NUS National University of Singapore

Strategic Repurposing of Abandoned Cropland for Aquifer Recharge and Renewable Energy Boosts Water-Food-Energy Sustainability

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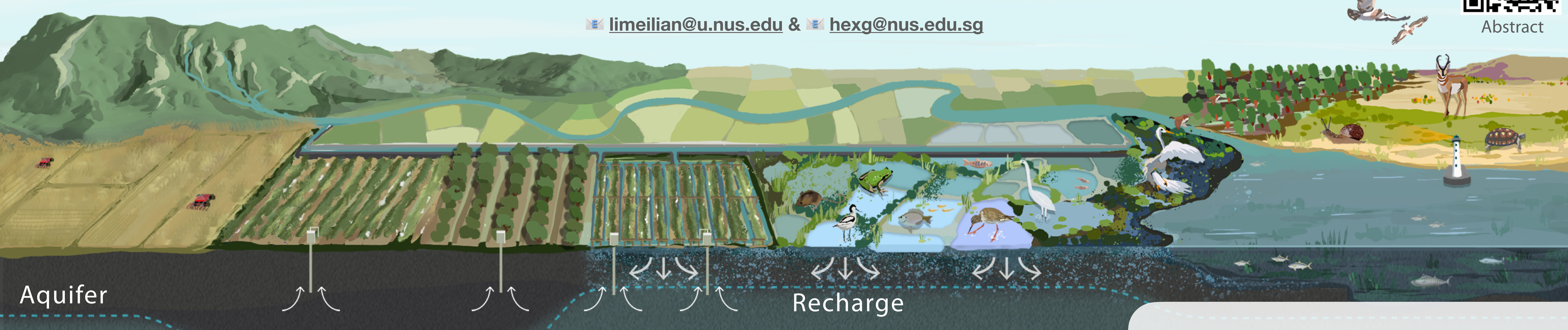
Abstract

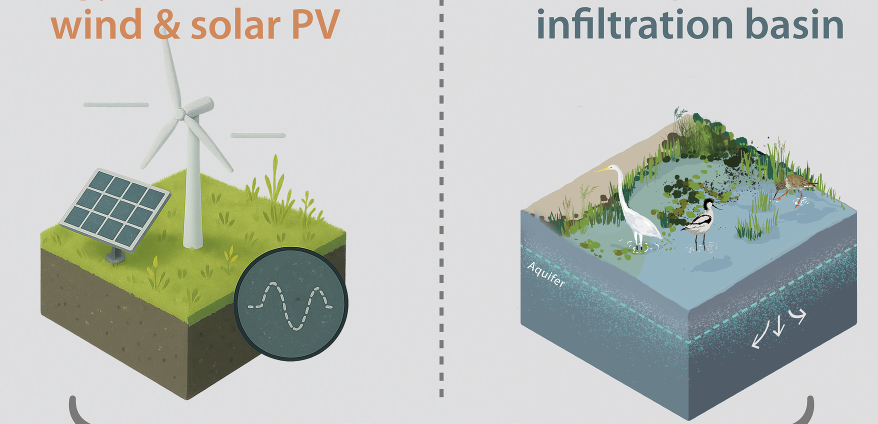


Takeaways

- **Integrated land-use planning tool**: A multi-objective spatial optimization framework to repurpose abandoned cropland for **solar**, **wind**, and **managed aquifer recharge (MAR)**, jointly supporting energy, water, and economic goals.
- **Suitability and potential assessment**: Global assessment of siting suitability and estimation of theoretical maximum potential (~1.1×10^4 km^3/year for MAR, ~440 GW for solar, ~111 GW for wind).
- **High-resolution spatial analysis**: High-resolution (30 arc-second) spatial analysis enables fine-scale mapping and reveals optimal locations for effective resource use.
- **Optimization under real-world constraints**: These results provide a foundation for spatial optimization that will incorporate meteorological and hydrological constraints to inform real-world decision-making.

Motivation

Renewable energy expansion	Water storage expansion
Triple renewable power capacity needed by 2030 to stay on the 1.5°C pathway (IEA, 2023)	**460** km^3/year of water storage needed for future irrigation (Schmitt et al. 2022)
Variable Renewable Energy (VRE): onshore wind & solar PV	Managed Aquifer Recharge (MAR): infiltration basin



Challenges & Opportunities

- Land-use conflicts
- Multi-objective conflicts

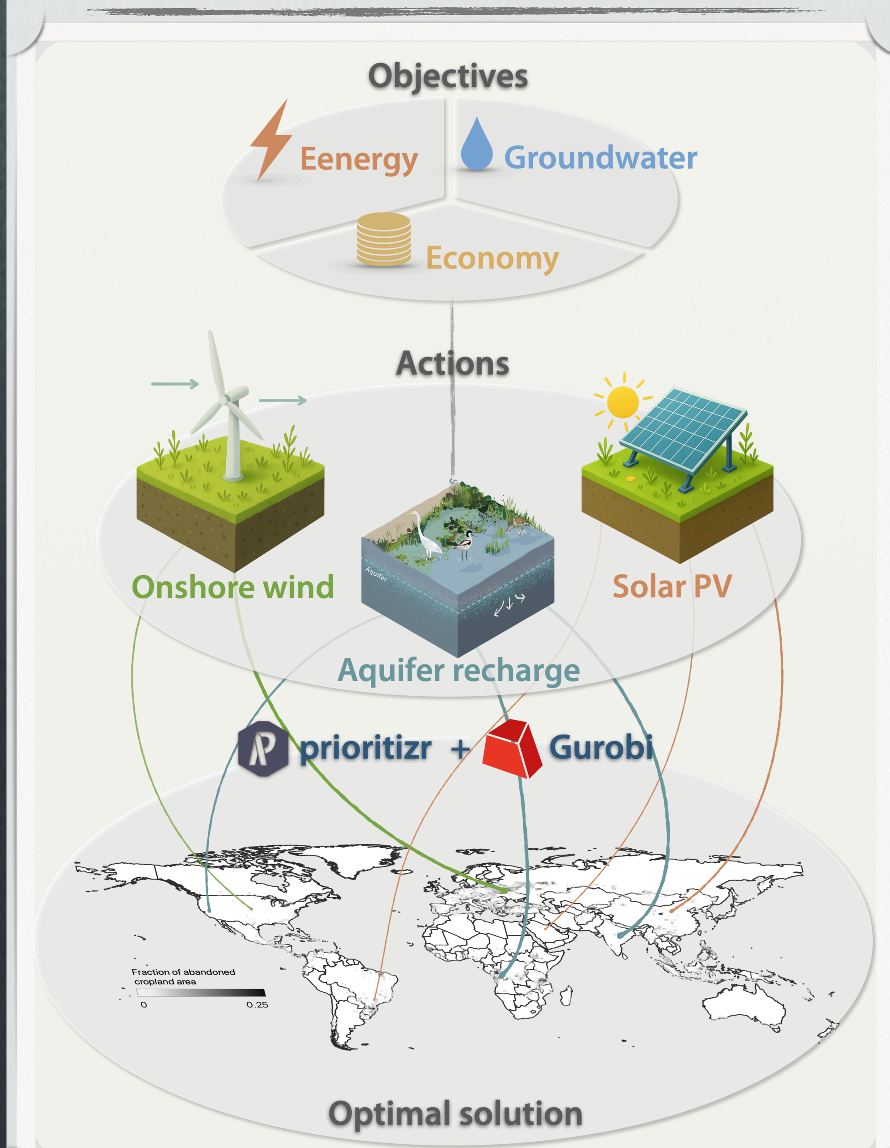
→ Integrated planning on abandoned cropland

Goal

Develop an integrated spatial planning framework for MAR and VRE to:
- Quantify potential on abandoned cropland
- Pinpoint optimal locations for water, energy, and economic objectives

Methods

1. Overall Framework



2. Action Suitability

Onshore wind Wind speed > 6 m/s

Solar PV Global Horizontal Irradiation (GHI) > 4 kWh/m²/day

Shared constraints
- Elevation < 2000 m
- Slope ≤ 20%
- Population density ≤ 100 inhabitants/km²
- Distance to road ≤ 50 km
- Distance to grid ≤ 50 km
- Exclude protected areas and water bodies
- Sites with ≥ 20 MW potential

Reference: Sterl et al. (2022)

Aquifer recharge: infiltration basins
- Groundwater depth ≥ 6 m
- Ks ≥ 10 cm/day
- N (Monthly average temperature > 5°C) > 3
- (Recharge capacity - PET) > 50% of recharge capacity

Abandoned cropland: Zheng et al. (2023)

3. Resource Potential

- Deployable capacity for varibale renewable energy (VRE):

$$\text{capacity}_{\text{VRE}} = \underbrace{\rho_{\text{deploy}}}_{\text{Deployable capacity density [MW/km}^2]} \times \overbrace{A_{\text{suitable}}}^{\text{Suitable area [km}^2]} \times \underbrace{D_{\text{usable}}}_{\text{Land use discount factor [\%]}}$$

→ meteorologic conditions → actual generation

- Recharge capacity for managed aquifer recharge (MAR):

$$\text{capacity}_{\text{MAR}} = \overbrace{r_{\text{recharge}}}^{\text{Recharge rate [m/day]}} \times A_{\text{suitable}} \times \overbrace{T_{\text{recharge}}}^{\text{Recharge time [day]}}$$

→ hydrological conditions → actual recharge

4. Economic Analysis & Optimization

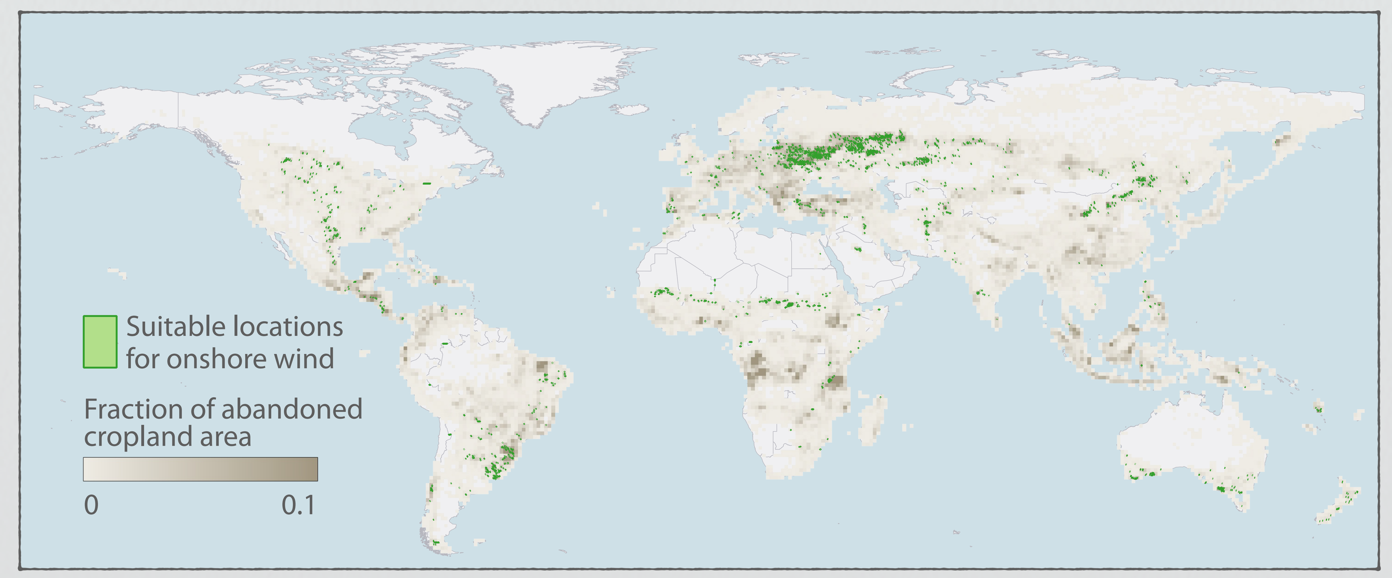
Objective function:

$$\min \underbrace{\text{cost}^{\text{total}}}_{\text{Total cost}} = \sum_a \sum_p \left(\overbrace{\text{cost}^{\text{cap}}_{a,p}}^{\text{Capital cost of action } a \text{ at pixel } p} + \underbrace{\text{cost}^{\text{O\&M}}_{a,p}}_{\text{Operation and maintenance cost}}\right) \times \overbrace{I_{a,p}}^{\text{Binary indicator of selecting action } a \text{ at pixel } p}$$

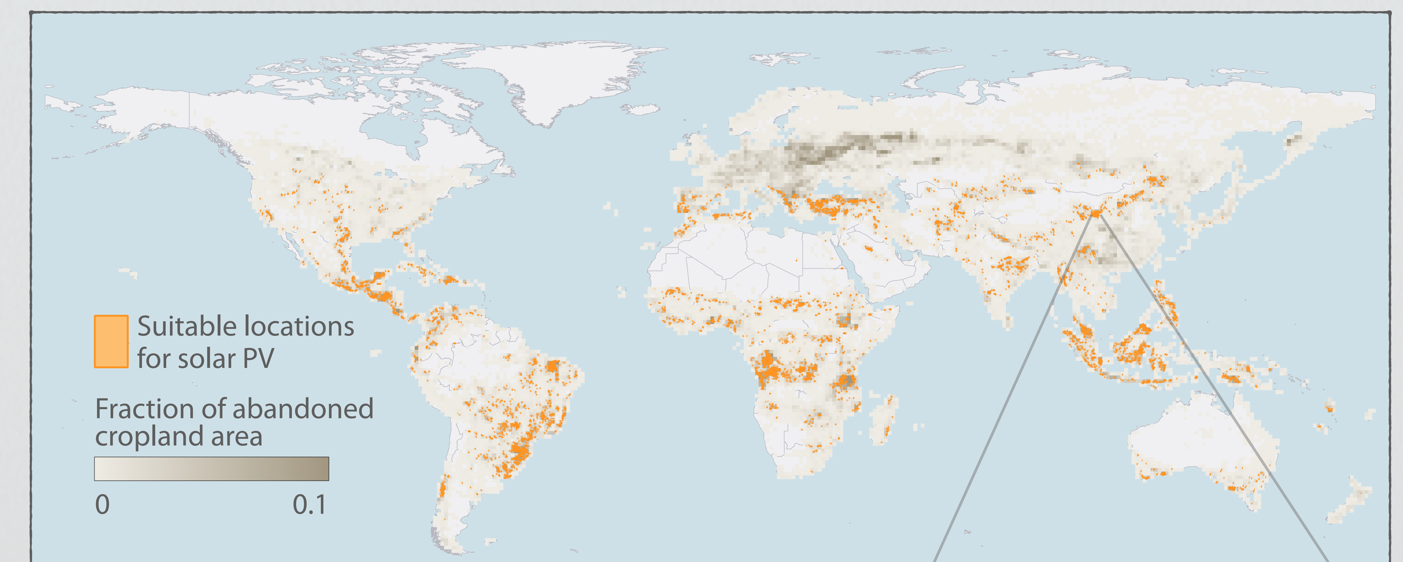
Subject to:
- Actual energy generation ≥ renewable energy targets
- Actual groundwater storage increase ≥ groundwater storage targets

Results

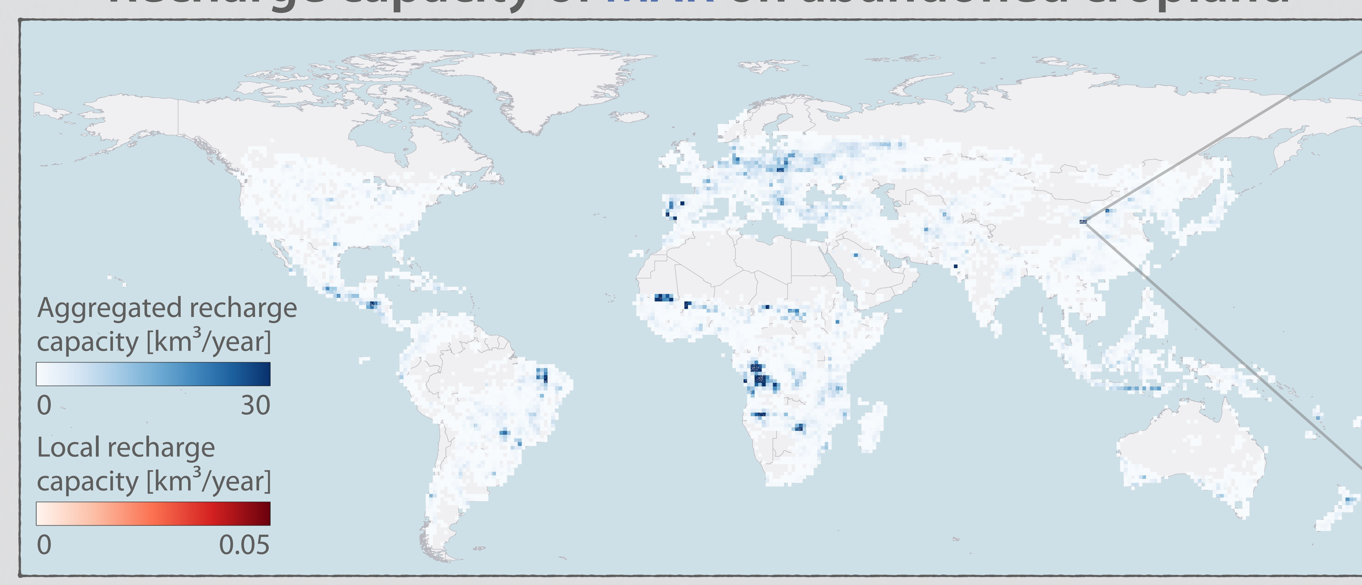
Suitable onshore wind locations on abandoned cropland



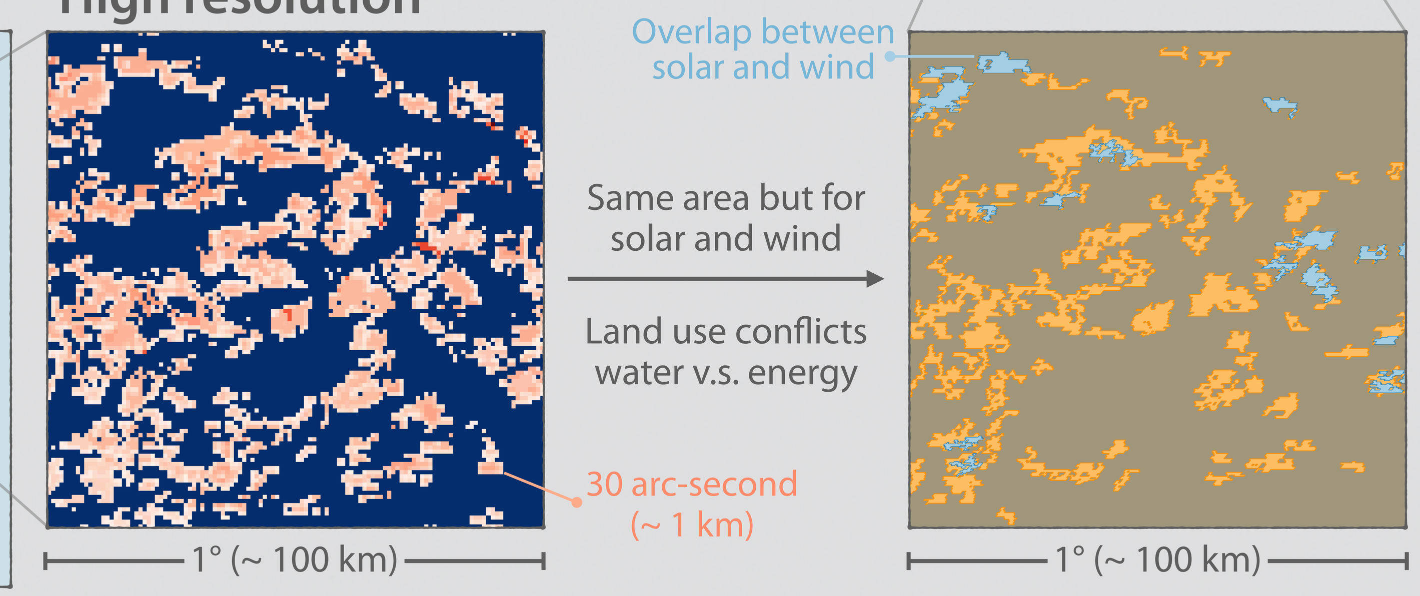
Suitable solar PV locations on abandoned cropland



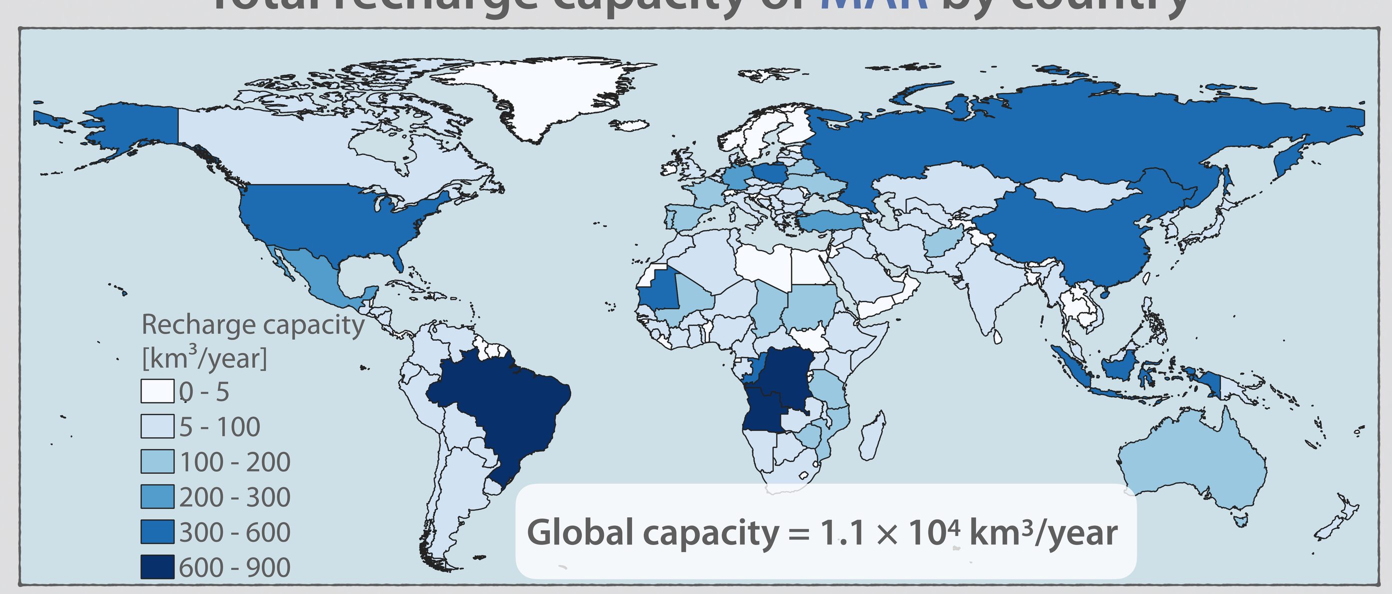
Recharge capacity of MAR on abandoned cropland



High resolution



Total recharge capacity of MAR by country



Total deployable capacity of VRE by country