Investment needs and energy use options for irrigation water use efficiency improvements and sustainable food system transition in Central Asia

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Motivation:

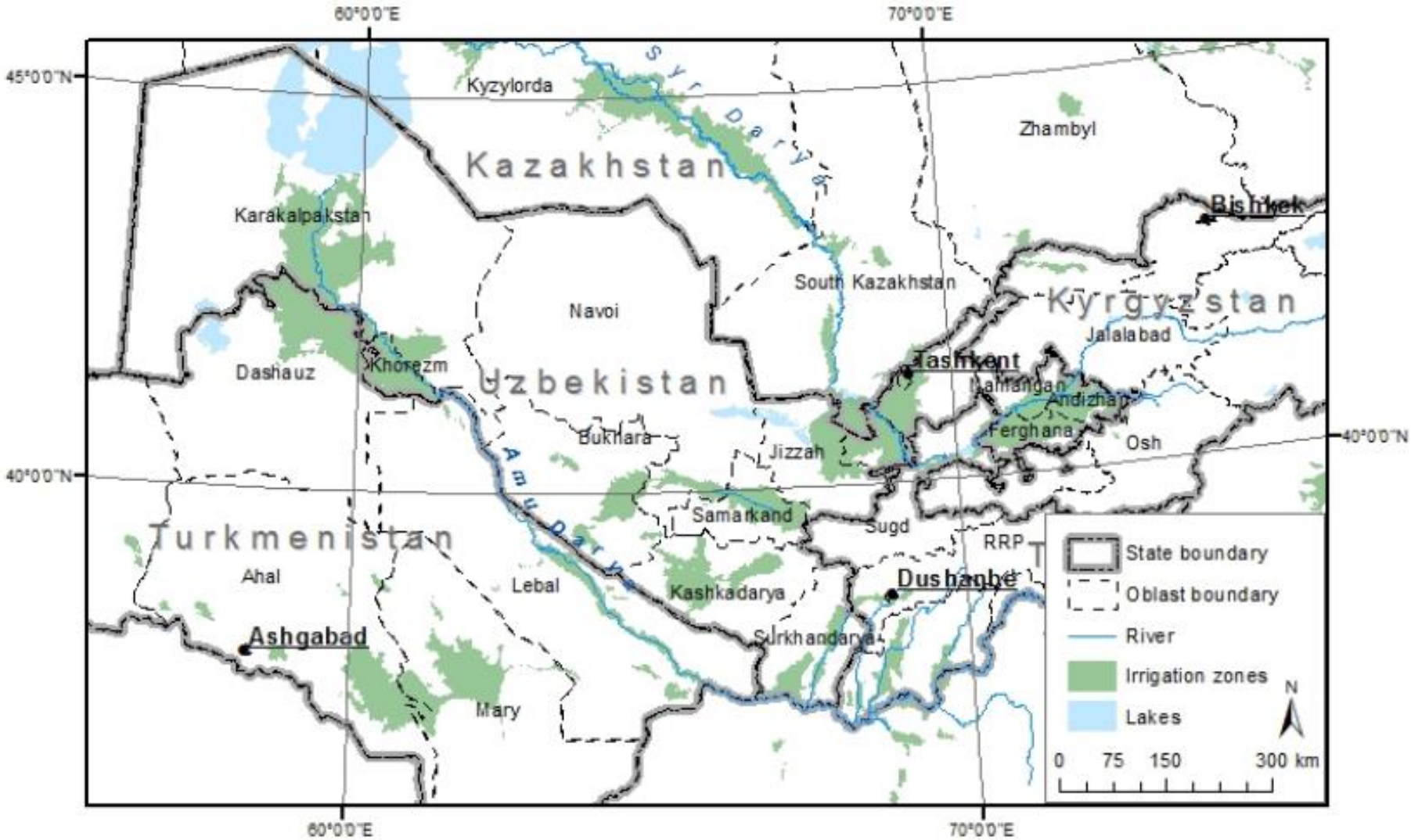
- Competition for energy, water and land uses is a growing challenge in most of the river basins across the world
- Renewable energies are being prioritized over fossil fuel energy sources to reduce GHG emissions and support climate policies
- However, less efficient practices of water and energy uses are still dominant consequently impeding sustainable resource uses
- Therefore, finding cost-effective ways of more efficient uses of water and energy resources is of utmost importance for sustainable development

Outline:

- Study area (Problem statement and research questions)
- Basin-wide hydro-economic modeling (HEM): an overview
- Hydro-economic modeling application
- Results:
  - Case I: Water use efficiency investments
  - Case II: The role of renewable energies (wind, solar)
- Challenges and future research prospects

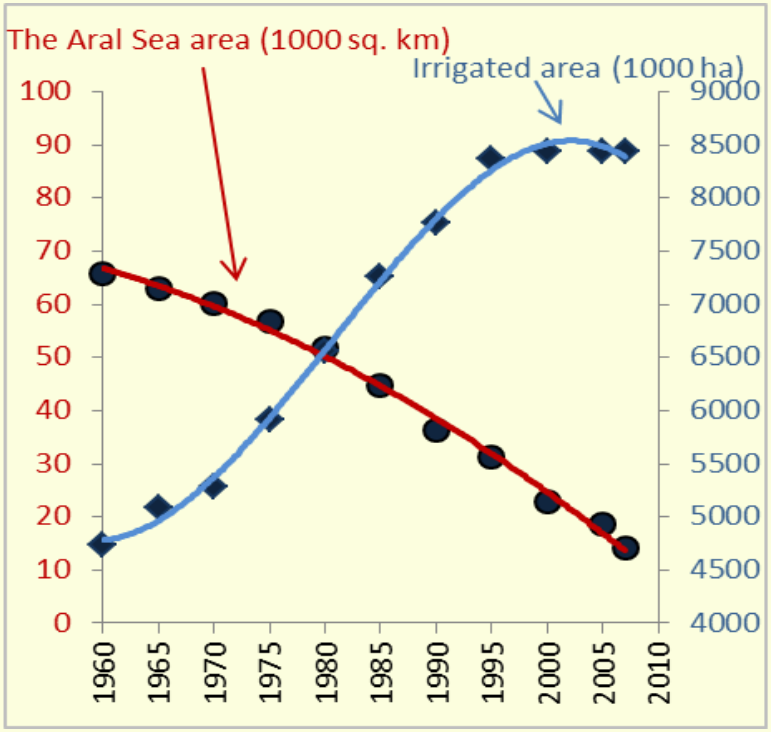
The Aral Sea Basin (Central Asia)
The problems and research questions

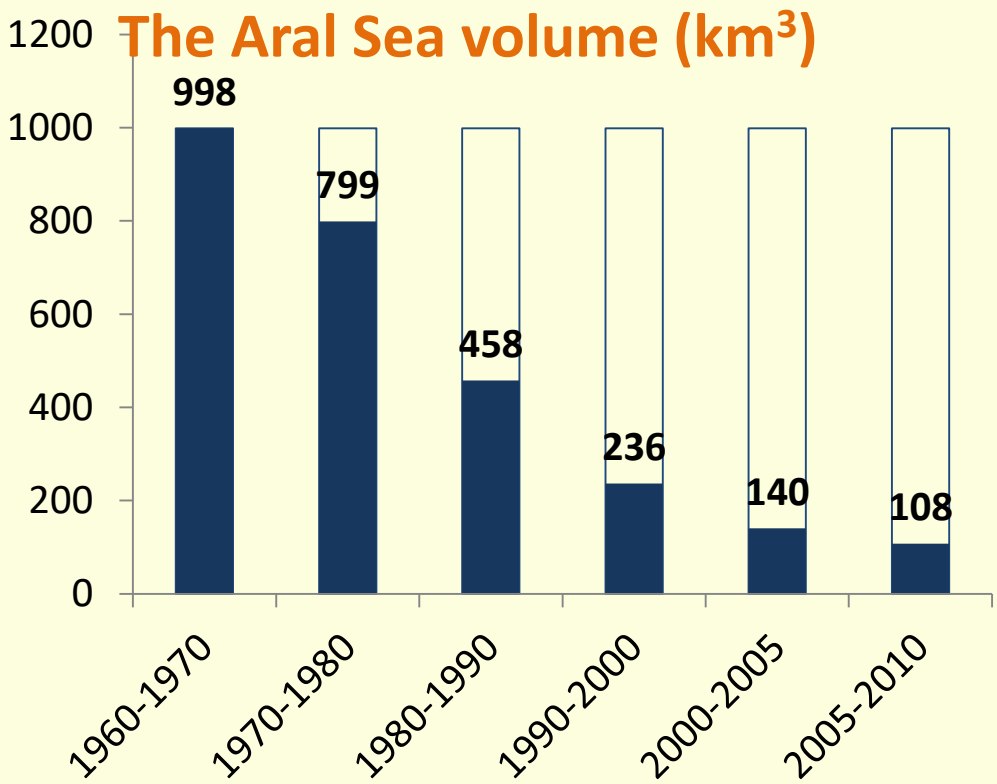
The Aral Sea basin map



Source: Bekchanov and Lamers (2016) (The Effects of Energy Constraints on Water Allocation Decisions…)

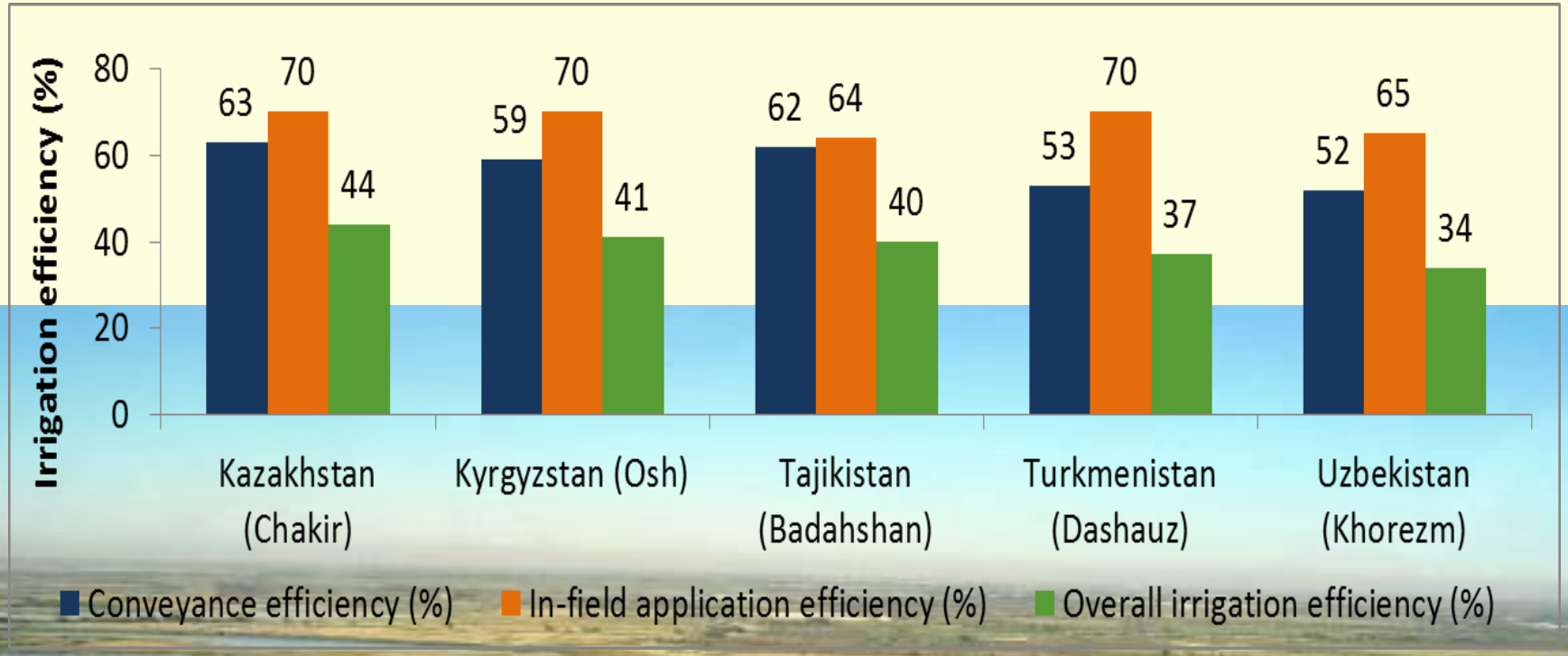
The tremendous expansion of irrigation since 1960s in particular for cotton production led to the Aral Sea desiccation (1960-2009), one of the worst human-made disasters in the world





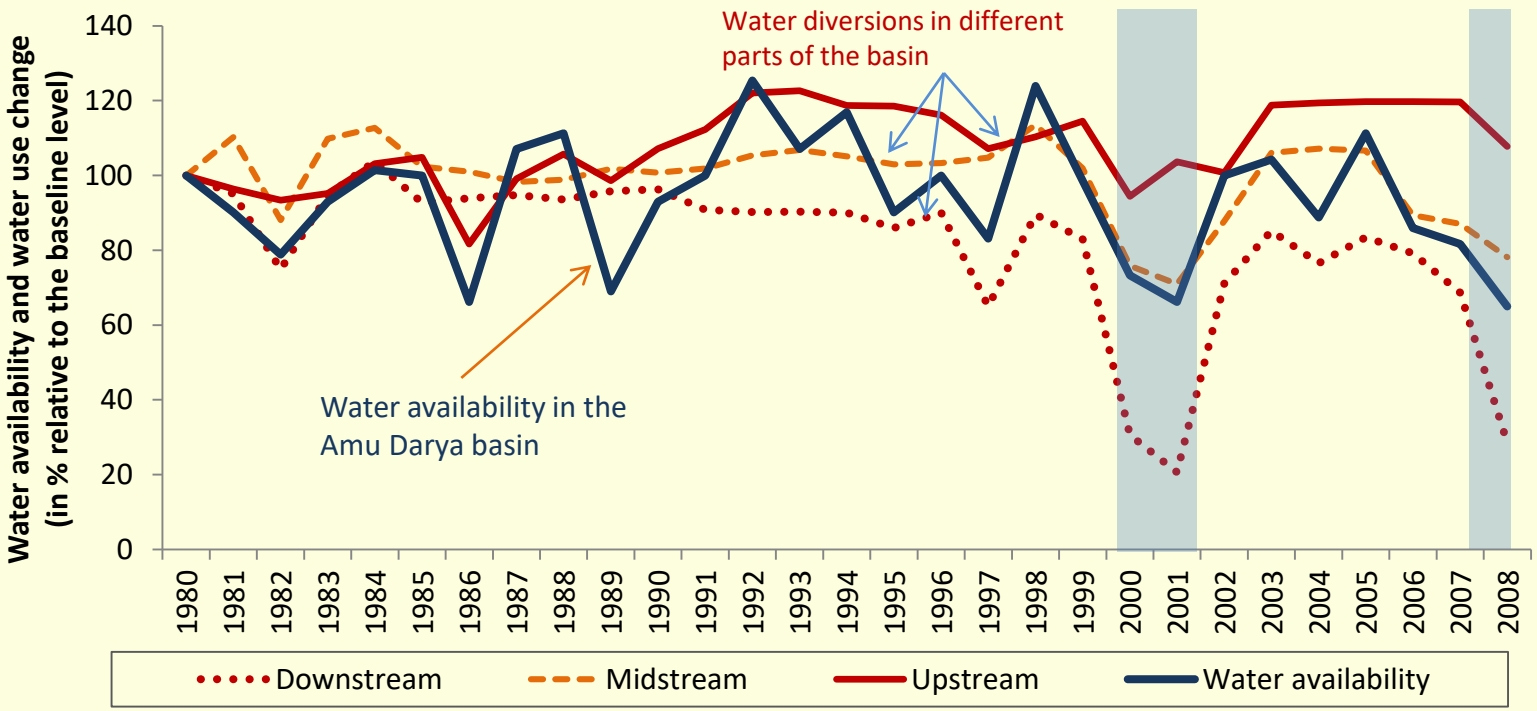
Source: Based on Micklin (2010) , MAWR (2010), FAO (2013)

Low Irrigation Efficiency Shows Substantial Potential for Coping with Climate Change Effects and Reduced Environmental Flow



Source: Bekchanov (2014), PhD Thesis

Following the demise of centralized water management and consequent change of reservoir release mode to enhance hydro-power production, downstream regions with high land productivity faced decreased water availability



Source: Based on Dukhovny et al. (2008), UzHydromet (2009), and SIC-ICWC (2011)

Research questions:

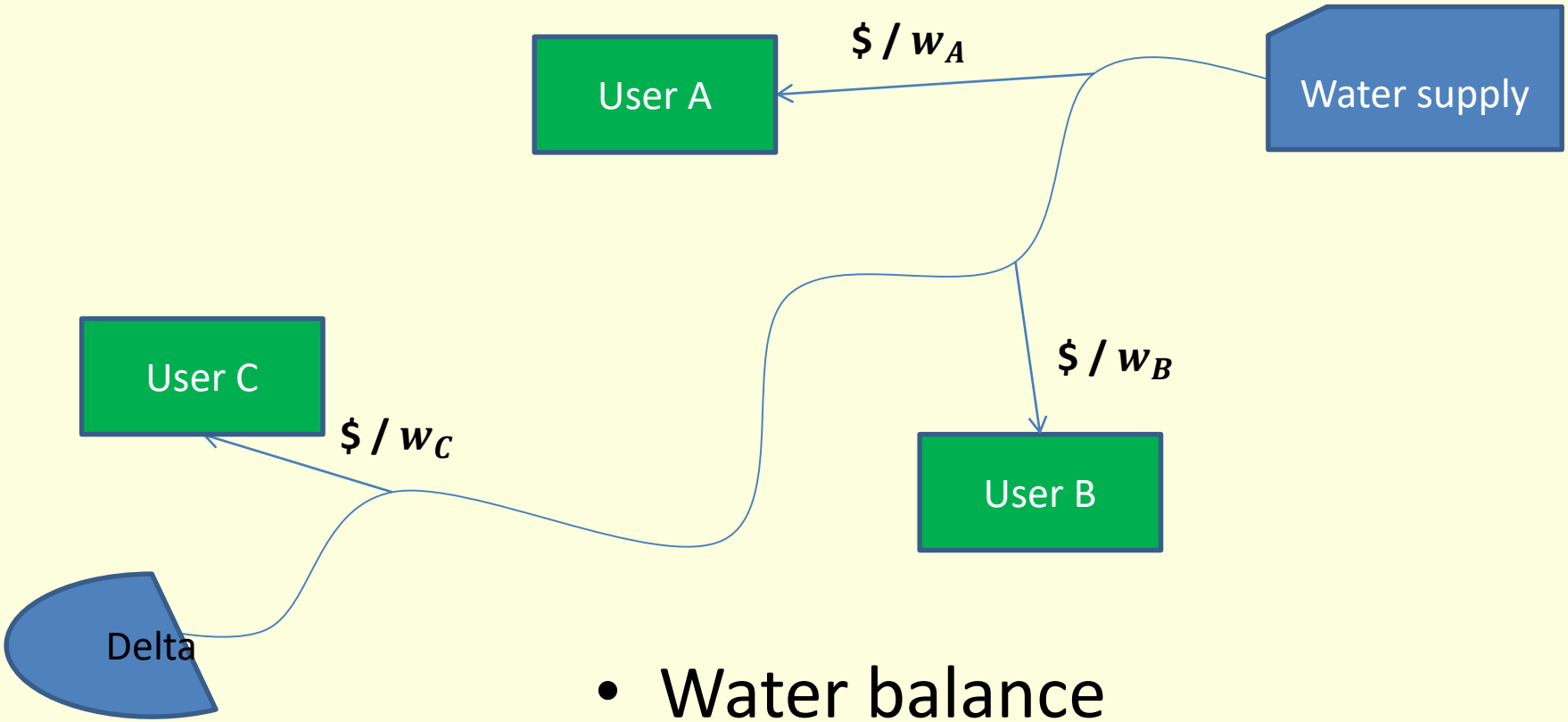
- How limited investments can be allocated for optimizing water use efficiency across the basin (among the irrigation sites and crop production activities)?

- How water scarcity can be impact on the importance of water use efficiency improvements?

- What are the roles of renewable energies (solar, wind, bio) as an alternative to hydropower and fossil-based fuel?

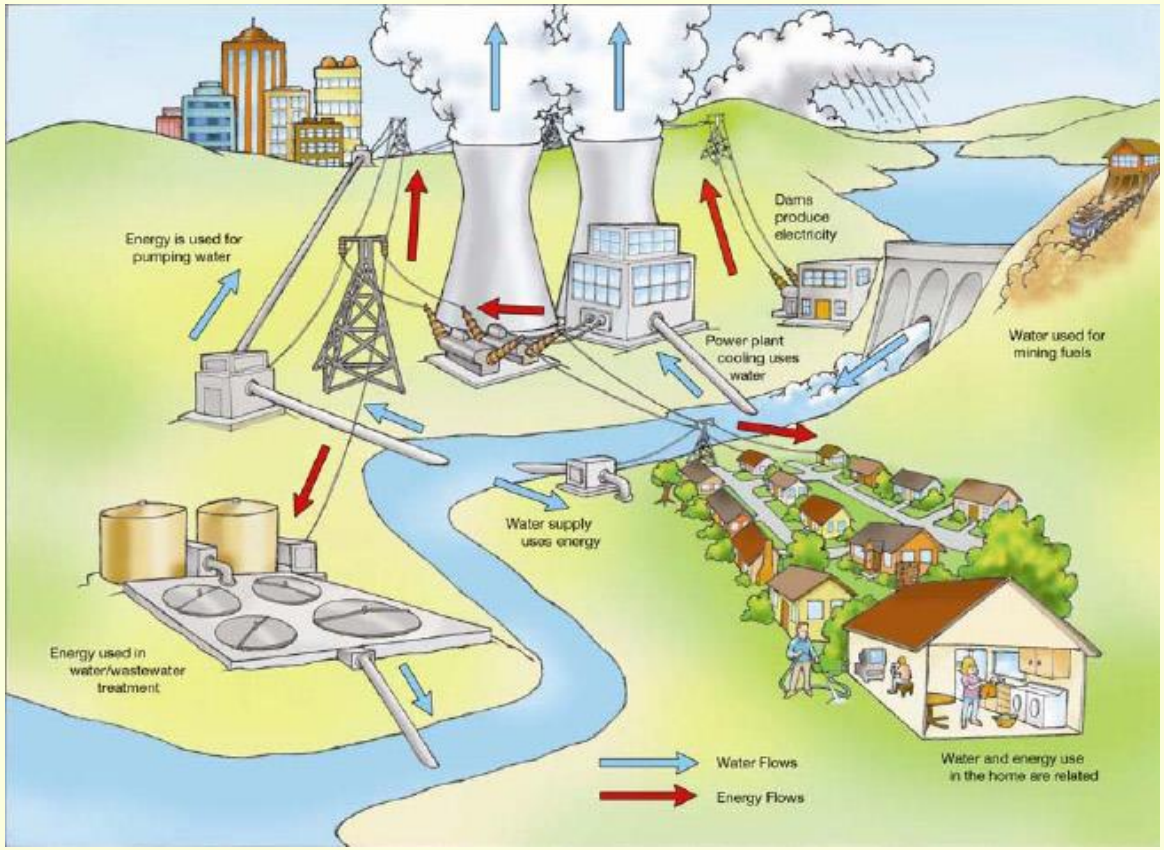
Integrated hydro-economic assessment: an overview

Stylized hydro-economic modeling structure



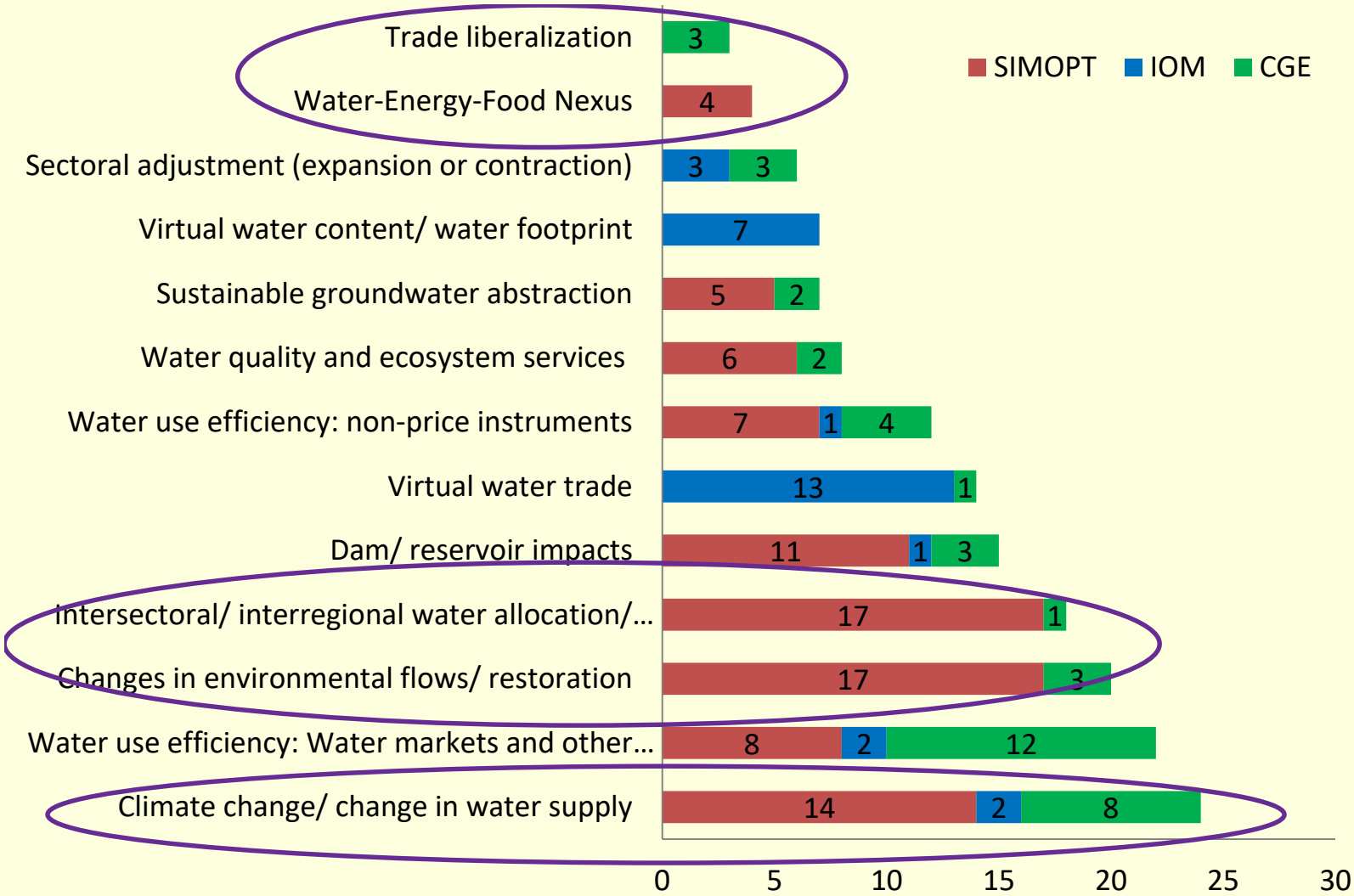
- Water balance
- Water use benefit functions
- Equi-marginality principle

River basin complexity



- Water supply and use
- Energy supply/use
- Irrigation systems
- Hydropower systems
- Production and markets
- Institutions, power, politics

Themes in hydro-economic modeling studies:



Source: Bekchanov et al. (2016) (Systematic review of hydro-economic modeling applications)

Application of the hydro-economic modeling

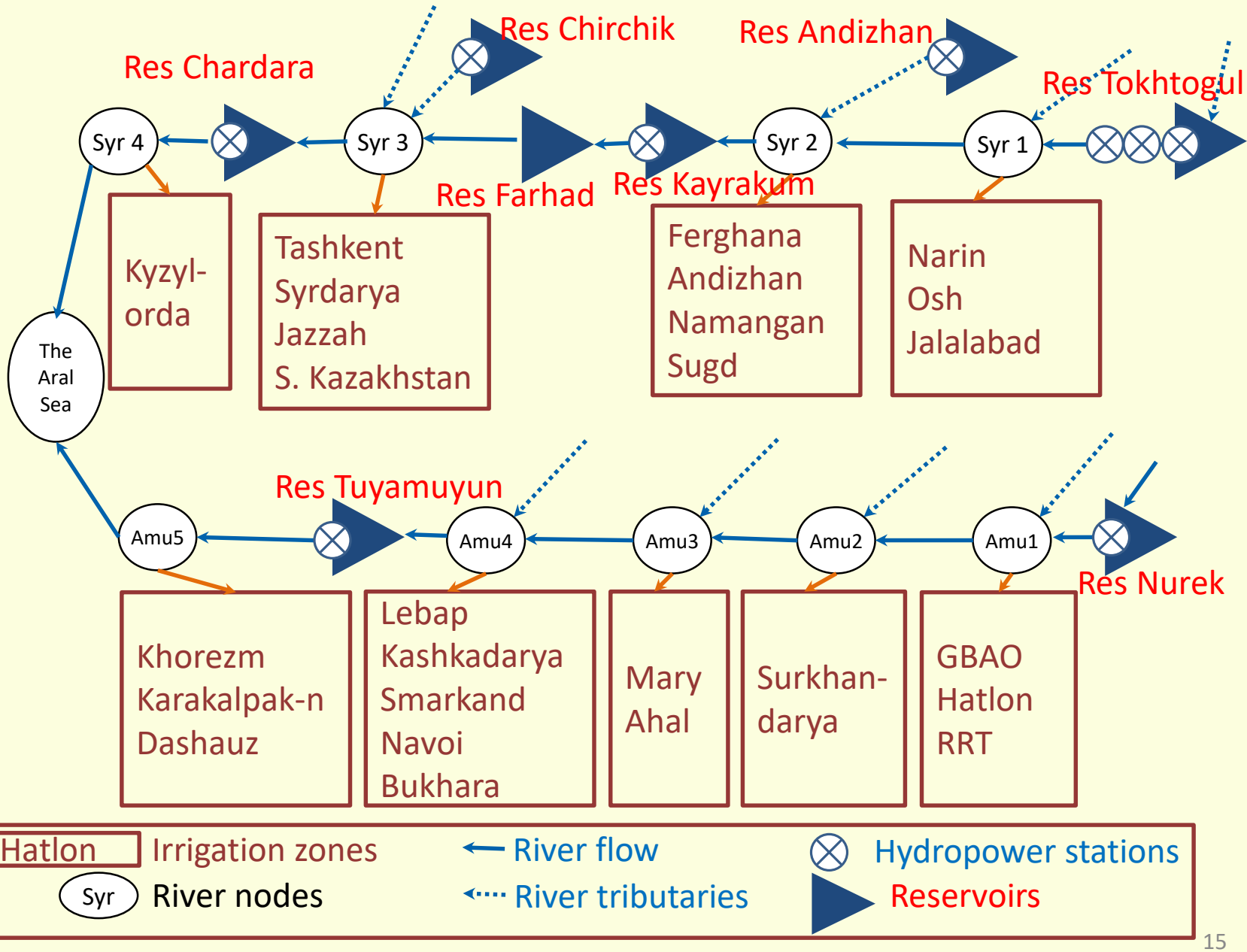
River node scheme of the Aral Sea Basin

8 river nodes

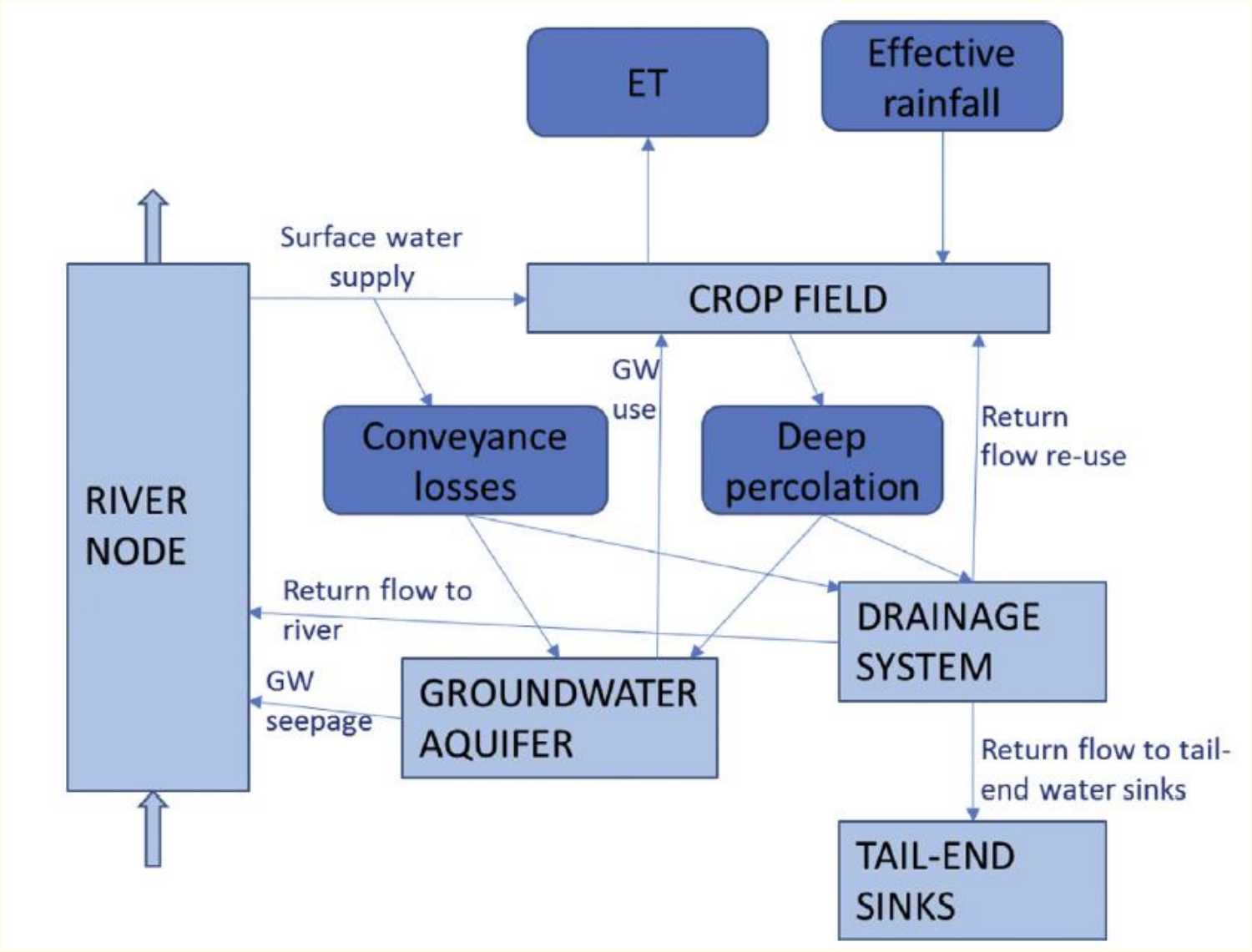
32 main river tributaries

26 irrigation zones

11 crops



Water balance relationships in irrigation site



Method

A hydro-economic model with annual planning horizon and monthly time steps

Crop-specific
Inter-regional
Seasonal

Objective function:

Irrigation benefit

$$\sum_c \sum_r \sum_t \left(Revenue_{c,r,t} - Costs_{c,r,t}\right) +$$

c-crop, r-region, t-technology

Hydropower production benefit

$$\sum_h \sum_s energy\_price_{h,s} hydropower\_prod_{h,s} +$$

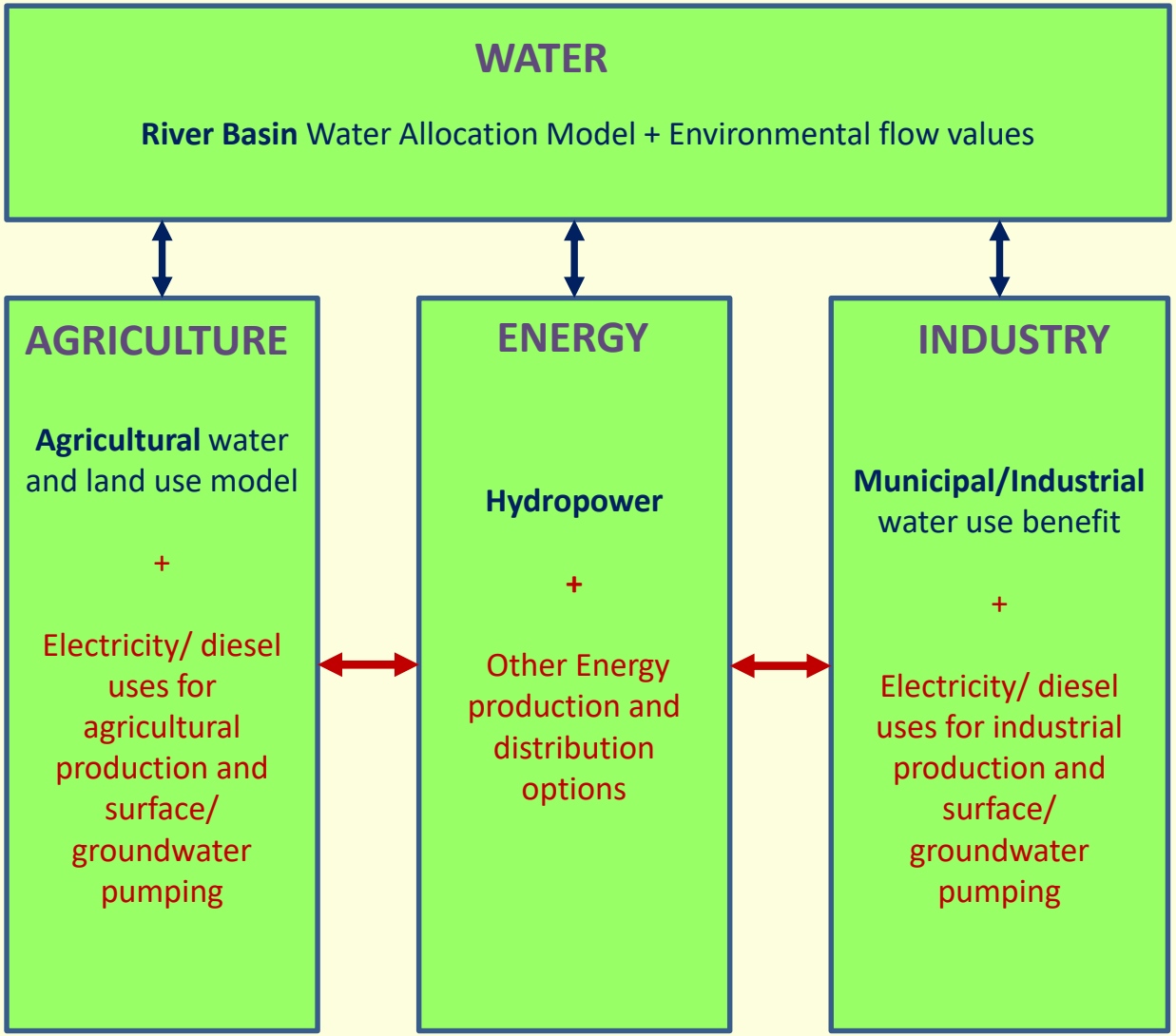
h-hydropower station, s-season (month)

Environmental flow benefit

$$environ\_ben\_per\_water \sum_s environ\_flow_s \rightarrow \max$$

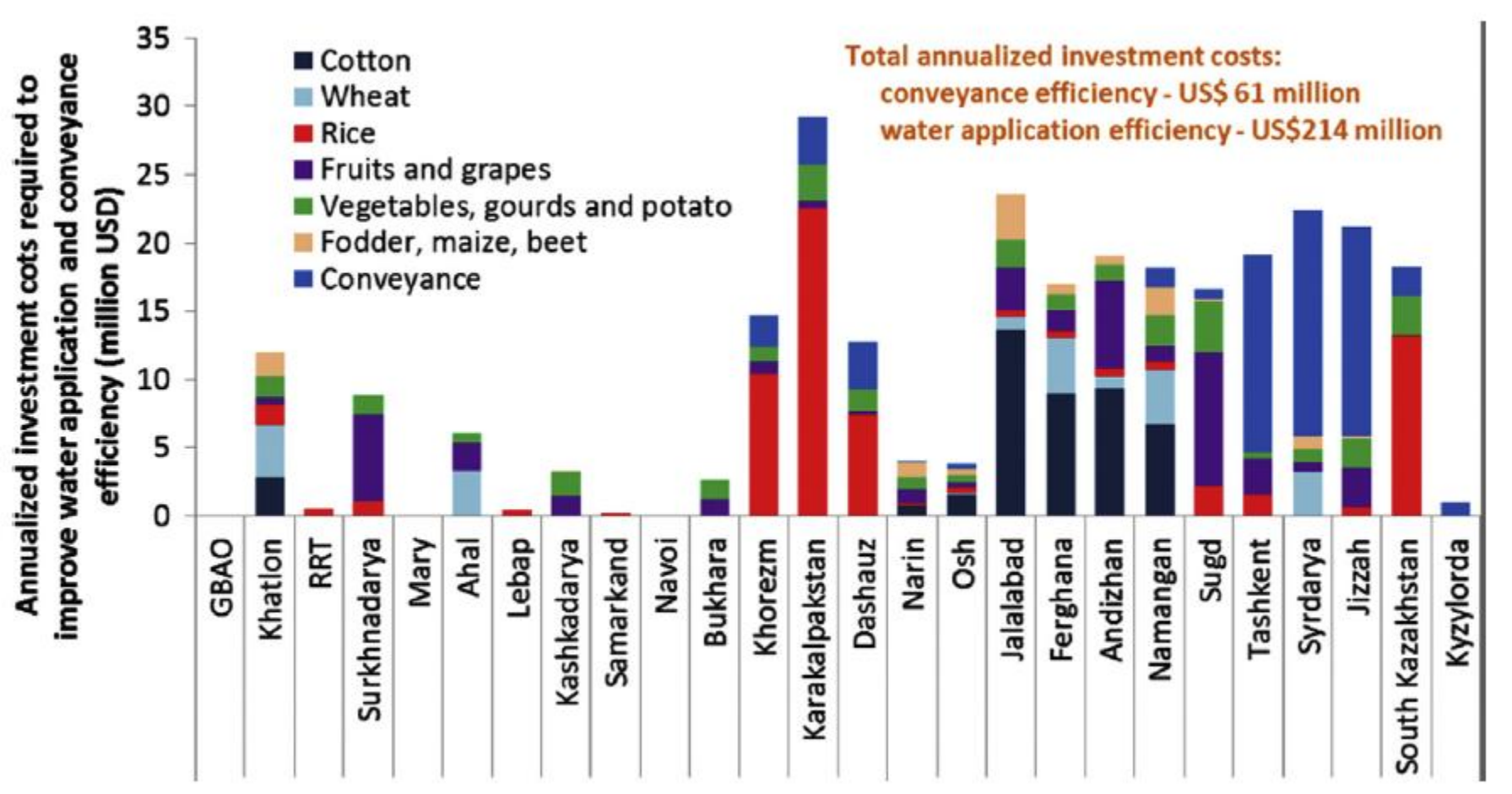
17985 equations and 18405 variables

Hydro-economic model with energy supply and demand (balance) component (HEM+EN)



Case I: Optimal irrigation efficiency improvement (adaptation) investments

Substantial investments needed to improve irrigation efficiency of rice production in downstream regions and cotton production in Ferghana Valley



Source: Bekchanov et al. (2015) dx.doi.org/10.1016/j.wre.2015.08.003

Positive Effects of Adopting Climate Change Adaptation Options Increases with the Depth Of Water Shortage

Scenarios	Water supply			Change compared to the optimal (baseline) scenario		
	Normal	90% of normal	80% of normal	Normal	90% of normal	80% of normal
Agricultural benefits (US$ million)						
OPT−	2776	2558	2213	0.0	0.0	0.0
OPT+	3378	3283	3131	21.7	28.4	41.5
Hydropower production benefits (US$ million)						
OPT−	395	349	320	0.0	0.0	0.0
OPT+	413	366	323	4.6	5.0	0.9
Environmental benefits (US$ million)						
OPT−	39	30	27	0.0	0.0	0.0
OPT+	47	36	27	20.8	21.7	2.0
Total benefit (US$ million)						
OPT−	3210	2937	2560	0.0	0.0	0.0
OPT+	3839	3685	3481	19.6	25.5	36.0

Source: Bekchanov et al. (2015) dx.doi.org/10.1016/j.wre.2015.08.003

The role of public (government) and private (farms) sector to implement the water use efficiency measures:

Public sector (government):

- Invest in improving the efficiency of main irrigation canals
- Make the improved irrigation technologies (e.g., drip irrigation and laser guided land leveling) available at the national market at reasonable price
- Improve land tenure

Private farms:

- Invest in improving field application efficiency and efficiency of on-farm canals
- Environmental consciousness and responsibility over their water overuse

Conclusions:

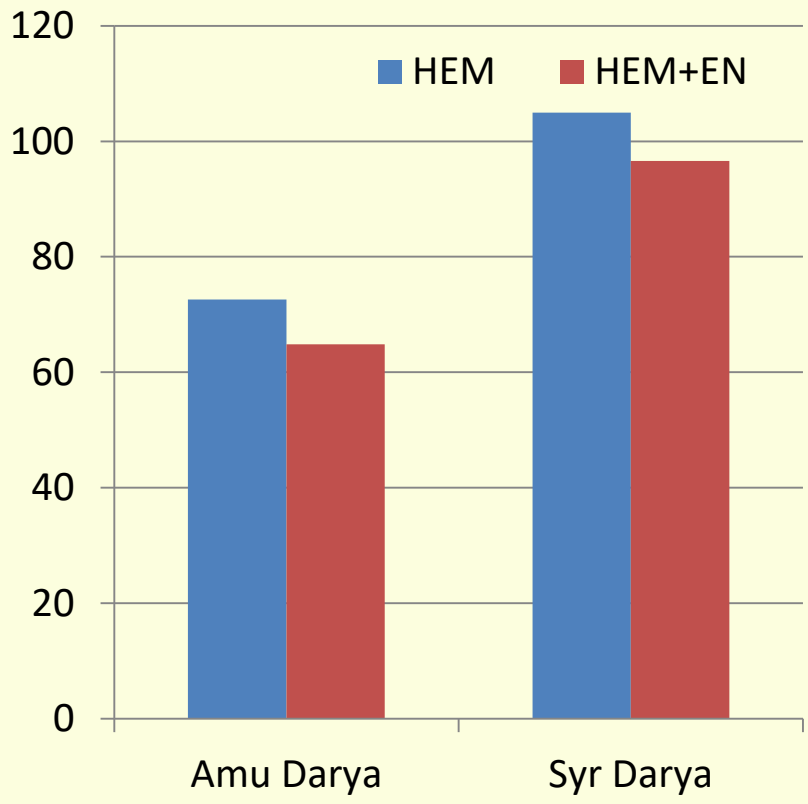
- Substantial investments are required to enhance field water application efficiency in rice production in downstream regions and cotton sector in Ferghana Valley regions

- Water scarcity increases the importance (role) of the improved irrigation efficiency

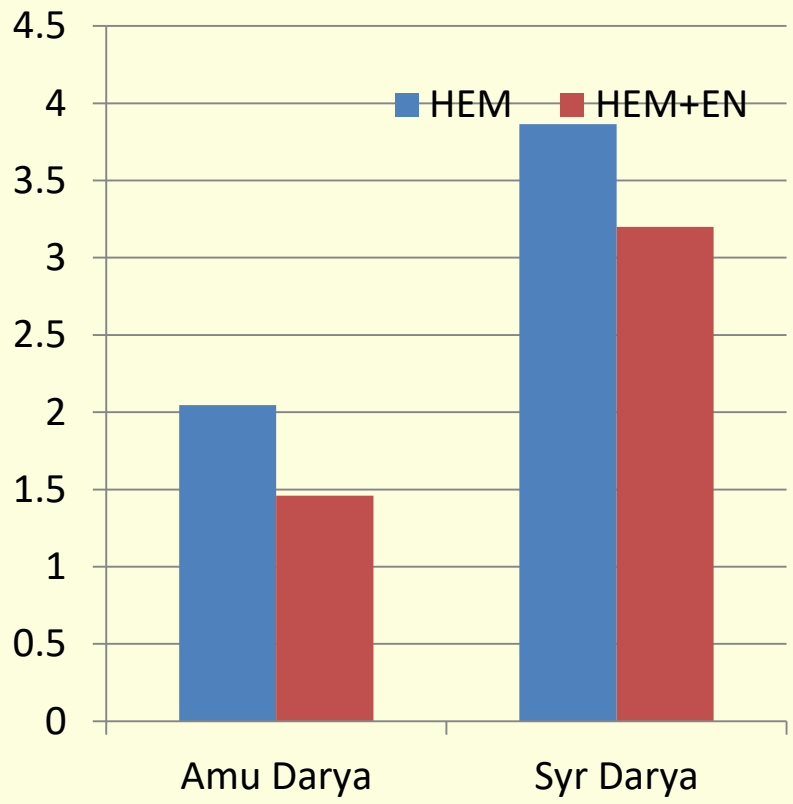
- Active participation of both government and private farms is essential for the success of the technological reforms

Case II: Energy requirements for food-water system

Energy to Water Impact: Optimal water allocations (km^3) at basin scale according to HEM and HEM+EN



Surface water



Ground water

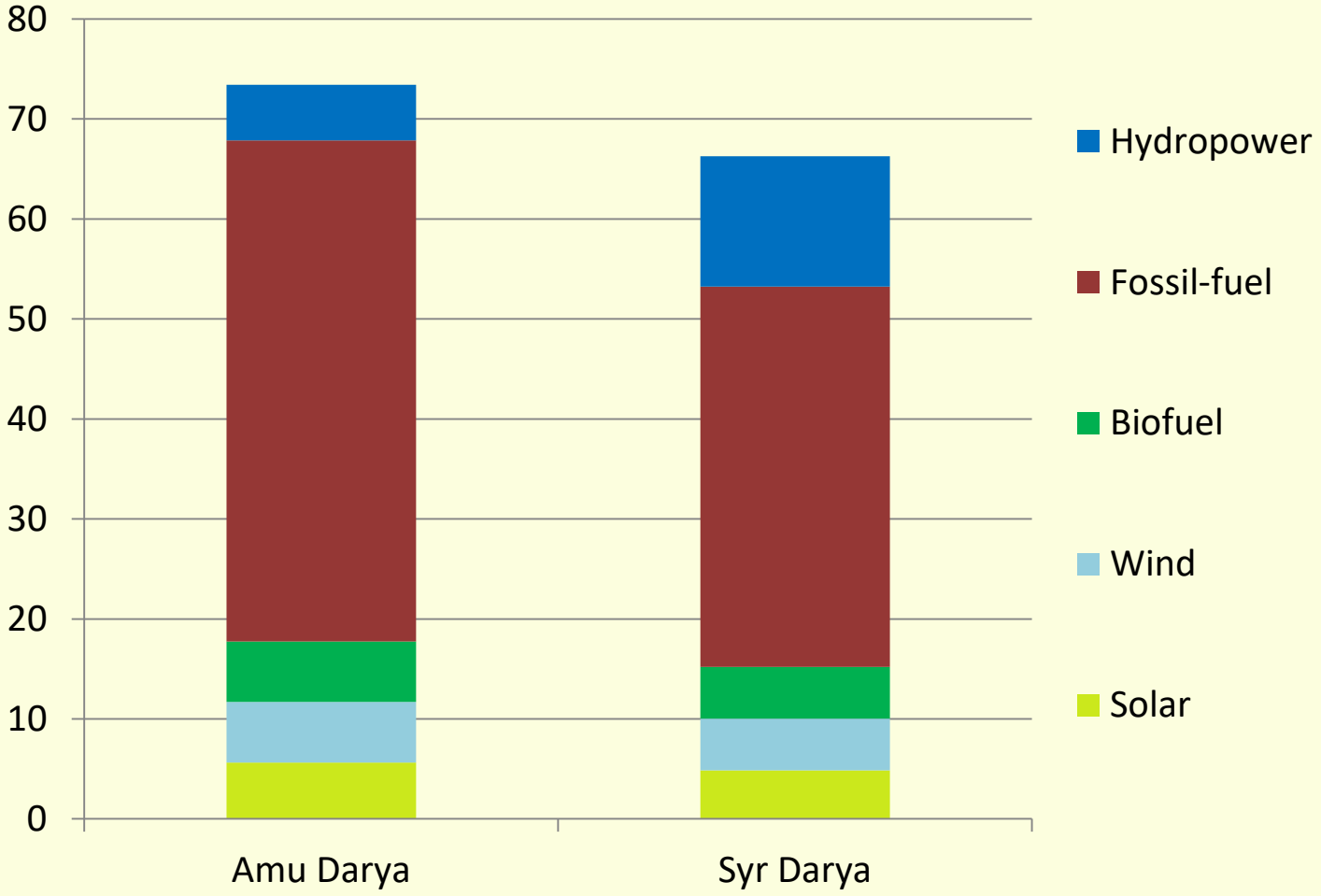
Source: Bekchanov and Lamers (2016) (The Effects of Energy Constraints on Water Allocation Decisions…)

Irrigation Water supply to Energy Impact: Optimal hydropower production benefits according to HEM and HEM+EN

Basin	Provinces	Hydropower Benefits (million USD)		Difference between Exp1 and Exp2 (%)
		Exp1: Without Energy Block	Exp2: With Energy Block	
Amu Darya	Nurek	183	189	3
	Tuyamuyun	7	9	28
Syr Darya	Tokhtogul (KG)	101	99	-2
	Kurupsay (KG)	30	29	-2
	Tashkumir (KG)	16	16	-2
	Shamaldisay (KG)	6	5	-2
	Uchkurgan (UZ)	21	20	-2
	Andizhan (UZ)	9	10	12
	Kayrakum (TJ)	9	9	0
	Farhad (UZ)	1	1	1
	Shardara (KZ)	5	5	7
	Chirchik (UZ)	28	31	11
	Total:	**413**	**422**	**2**

Source: Bekchanov and Lamers (2016) (The Effects of Energy Constraints on Water Allocation Decisions…)

Optimal energy production sources (million MWh)



Source: preliminary assessments

Conclusions:

- Consideration of the energy supply and balance constraints considerably change optimal water allocations

- Optimal water allocations decrease substantially in irrigation sites located in higher altitudes than river node or sites depended on long and unlined irrigation channels

- Renewable energy options may have limited role for irrigation due to low irrigation profitability but can be important option when their costs decrease in the long run

Future perspectives and challenges

Further research:

- Finer spatial resolution
- Consideration of digitalization technologies for effective water and land management
- Better representation of environmental, human health and welfare impact aspects
- Integrating general equilibrium (multi-regional) and process-based hydro-economic modeling (hard link)

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Optimizing irrigation efficiency improvements in the Aral Sea Basin

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Article

The Effect of Energy Constraints on Water Allocation Decisions: The Elaboration and Application of a System-Wide Economic-Water-Energy Model (SEWEM)

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