Integrated Assessment of Water in the GCAM Framework

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Research questions

- How to effectively incorporate a representation of the water system in IAMs endogenously?

- How much of an effect will water have on energy and land use decisions in IAMs?

- How does a carbon and water constrained future differ from the traditional carbon limited scenarios in IAMs? And what is the role of adaptation?

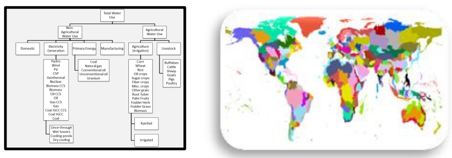
Source: http://www.ipemed.coop

Source: https://www.carbontrust.com

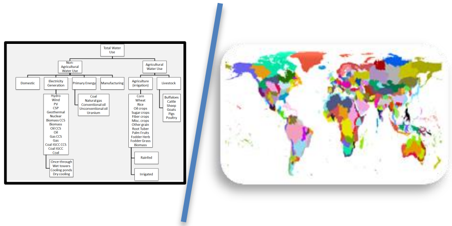
CHALLENGE: Fully Incorporating Water in a Highly-Resolved IA Model

Demand | Supply

Phase I — Building water demand and supply modules in GCAM

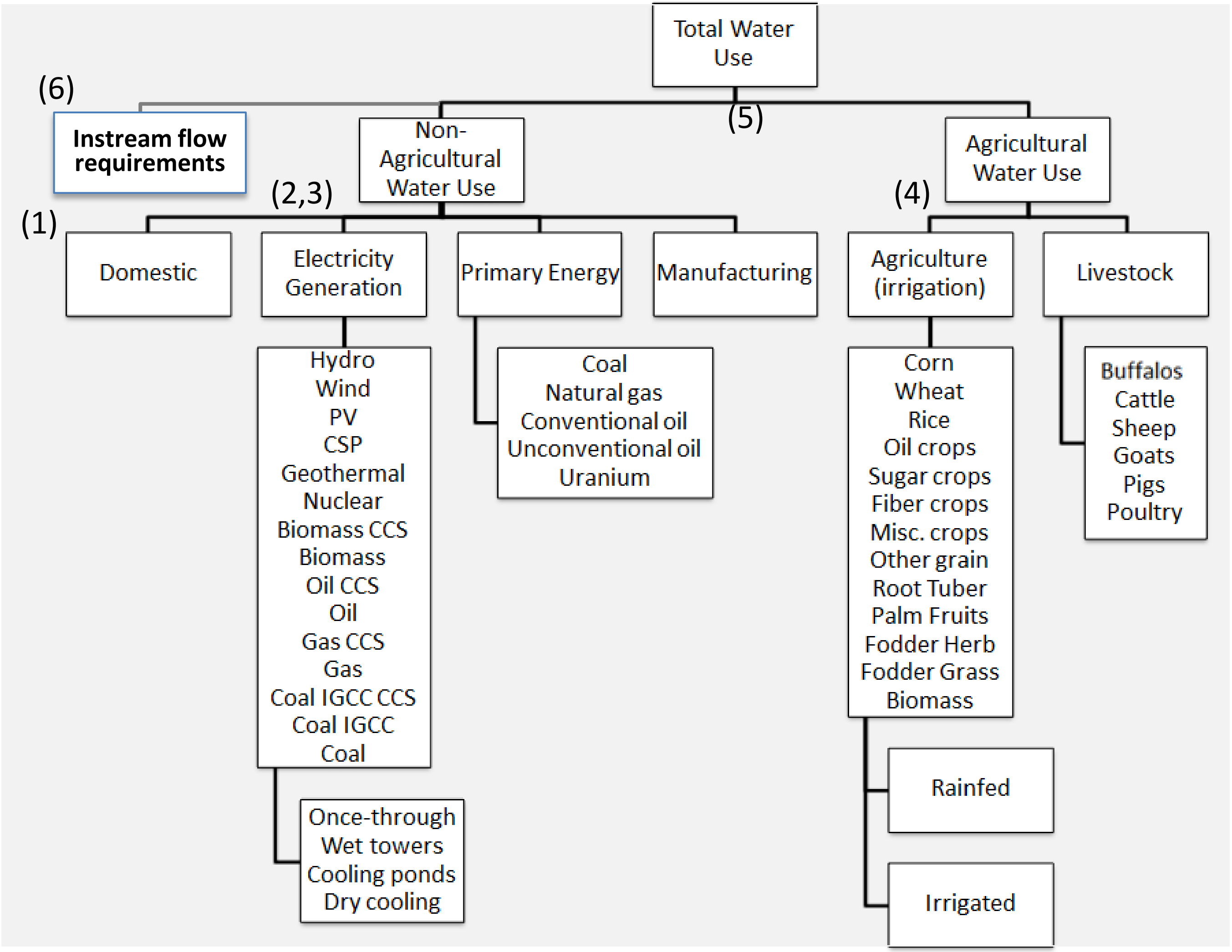


Phase II — Superimposing water demand and supply to assess water scarcity



Phase III — Reconciling water demand & supply at the river basin scale to capture adaptive feedbacks on energy & land use decisions

Representing Water Demands

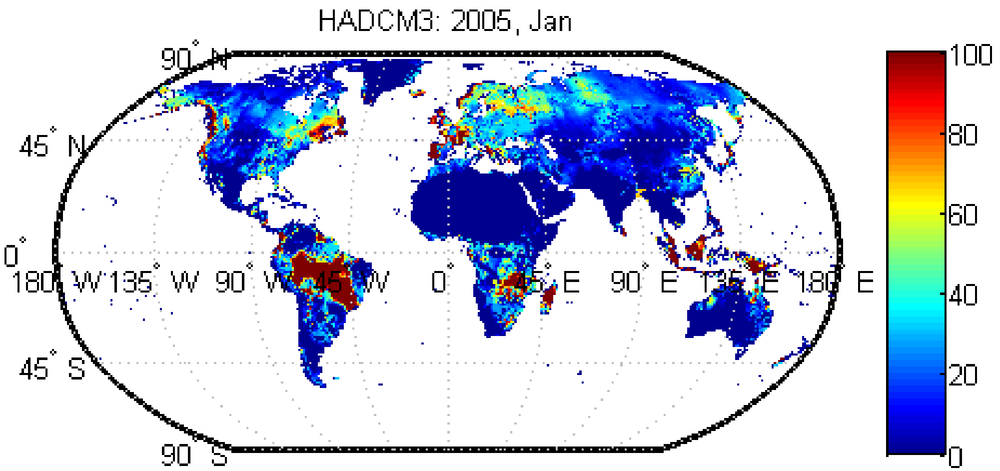


GCAM tracks water demands for several sectors, subsectors, and technologies, & at various spatial scales

(1) Hejazi et al. (2013). Hydrological Sciences Journal
(2) Kyle et al. (2013). Int. J. of Greenhouse Gas Control
(3) Davies et al. (2013). Advances in Water Resources
(4) Chaturvedi et al. (2013). Mitigation & Adaptation Strategies for Global Change.
(5) Hejazi et al. (2014). Technological Forecasting and Social Change
(6) Kim et al. (accepted). Climatic Change

Representing water supplies

- GCAM has a global hydrologic model
- Modified River Transport Model scheme
- 233 Basins



Hejazi et al. 2014. Hydrology & Earth Sys. Sc.

- Requires climate information from GCMs as inputs
- Monthly temporal scale
- 0.5x0.5 degree spatial resolution

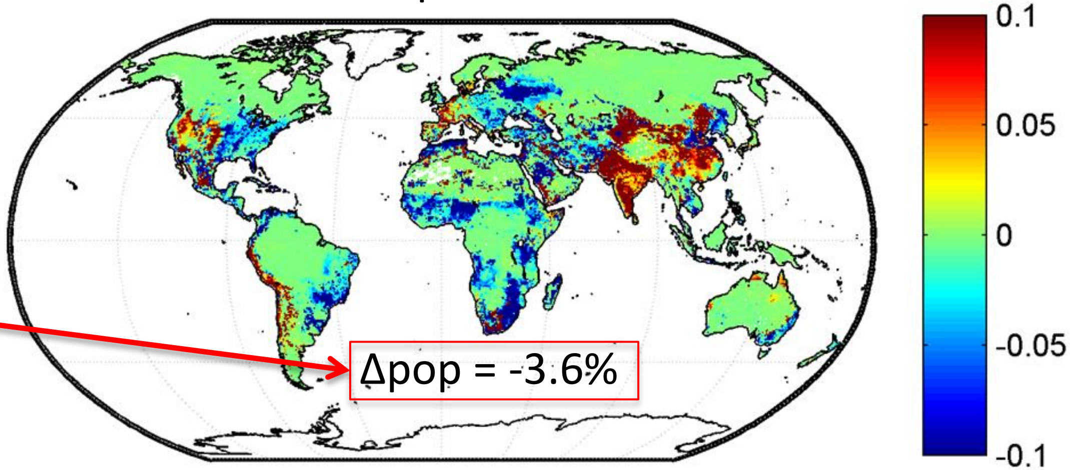
Water is likely a constraining factor!!!

- The percent of global population living in grids classified as water scarce in 2095 depends substantially on the role of bioenergy in future pathways.

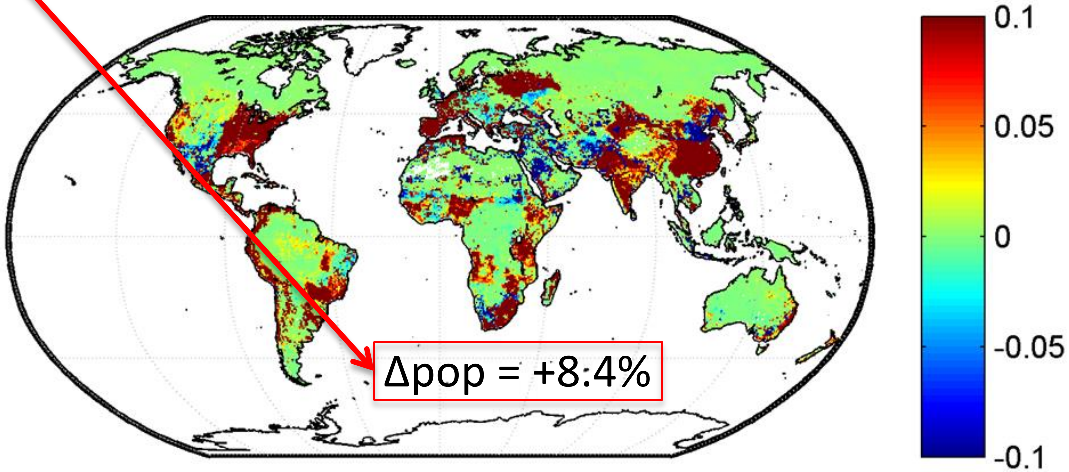
Figures show water scarcity associated with different pathways toward roughly 4 W/m^2 relative to a higher-emissions reference scenario leading to forcing of roughly 8.5 W/m^2. Scarcity defined as annual water demand over annual water supply.

Hejazi et al. 2014. Hydrology & Earth Sys. Sc.

Limited biomass production scenario



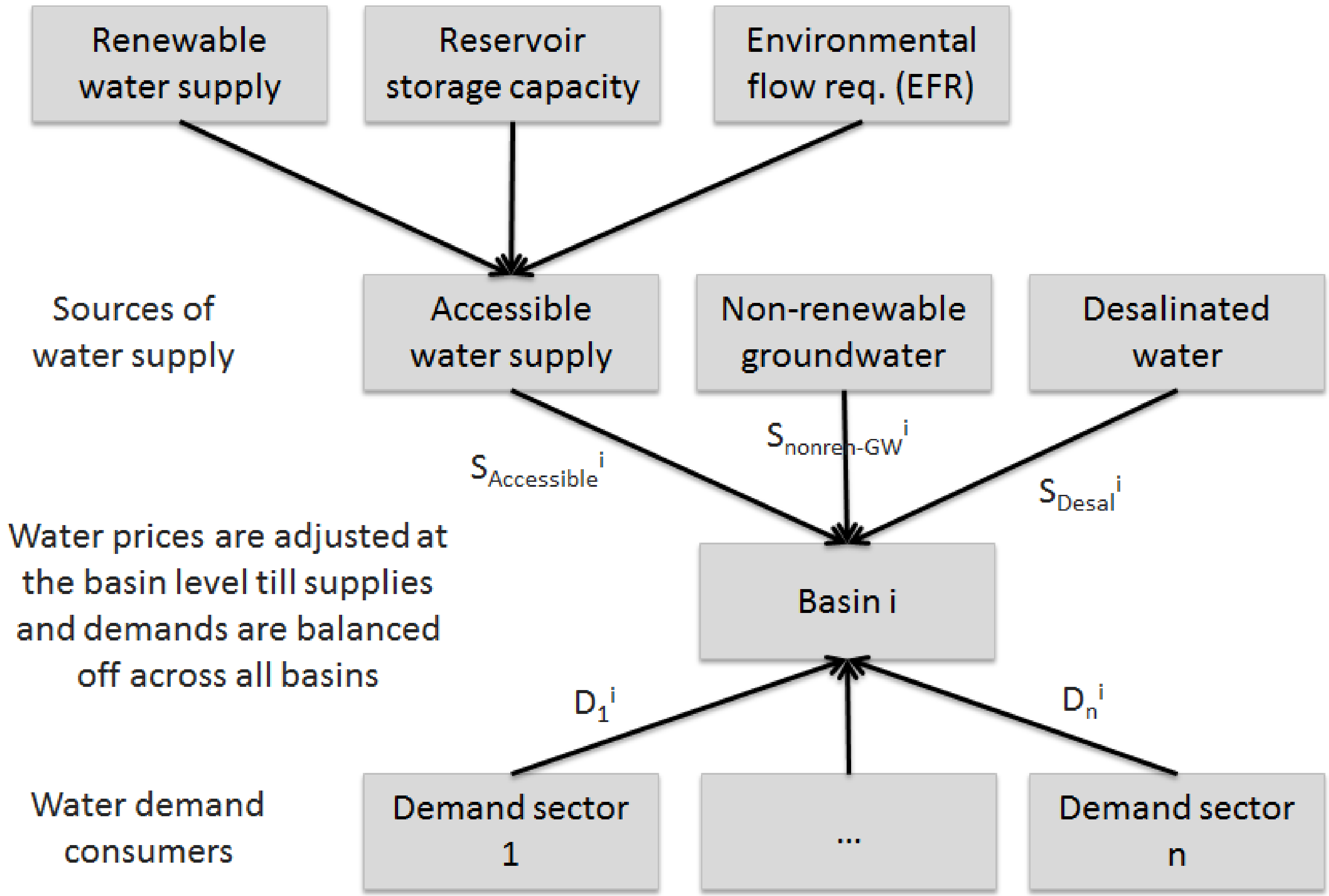
Extreme biomass production scenario



1. How will water scarcity feedback to affect agricultural productions under a reference scenario?

water / carbon	Unconstrained	Constrained
Reference	Reference - unconstrained	Reference - constrained

Schematic of the water allocation mechanism at the basin scale in GCAM



Defining Accessible Water

$$\text{Accessible water}_i = \text{MIN}(Q_i\text{-}EFR_i, BF_i\text{-}EFR_i\text{+}Res_i)$$

Q_i: Total annual streamflow for basin i
EFR_i: Total environmental flow requirement
BF_i: Total annual baseflow for basin i
Res_i: Total reservoir storage capacity for basin i

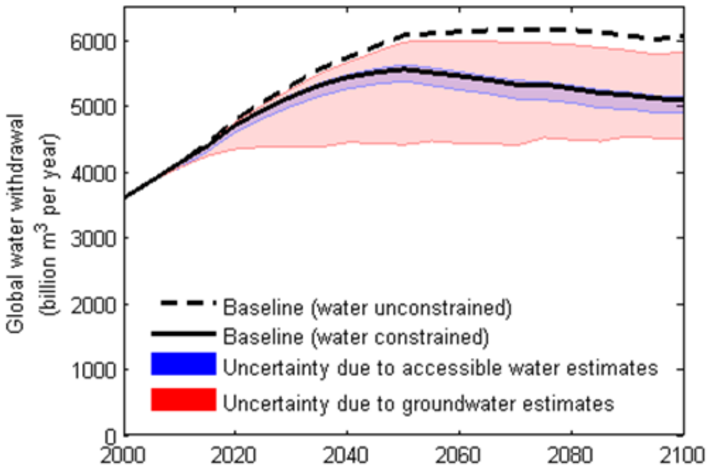
GLOBAL ESTIMATES	[Billion m^3]	Percent
Total annual streamflow	39,555	
Uncaptured floodwater • Total Reservoir Storage Capacity	19,718 6,197	49.9%
Total baseflow • Environmental flow requirements	19,837 3,863	50.1%
Accessible Freshwater	21,047	53.2%

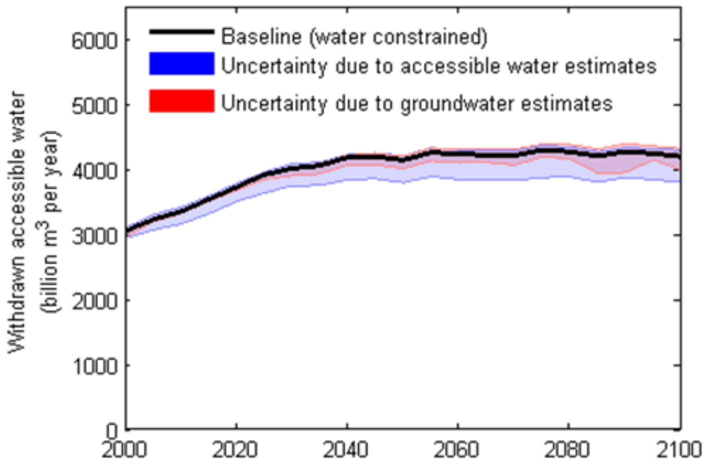
Scenarios

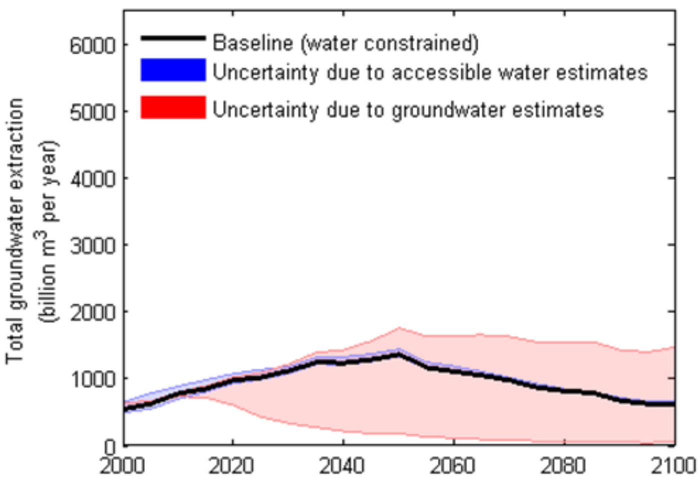
Table 1. List of all the simulated scenarios to explore the range of uncertainty associated with the estimates of accessible water availability and the cost of groundwater pumping and distributions.

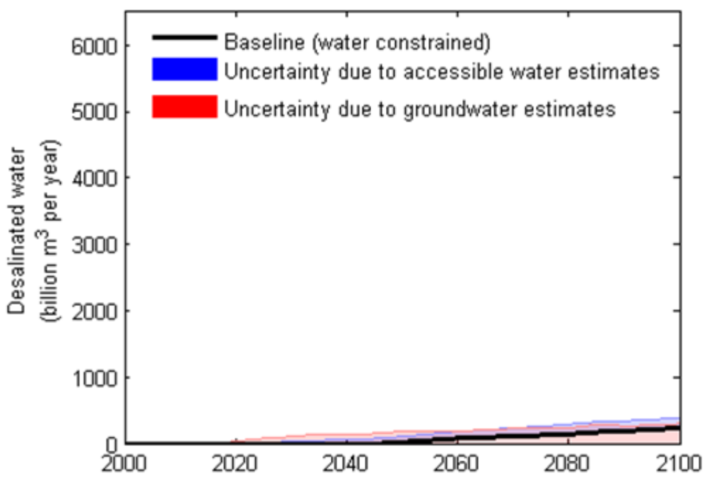
Altered variable	Method/Value	Scenario Name	Reference
Runoff	GCAM Hydrology	Baseline	Hejazi et al. 2014
	Reanalysis data I (WBMc)	ScenAW1	Fekete et al. 2000
	Reanalysis data II (GSCD)	ScenAW2	Beck et al. 2013
Climate model (GCM)	Ens. mean	Baseline	Mitchell et al. 2004
	CGCM2	ScenAW3	Mitchell et al. 2004
	CSIRO2	ScenAW4	Mitchell et al. 2004
	HADCM3	ScenAW5	Mitchell et al. 2004
	PCM	ScenAW6	Mitchell et al. 2004
Baseflow	Ens. mean	Baseline	Beck et al. 2013 & ref. therein
	Method 1 (BFI1)	ScenAW7	Beck et al. 2013 & ref. therein
	Method 2 (BFI2)	ScenAW8	Beck et al. 2013 & ref. therein
	Method 3 (BFI3)	ScenAW9	Beck et al. 2013 & ref. therein
	Method 4 (BFI4)	ScenAW10	Beck et al. 2013 & ref. therein
Groundwater depth	Median	Baseline	Fan et al. 2013
	90%	ScenGW1	Fan et al. 2013
	10%	ScenGW2	Fan et al. 2013
Shape parameter α/β	0.5	Baseline	This study
	1.00 (linear)	ScenGW3	This study
	0.40	ScenGW4	This study
	0.30	ScenGW5	This study
	0.20	ScenGW6	This study

Global estimates of water withdrawals under the water constrained & unconstrained scenarios









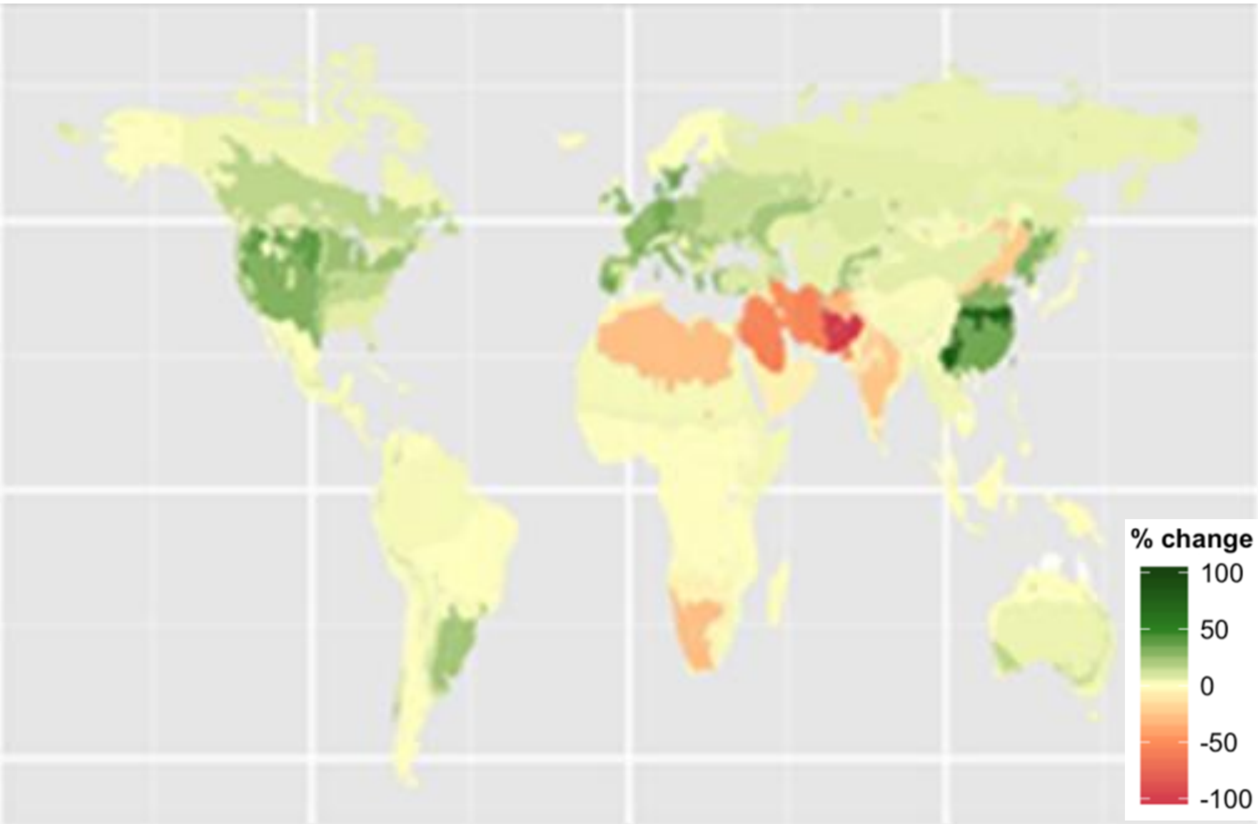
Kim et al. (accepted).

Balancing water availability and demand at the basin level in GCAM

- Adaptive decisions to water scarcity will alter agricultural and land use patterns

- Non-renewable groundwater availability and extraction costs are key determinants of withdrawal projections.

Percent changes in wheat production in 2100



Kim et al. (accepted). Climatic Change

The effect of constraining both water & carbon in GCAM

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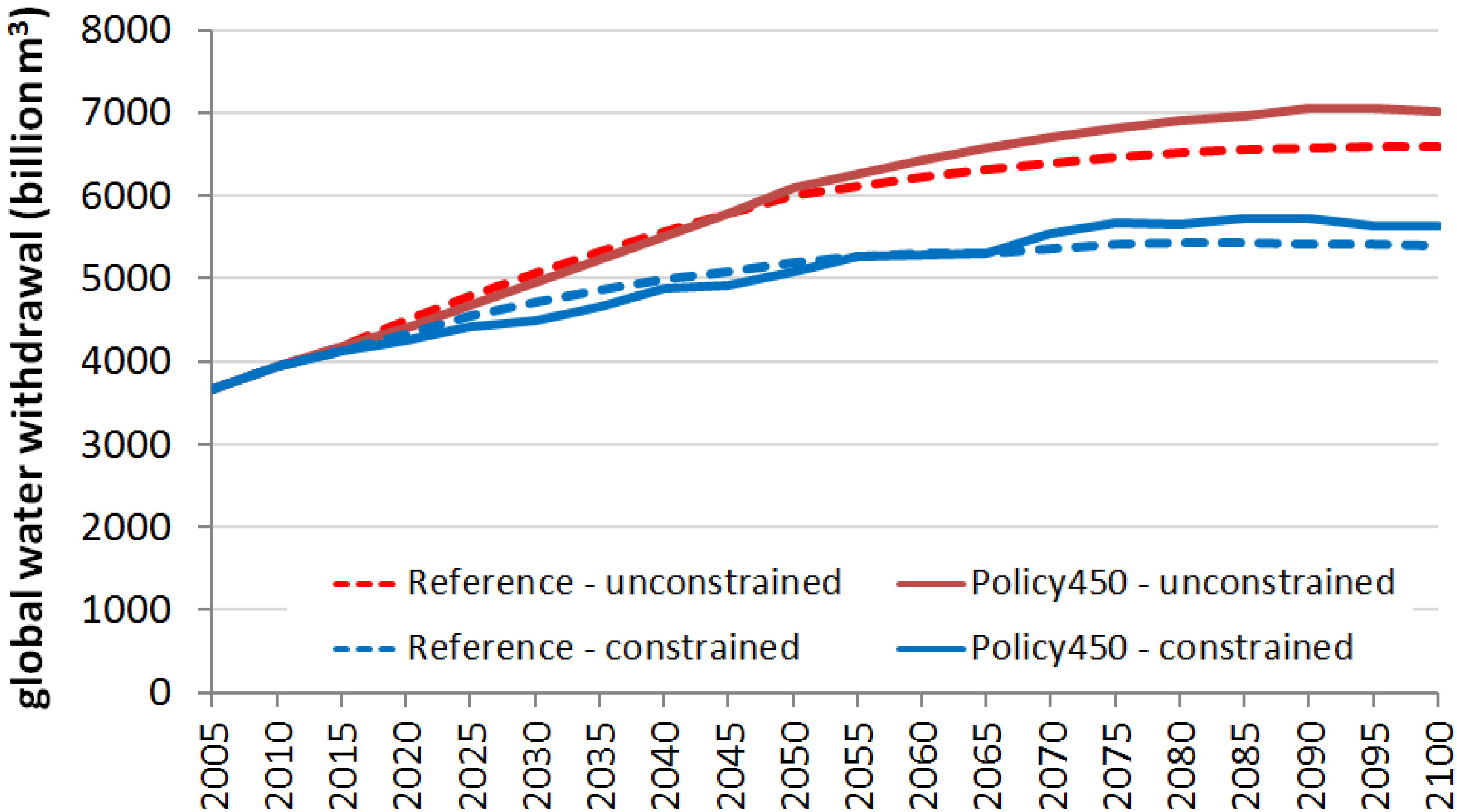
Preliminary

2. How will energy and land systems differ under a carbon + water constrained future?

carbon \ water	Unconstrained	Constrained
Reference	Reference - unconstrained	Reference - constrained
Mitigation Policy 450	Policy450 – unconstrained	Policy450 - constrained

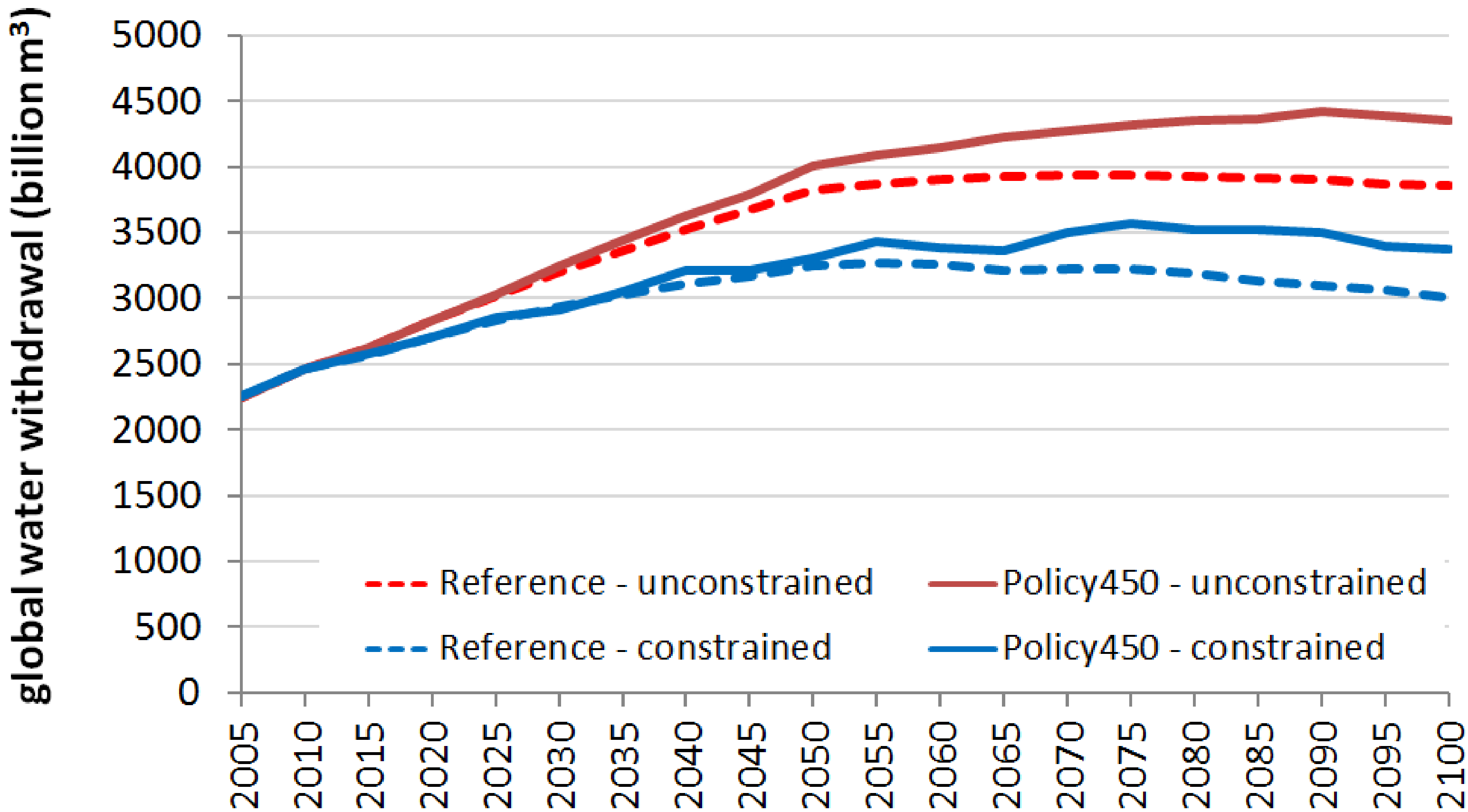
Global water use

- Less water is demanded when constraining water, but little change when constraining carbon & water (decreasing early on and then increasing)



Irrigation water use

- Higher irrigation demand under the mitigation scenario, primarily driven by the increase in irrigated biomass



Biomass irrigation water use

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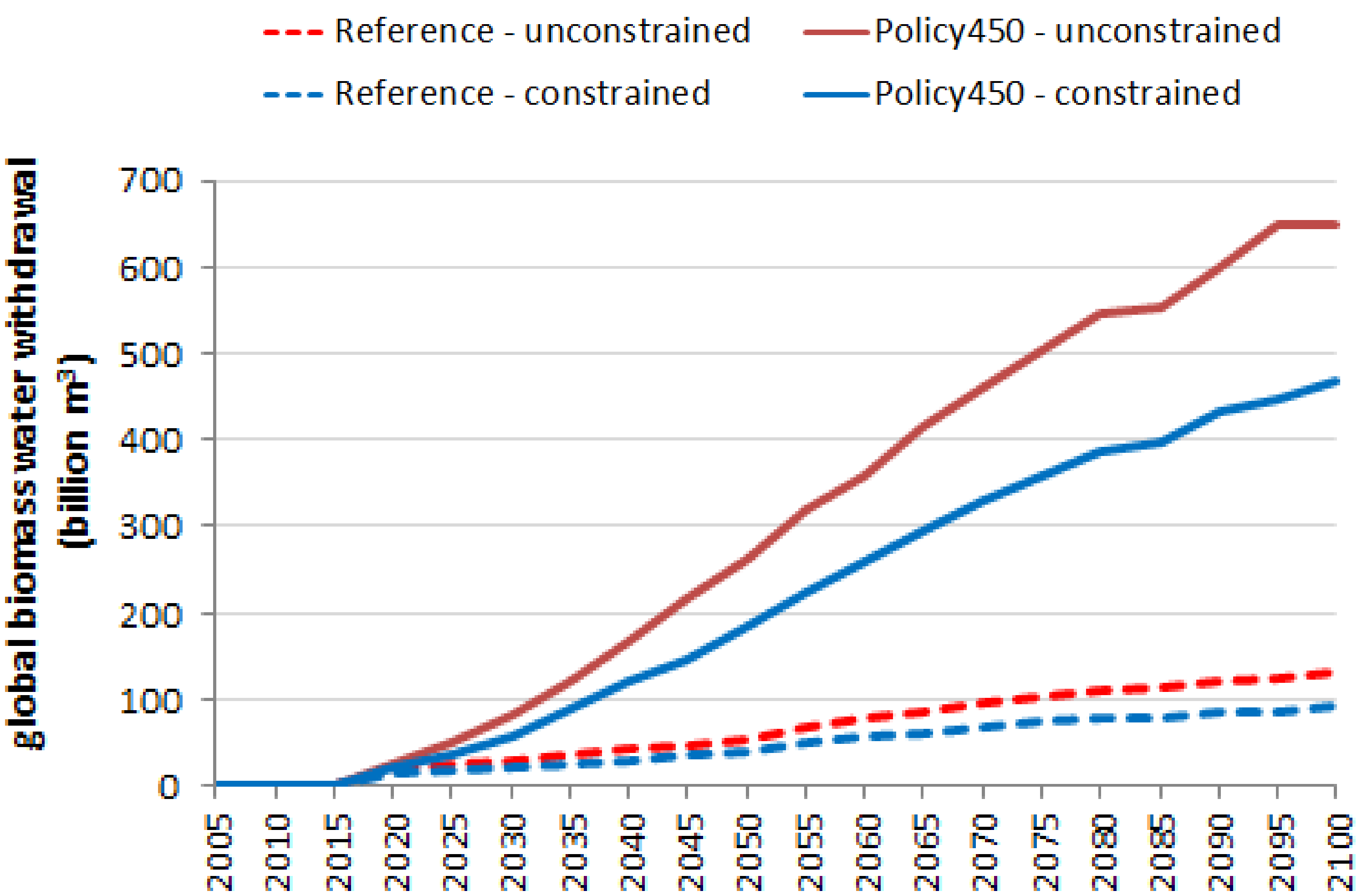
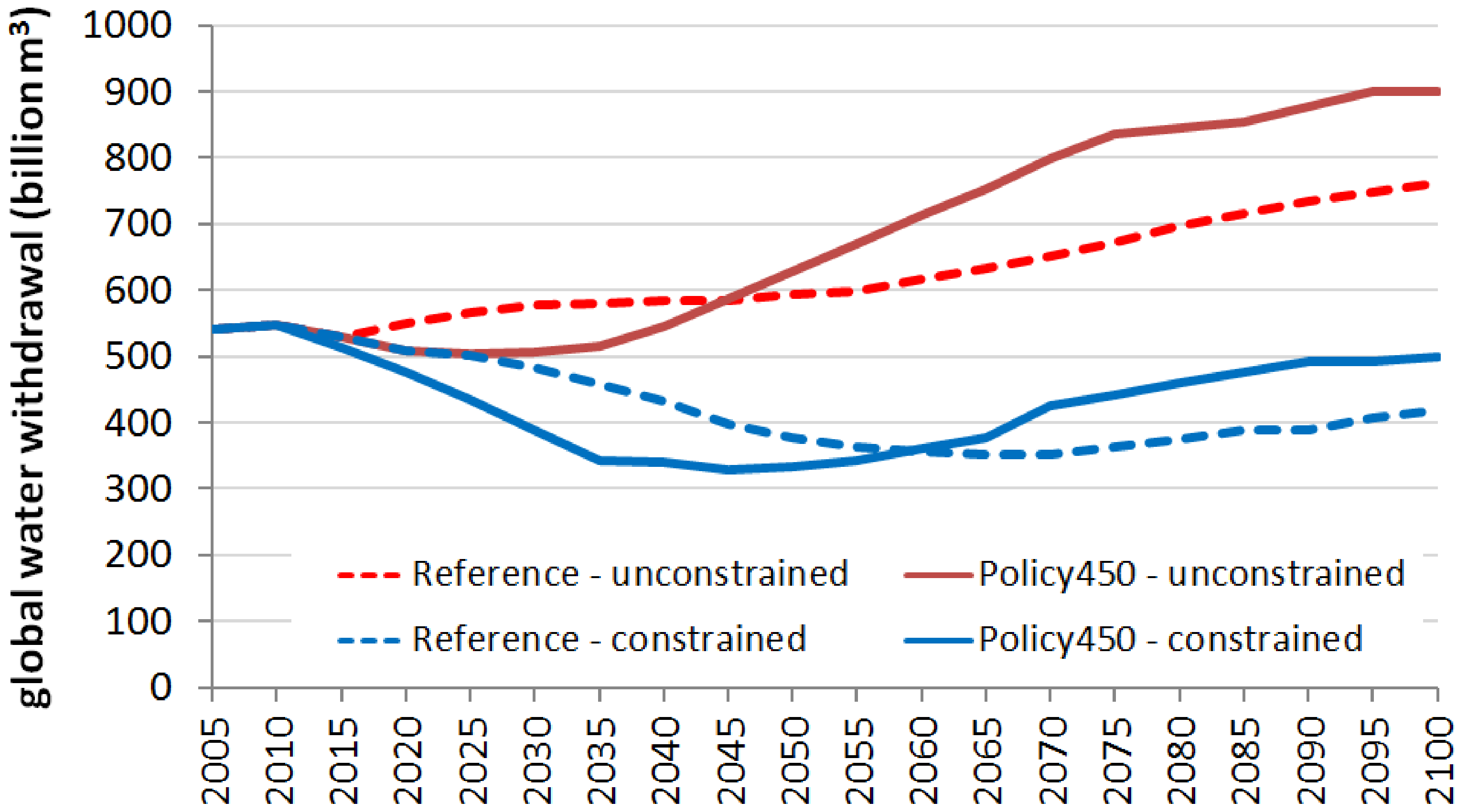
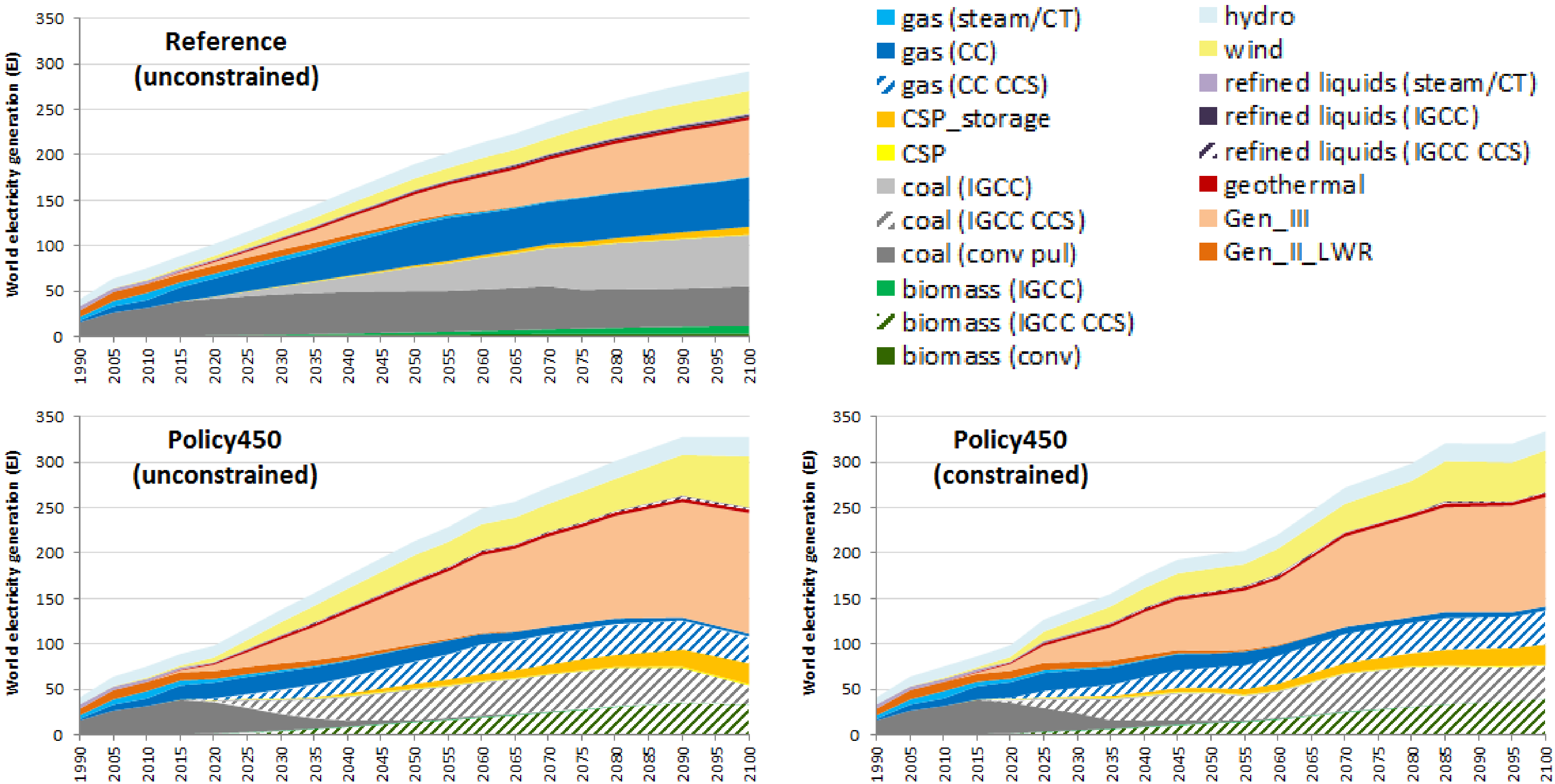


Global electricity water use (freshwater)

- The electricity sector shows a similar response during the 2nd half of the century; increasing electricity water use under the mitigation scenario

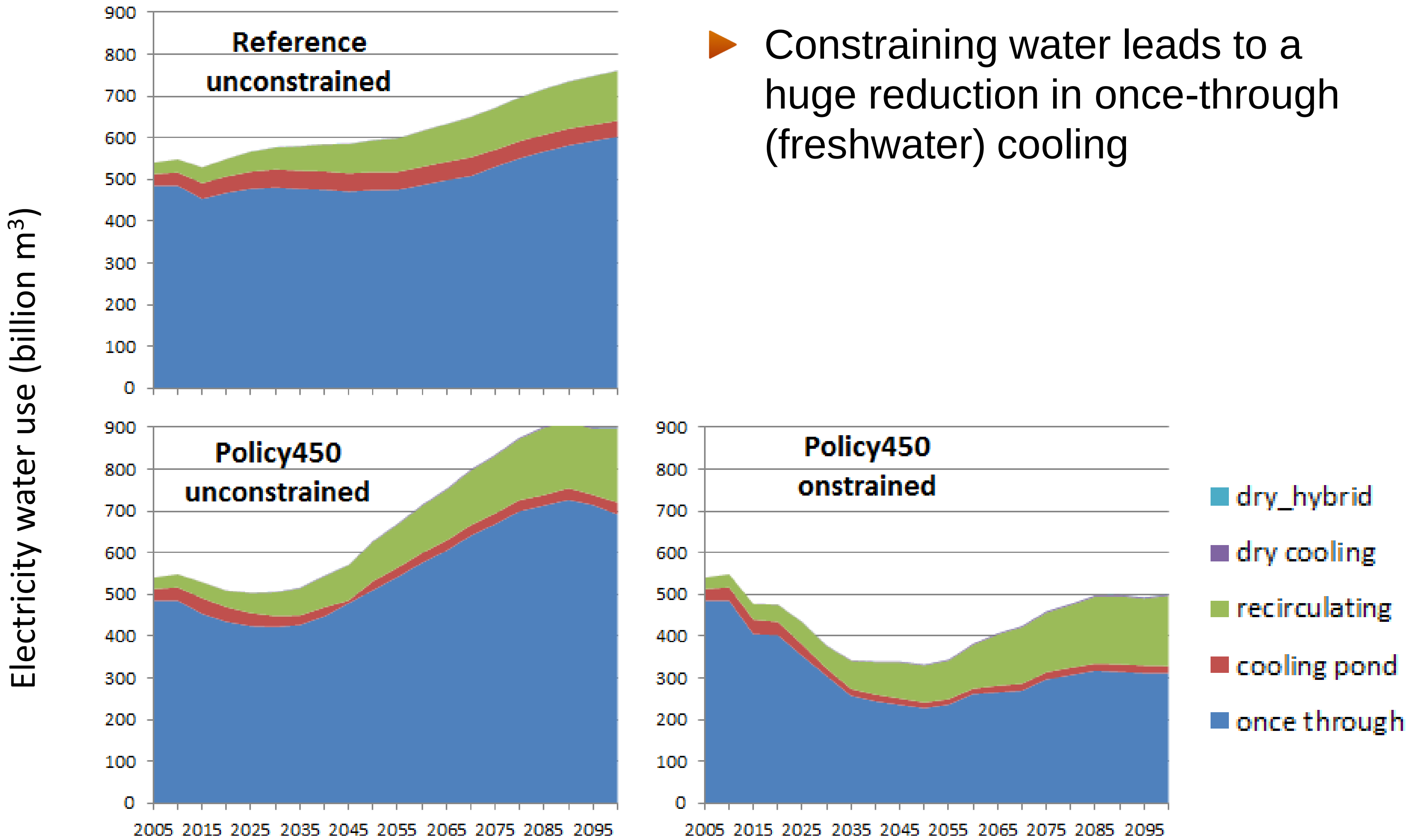


Electricity generation: Little change in global electricity mix due to water constraints



The role of cooling technologies: the transition in the cooling technologies explains the difference

- Constraining water leads to a huge reduction in once-through (freshwater) cooling



Future Directions

- A range of model improvements:
  - The role of adaptation vs mitigation – what if adaptation was not allowed to come in so easily
  - Closer mapping between land/electricity and water basins
  - Distinguishing between renewable and non-renewable groundwater and their associated costs
  - Energy demands in the water sector (e.g., desalination and groundwater pumping)
- Shorter temporal dynamics (e.g., droughts) and the ability to store water and food within and over multiple years

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Questions

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