Introduction to the Nexus Solutions Tools and its real-World case studies

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Workshop on the introduction of Integrated Assessment Modelling and understanding the multi-sectoral policy insights

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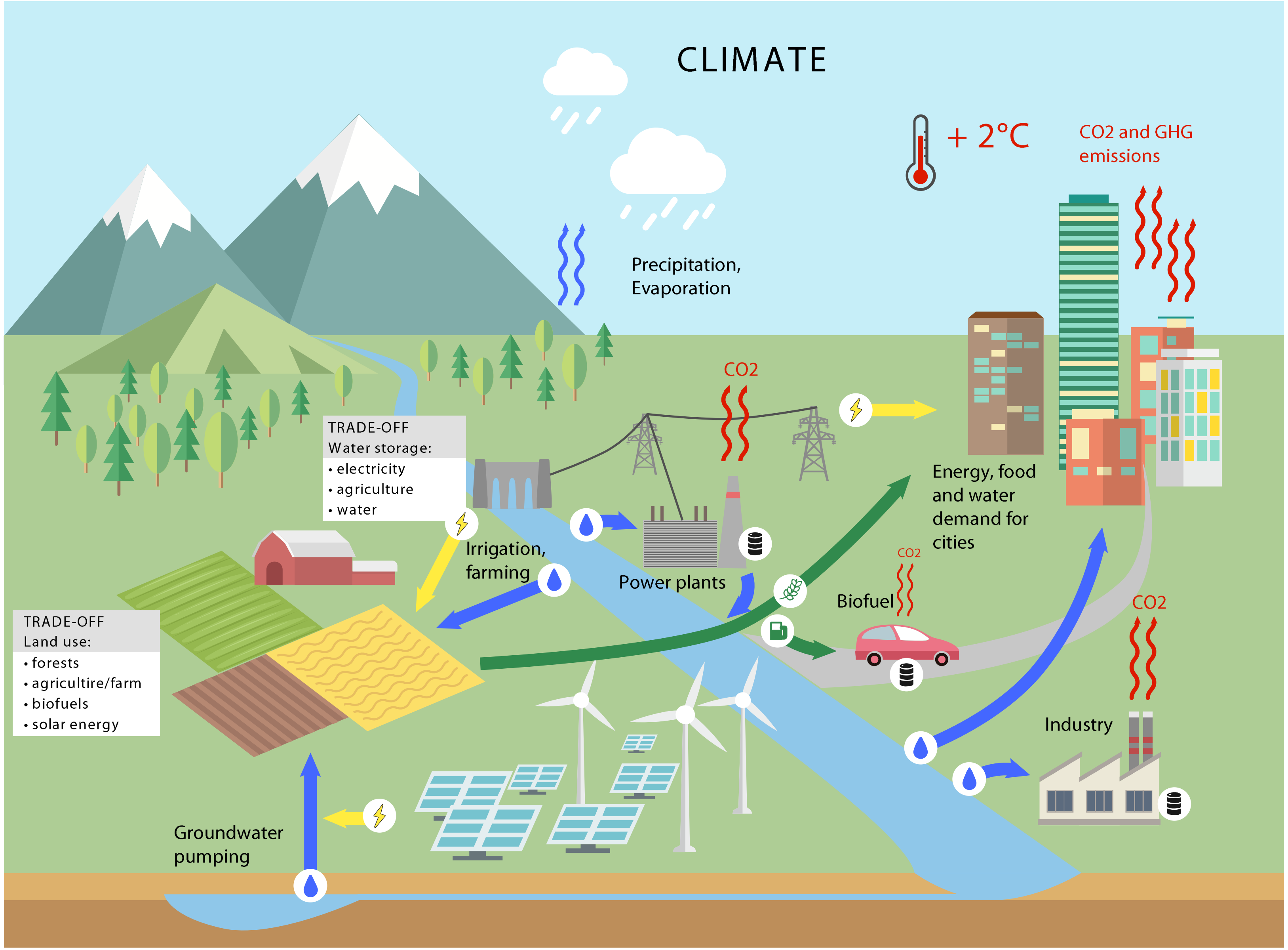
Centre for Water Informatics & Technology, LUMS, Lahore

Overview

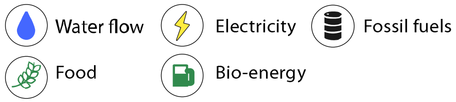
- Introduction to Nexus concept and models
- NEST:
  - ⇒ What is it? Methods, use, data
  - ⇒ How to access and use it
- New MESSAGEix-Nexus module, the new NEST
- Our way forward

Climate-Land (food)-Energy-Water Nexus



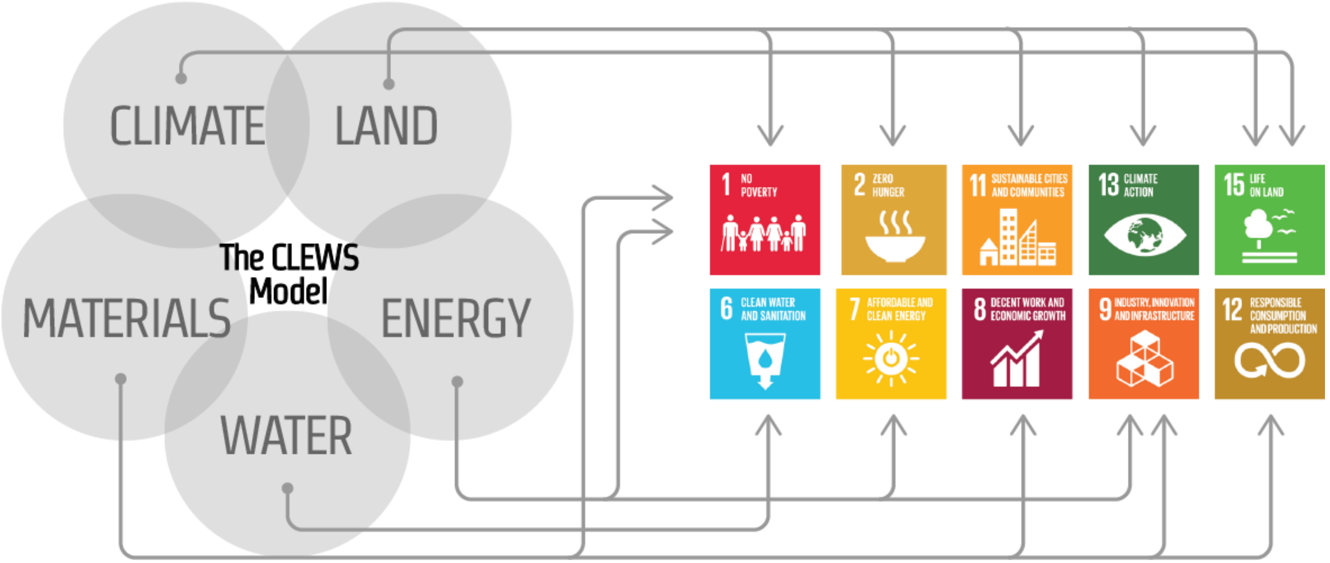
Vinca et al., 2021 Frontiers in Environmental Science

1. WHEN IS CLEW NEXUS RELEVANT?
2. CURRENT GAPS AND LIMITATIONS
3. RECOMMENDATIONS TO FOSTER THE USE OF NEXUS TOOLS

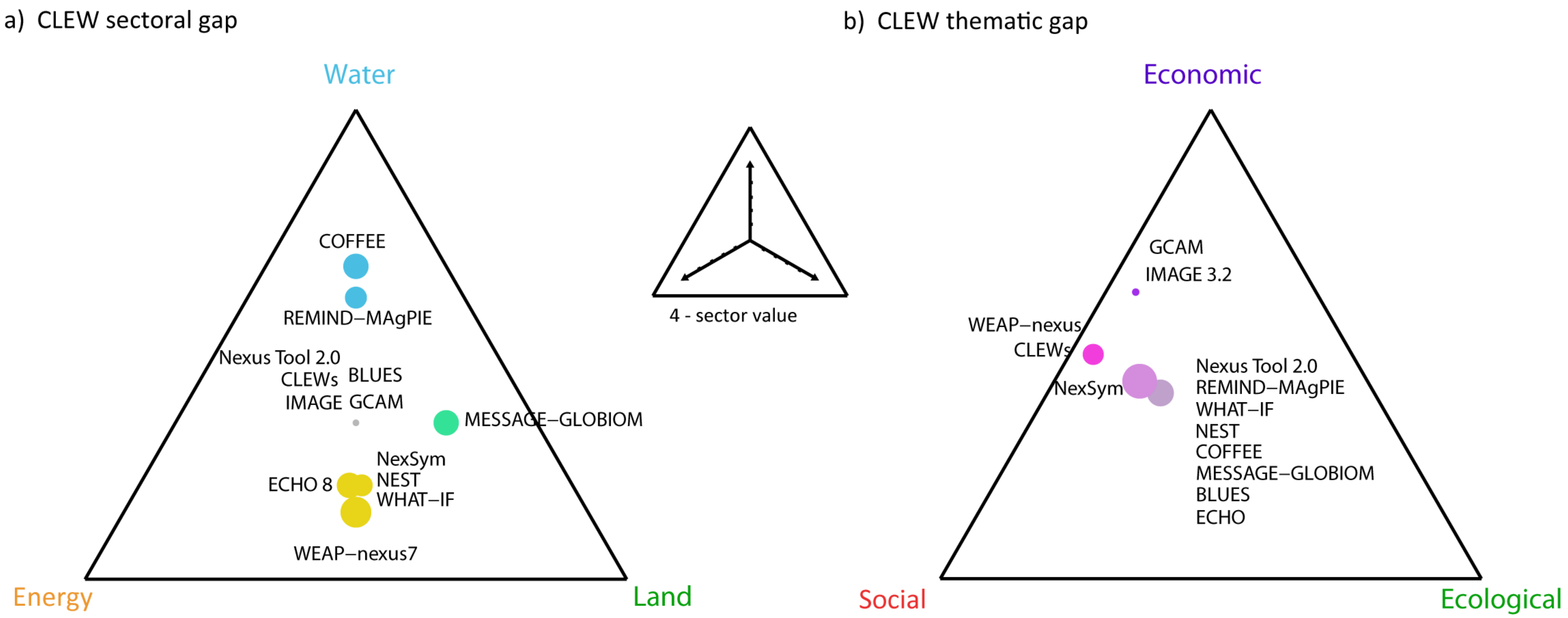


WEL nexus modelling and open-source

- Recent boom of new models or interlinkages of existing models.
  Different scales, model configurations (soft link-integrated)
  - Regional assessment, e.g. CLEWS
  - Global analysis, e.g. MESSAGE-GLOBIOM, GAMS
- Clear advantages of modelling and capturing nexus interactions among sectors.
  Higher uncertainty, difficult to assess: not enough studies to allow comparison, or very different models, not always well documented
- Open-source:
  code, software, data, analysis results



Sectoral gap – Theme gap

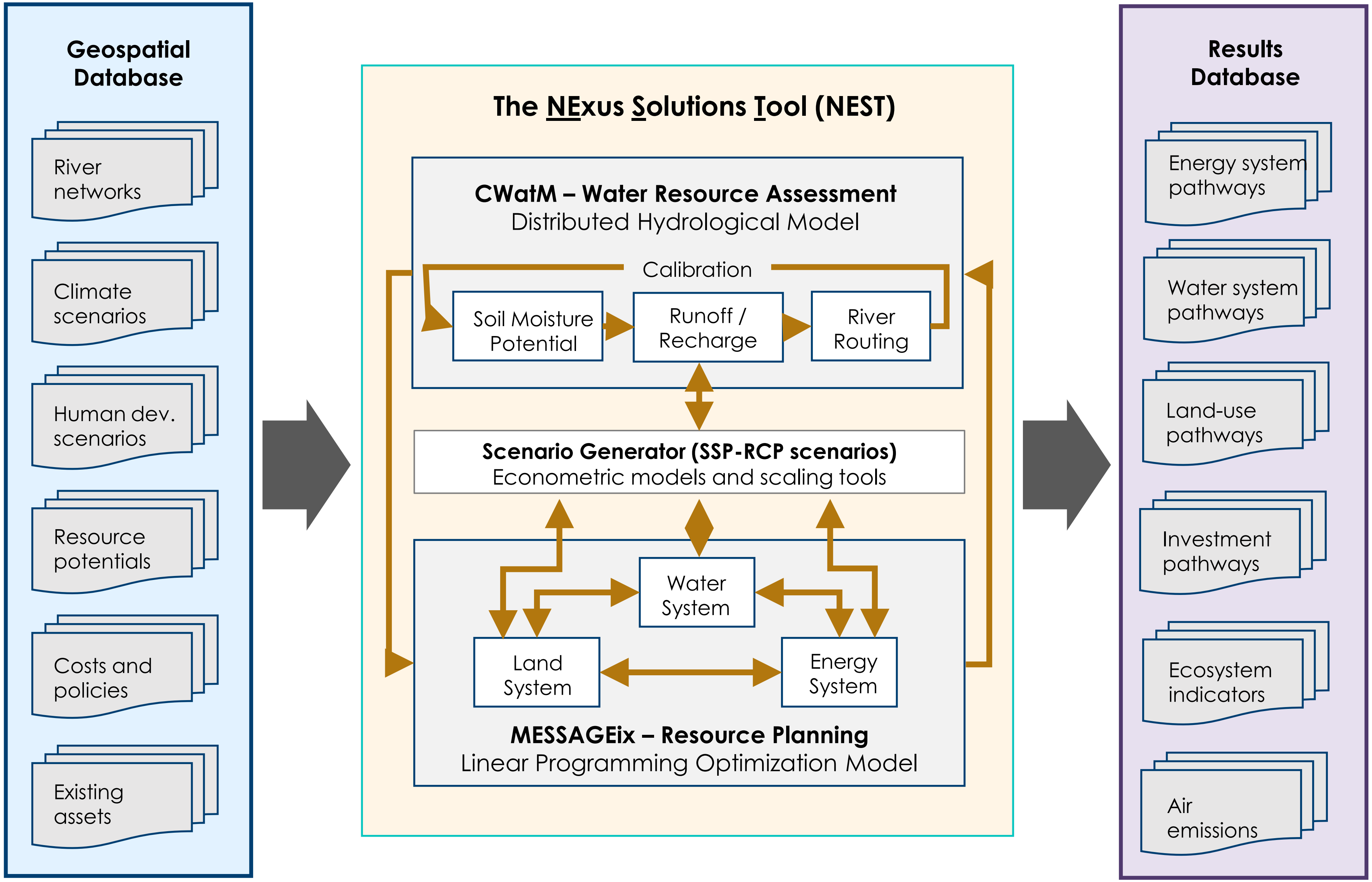


In average good balance in sectoral components

Simple macro-economic assumptions.
Lack of socioeconomic aspects: inequality, individual/corporate choices, governance
Stakeholder engagement → empirical models, ABMs

Vinca et al., 2021 Frontiers in Environmental Science

NExus Solutions Tools (NEST)



The core model

NExus Solutions Tools (NEST)

Distributed Hydrology

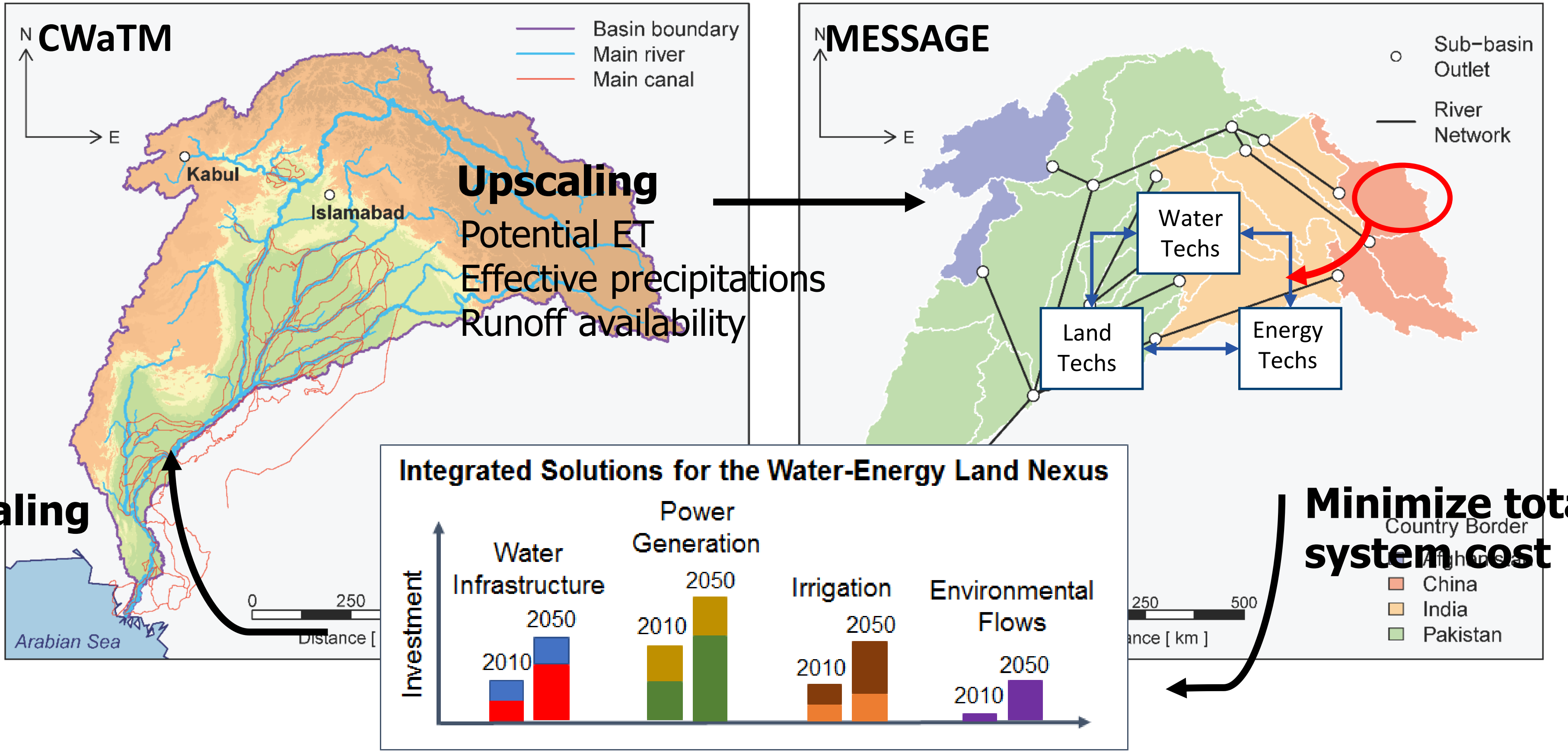
Community Water Model (CWatM)

(Burek et al., 2018)

Infrastructure Planning

MESSAGEix

(Huppmann et al., 2018)



Upscaling

Potential ET

Effective precipitations

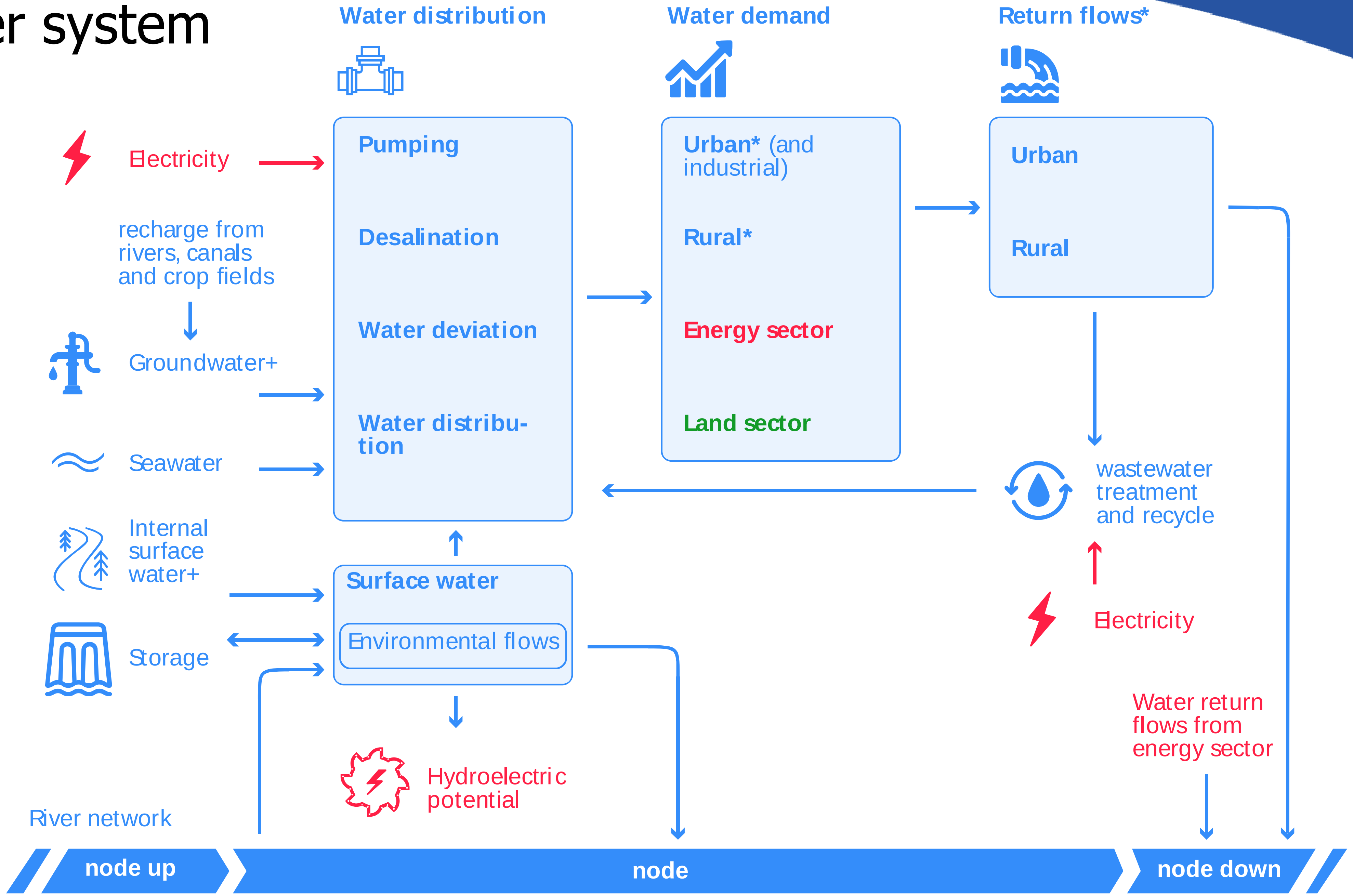
Runoff availability

Downscaling

Water and land-use

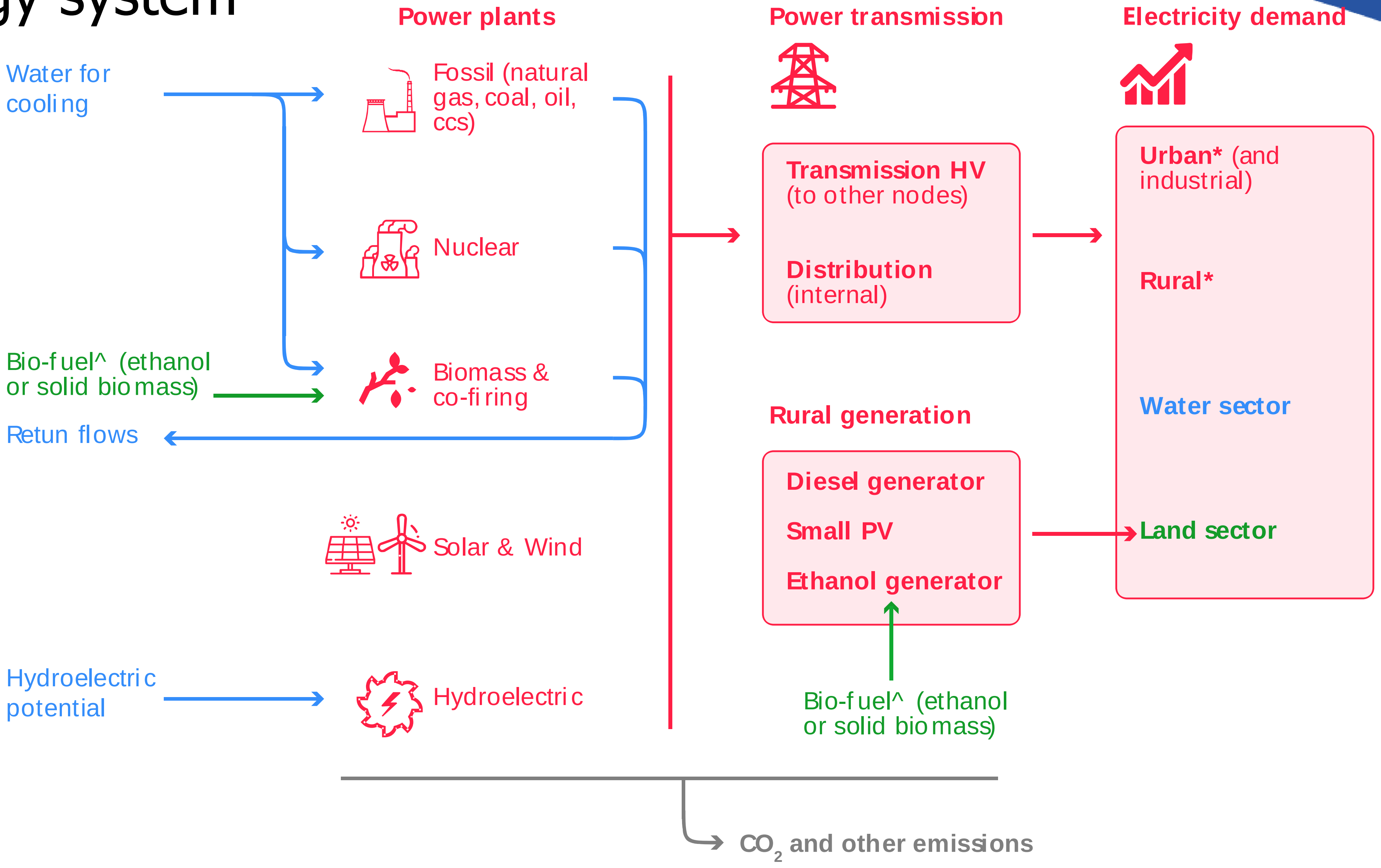
Minimize total system cost

Water system



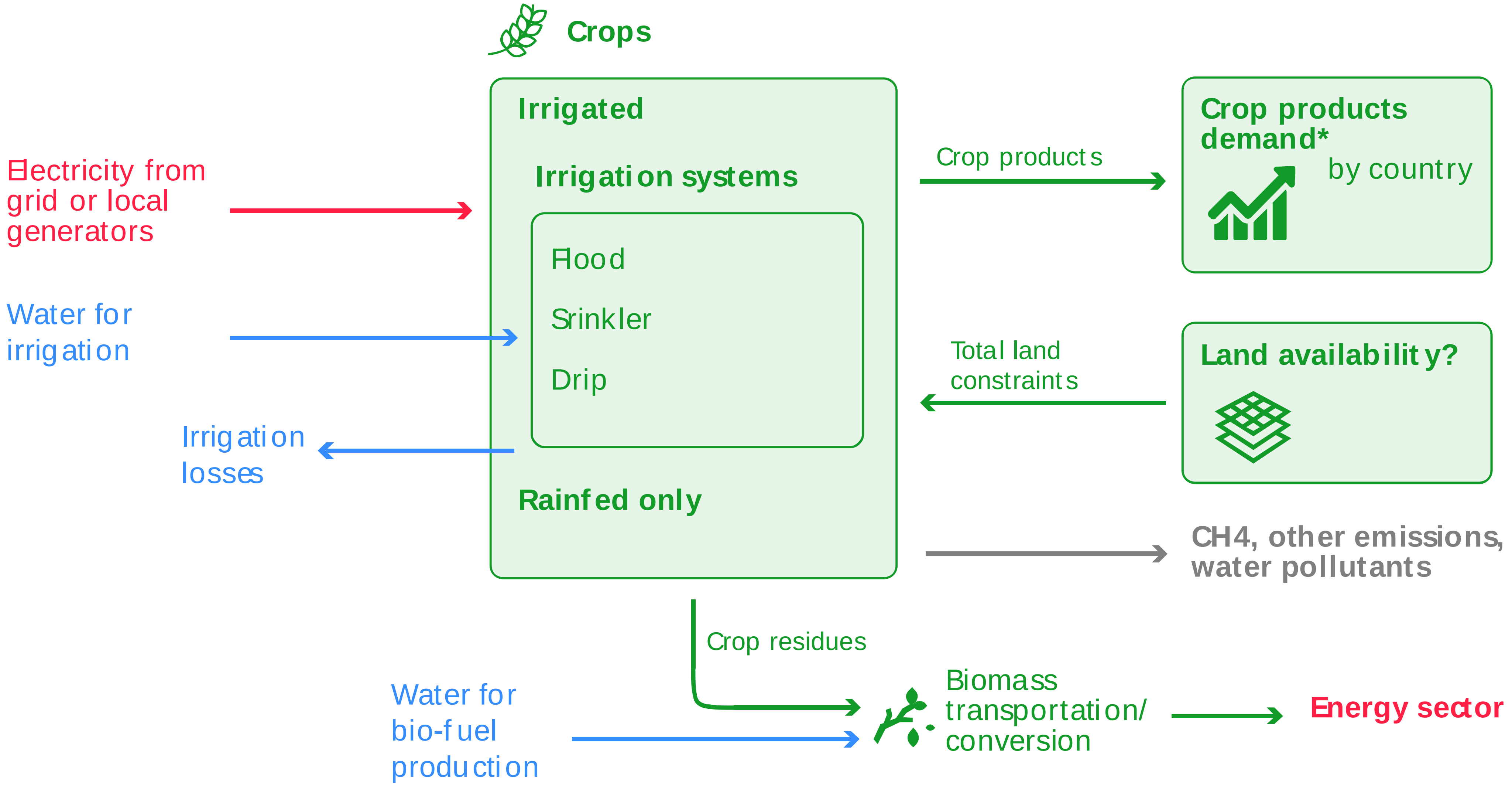
* exogenous
\+ limints are imposed based on informatio n from hydrolocial model

Energy system



* exogenous
^ crop residues can be transported as solid biomass or converted in ethanol, technolgies not represented here

Land system



* exogenous.
? total available area for agriculture based on historical data

Potential applications of the model for policy analysis

- Impacts of reduced resource availability and alternative allocation schemes
- Influence of technology-specific penetration targets on multi-sector development
- Quantification of investments required to meet future demands
- Identification of feasible transformation pathways for achieving socio-environmental objectives
- Effects of cooperative / non-cooperative strategies across countries

Input data

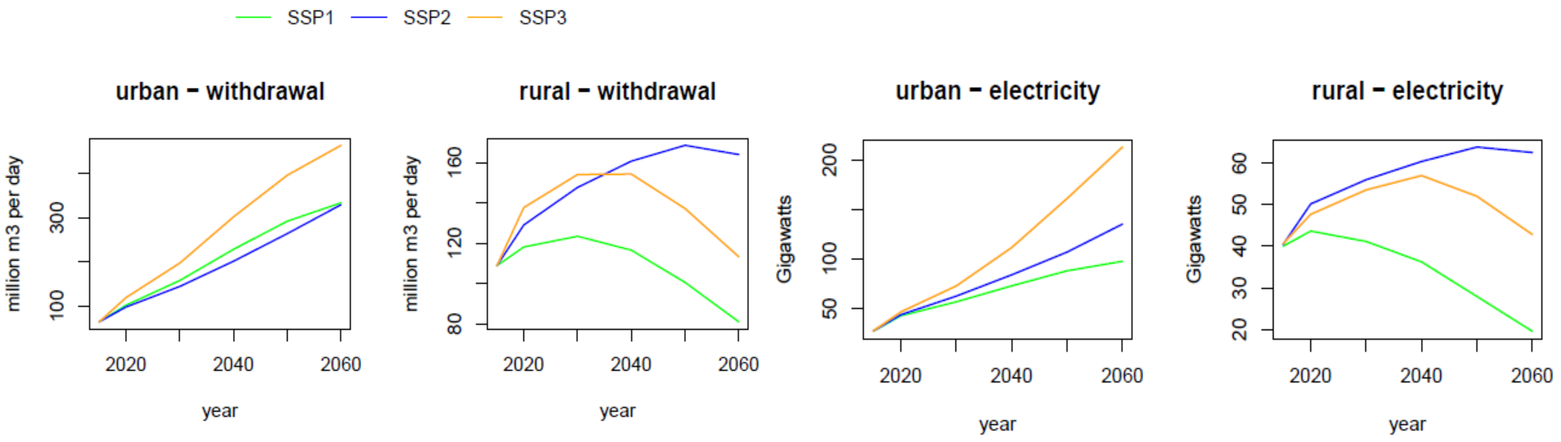
Mapping infrastructure, potentials and policies

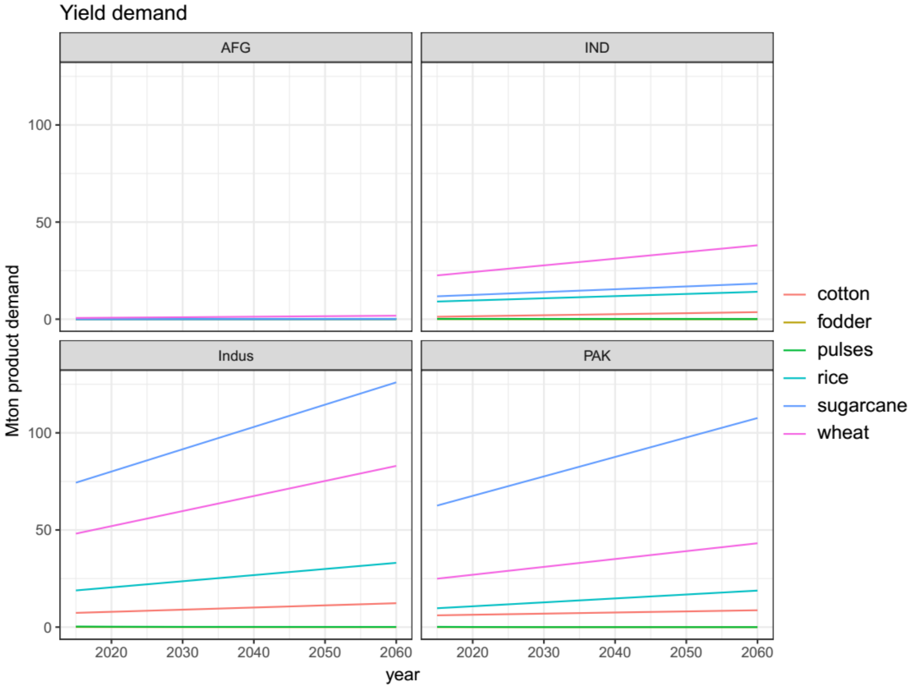
- Power generation and Reservoirs (existing and planned)
- Transmission and road networks
- Groundwater pumping capacity
- Wind, PV and hydropower potentials
- Assessment of demands

Installed Hydropower Capacity

- Land use and production maps
- Indus water treaty allocations
- Urban water transfers (e.g., Karachi)
- Irrigation technologies local data

Urban and rural water withdrawal and electricity demand





Shaping scenarios

Business-as-usual (or Baseline) with calibrated population, water, energy and crop demand

Projections based on SSP2 database and RCP6.0 climate assumptions

> Research question: *what are the costs and implications to achieve SDG in the region?*

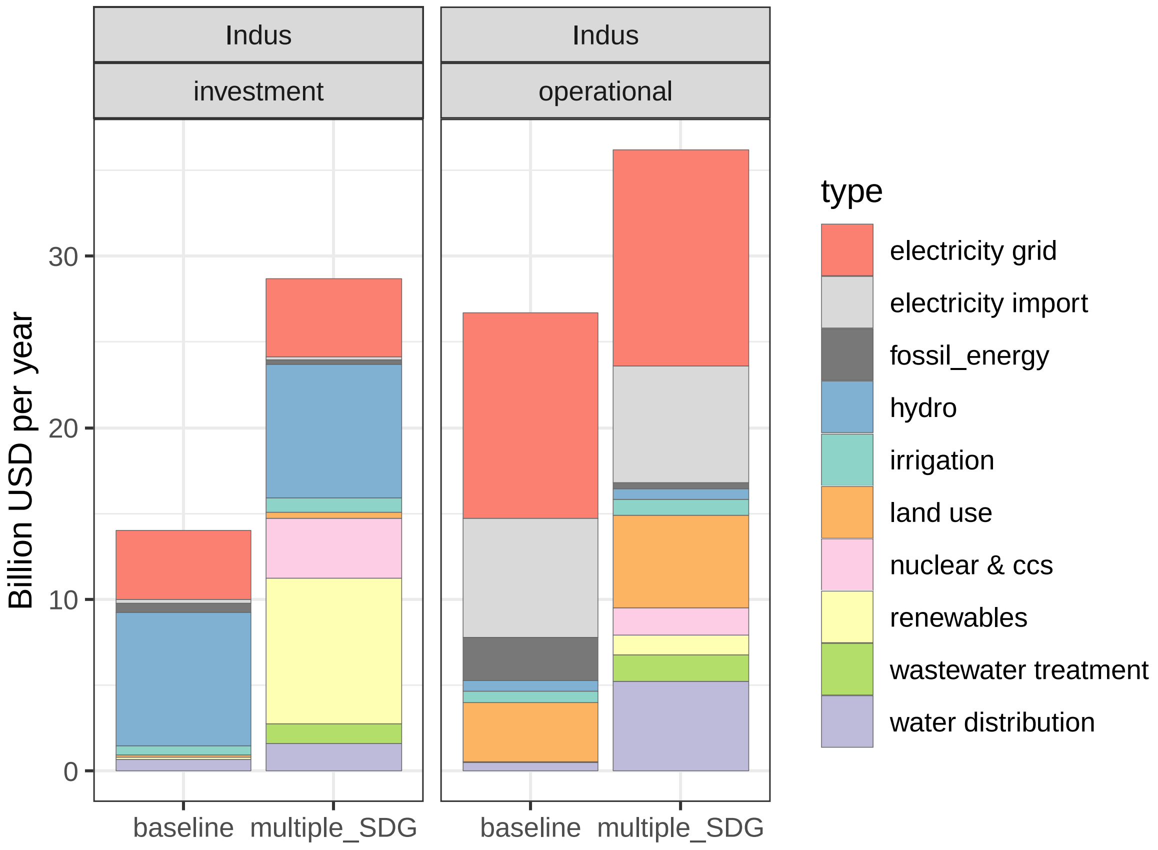
> Identify sectors, parameters, constraints that can be changed to model specific policies or changes that address the research question

	BAU	**SDG**
Energy	NDC implementation	NDCs + GHG targets for carbon neutrality in 2050
Water treatment/ sanitation	Projection of current rates with GDP growth	Increased access: i.e Urban sanitation access 95%
Water efficiency	No measures	Limits water withdrawals for agriculture
Environmental flows	No policy	Satisfy minimum requirements at Indus Delta
Land	Projected trend of flood irrigation use	Diverse irrigation possibilities and crop shifts

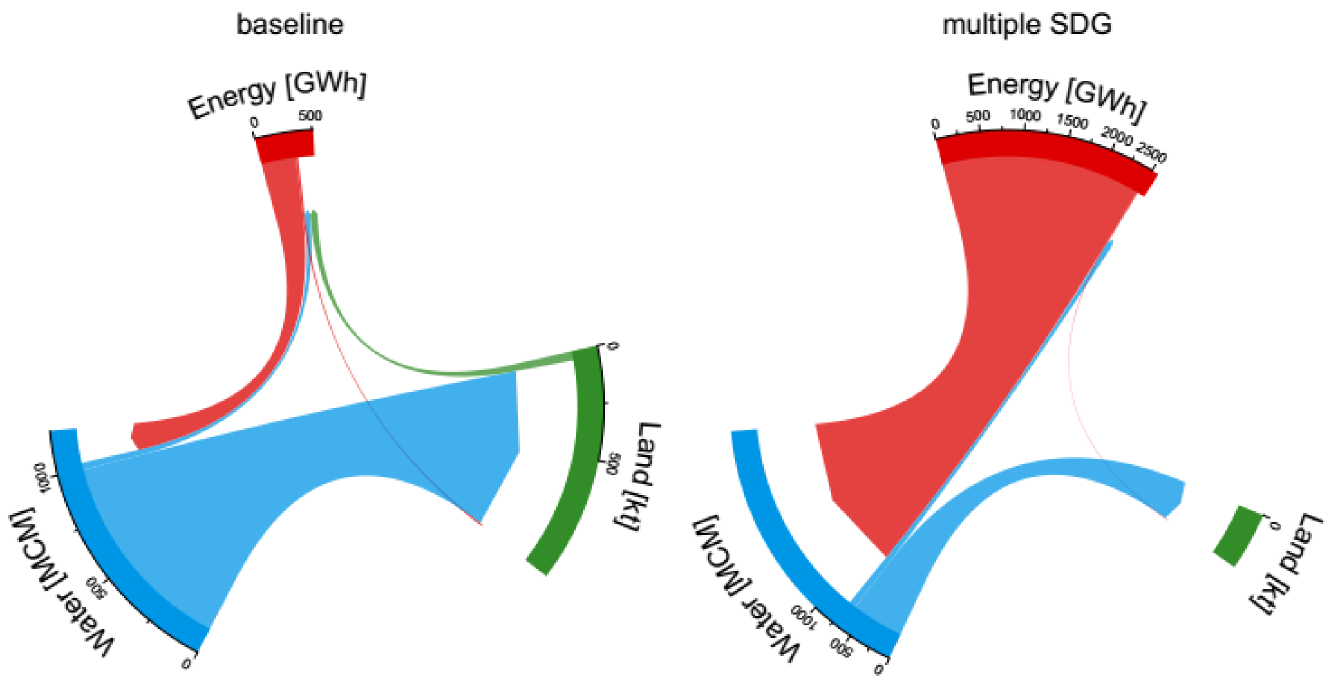
Model application

Comparing baseline with preliminary SDG 6 + 7 + 13 scenario

Average yearly costs for the entire basin (2020-2050)



Average yearly cross-sectoral energy, water and biomass flows



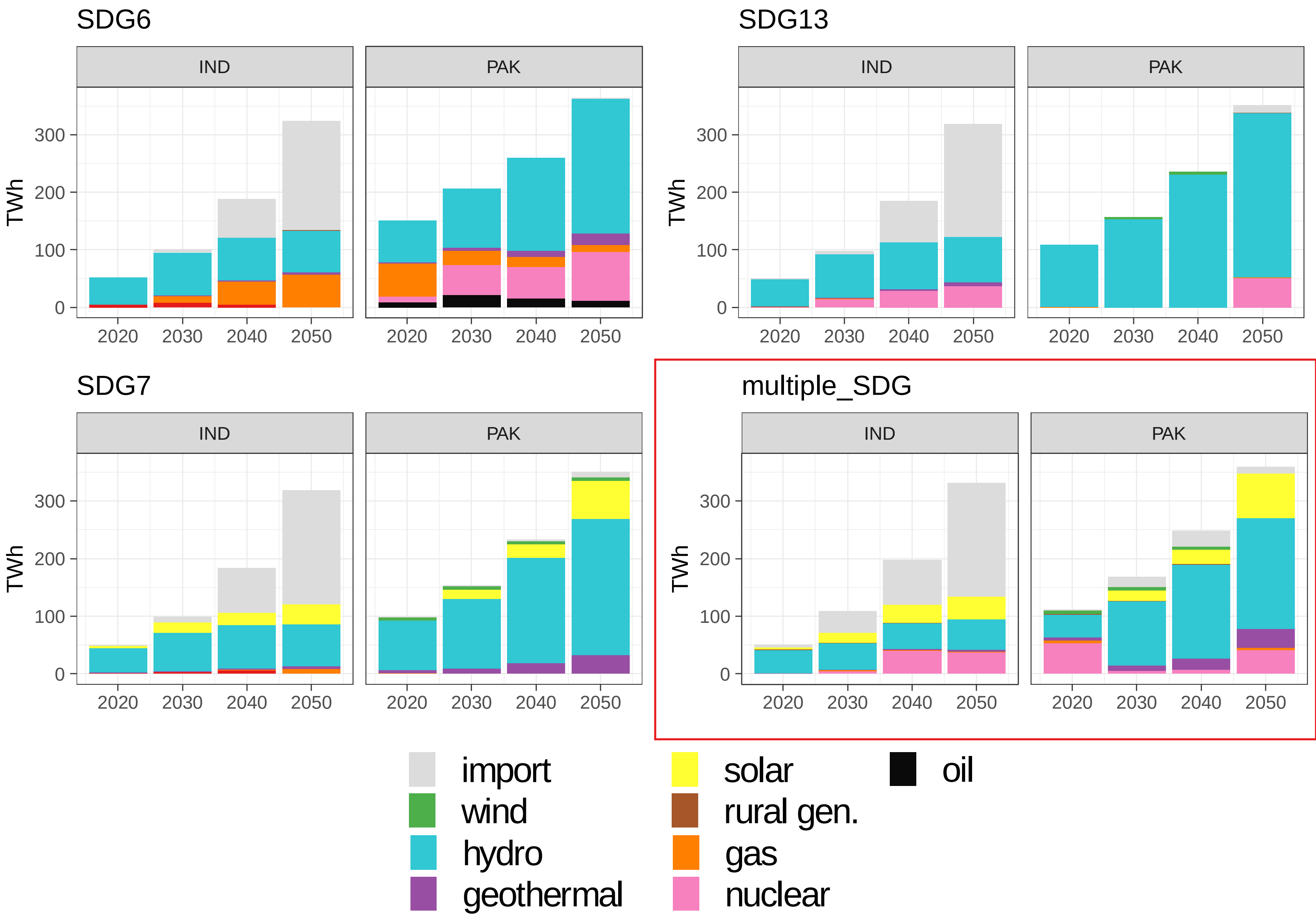
Low carbon tech and wastewater distribution and treatment.
Use of more efficient, but costly irrigation technologies.
Higher land requirements

Less water used in agriculture
Much more energy required for pumping, treating, water infrastructure, power plants

Importance of integrated framework

- More efficient solution
- Cost effective
- Take into account synergies

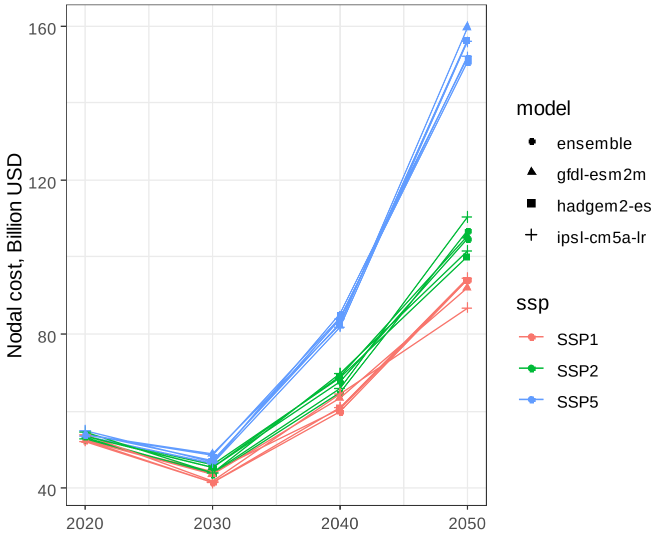
Electricity production under different scenarios

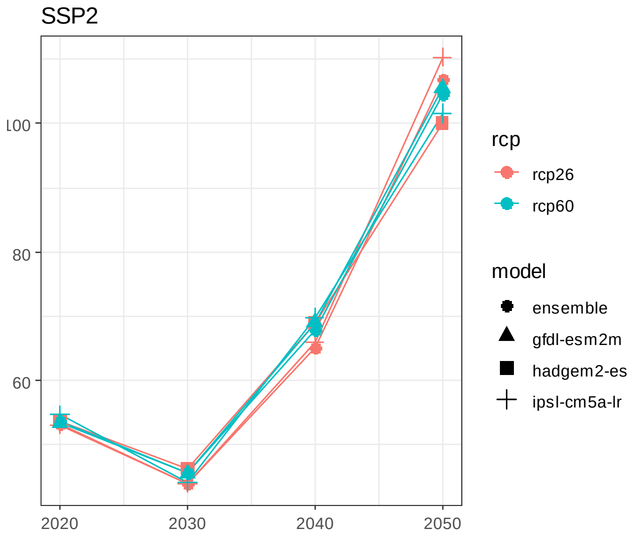


Sensitivity

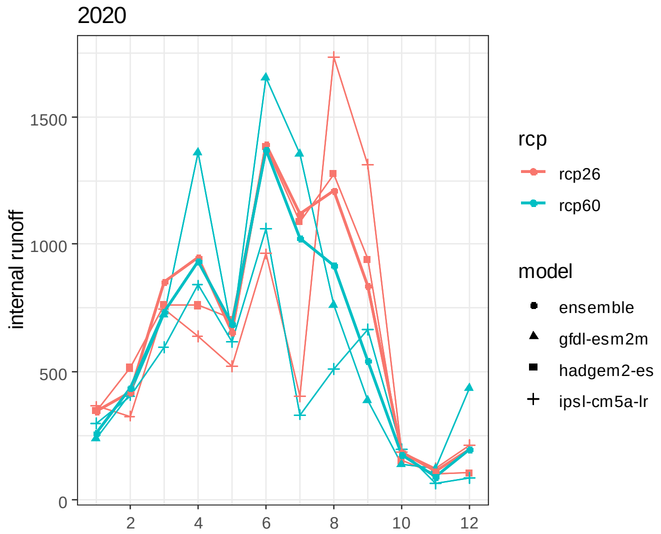
baseline scenario, different SSPs, climate models and climate scenarios (RCP 2.6 and 6.0)

Cost



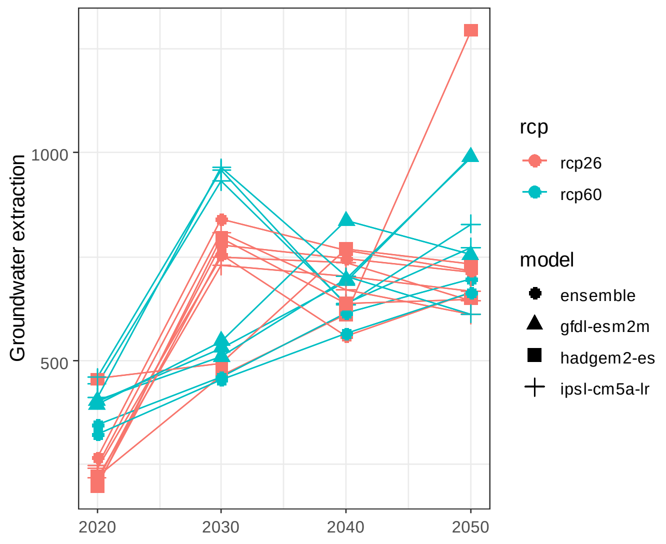


Internal runoff from CWATM same for all SSP



Water use:
Most noticeable differences among models and scenarios, rather than SSPs

Groundwater extraction



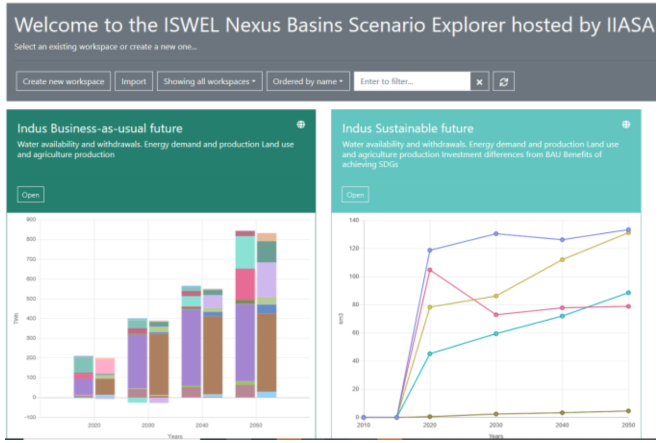
Open-source tool

- CWaTM and MESSAGEix are open-source tools, accessible and well documented online (limitation on solvers)
- NEST has it's own documentation (Vinca et al., 2020, GMD) open Github repository, interactive scenario explorer
- Limitations: Availability vs accessibility/ user friendly. Data
- Different audience:
  - ⇒ scientific: interest in data and model
  - ⇒ policy makers: interested in interactive tools

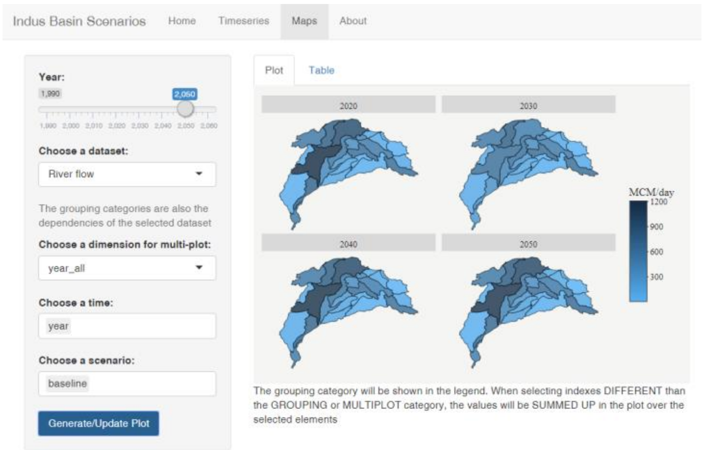
GitHub

https://github.com/iiasa/NEST

https://data.ene. iiasa.ac.at/nexus-basins/



http://vinca.shinyapps.io/indus_explorer



Geoscientific Model Development
An interactive open-access journal of the European Geosciences Union

The Nexus Solutions Tool (NEST): An open platform for optimizing multi-scale energy-water-land system transformations

Adriano Vinca[1,2], Simon Parkinson[1,2], Edward Byers[1], Peter Burek[1], Zarrar Khan[3], Volker Krey[1,4], Fabio A. Diuana[5,1], Yaoping Wang[1], Ansir Ilyas[6], Alexandre C. Köberle[7,5], Iain Staffell[8], Stefan Pfenninger[9], Abubakr Muhammad[6], Andrew Rowe[2], Roberto Schaeffer[5], Narasimha D. Rao[10,1], Yoshihide Wada[1,11], Ned Djilali[2], and Keywan Riahi[1,12]

Access, download and run NEST

Prerequisites:

- GAMS with active license, R, (Rstudio recommended), download and install the *gdxrrw* R package from here
- Check paths: GAMS, R

1. Download (or clone with Github) the folder from : https://github.com/iiasa/NEST
2. Unzip the folder
3. Open the R project and *multiple_scenario_new.r*
4. Define path: INDUS_IX_PATH (and restart Rstudio), update GAMS path in *basin_msggdx.r*)
5. RUN

Scenario names

Policy options

```
# Scenario names
scens = c(  'baseline0',
        'baseline',
        'no_planned_hydro',
        'baseline_coop',
        'no_hydro_EMI_res',
        'SDG6') # no flood in HIST_AGRICULTURE

# Data frame containing the various settings for each scenario
policy_settings.df = data.frame( scen_name = scens , stringsAsFactors = F ) %>%
    mutate( SSP = rep('SSP2', length(scens) ),
        climate_model = rep('ensemble', length(scens) ),
        climate_scenario = rep('rcp60', length(scens) ),
        REDUCE_RUNOFF = rep( F, length(scens) ),
        IND_TREAT =           c( T, T, T, F, T ,T ),
        ENV_FLOWS =           c( F, F, F, F, F ,F ),
        SDG6 =                c( F, F, F, F, F ,T ),          # SDG6
        EMISS =               c( F, F, F, F, T ,F ),         # GhG Emission
        SDG7 =                c( F, F, F, F, F ,F ),       # SDG7: solar/wind target
        GROUNDWAT =           c( F, T, T, T, T ,T ),      # groundwater extraction b
        CONSTRAINT_LAND =     c( F, F, F, F, F ,F ),     # constraint available land
        CHANGE_FOOD_DEMAND =c( F, F, F, F, F ,F ),      # change food demaind, custo
        FIX_ELEC_IMPORT =     c( F, T, T, T, T ,T ),
        SMART_IRR_WATER =     c( F, F, F, F, F ,F ),
        RAINFED_LAND    =     c( T, T, T, T, T ,T ),
        NOT_PLANNED_HYDRO = c( F, F, T, F, T ,F ),
        FULL_COOPERATION =  c( F, F, F, T, F ,F ),
        HIST_AGRICULTURE =  c( T, T, T, T, T ,T )
  ) %>%
  gather(key,value,2:length(.))
```

MESSAGEix-Nexus

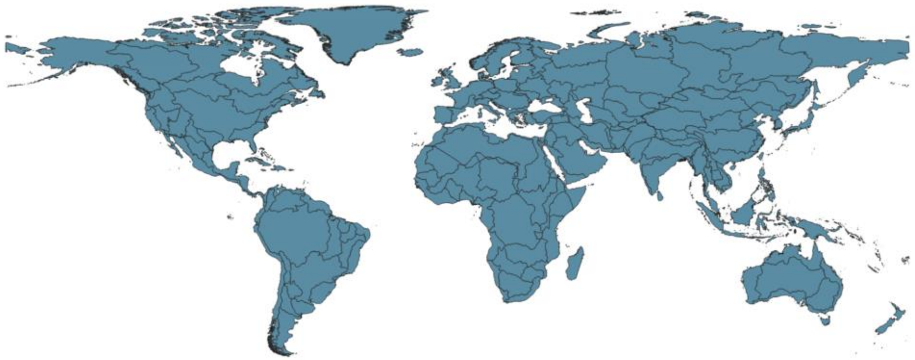
Module of the MESSAGEix-GLOBIOM family

Water System

- Water availibility
- Sectoral water demands
- Supply & distribution
- Water table depth

Harmonization & upscaling

Water Sector
~202 regions/basins



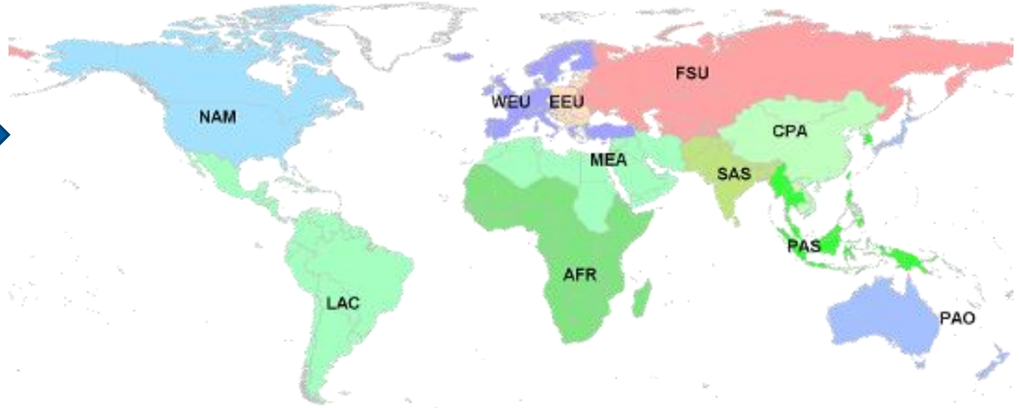
Land System

- Irrigation water
- Crop efficiency
- Crop types
- Biomass trajectories

GLOBIOM emulator

Energy Sector
11 region

water <->energy, land sector



*ISIMIP Output data from Global Hydrological Models - https://www.isimip.org/
**GLOBIOM – Global Biospehere Management model - https://iiasa.github.io/GLOBIOM/

Approach: MESSAGEix-GLOBIOM IAM

IIASA

Climate policy

2.6 W/m² target

SDG measures

Food Heathy (EAT-Lancet) diet, reduce food waste

Water Efficiency improvements, environmental flow constraints, piped water access, wastewater treatment

Energy Maximized electrification, phase-out traditional bio, cooling gap

Life on land Protected natural land (>30%)

Based on: Doelman et al. 2022, MESSAGE-ACCESS, Van Vuuren et al., 2019, Parkinson et al., 2019, Frank et al., 2021, Hasegawa et al., 2015, Pastor et al., 2019

Climate impacts

RCP 2.6, 6.0

- Hydrology: Precipitation pattern/runoff, groundwater intensity
- Crop Yield changes
- Renewable energy
- Cooling/heating demand
- Desalination potential
- Power plant cooling capacity

Based on: *ISIMIP 2b (Frieler et al. 2017),Byers et al., 2018, Gernaat et al., 2021 etc.)*

NAVIGATE

Approach – Climate Impacts

Climate impact	Approach	IMAGE	MESSAGEix-GLOBIOM
Renewable supply (wind, PV, CSP, hydro, bioenergy)	Different costs supply curves based on 0.5x0.5 grid calculations [Gernaat, et al. 2021]	Yes	Yes, hydropower only
Heating / cooling demand	Impact via population weighted HDD, CDD based on 0.5 x 0.5 grid [Byers, et al. 2018]	Yes	Yes
Water availability	Runoff and groundwater recharge from LPJmL calculated at 0.5 x 0.5 grid (ISIMIP 2b) [Frieler et al., 2017]	Yes	Yes
Crop yields	IMAGE: Crop yield change due to climate change calculated in LPJmL on 0.5 x 0.5 grid [Schaphoff et al., 2018] MESSAGE-GLOBIOM: Crop yields from [Byers et al., 2018] are used in the GLOBIOM model.	Yes	Yes
Power plant cooling & desalination potential	Power plant cooling: van Vliet 2016 Desalination: specific analysis	No	yes

Scenario	Climate Forcing (W/m²)	SDGs	Impacts
SSP2-noCF	6.0	No additional effort	Frozen to 2020
SSP2-CF	6.0	No additional effort	
SSP2-SDG-noCF	6.0	2 ZERO HUNGER; 6 CLEAN WATER AND SANITATION; 7 AFFORDABLE AND CLEAN ENERGY; 15 LIFE ON LAND	Frozen to 2020
SSP2-SDG-CF	6.0	2 ZERO HUNGER; 6 CLEAN WATER AND SANITATION; 7 AFFORDABLE AND CLEAN ENERGY; 15 LIFE ON LAND	
SSP2-26-SDG-CF	2.6 13 CLIMATE ACTION	2 ZERO HUNGER; 6 CLEAN WATER AND SANITATION; 7 AFFORDABLE AND CLEAN ENERGY; 15 LIFE ON LAND	
SSP2-26-CF	2.6 13 CLIMATE ACTION	No additional effort	

SSP2 – Middle of the Road Socio Economic Pathway
CF – Climate Feedback

Access MESSAGEix-Nexus (in progress)

GitHub code

documentation

MESSAGEix

https://github.com/iiasa/message_ix

https://docs.messageix.org/en/stable/

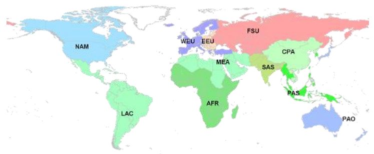
MESSAGEix-GLOBIOM model

https://github.com/iiasa/message-ix-models/

https://docs.messageix.org/projects/models/en/latest/

Upcoming work - Flexibility across scales

MESSAGEix (Global)

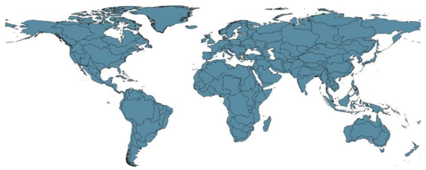


Downscale/Prototype
(existing method)

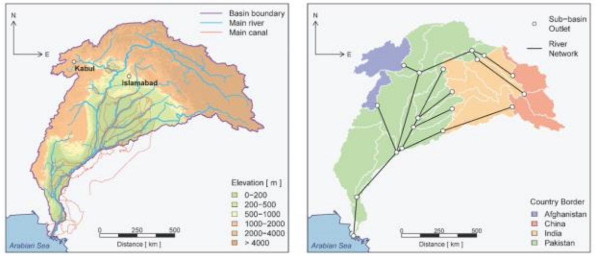
MESSAGEix-Country

Updated country scale model with water representation as in global model

Add water-nexus to the country model



NEST Indus (Basin)



Improve existing model structure to be flexible to other regions in future

Bottom-up approach/sub-catchment level

MESSAGEix-Nexus (National/Basin)

The way forward

Summary of Key Challenges & Recommended Actions

Scope & Definition

Key Challenges

- Vague definition can be barrier to applications
- Restrictive definition could hamper developments

Recommended Actions

- Establish nexus community of practice
- Establish online platform to maintain, curate and share nexus knowledge
- Hold expert workshops to discuss scope & definition
- Maintain evolving nexus definitions & scope on nexus platform

Methodology

Key Challenges

- Lack of access to nexus data across sectors and scales is an issue
- Numerous methodologies without a comparison framework

Recommended Actions

- Create open-source central nexus data repository with standardized data units
- Organize inter-model comparison with controlled case studies
- Online dashboard to communicate inter-model results to public

Application

Key Challenges

- Limited explicit nexus implementation in practice
- Lack of nexus metrics & policy instruments
- Lack of communication between science, policy & public

Recommended Actions

- Maintain nexus success stories and failures in online platform to promote applications
- Establish clear nexus metrics and reporting mechanisms to be used by funders and governments as well as for impact and project assessments

Future Directions

Key Challenges

- Inertia & existing siloed structure of institutions
- Tradeoffs between sectors & stakeholders
- Short terms of policymakers
- Lack of training & public awareness

Recommended Actions

- Maintain list of short and long-term nexus challenges and goals with corresponding links to relevant actions, data, case studies and knowledge on the nexus platform

Kahn et al., 2022, Frontiers in Environmental Science

Main conclusions

- Integrated analysis gives more complete answers than single sector assessments
- Difficult to compare/validate results:
  More multi-model intercomparison is needed;
  Need for more shared common assumptions in modelling community (like SSP, SDG for water and land)
- Open-source, where to focus our efforts: code, data or interactive tools?
  - ⇒ Scientists: data, well documented code/software
  - ⇒ Policy makers: simplified interactive models, results visualization explorers

Thank you very much for your attention!

For more detail about the model, scenarios and results:

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nature sustainability
ARTICLES
https://doi.org/10.1038/s41893-020-00654-7
Check for updates

Transboundary cooperation a potential route to sustainable development in the Indus basin

Adriano Vinca[1,2]✉, Simon Parkinson[1,2], Keywan Riahi[1,2,3], Edward Byers[1], Afreen Siddiqi[4,5], Abubakr Muhammad[6], Ansir Ilyas[6], Nithiyanandam Yogeswaran[7], Barbara Willaarts[1], Piotr Magnuszewski[1], Muhammad Awais[1,2], Andrew Rowe[2] and Ned Djilali[2,8]

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Climate-Land-Energy-Water Nexus Models Across Scales: Progress, Gaps and Best Accessibility Practices

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Back up slides

Multiple objective scenario: water use

Mostly nuclear replacing fossil fuel, cooling technologies with low water consumption (e.g. air cooling)