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Integrated modeling for assessing water-energy-land nexus

Application of a hydrological and hydro-economic modeling framework for the Zambezi basin

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

Made for minds.

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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)

Zambezi Challenges

Based on stakeholder meeting and bi-lateral meetings

Water-Agriculture/Land

Low agricultural productivity driven by inadequate practices, high exposure to pests and diseases, poor quality seeds.

New irrigation developments might impact hydropower generation downstream

Water-Energy

Large hydropower development to address electricity shortage can be compromised by high climate variability

Dam management operations need to be optimized for multiple uses. So far most are only for hydropower

New hydropower development continue threatening wetlands and safari tourism

High deforestation rates related to the use of charcoal as main energy source in rural areas

Sedimentation of dams constrains storage and energy production

Capacities

Data-related: insufficient monitoring networks, lack of data sharing among riparian countries, non harmonized data storage, little knowledge on groundwater balance

Knowledge-related: Low capacities for basin-wide planning, development and management, low capacities of farmers

Governance

Inadequate understanding and coping mechanisms for CC (**sectoral adaptation policies**)

Low access to WASH facilities

Low access to electricity (rural areas <6%)

Insufficient transboundary cooperation. Riparian countries regard the **ZAMCOM agreement as still weak**, no yet explicit benefit sharing

Limited government investments in key drivers of Ag. Growth

Barriers to trade

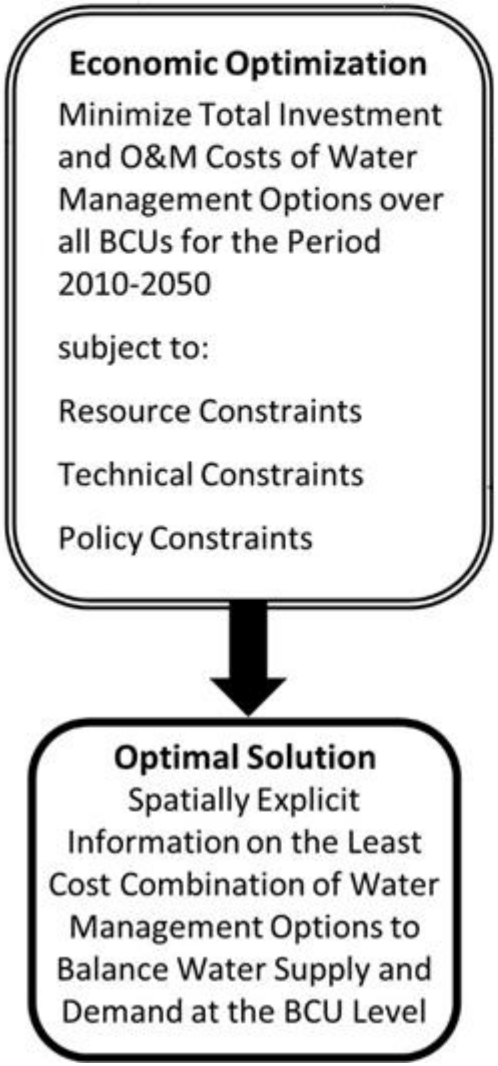
Hydro-economic modeling

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

Research Objectives

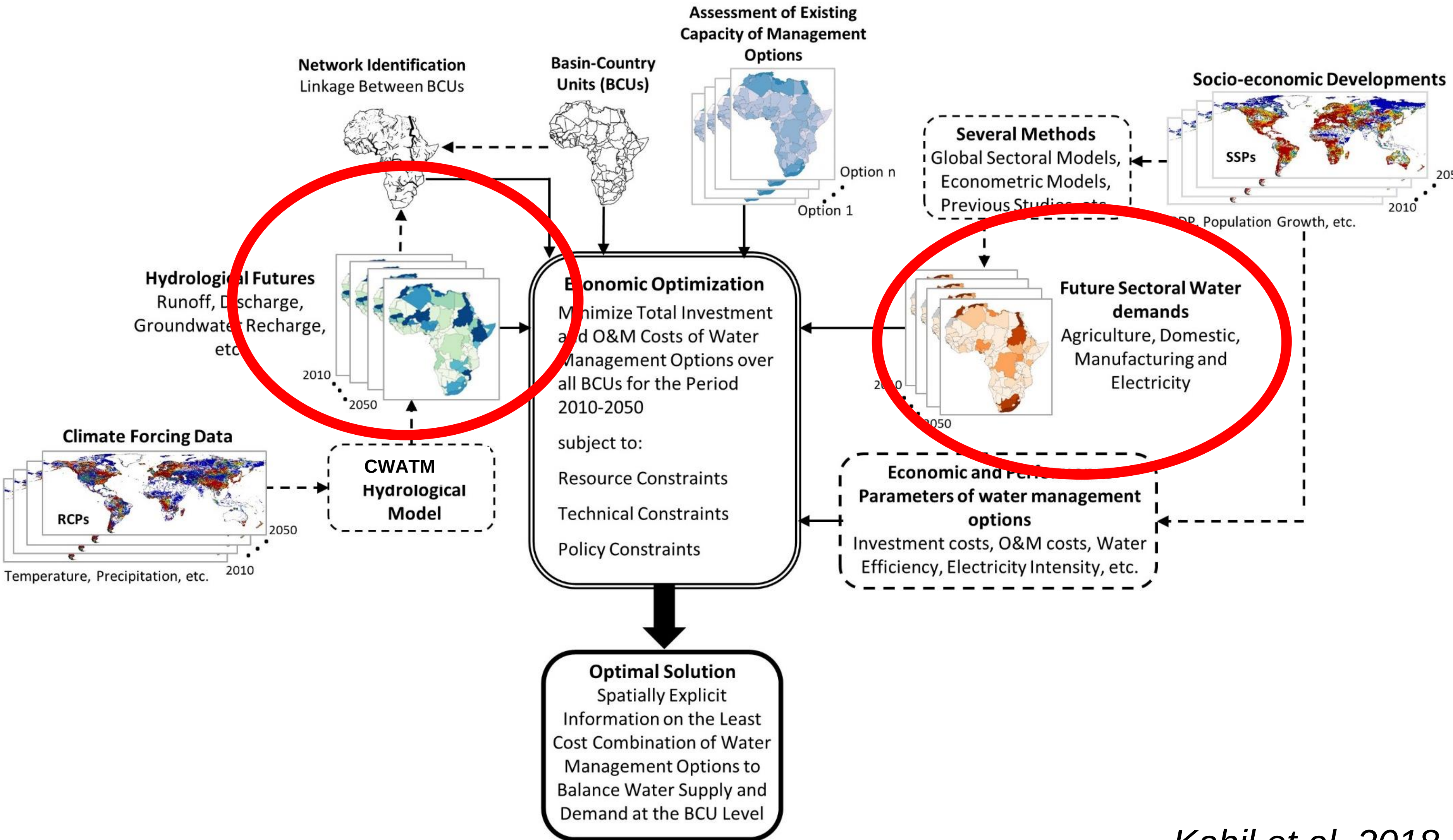
Develop a new **integrated hydro-economic modeling tool** for water and electricity sector **expansion planning** in Africa

- 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



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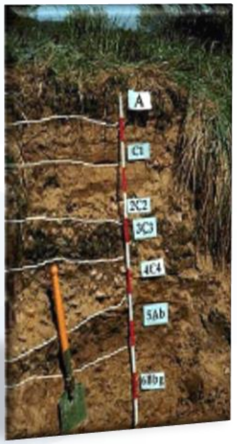
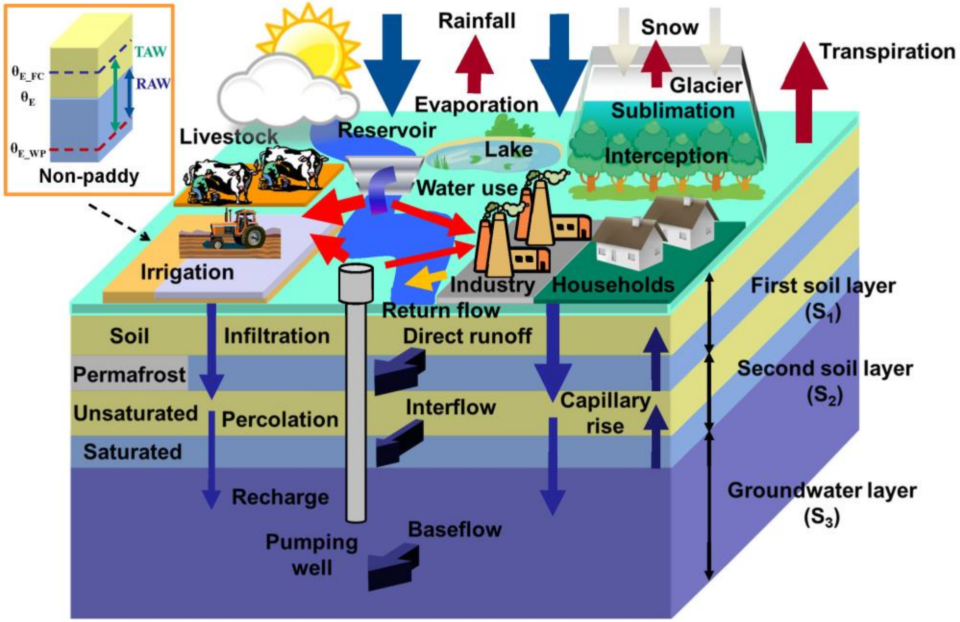
Hydrological model: Community Water Model (CWATM)



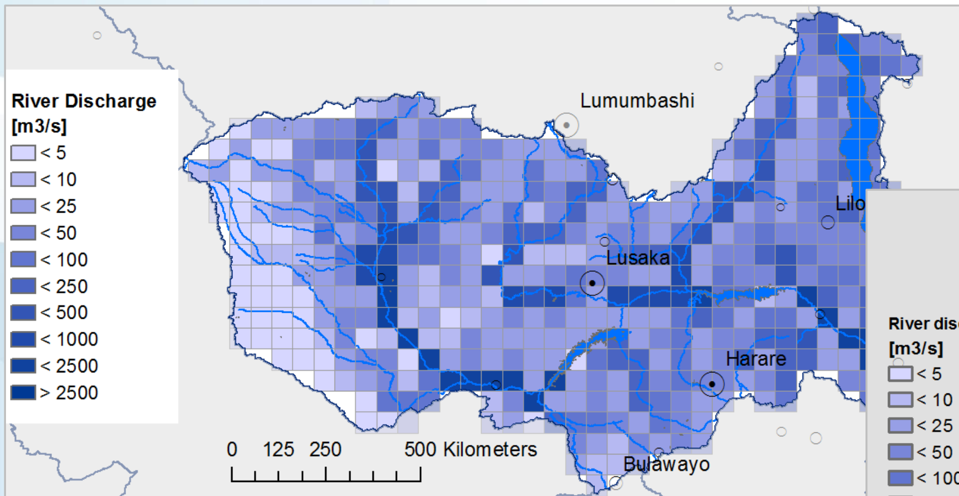





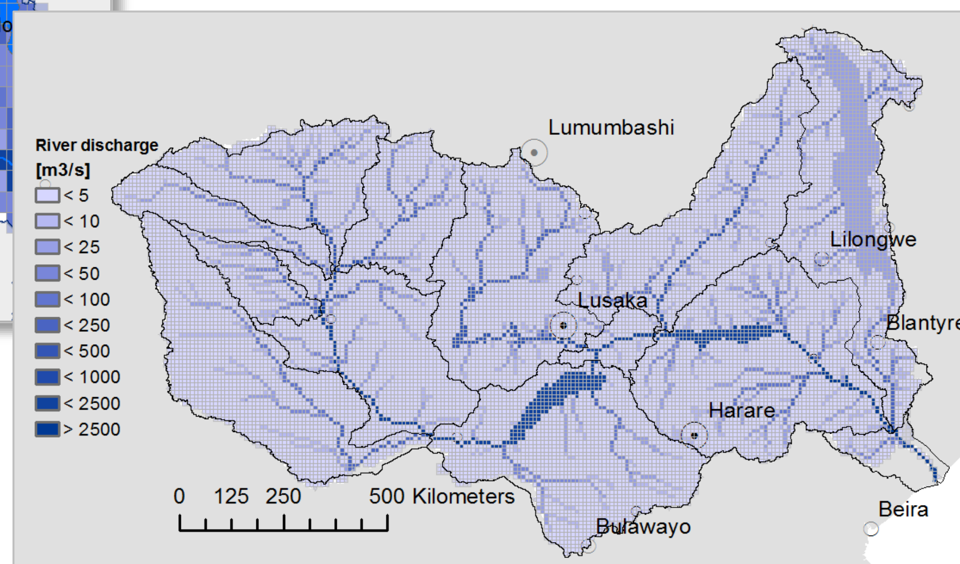
http://www.iiasa.ac.at/cwatm
https://cwatm.github.io/

Water availability and demand analysis

Improving resolution of the water model CWatM from 0.5° to 5’



CWATM 0.5° (~50 x 50 km)

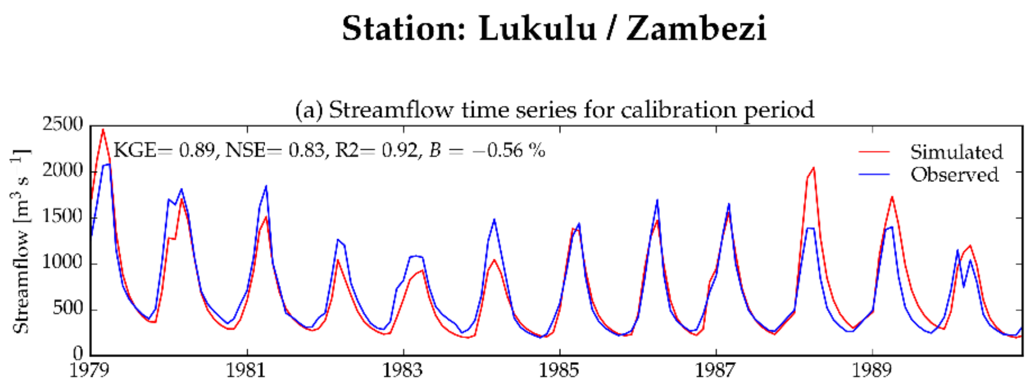


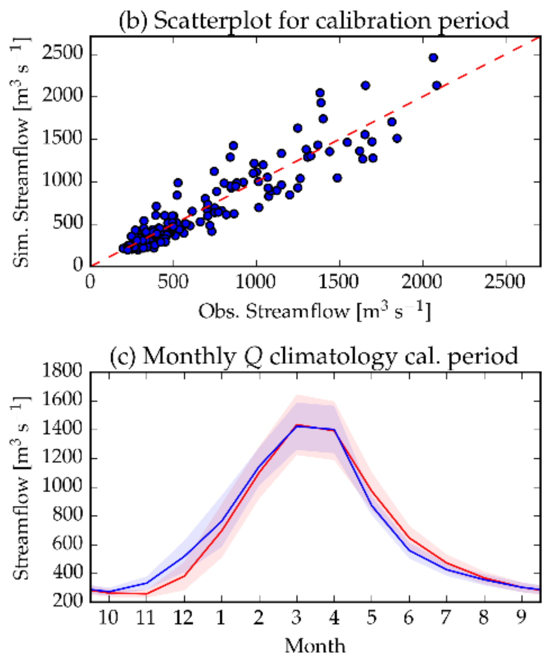
CWATM 5’ (~10 x 10 km)

Zambezi results from Community Water Model CWATM
Historical period (1979-2010)
Average discharge [m³/s]

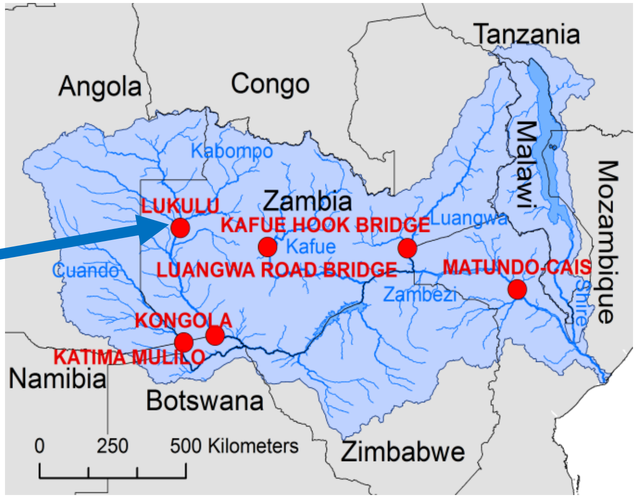
CWATM Zambezi – 5'

Calibration of discharge for e.g. Lukulu





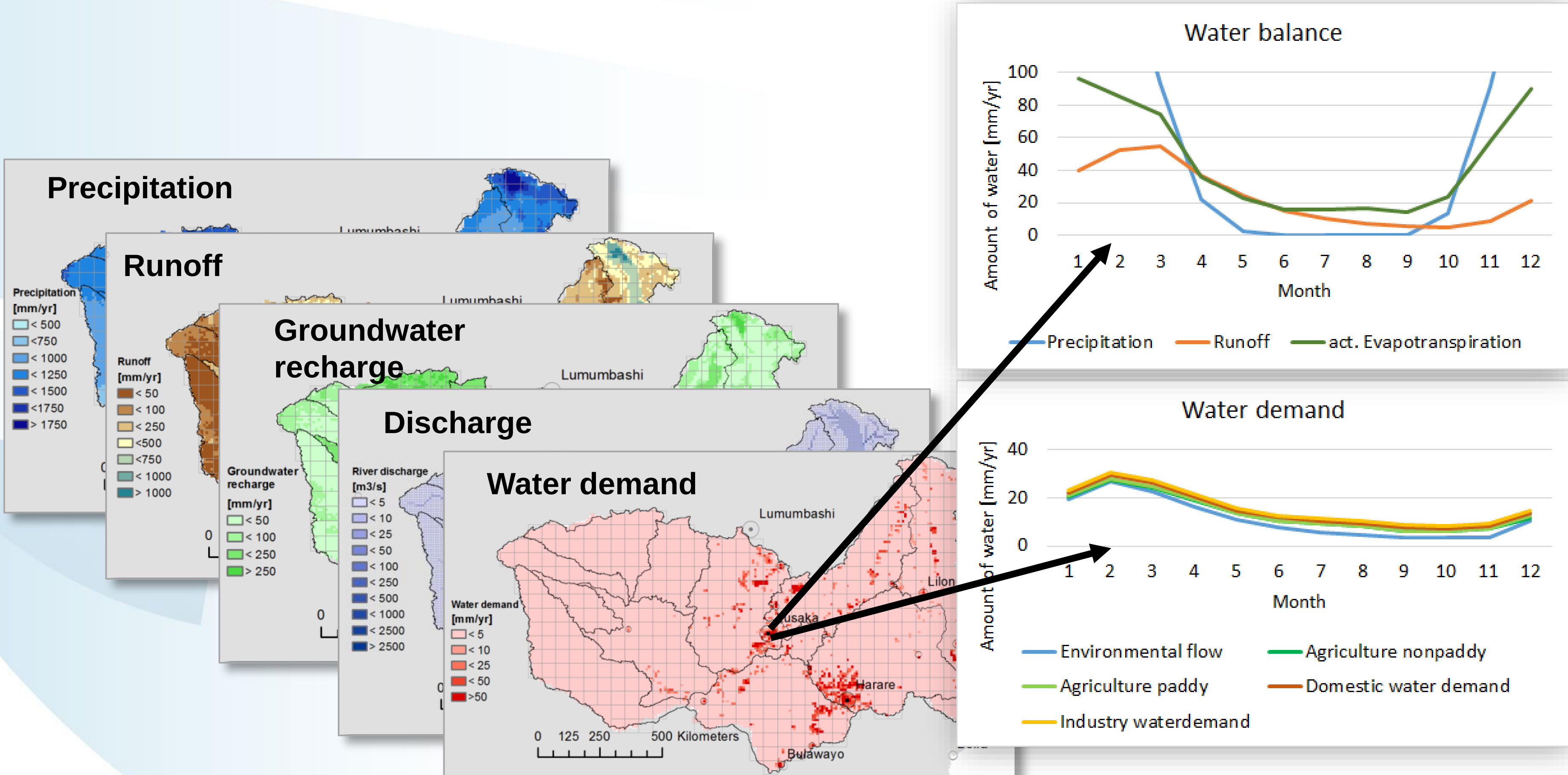
	Obs.	Sim.
KGE		0.893
NS		0.830
NSlog		0.848
R2		0.923
Bias		-0.56%
RMSE		189
MAE		135
Mean	706	702
Min	196	196
5 %	236	217
50 %	515	515
95 %	1652	1636
99 %	1980	2135
Max	2084	2464



Objective function used:
Kling-Gupta efficiency (KGE)
KGE = 0.89

NS = 0.83
R^2 = 0.92
Bias = -0.6%

Input from CWatM into ECHO



Zambezi results from Community Water Model (results for different SSPs/RCPs)

Preliminary scenario analysis:
Focus on water infrastructure pathways to 2050

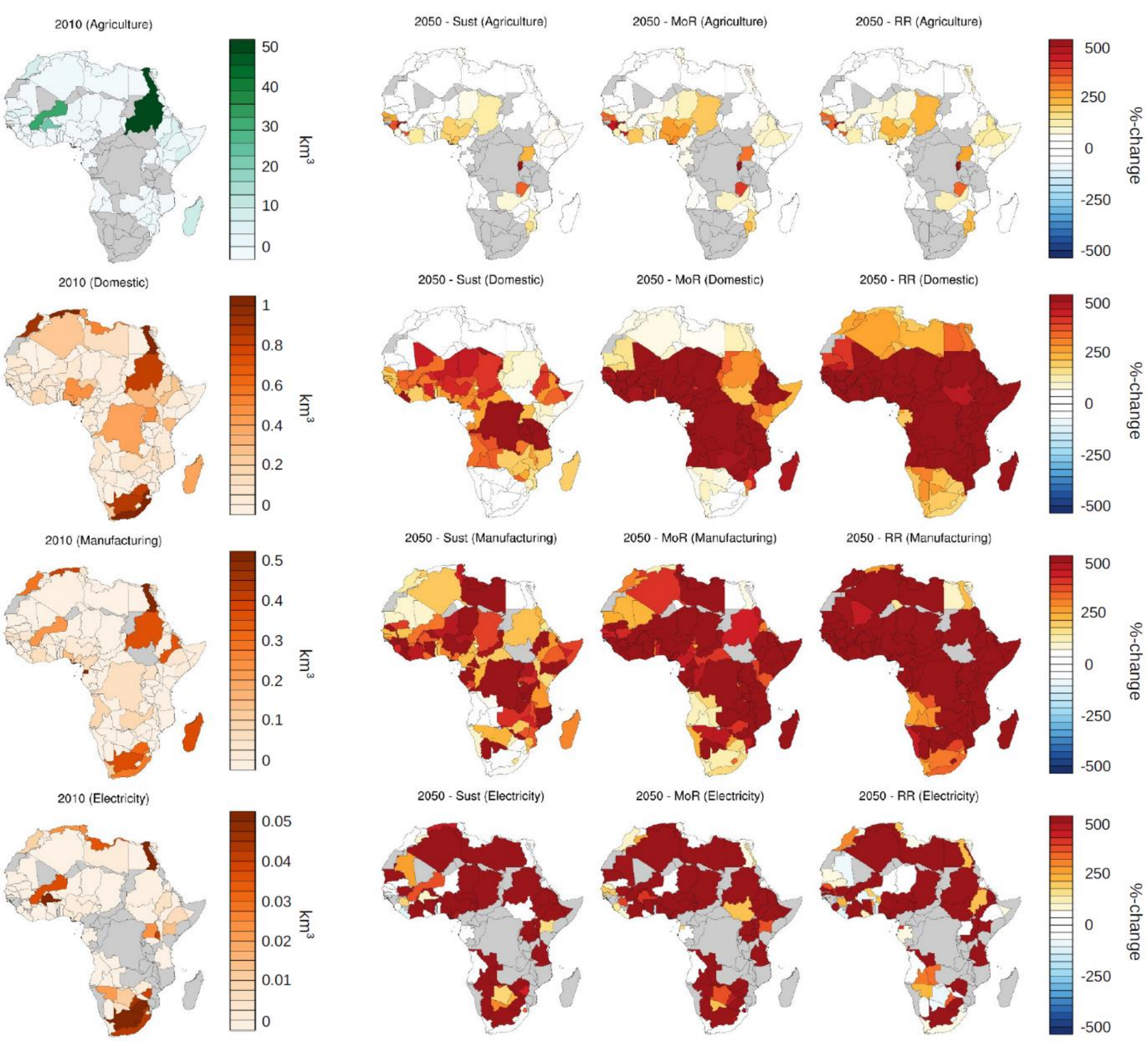
Three socio-economic and climatic scenarios:

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.*

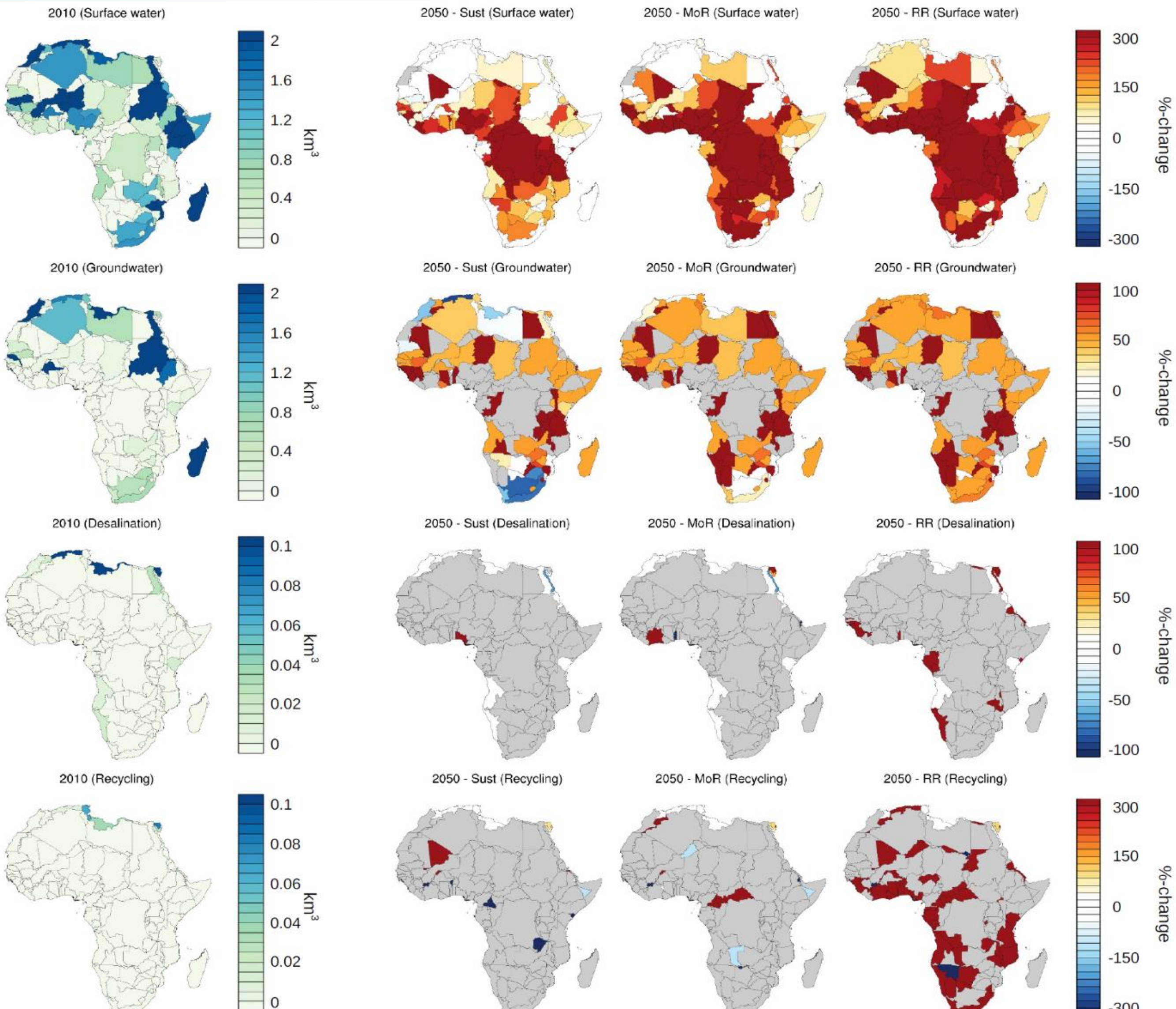
3. Sustainability **(Sust)**: Water demand decreases over time in all water sectors and water availability increases, compared to *MoR*.

Results Africa:
Sectoral water withdrawal – 2010 - 2050



Kahil et al. 2018

Results Africa:
Water withdrawal by source – 2010 - 2050



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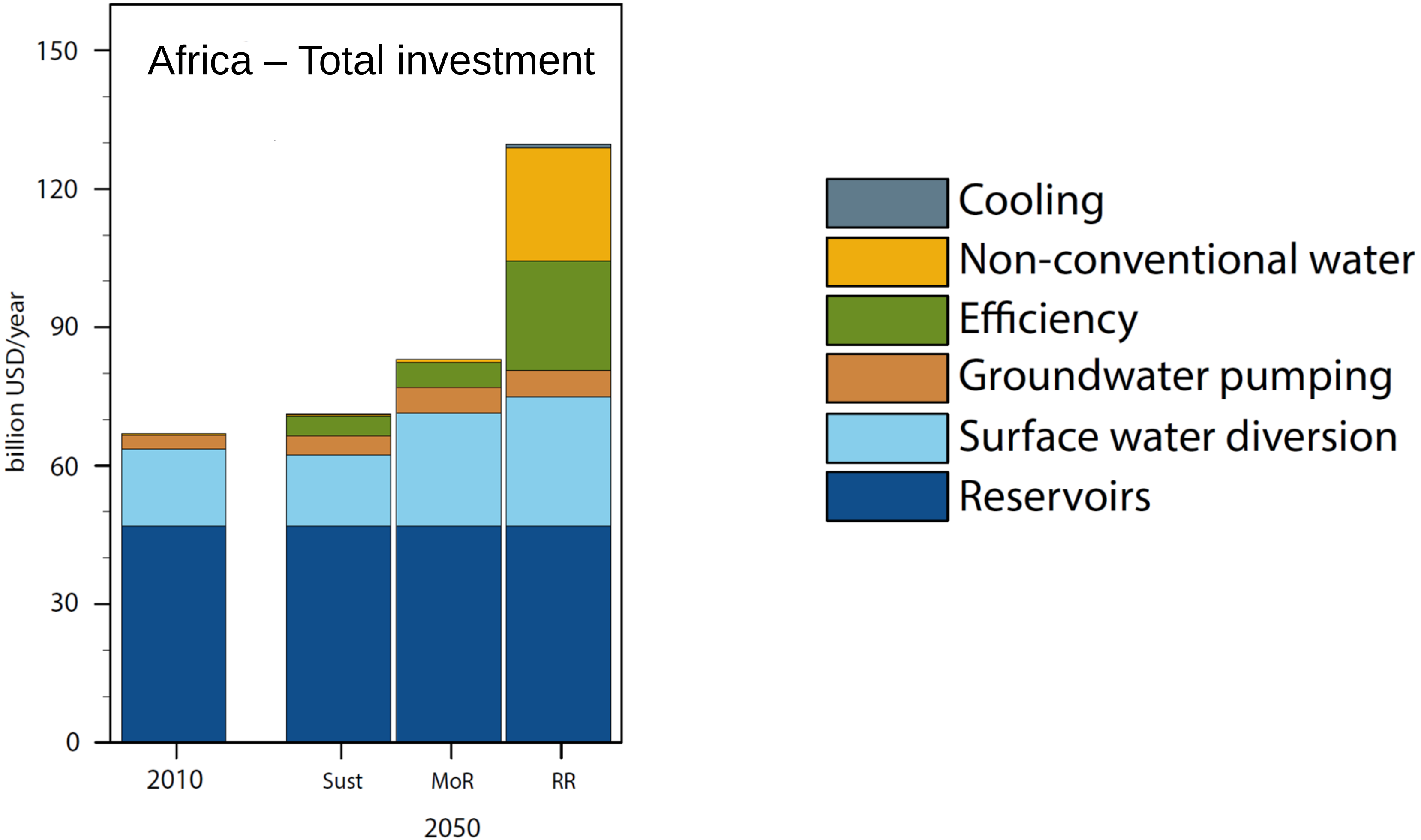
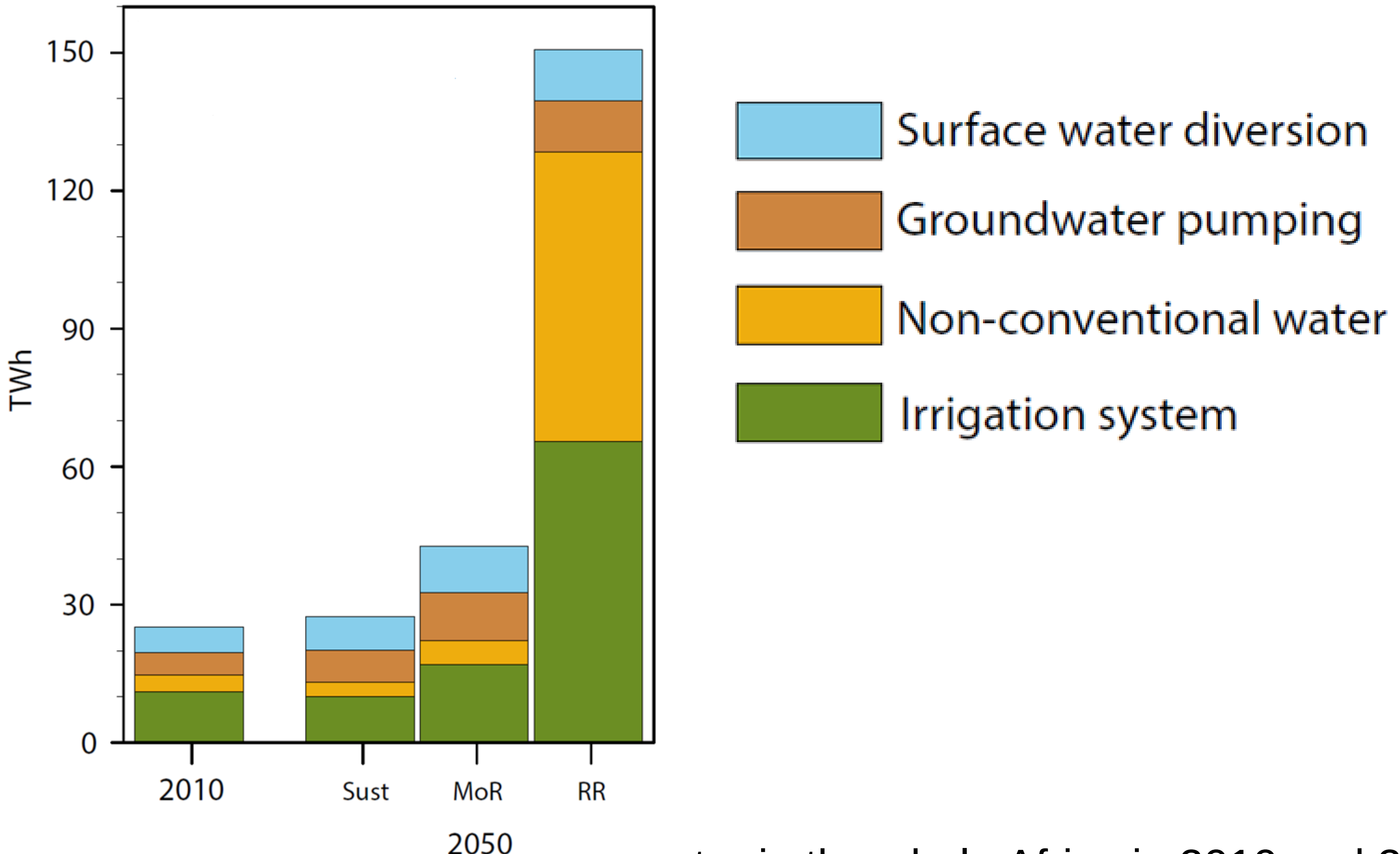
Results Africa:
The cost of water management options



Annual water sector cost in 2010 and 2050 by scenario and management option for the African continent

Results Africa:
Increasingly electricity-intensive water sources

Africa – Electricity Demand from Water Supply



Electricity use of the water sector in the whole Africa in 2010 and 2050 by scenario and management option

Next steps

- Further harmonize scenario drivers and input data across water-energy-land components of the nexus modelling framework
- Address charcoal-deforestation nexus element
- Develop interfaces to manage linking of model components.
- Prepare integrated model results for baseline scenario
- Develop additional scenarios in cooperation with stakeholders.
- Analyse water quality issues using MARINA model

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

Conclusions

- In this study, we present the development of a new large-scale HE model (ECHO), which fully integrates biophysical, technological, and economic features of water resources systems. ECHO covers multiple sub-basin units interacting at continental-scale within a reduced-form transboundary river network, and involves the main water users at sub-basin level. The embedded linkages between sub-basin units and sectors at continental scale in ECHO provide a unique opportunity to model water management options at multiple spatial scales and account for their impacts on energy and agricultural sectors. ECHO was applied over Africa with the aim of demonstrating the benefits of this integrated hydro-economic modeling framework. Results of this application were found to be consistent with previous studies assessing the cost of water supply and adaptation to future socio-economic and climatic changes in Africa. Moreover, the results provide insight into several critical areas related to future investments in both supply and demand-side management options, the varying implications of contrasting future scenarios, and the potential tradeoffs among economic and environmental objectives. Overall, results highlight the capacity of ECHO to address challenging research questions related to the sustainable supply of water, and the impacts of water management on energy and food sectors and vice versa. As such, we propose ECHO as useful tool for water-related scenario analysis and policy options evaluation.

Thank you

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