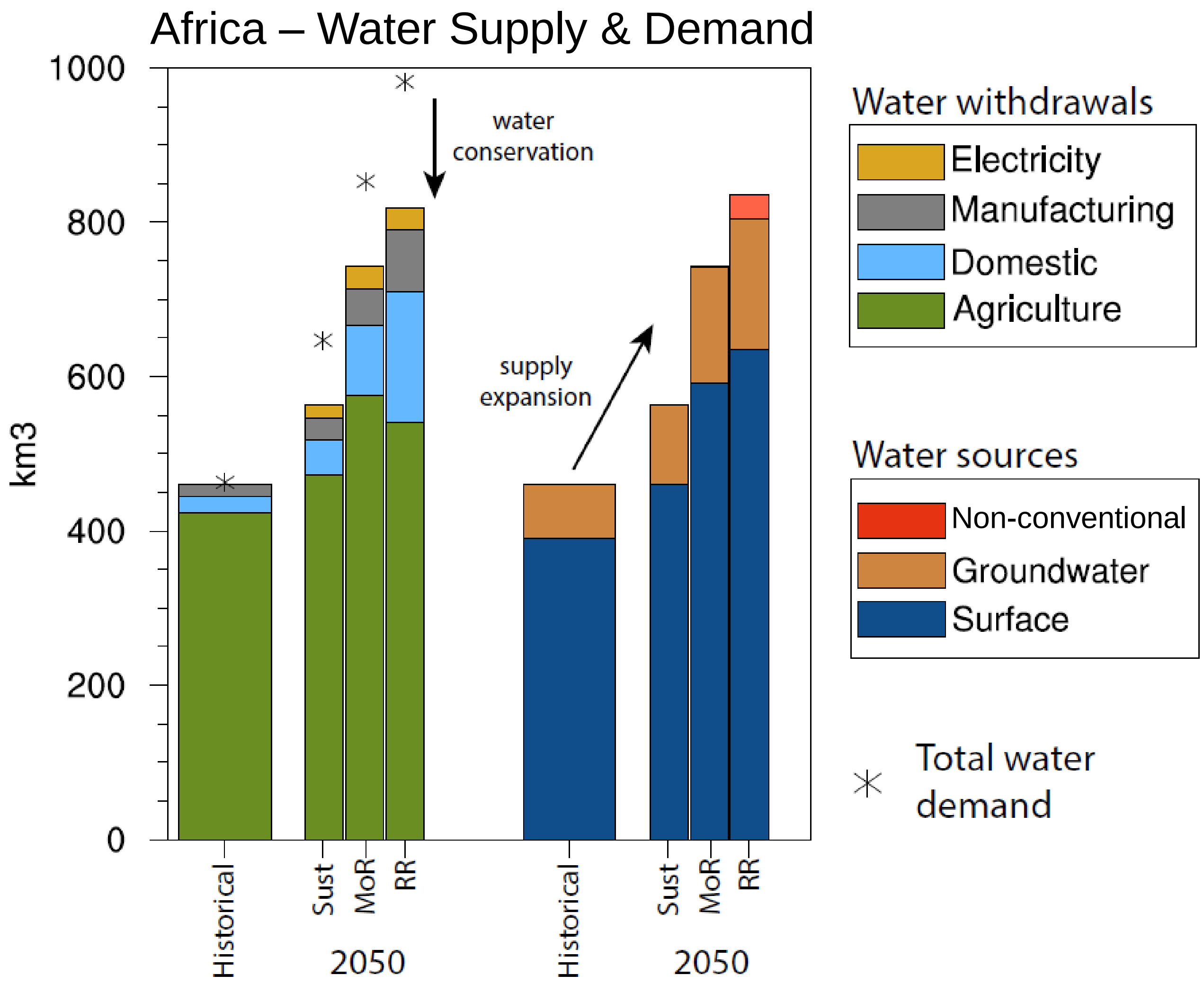
3/ Sustainability **(Sust)**: Water demand decreases over time in all water sectors and water availability increases, compared to *MoR*.

Average Annual Growth - Urban Water Withdrawals

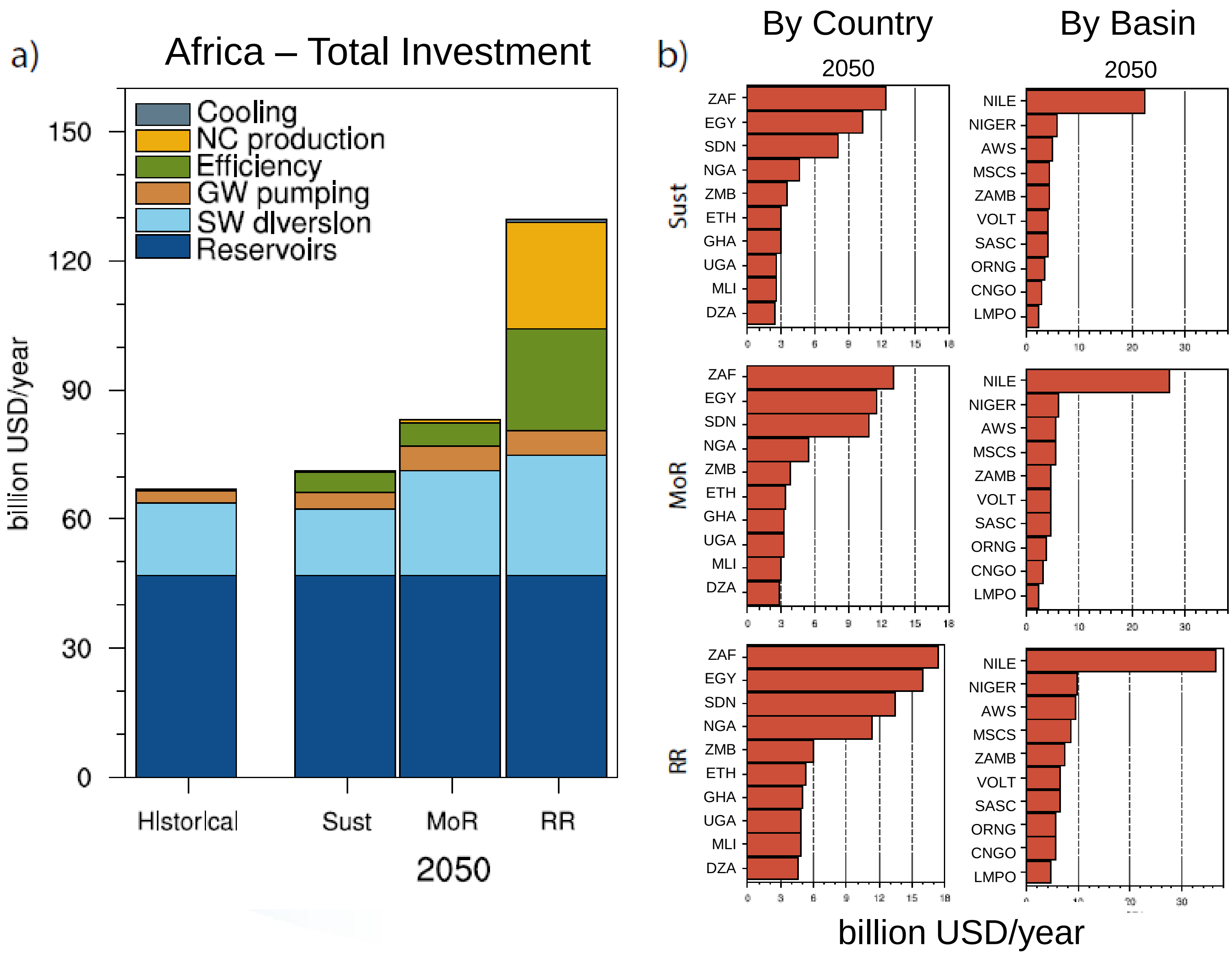


Parkinson et al. (2016)

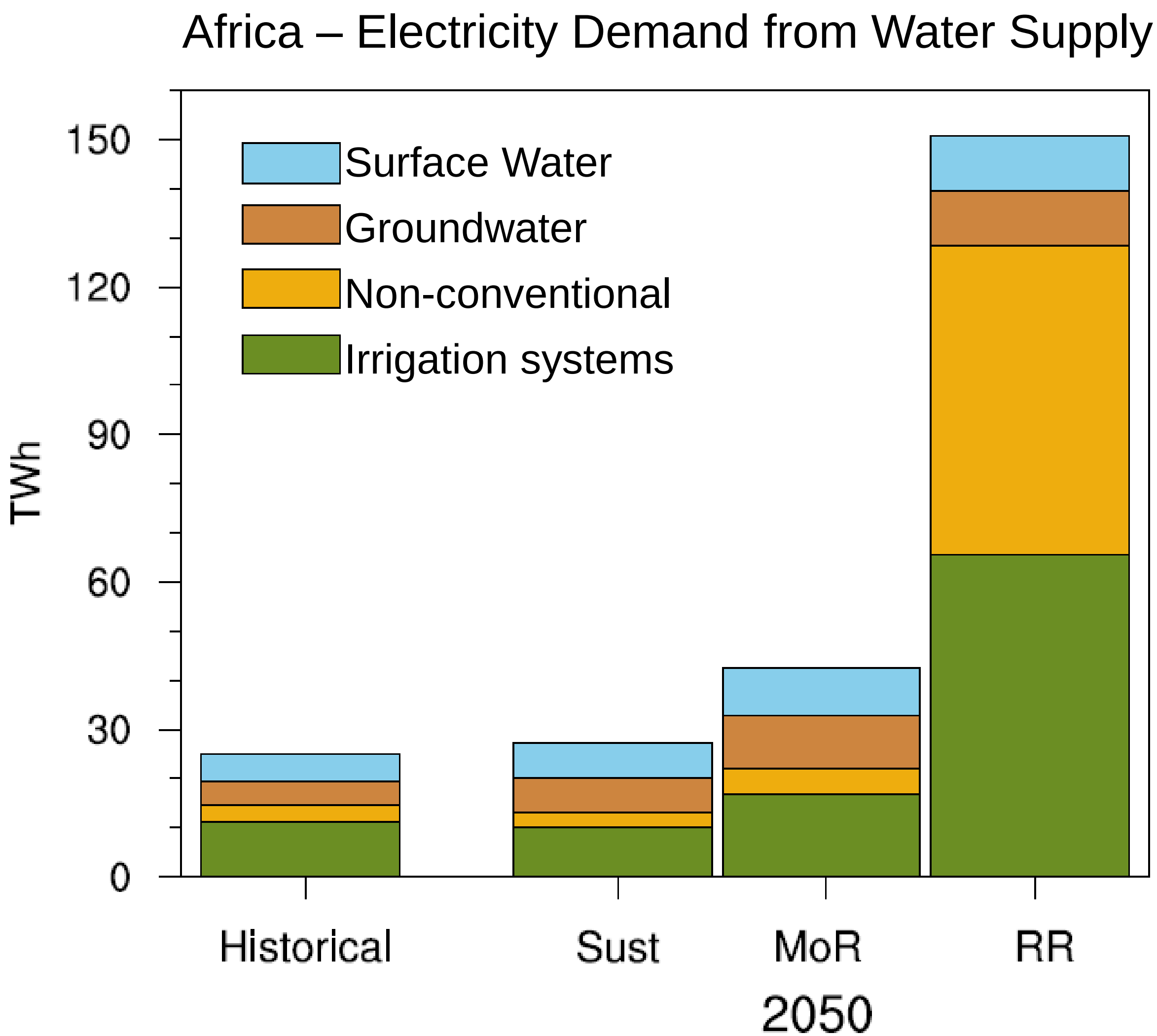
Results
Balancing water supply and demand

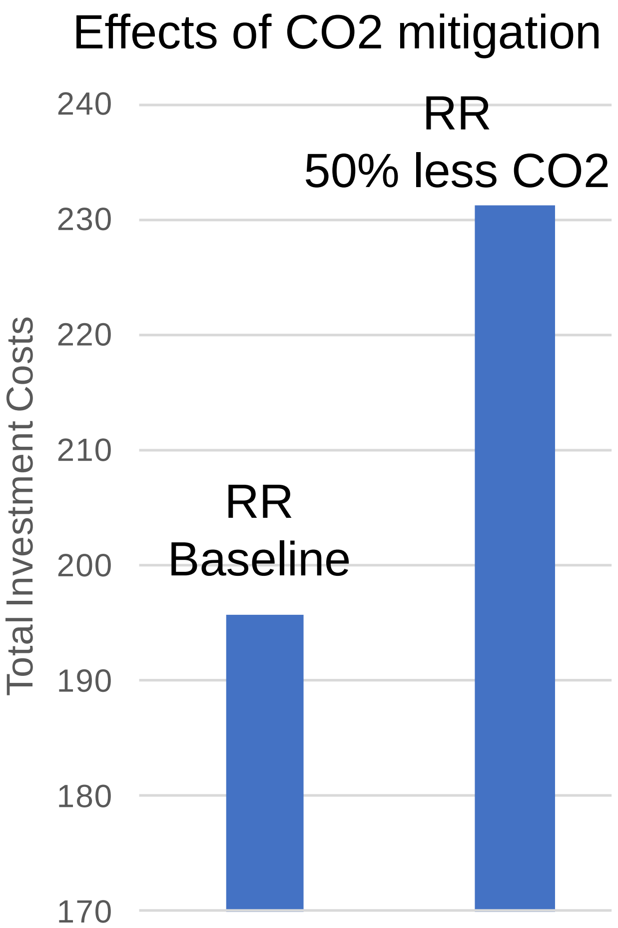


Results
Investment requirements



Results
Increasingly electricity-intensive water sources





Ongoing and future work

- Electricity sector calibration
- Planned projects
- Adaptive land use
- Integrated policy analysis
- Application to other regions

Conclusions

- **Water and energy access closely interlinked in Africa over multiple geographic scales**
  - Hydro-economic models need to be extended to incorporate energy and land-use transitions
- **Water infrastructure costs vary considerably**
  - Efficiency and behavioral changes can provide significant savings, especially in water-stressed regions
- **Climate change mitigation could drive up costs to supply freshwater**
  - Subsidies might be needed in some regions to protect low-income and vulnerable populations

Thank you!

Funding and support provided by:

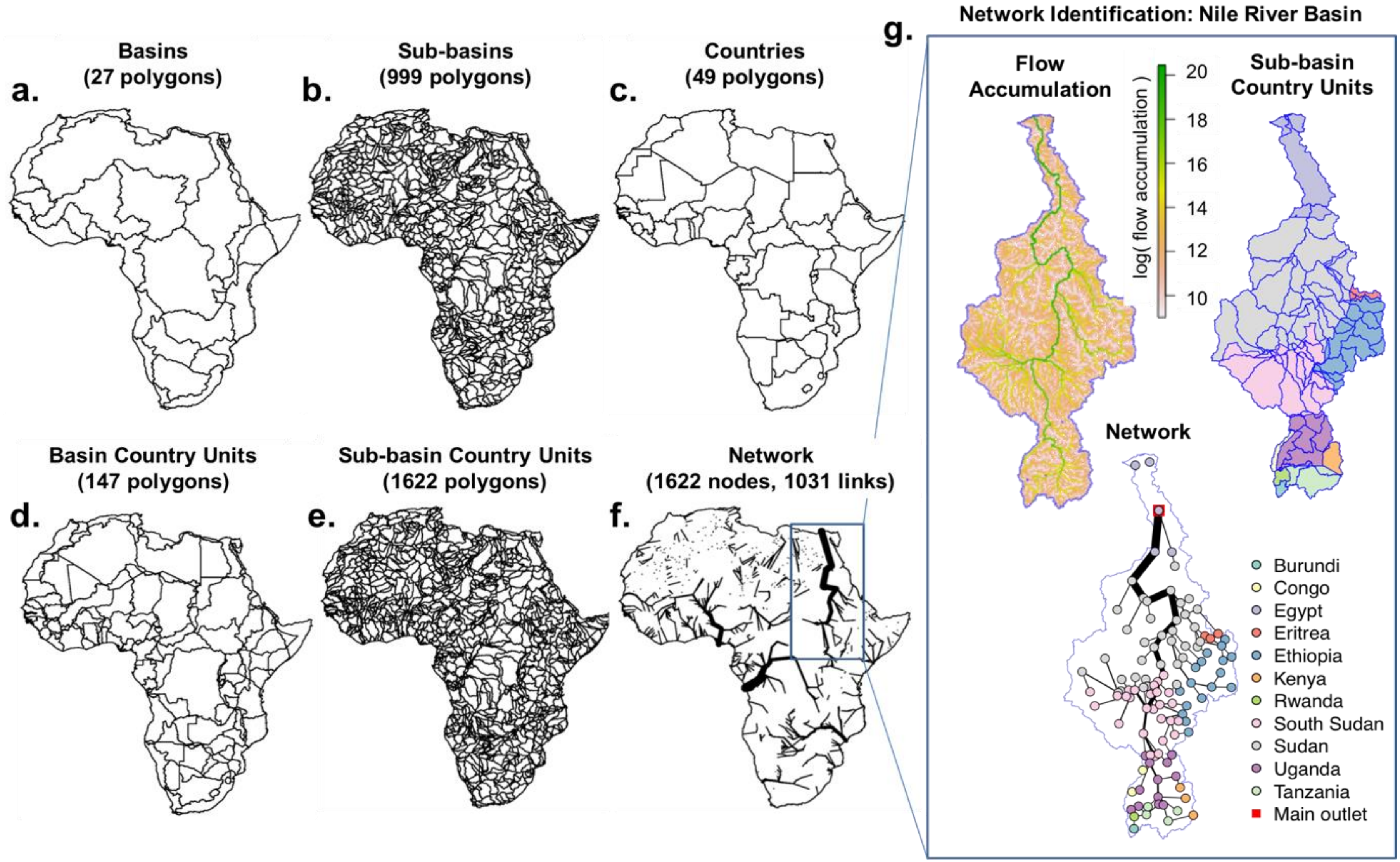
Extra

Features of the ECHO modeling framework

Drivers	Demand growth; Resource availability; Climate change; Administrative boundaries; Basin delineations; etc.
Processes	Reservoir management; Irrigation; Electricity generation; Water pumping; End-use efficiency; Wastewater treatment; etc.
Impacts	Prices; Demands; Emissions; Water quality; Environmental flow; Groundwater depletion; Resource security; etc.
Decisions	Extract resources; Operate infrastructure; Expand infrastructure; Trade resources; Fulfill SDG objectives; etc.

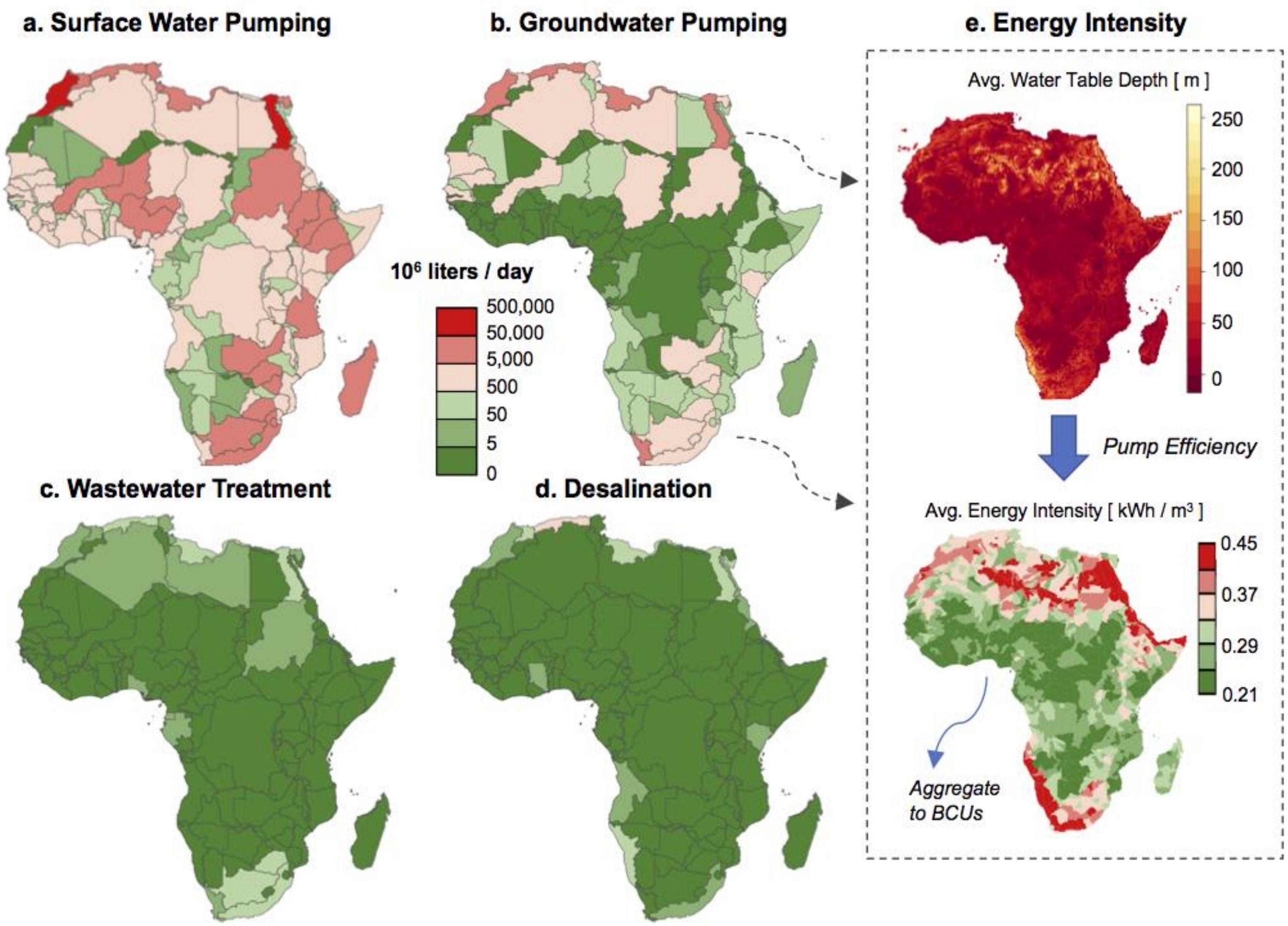
ECHO provides an integrated platform for exploring feasible adaptation options under human development and environmental constraints

Spatial delineation: Tracking transboundary flows



Data sources: HydroBASINS (Lehner and Grill,2013); GADM, 2015

Existing water infrastructure capacity

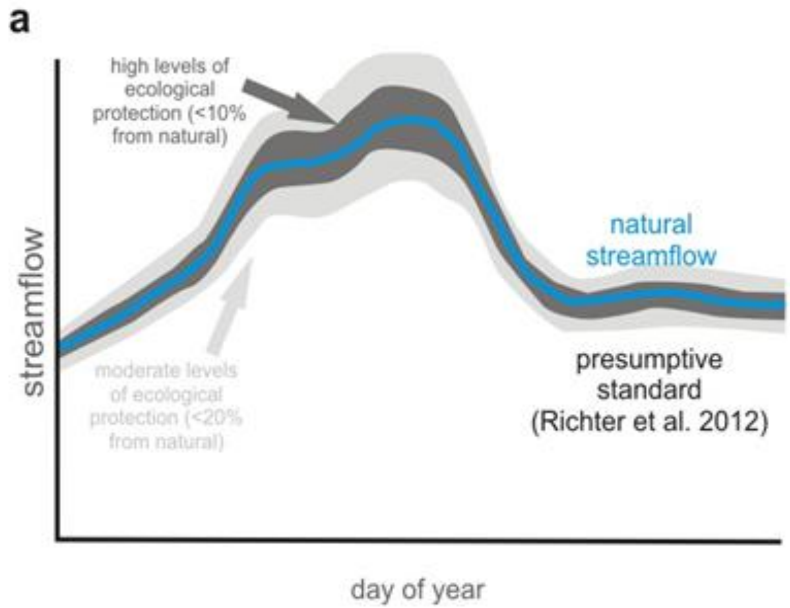


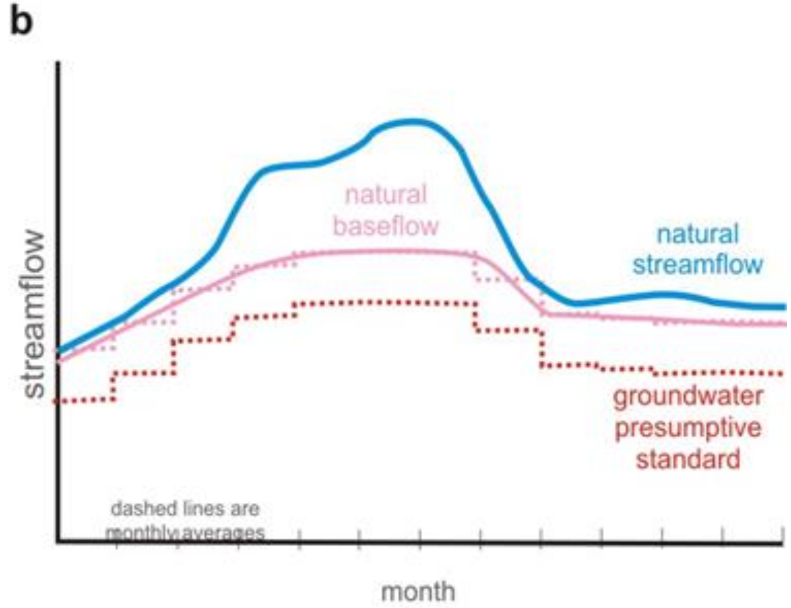
Data sources: Wada et al. 2011; AQUASTAT; Fan (2013); Desaldata (2015)

Presumptive standards for environmental flow protection as constraints on surface and groundwater withdrawals

Rivers

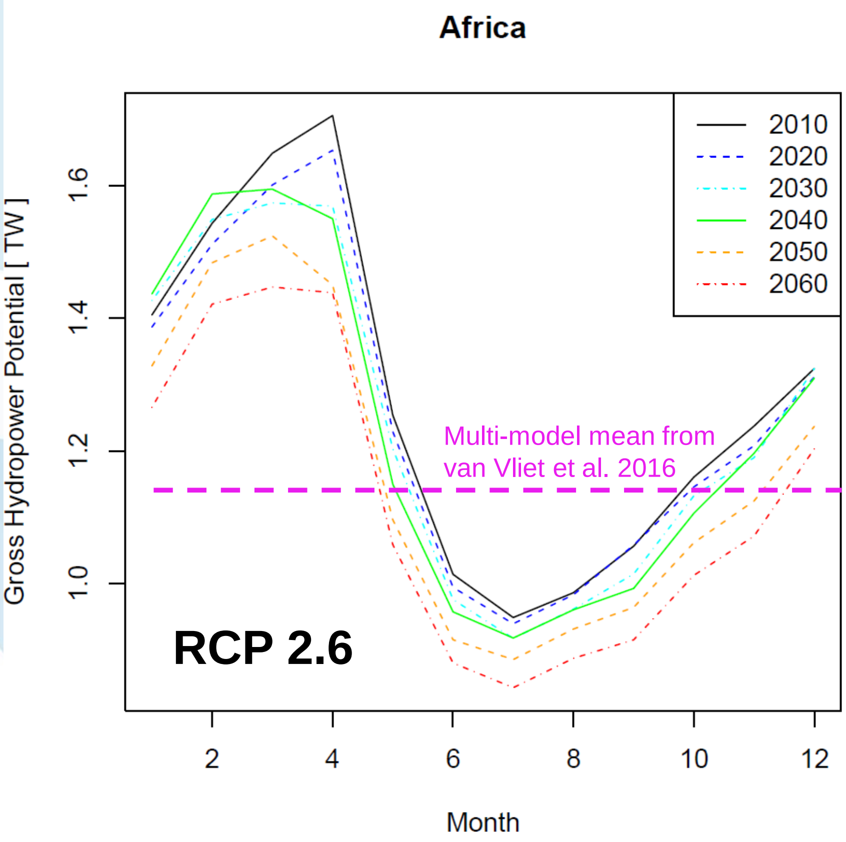
Aquifers

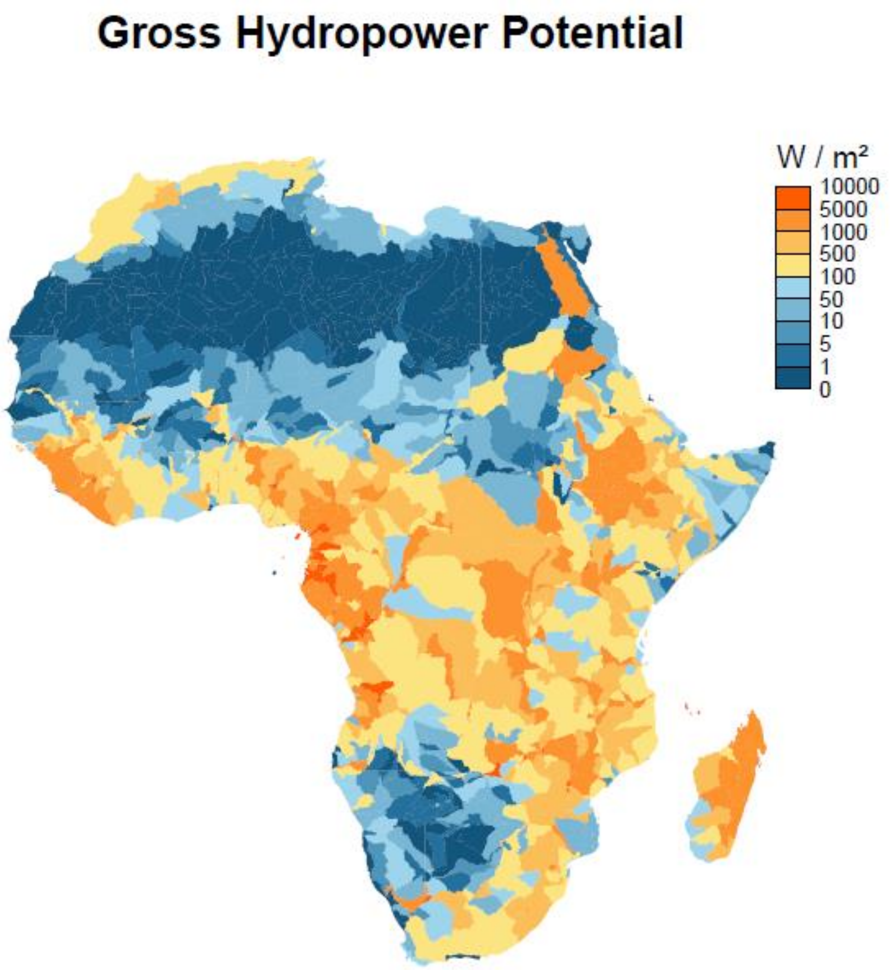




Gleeson and Richter, (2017)

Hydropower potential at the basin-county level





Future municipal water demands

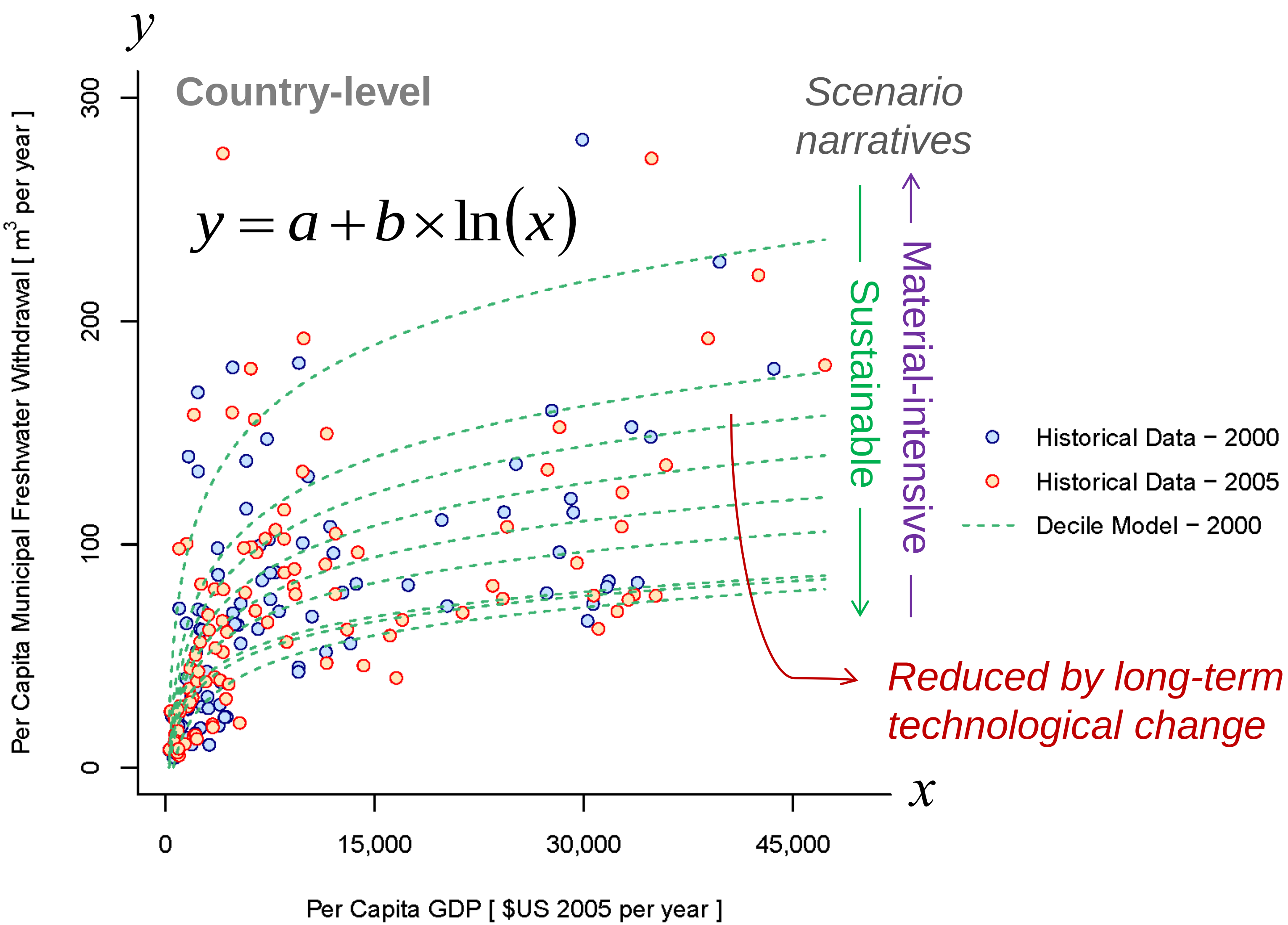


Figure: Per capita GDP vs. per capita freshwater withdrawal.

[Data from: FAO AQUASTAT ; World Bank Indicators]

Country-level results

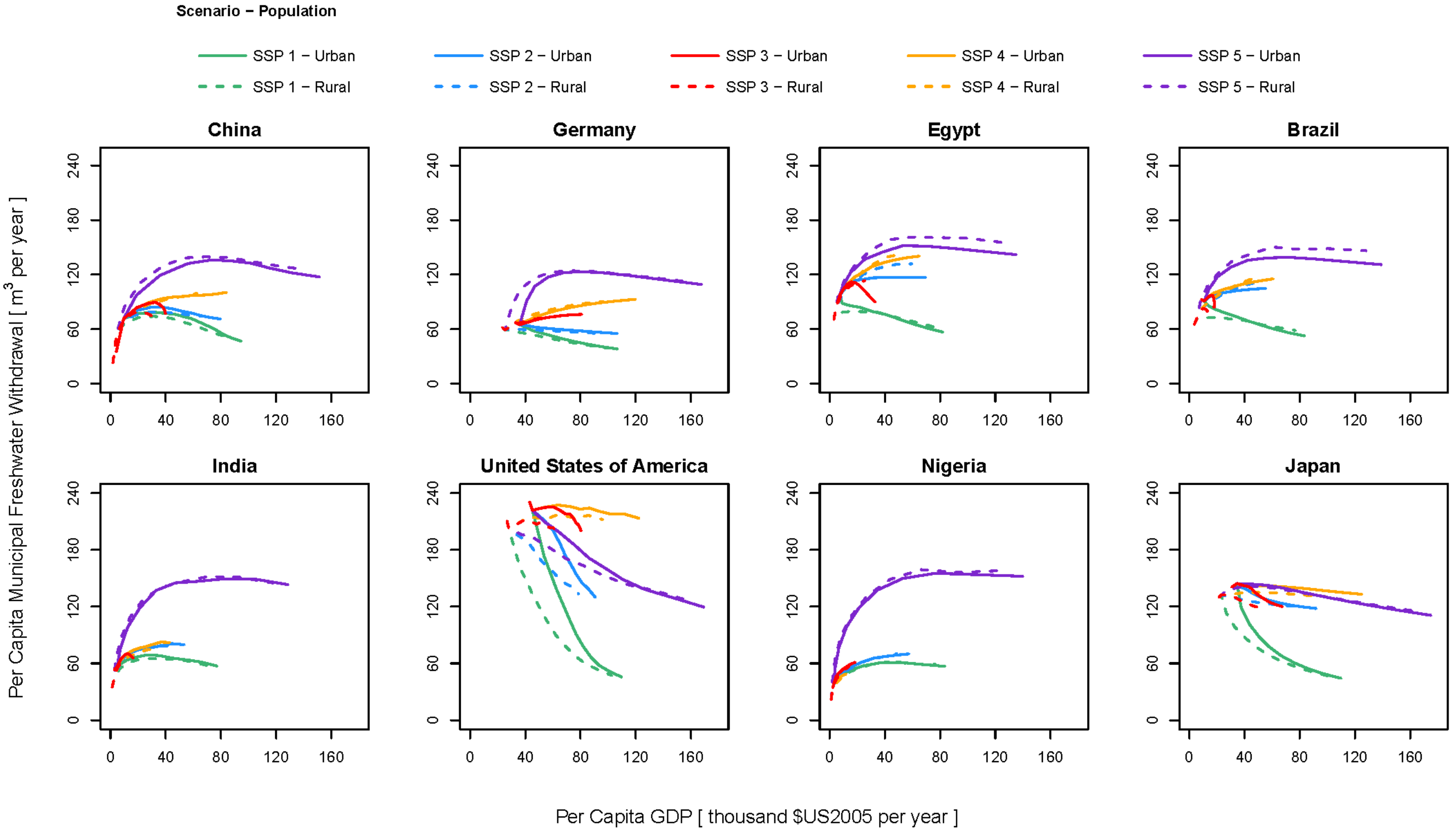
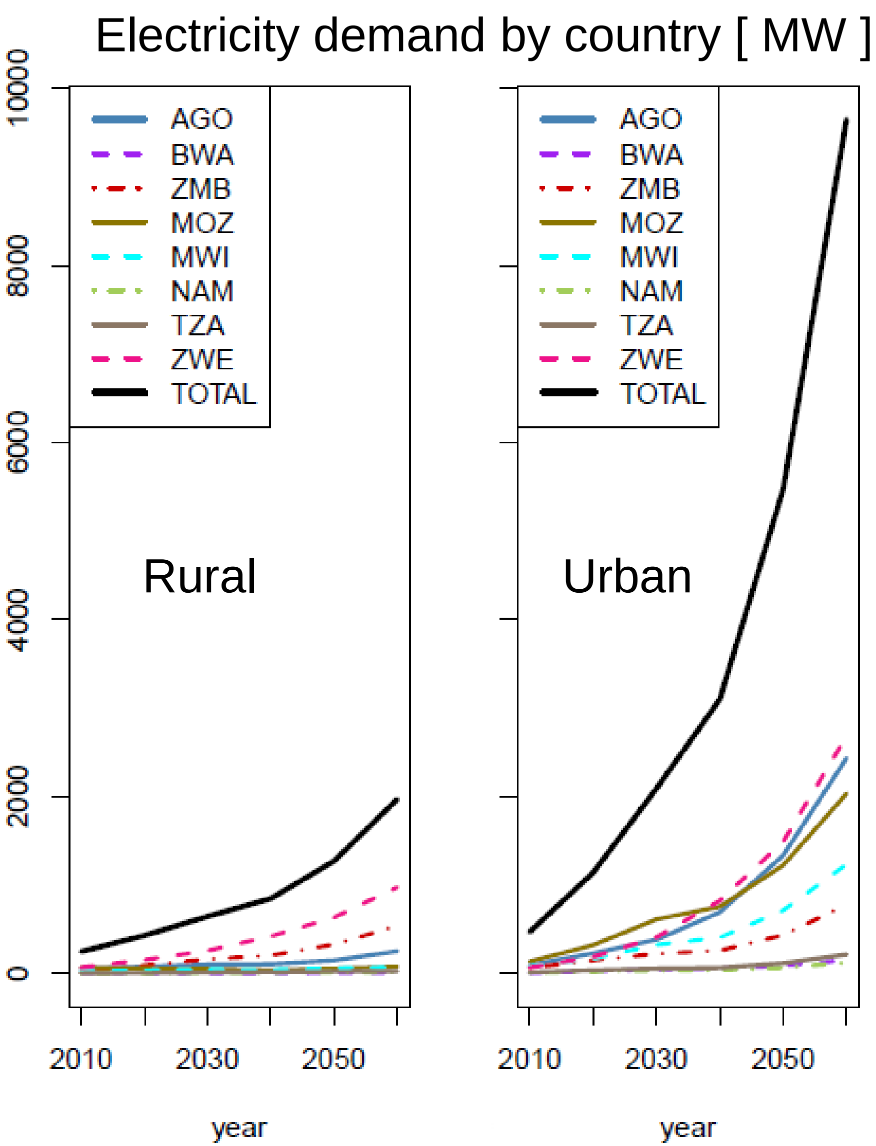


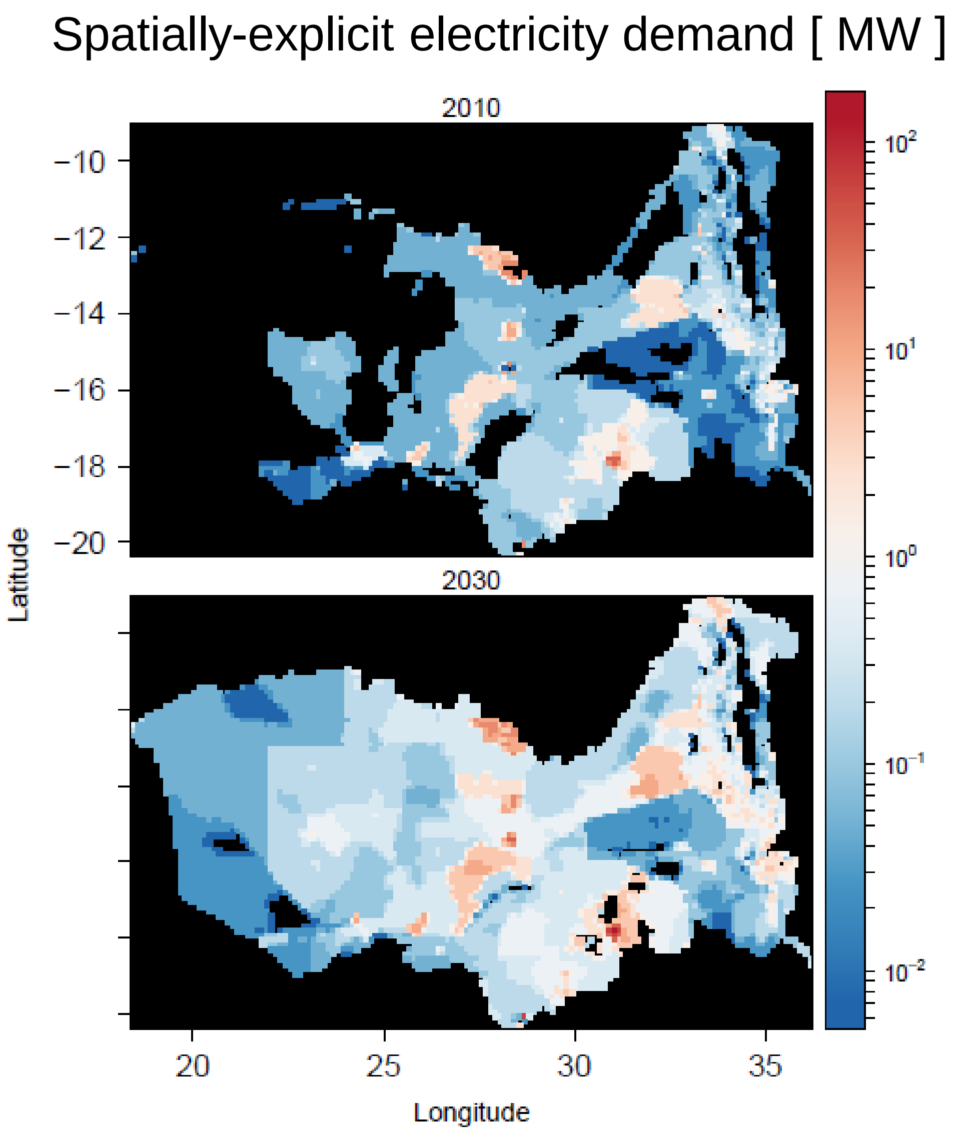
Figure: Demand curves obtained for eight countries (including technological change).

S Parkinson, et al. *Environmental Modelling & Software* (2016)

Innovations

Water, energy and food demand modeling at the basin-scale





Preliminary results

Existing infrastructure