science for global insight

Hotspots in land and water resource uses on the way toward achieving the Sustainable Development Goals

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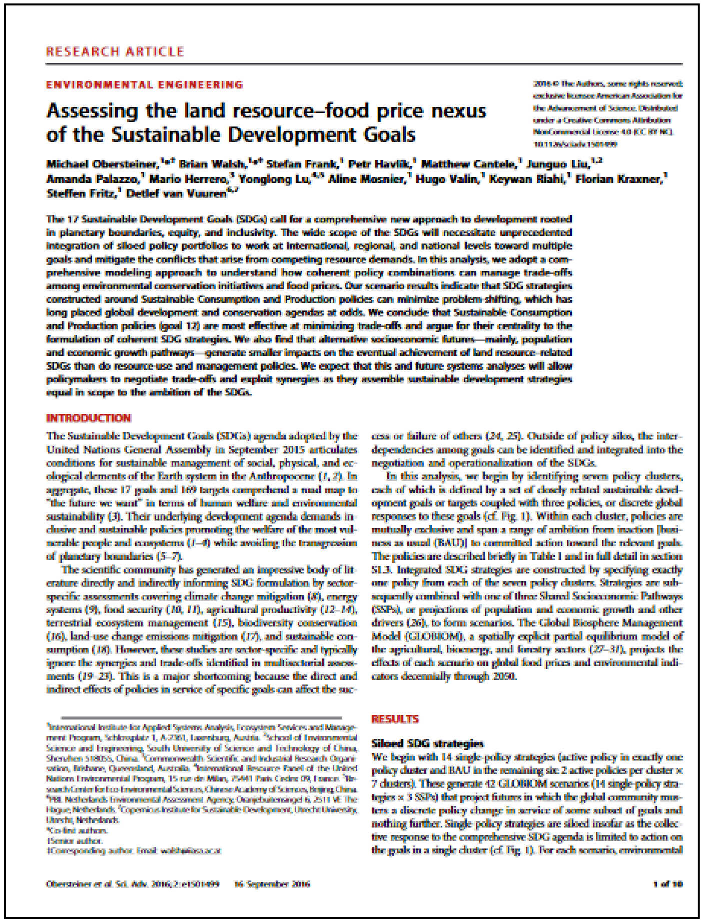
Introduction and Motivation

- The world’s population is growing, becoming richer, and changing their food preferences
- Irrigated agriculture has the potential to produce more on less land
- 70% of water withdrawals come from irrigated agriculture
- Demands from other sectors will increase (WFaS)
- What are the goals of the SDGs?
  - Can we identify tradeoffs among goals that focus on water for human and environmental uses?

Approaches to examining the SDG linkages and trade-offs

A GUIDE TO
SDG INTERACTIONS:
FROM SCIENCE
TO IMPLEMENTATION

INTERNATIONAL
COUNCIL
FOR SCIENCE



RESEARCH ARTICLE

ENVIRONMENTAL ENGINEERING

Assessing the land resource–food price nexus of the Sustainable Development Goals

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The 17 Sustainable Development Goals (SDGs) call for a comprehensive new approach to development rooted in planetary boundaries, equity, and inclusivity. The wide scope of the SDGs will necessitate unprecedented integration of siloed policy portfolios to work at international, regional, and national levels toward multiple goals and mitigate the conflicts that arise from competing resource demands. In this analysis, we adopt a comprehensive modeling approach to understand how coherent policy combinations can manage trade-offs among environmental conservation initiatives and food prices. Our scenario results indicate that SDG strategies constructed around Sustainable Consumption and Production policies can minimize problem-shifting, which has long placed global development and conservation agendas at odds. We conclude that Sustainable Consumption and Production policies (goal 12) are most effective at minimizing trade-offs and argue for their centrality to the formulation of coherent SDG strategies. We also find that alternative socioeconomic futures—mainly, population and economic growth pathways—generate smaller impacts on the eventual achievement of land resource–related SDGs than do resource-use and management policies. We expect that this and future systems analyses will allow policymakers to negotiate trade-offs and exploit synergies as they assemble sustainable development strategies equal in scope to the ambition of the SDGs.

INTRODUCTION

The Sustainable Development Goals (SDGs) agenda adopted by the United Nations General Assembly in September 2015 articulates conditions for sustainable management of social, physical, and ecological elements of the Earth system in the Anthropocene (*1*, *2*). In aggregate, these 17 goals and 169 targets comprehend a road map to "the future we want" in terms of human welfare and environmental sustainability (*3*). Their underlying development agenda demands inclusive and sustainable policies promoting the welfare of the most vulnerable people and ecosystems (*1*–*4*) while avoiding the transgression of planetary boundaries (*5*–*7*).

The scientific community has generated an impressive body of literature directly and indirectly informing SDG formulation by sector-specific assessments covering climate change mitigation (*8*), energy systems (*9*), food security (*10*, *11*), agricultural productivity (*12*–*14*), terrestrial ecosystem management (*15*), biodiversity conservation (*16*), land-use change emissions mitigation (*17*), and sustainable consumption (*18*). However, these studies are sector-specific and typically ignore the synergies and trade-offs identified in multisectorial assessments (*19*–*23*). This is a major shortcoming because the direct and indirect effects of policies in service of specific goals can affect the success or failure of others (*24*, *25*). Outside of policy silos, the interdependencies among goals can be identified and integrated into the negotiation and operationalization of the SDGs.

In this analysis, we begin by identifying seven policy clusters, each of which is defined by a set of closely related sustainable development goals or targets coupled with three policies, or discrete global responses to these goals (cf. Fig. 1). Within each cluster, policies are mutually exclusive and span a range of ambition from inaction [business as usual (BAU)] to committed action toward the relevant goals. The policies are described briefly in Table 1 and in full detail in section S1.3. Integrated SDG strategies are constructed by specifying exactly one policy from each of the seven policy clusters. Strategies are subsequently combined with one of three Shared Socioeconomic Pathways (SSPs), or projections of population and economic growth and other drivers (*26*), to form scenarios. The Global Biosphere Management Model (GLOBIOM), a spatially explicit partial equilibrium model of the agricultural, bioenergy, and forestry sectors (*27*–*31*), projects the effects of each scenario on global food prices and environmental indicators decennially through 2050.

RESULTS

Siloed SDG strategies

We begin with 14 single-policy strategies (active policy in exactly one policy cluster and BAU in the remaining six: 2 active policies per cluster × 7 clusters). These generate 42 GLOBIOM scenarios (14 single-policy strategies × 3 SSPs) that project futures in which the global community musters a discrete policy change in service of some subset of goals and nothing further. Single policy strategies are siloed insofar as the collective response to the comprehensive SDG agenda is limited to action on the goals in a single cluster (cf. Fig. 1). For each scenario, environmental

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Water: Good to the last drop and used to the last drop

Land: produce more with less inputs and with less impact

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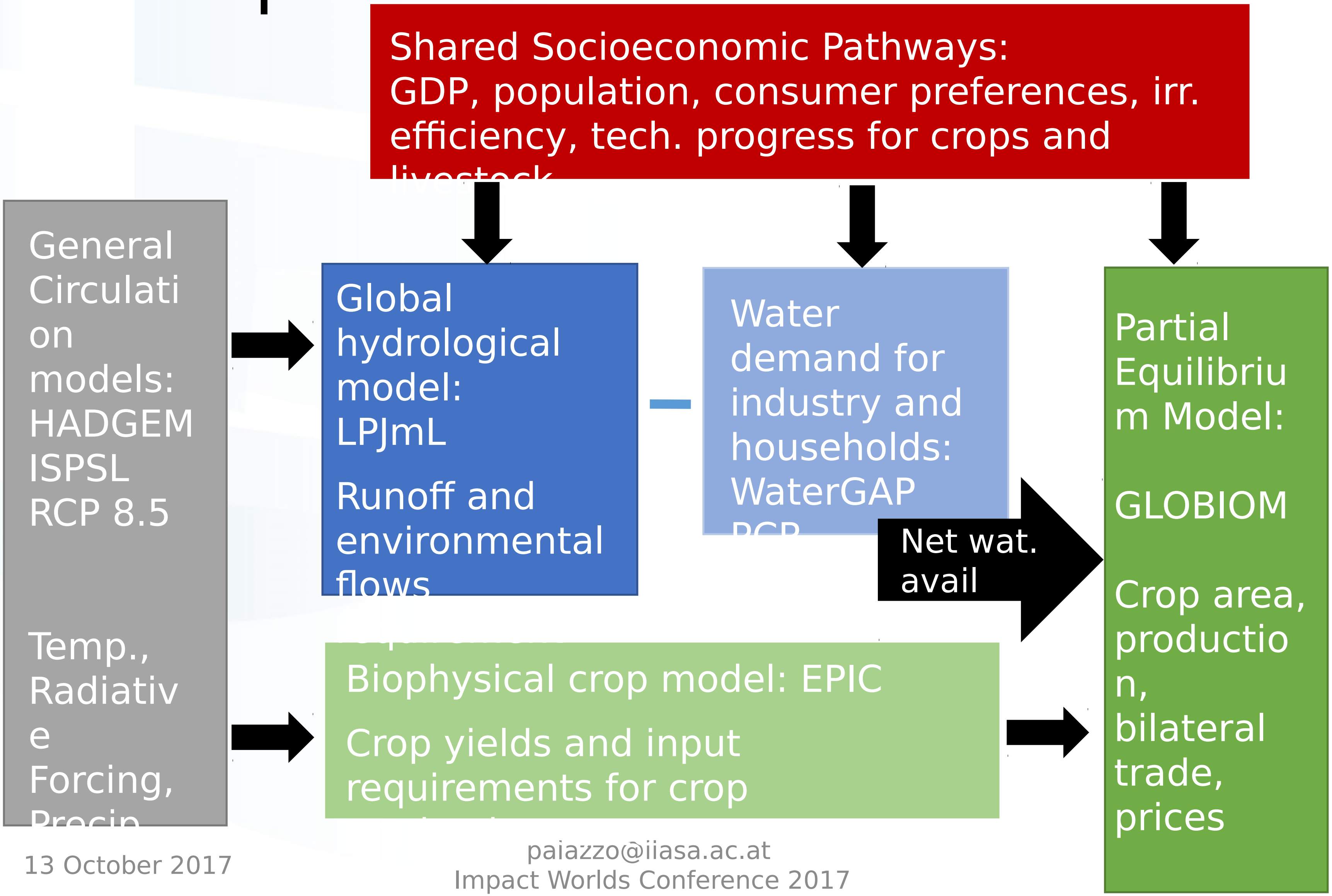
Methods

Conceptual Framework



Shared Socioeconomic Pathways:
GDP, population, consumer preferences, irr. efficiency, tech. progress for crops and livestock

General Circulation models:
HADGEM
ISPSL
RCP 8.5

Temp., Radiative Forcing, Precip

Global hydrological model:
LPJmL

Runoff and environmental flows

Water demand for industry and households:
WaterGAP
RCP

Net wat. avail

Biophysical crop model: EPIC

Crop yields and input requirements for crop

Partial Equilibrium Model:

GLOBIOM

Crop area, production, bilateral trade, prices

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Global Biosphere Management Model (GLOBIOM)

- Global scale model based detailed spatial resolution (>200k cells)
- Partial equilibrium
  - Agricultural, wood and bioenergy markets
  - 30 world regions
  - Bilateral trade flows based on spatial equilibrium approach
- Bottom-up approach
  - Explicit description of production technologies a la Leontief
  - Technologies specified by production system and grid cell
- Linear programming approach
  - Maximization of consumer + producer (incl. trade costs) surplus
  - Non linear expansion costs
  - Optimization constraints
- Base year: 2000
- Time step: 10 years
- Time horizon: 2030/2050, but also 2100

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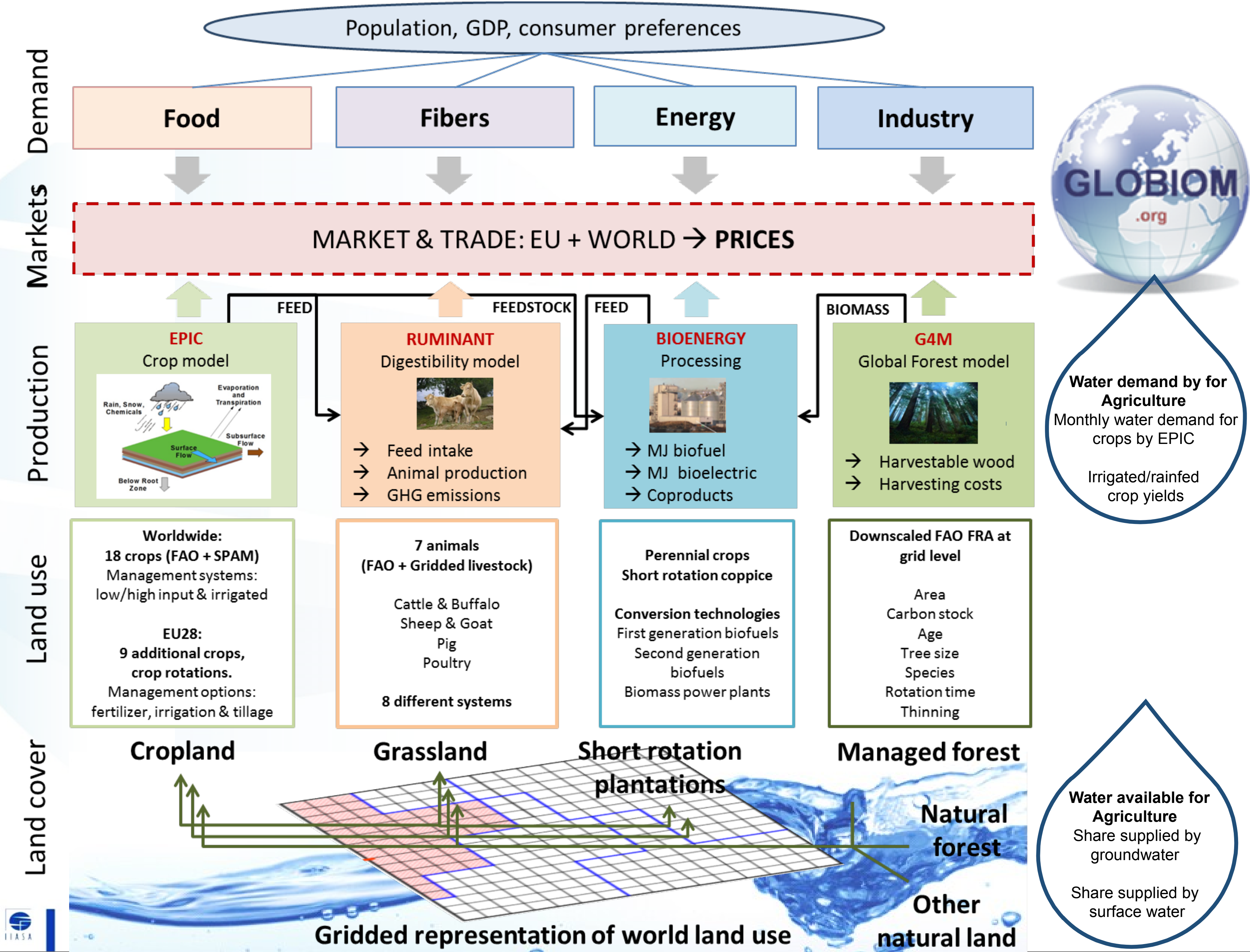


Demand

Population, GDP, consumer preferences

Food

Fibers

Energy

Industry

Markets

MARKET & TRADE: EU + WORLD → **PRICES**

FEED

FEEDSTOCK

FEED

BIOMASS

Production

EPIC
Crop model

RUMINANT
Digestibility model

- → Feed intake
- → Animal production
- → GHG emissions

BIOENERGY
Processing

- → MJ biofuel
- → MJ bioelectric
- → Coproducts

G4M
Global Forest model

- → Harvestable wood
- → Harvesting costs

Water demand by for Agriculture
Monthly water demand for crops by EPIC

Irrigated/rainfed crop yields

Land use

Worldwide:
18 crops (FAO + SPAM)
Management systems:
low/high input & irrigated

EU28:
9 additional crops, crop rotations.
Management options:
fertilizer, irrigation & tillage

7 animals
(FAO + Gridded livestock)

Cattle & Buffalo
Sheep & Goat
Pig
Poultry

8 different systems

Perennial crops
Short rotation coppice

Conversion technologies
First generation biofuels
Second generation biofuels
Biomass power plants

Downscaled FAO FRA at grid level

Area
Carbon stock
Age
Tree size
Species
Rotation time
Thinning

Land cover

Cropland

Grassland

Short rotation plantations

Managed forest

Natural forest

Other natural land

Gridded representation of world land use

Water available for Agriculture
Share supplied by groundwater

Share supplied by surface water

IIASA

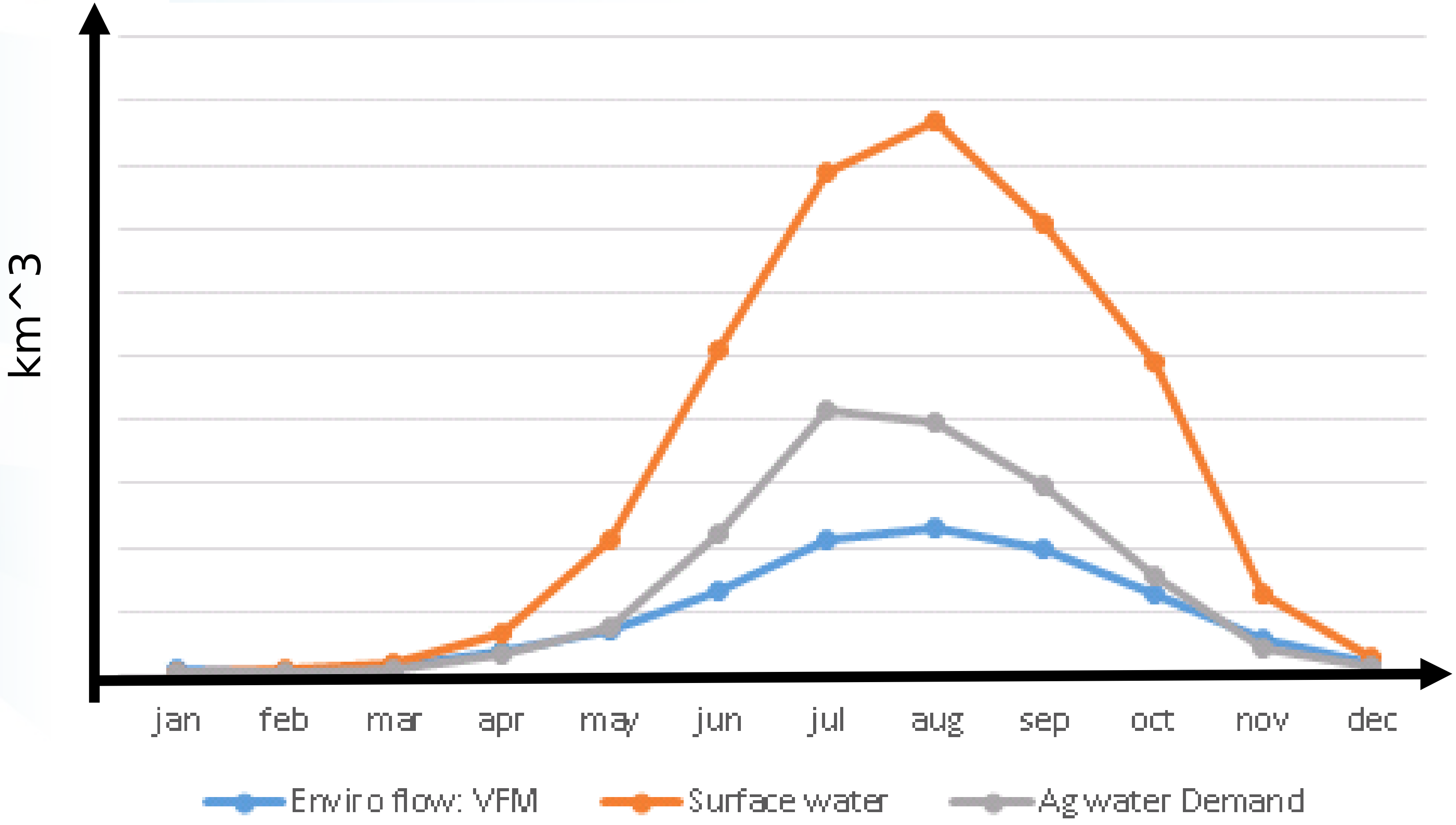
Representing irrigation as a crop production system

- Irrigation water demand by crop
  - Crop water requirement calculated by EPIC
    - Climate change: change in precipitation, temperature ▭ irrigation requirement (5 GCMs)
  - Monthly water demand based on crop calendar by EPIC
- Irrigated cropland area from SPAM (IFPRI) and calibrated with FAO statistics
- Irrigation by systems
  - Basin, furrow, sprinkler, drip
  - Differentiated by cost, efficiency, and crop and biophysical suitability (Sauer et al. 2010)
    - Suitability at simulation unit and homogenous response unit level

Representing biophysical and economic scarcity

- Biophysical scarcity
  - Water use is physically limited by water available by source at the land unit
    - Water Source: source of irrigation supply: surface and groundwater (Siebert et al 2010: share of land supplied by groundwater)
    - Surface water availability from LPJmL
      - LU level (200 x 200 km); monthly availability
      - IIASA's CWM (IS-WEL)
    - Demand for water from other sectors:
      - WaterGap and PCR-GLOBWB: domestic, industry (water for power plant cooling is included) for SSP2 (Wada et al. 2016: WFaS)
      - Environment flows (Pastor et al 2014: VFM)
- Economic Scarcity
  - Increase in the demand/use of surface water increases the water price at the regional level
    - IIASA's ECHO model (IS-WEL)
  - Irrigation demand aggregated and calibrated to Aquastat (year 2000 at country level)
  - Shifted proportionally to changes in biophysical availability for future projections

Representing temporal characteristic of water



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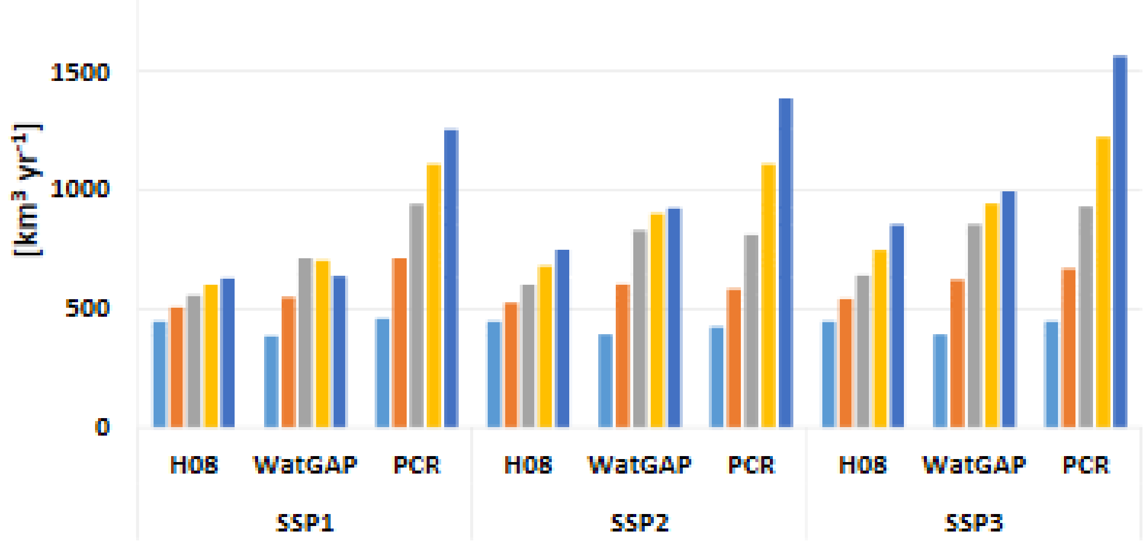
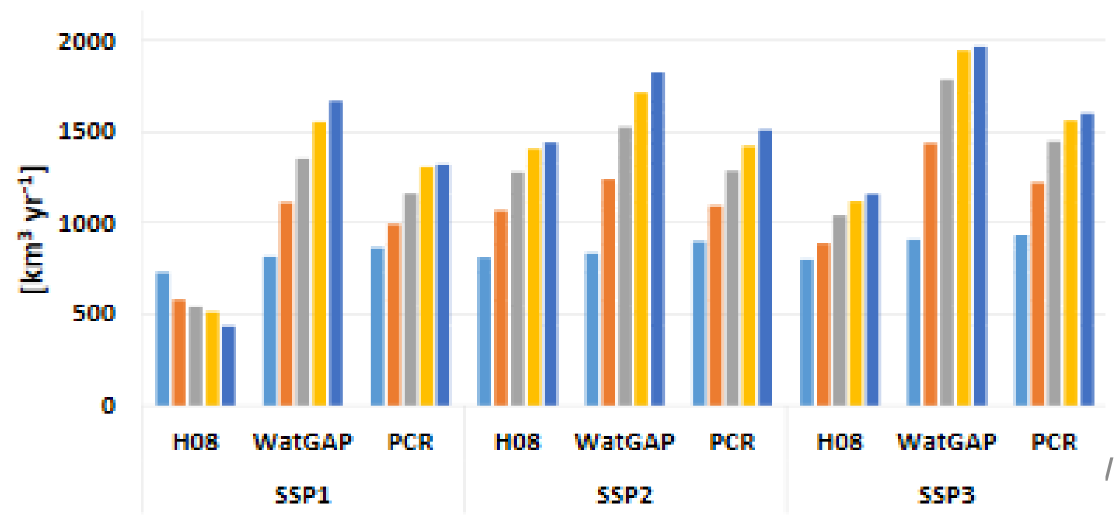
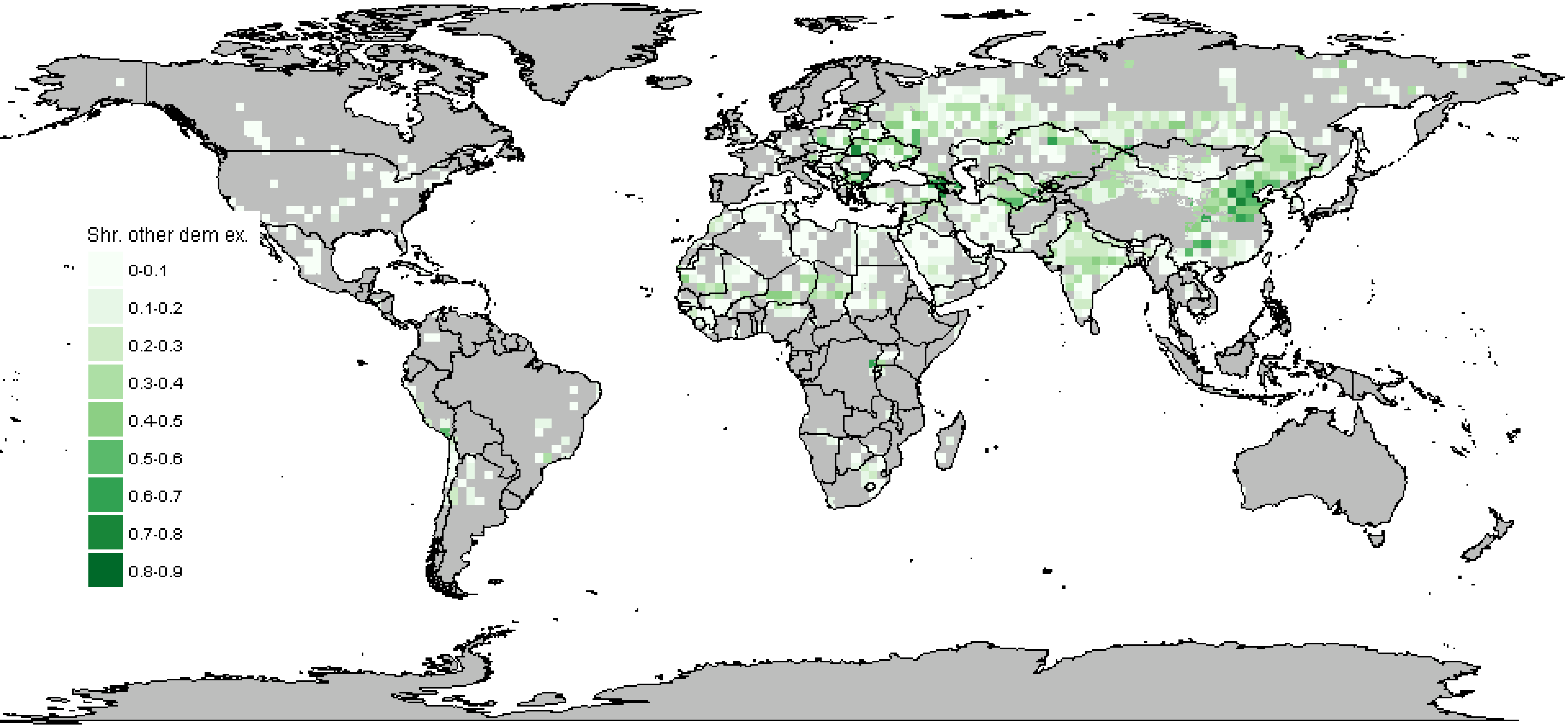
Why do we care about the monthly time step?

Water demand from other sectors (domestic, industry) is growing and in some cases exceeds the surface water available





Share of other sector demands exceeding monthly availability in 2050 (SSP2)



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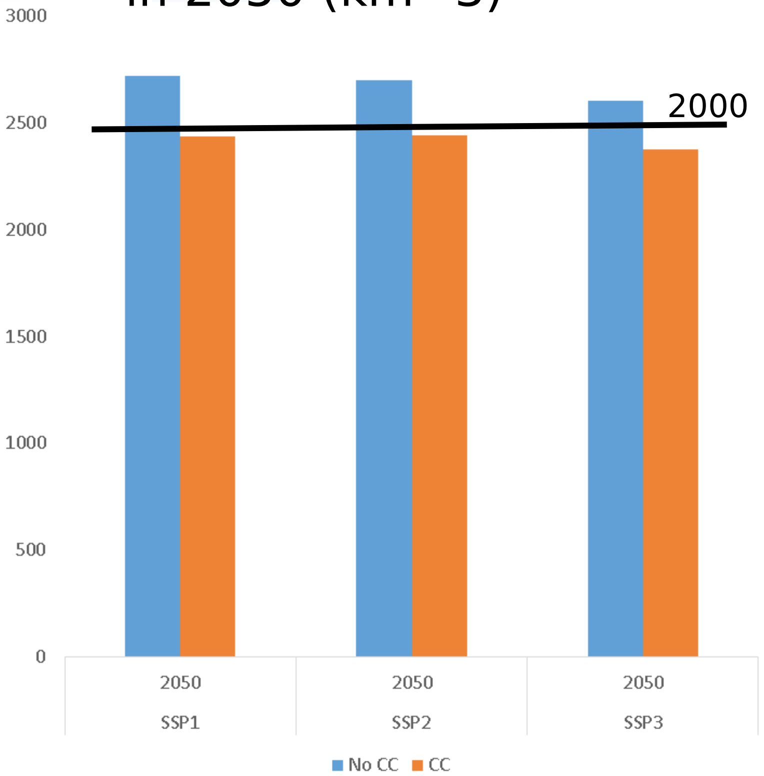
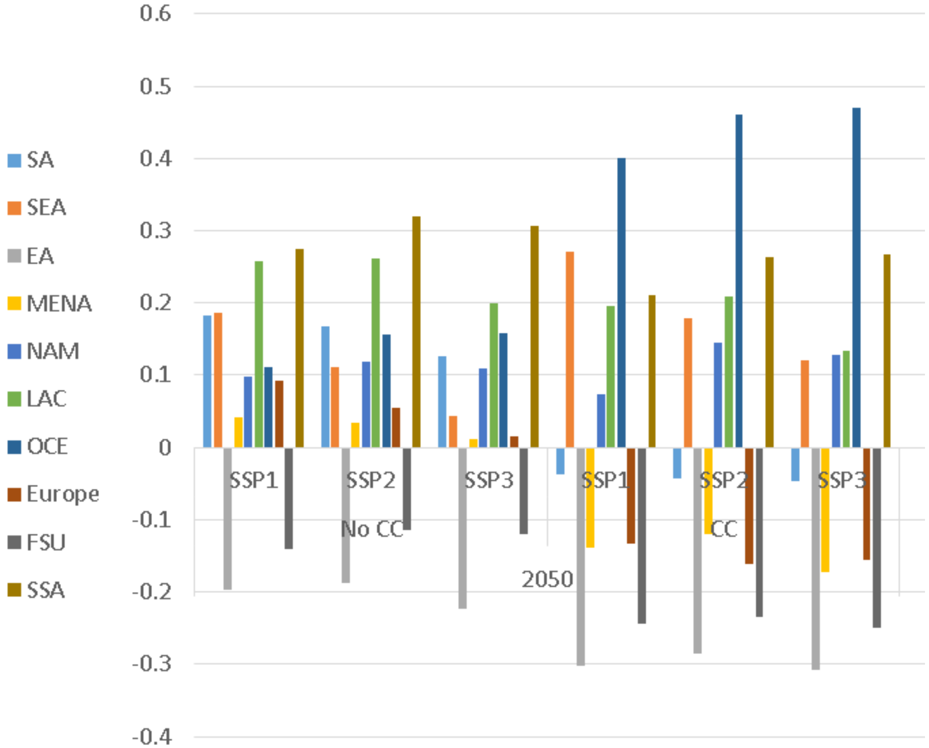
Water demand for irrigation may follow similar global patterns, however water is local

Water demand for irr from in 2050 (km^3)

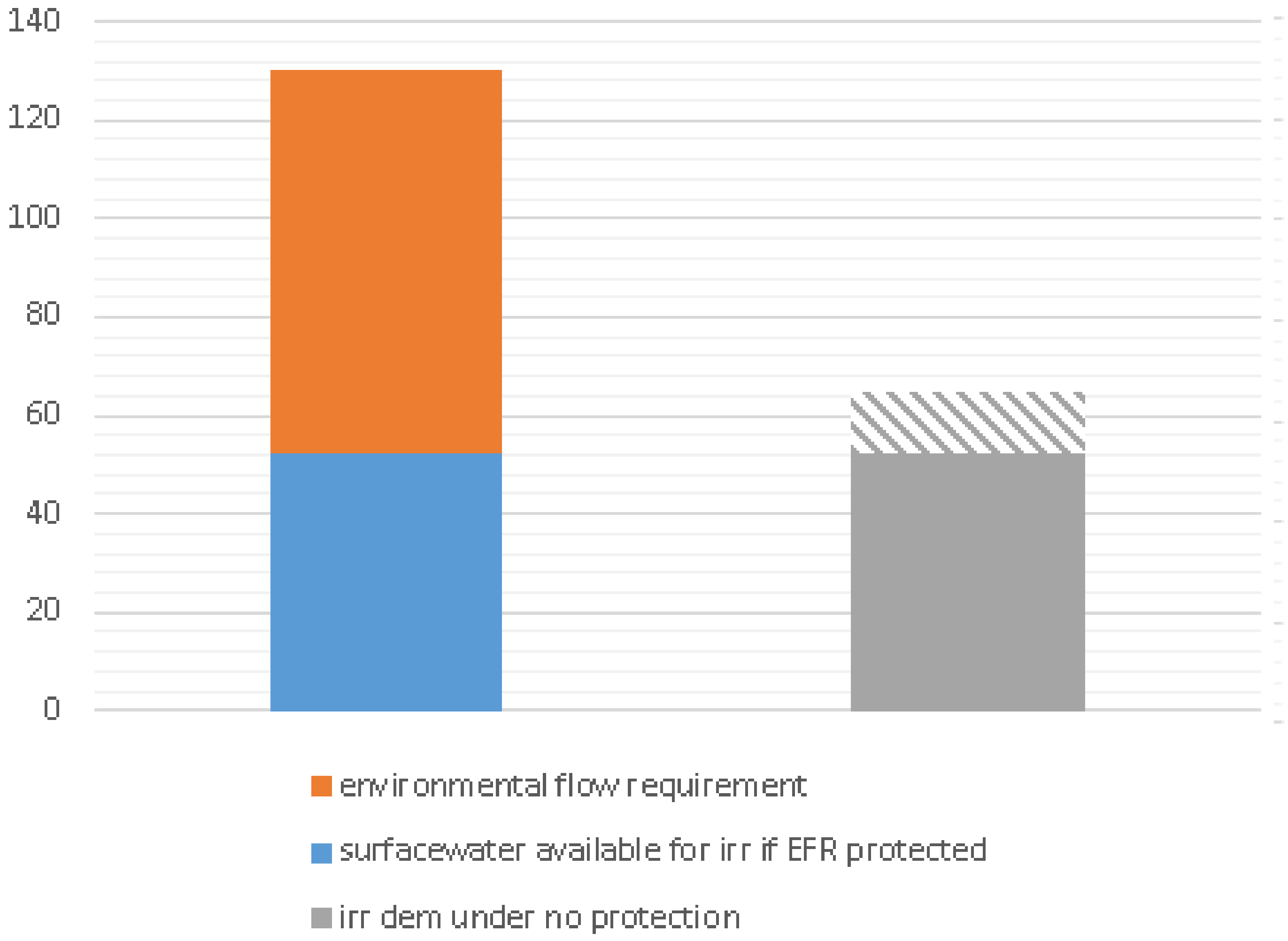


Change in water demand for irr from 2000 to 2050

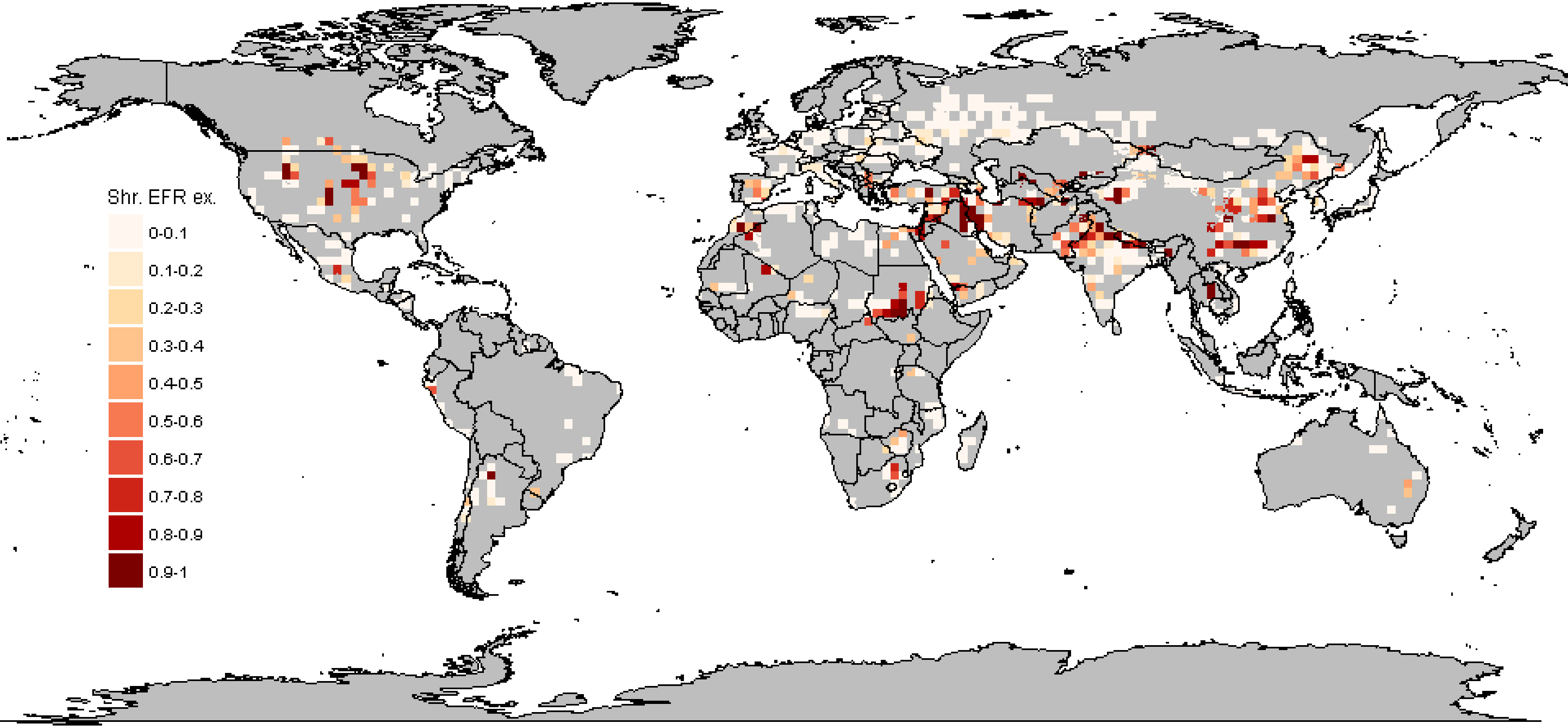


Water Exploitation Index: highlighting where ag exceeds environmental flow requirements

WEI: ~ 0.17



Ag (irrigated) production limited to residual water after domestic and industry but no EFR



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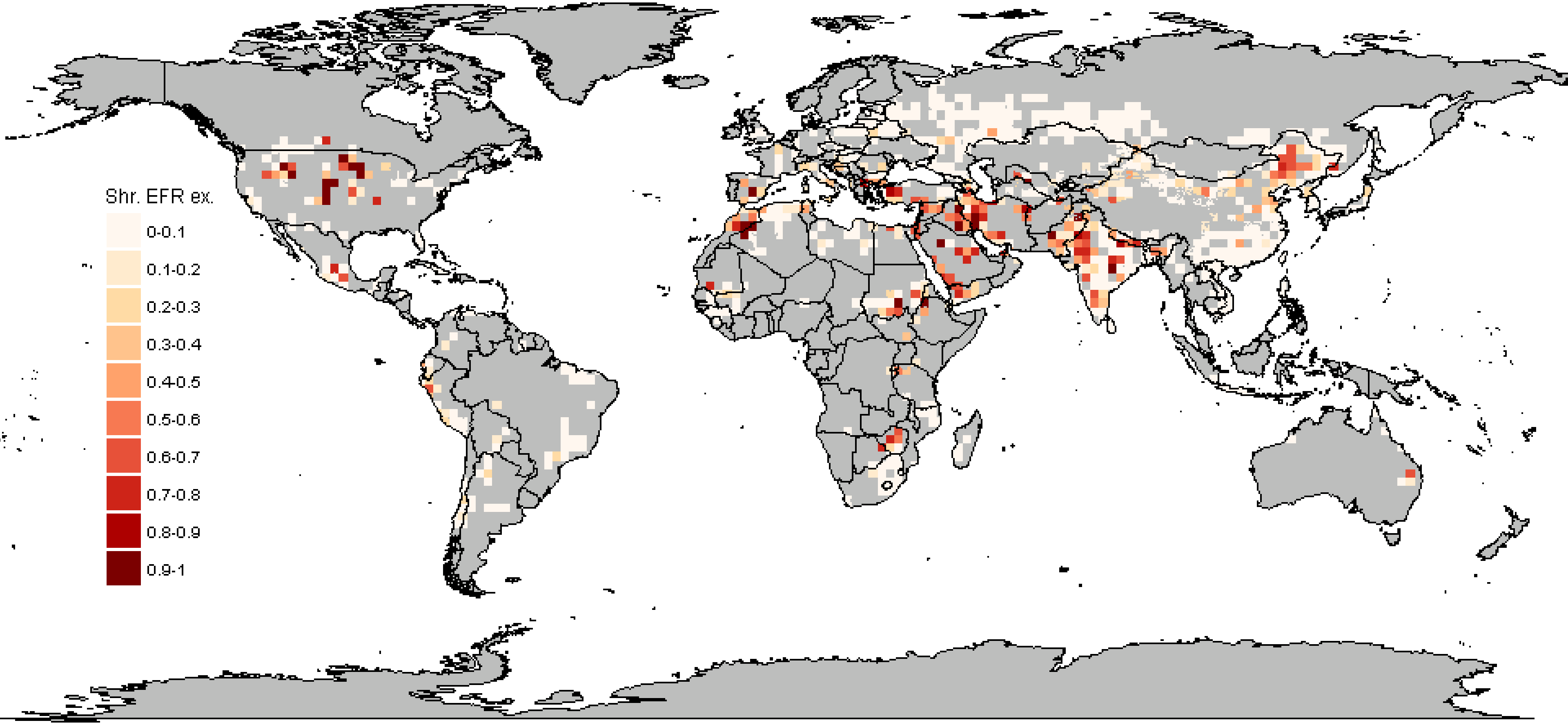
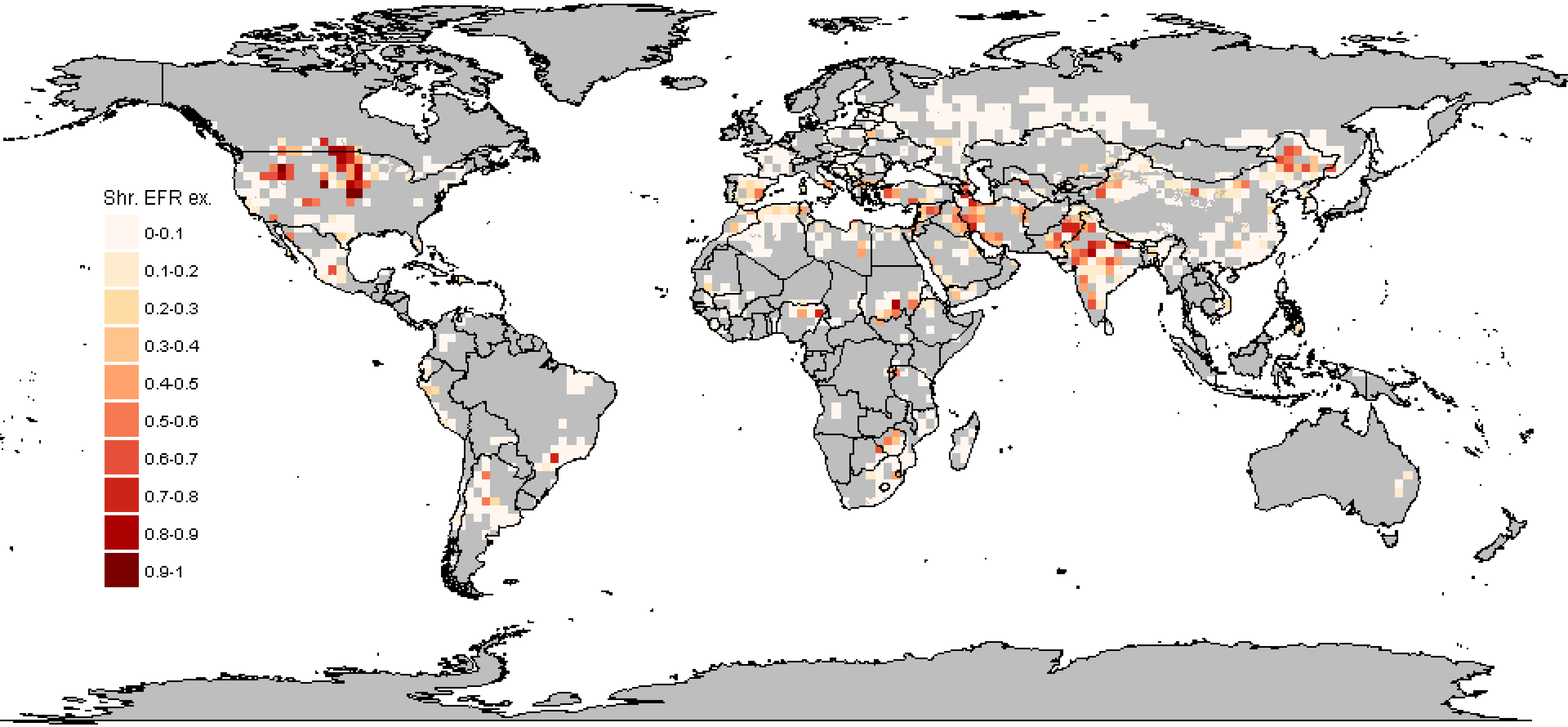
Ag (irrigated) production limited to water left after domestic and industry but no EFR



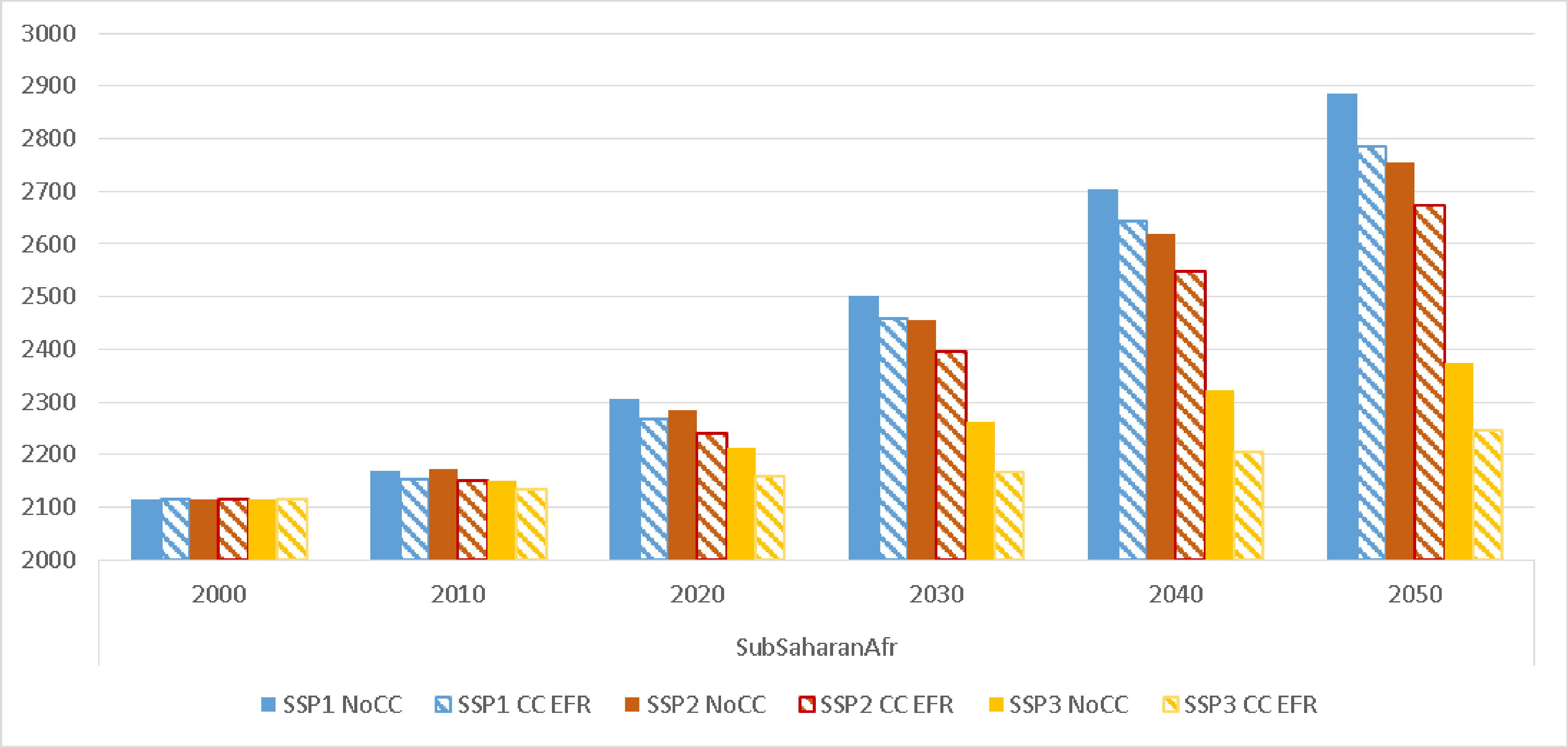
SSP1, NoCC, 2050, Preliminary Results

Ag (irrigated) production limited to water left after domestic and industry but no EFR



SSP1, GCM1, 2050, Preliminary Results

Ag (irrigated) production limited by water demand from all other sectors and protection of the EFRs: Food Security



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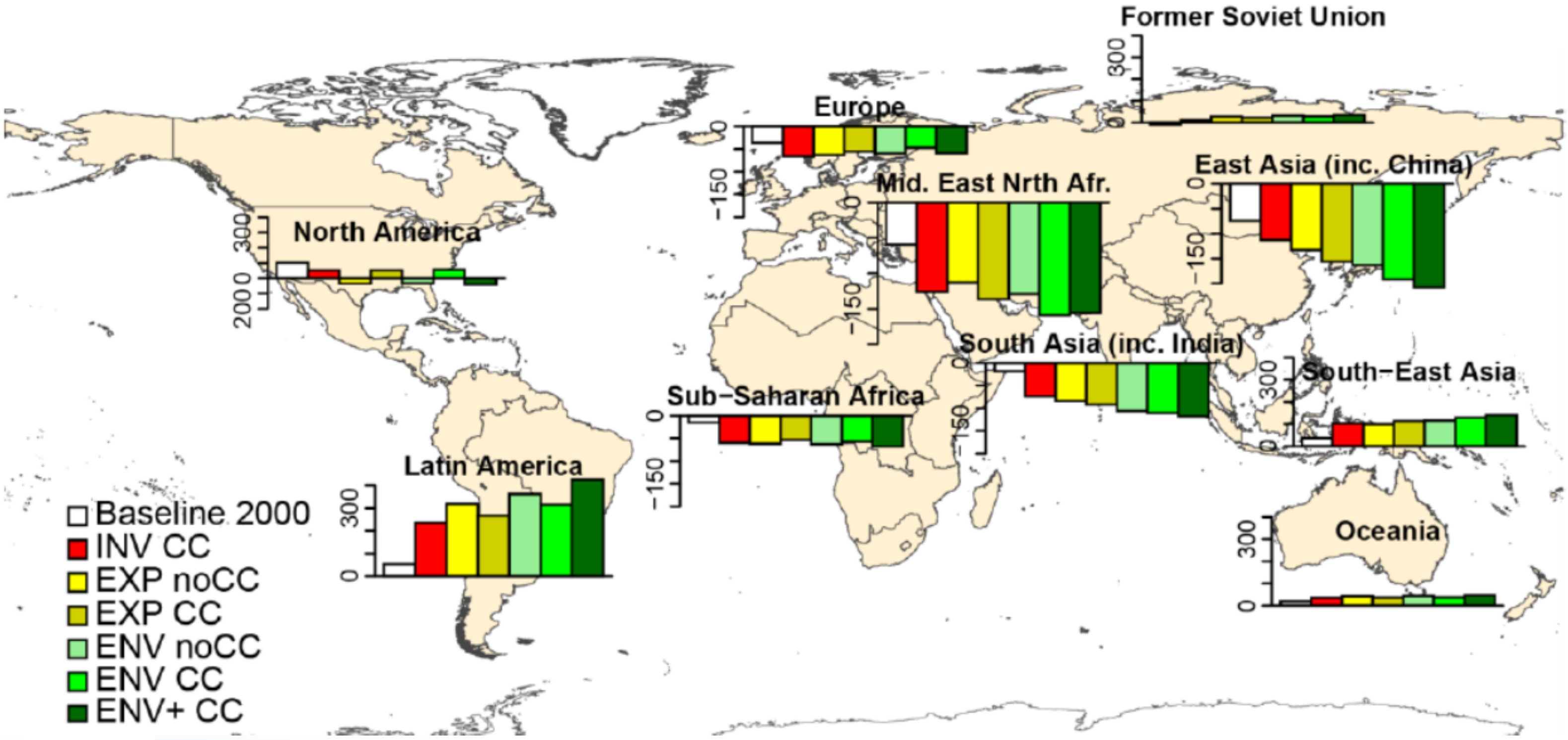
Irrigation and environmental flows: trade as a mitigation option



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Balancing food security and water for the environment under global change

Conclusions

- Future climate change may make more water available in but not always when it can be utilized by agriculture
  - Temporal issues matter for the environment and agriculture
- Demand for water from other sectors will increase in places where there is already water scarcity
  - Increasing the competition with agriculture
- Protections of environmental streamflows can have consequences on food availability
  - Though to some extent trade can mitigate these consequences
- Next steps and limitations
  - water supply costs (IIASA’s ECHO model)
  - Further testing with ISIMIP GHMs under wider range of GCMs
  - Dynamic crop calendar
  - Water storage (IIASA’s CWM)

Thank you!

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ISWEL
Integrated Solutions for Water-Energy-Land

Partnership:

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