MESSAGEix-GLOBIOM and NEST: modelling land-use, water and energy systems to assess SDGs and climate impacts at the global, national and basin scales

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ETSAP Webinar: Integrating Sustainable Development Goals Into Energy Systems Modelling
Summary

- ECE research and Energy-Water-Land research and tools
- Models and previous analyses
  ⇒ MESSAGEix-GLOBIOM
  ⇒ NEST
- Data requirement
- Ongoing activities
Multiple environmental challenges (climate crisis, ecosystems collapse) with negative impacts on well-being and inherently connected to social challenges (widening inequality, nationalism and political fragmentation).

Difficulty of the human systems to stay within the long-term physical boundaries of the planet when the objectives of the political reality are often short-term.

Many of the pressing environmental problems are global in nature but require regional, national and local implementation, further amplifies these challenges.
Climate-Land (food)-Energy-Water Nexus

ECE tools used to explore SDGs and climate interconnections:

- IIASA IAM, including MESSAGEix-GLOBIOM
- The Nexus Solutions Tool (NEST)
- Hotspot explorer
Global Hotspots Assessment

Byers et al., 2018, ERL

Hotspot explorer
https://hotspots-explorer.org/
ISWEL: Global analysis of vulnerability hotspots

3 climate scenarios (1.5 / 2 / 3 °C)

3 Socioeconomic scenarios (SSPs 1-3)

Indus basin multi-sector risk score 2.0°C
Headline results

~2.6 billion living in hotspots with multi-sector risk at 2.0°C in 2050

⇒ This approximately halves/doubles in 1.5°/3.0 °C

Cumulative risks of 1.5°C warming

Population affected by various risks (millions of people)

- Heatwave exposure: 3,960
- Water stress: 3,340
- Risk to power production: 334
- Crop yield change: 35
- Habitat degradation: 91

Models
MESSAGEix-GLOBIOM

- optimize the energy system to satisfy specified energy demands (and other constraints) at the lowest costs
- 5-10 year timesteps
- 11-14 macro regions
- Linear programming optimization model (GAMS), python and R API
- Open access (non free solver)

Interlinkages with other sectors and feedback effects

MESSAGEix-GLOBIOM

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Global Biosphere Management Model (GLOBIOM)

- Partial equilibrium model
- Trade: market equilibrium
- Flexible demand regions aggregates (37 regions)
- Spatially explicit supply
- Recursively dynamic: 1 to 10 years time step
- Linear programming optimization model (GAMS)
- Open access strategy under development
Interaction MESSAGEix-GLOBIOM

- Lookup table for integration: 2-dimensional scenario matrix
  - AFOLU carbon prices: 12 different price trajectories up to 2100
  - Biomass prices for bioenergy: 7 different price trajectories up to 2100
  - In total 84 scenarios – MESSAGE can then interpolate
To represent land-based mitigation potentials in IAMs, they need information on the biomass and emission reduction potential for bioenergy.

Lookup-table allows to represent:

1. Biomass supply curve conditional a given carbon price
2. Marginal abatement cost curve conditional on a given biomass demand

Land-use SDG under 1.5C mitigation target: Implications on land related indicators

carbon budget, results for 2050

• Considering full SDGs requires 30% lower water for irrigation
• 19% lower demand for livestock while increasing food demand by 10% in full SDG
• Higher natural forest areas across all indicators
# Key water-energy-climate tradeoffs

<table>
<thead>
<tr>
<th></th>
<th>Energy-land-climate</th>
<th>Water</th>
<th>SDGs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>2.0°C</td>
<td>BAU</td>
<td></td>
</tr>
<tr>
<td>1.5°C</td>
<td>1.5°C</td>
<td>BAU</td>
<td></td>
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<tr>
<td><strong>SDG6</strong></td>
<td>2.0°C</td>
<td>SDG6</td>
<td></td>
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<tr>
<td><strong>SDG6 + 1.5°C</strong></td>
<td>1.5°C</td>
<td>SDG6</td>
<td></td>
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</tbody>
</table>

**Water-intensity** of energy sector
- Solar PV, wind
- Nuclear, CCS, Hydro
- Fossil fuel extraction & bioenergy

**Energy-intensity** of water supply & treatment
- Distribution, GW pumping & desalination
- Recycling and wastewater treatment

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Parkinson, S., et al., *Environmental Research Letters*, 2019
Water-stressed regions need to find alternative sources of freshwater supply to meet increasing demands!
Infrastructure demand balancing clean water and climate

+40% to meet 1.5°C + SDG6

Parkinson, S., et al., *Environmental Research Letters*, 2019
SDG indicators: LED in comparison to Baseline, 2C and 1.5C Scenarios (adapted from IPCC SR1.5, Figure 5.3a)

Source: IPCC SR1.5, adapted from Figure 5.3a
Nexus Solutions Tool (NEST)

Vinca et al., 2020, GMD

Vinca et al., 2020, Nat Sust
Transboundary Models

**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

**Minimize total system cost**

**Integrated Solutions for the Water-Energy Land Nexus**

Vinca et al., 2020, GMD
Water system

- Water distribution
  - Pumping
  - Desalination
  - Water deviation
  - Water distribution
  - Surface water
    - Environmental flows
  - Hydroelectric potential
- Water demand
  - Urban* (and industrial)
  - Rural*
    - Energy sector
    - Land sector
- Return flows*
  - Urban
  - Rural
  - Wastewater treatment and recycle
  - Water return flows from energy sector
  - Electricity

* exogenous
+ limits are imposed based on information from hydrological model
Energy system

Power plants
- Fossil (natural gas, coal, oil, CCS)
- Nuclear
- Biomass & co-firing
- Solar & Wind
- Hydroelectric

Power transmission
- Transmission HV (to other nodes)
- Distribution (internal)
- Rural generation
  - Diesel generator
  - Small PV
  - Ethanol generator
  - Bio-fuel\(^\wedge\) (ethanol or solid biomass)

Electricity demand
- Urban\(^*\) (and industrial)
- Rural\(^*\)
- Water sector
- Land sector

\(^*\) exogenous
\(^\wedge\) crop residues can be transported as solid biomass or converted in ethanol, technologies not represented here

CO\(_2\) and other emissions

Water for cooling

Bio-fuel\(^\wedge\) (ethanol or solid biomass)

Return flows

Hydroelectric potential

\(23\)
Land system

Crops

Irrigated

Irrigation systems

- Flood
- Sprinkler
- Drip

Rainfed only

Crop products demand* by country

Total land constraints

CH4, other emissions, water pollutants

Land availability?

Crop products

Electricity from grid or local generators

Water for irrigation

Irrigation losses

Water for bio-fuel production

Crop residues

Biomass transportation/conversion

Energy sector

* exogenous.

Total available area for agriculture based on historical data
Research Question
How to strike a balance between objectives? ... and at what cost?

SDGs

2. Zero Hunger
3. Clean Water and Sanitation
7. Affordable and Clean Energy
13. Climate Action

Transboundary Agreements

India
Pakistan
Afghanistan
Benefits and changes with transboundary cooperation

Ideal cooperation:
• Electricity trade
• Common food hub
• Optimal river flow allocation

Socio-Environmental benefits

Average yearly expenditure
Data
Data

Sources
- Socioeconomic and climate pathways (SSP, RCP)
- Global/National database (e.g. IEA, WB, FAO)
- Other models (e.g. demand projections)
- Local data

Format
- Timeseries vs parameters (efficiency, emission factor)
- Regional definition
- Spatial data, upscaling/downscaling

Use
- Model setup, parametrization
- Model validation
- Scenario definition

Open access: issue and opportunity
https://docs.messageix.org/projects/models
Power plant cooling technology shares at the basin-country level

- **Once through cooling - freshwater**
- **Closed-loop cooling - freshwater**
- **Once through cooling – sea water**
- **Air cooling**

Data sources: Raptis et al. (2016); WEPP (2015); hydroBASINS (2015); Fricko et al. (2016)
Input data of NEST

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

Installed Transmission Capacity

Groundwater Pumping in 2010 [billion cubic meters per year]

Wind and PV average capacity factor (based on hourly data)

Urban and rural water withdrawal and electricity demand

Land use and production maps
- Indus water treaty allocations
- Urban water transfers (e.g., Karachi)
- Irrigation technologies local data
Ongoing activities
MESSAGEix-Nexus Module (in progress)

- Water Sector
  - ~210 regions/basins
  - Harmonization & upscaling
  - Water <-> energy, land sector

- Energy Sector
  - MESSAGE-GLOBIOM
    - 11 region
  - Irrigation Water

LPJmL*
- Hydrological data from ISIMIP2b

*LPJmL – Dynamic Global Vegetation Model (DGVM)- [https://www.isimip.org/impactmodels/details/81/](https://www.isimip.org/impactmodels/details/81/)

MESSAGEix-Nexus Module (in progress): climate impacts

**Water System**
- Water availability
- Potential of desalination

**Energy System**
- AC cooling demand and gap
- Hydropower, solar, wind potentials
- (Water for cooling power plants)

**Land System**
- Crop yields
- Evapotranspiration

Water <-> energy, land sector
Flexibility across scales (in progress)

MESSAGEix-Nexus (Global)

MESSAGEix-Country

Updated country scale model with water representation as in global model

Top-down approach to downscale energy & water components from national model

NEST Indus

MESSAGEix-Nexus (National/Basin)

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

Bottom-up approach/sub-catchment level
MESSAGEix-GLOBIOM and NEST: modelling land-use, water and energy systems to assess SDGs and climate impacts at the global, national and basin scales

Thank you!

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References:
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IPCC SR1.5
MESSAGE-GLOBIOM documentation
https://hotspots-explorer.org/
Visit the IAMC 1.5°C Scenario Explorer at [https://data.ene.iiasa.ac.at/iamc-1.5c-explorer](https://data.ene.iiasa.ac.at/iamc-1.5c-explorer)
Integrated water systems modeling in MESSAGEix
Access to piped water infrastructure under different scenarios

Baseline

SDG6 Pathway

Target 6.1
Universal access to safe drinking water by 2030
Access to wastewater treatment under different scenarios

Baseline vs SDG6 Pathway

Fraction of return-flow treated vs Year

South Asia, Sub-Saharan Africa, Eastern Europe, M. East & N. Africa, Latin America, Former Soviet, Pacific Oceanic, Western Europe, Pacific Asia, North America, Central Asia (China)

Target 6.3: Half of all wastewater treated by 2030
Projecting infrastructure demand under clean water goals

Projected capacity in 2030 [million cubic meters]

Criteria for expansion
- Distance to coastline
- Water scarcity level from CWatM

Where can we expect advanced water technologies to expand?

Projected capacity in 2030 [million cubic meters]

Gridded income projections, municipal withdrawals and return flows

Gridded piped water access and wastewater collection projections