International Institute for Applied Systems Analysis

IIASA

water Futures and Solutions

Asian water futures
- Multi scenarios, models and criteria assessment -

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WAT Program

International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

Water future and solutions (WFaS) initiatives

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18 April 2016 EGU, Vienna

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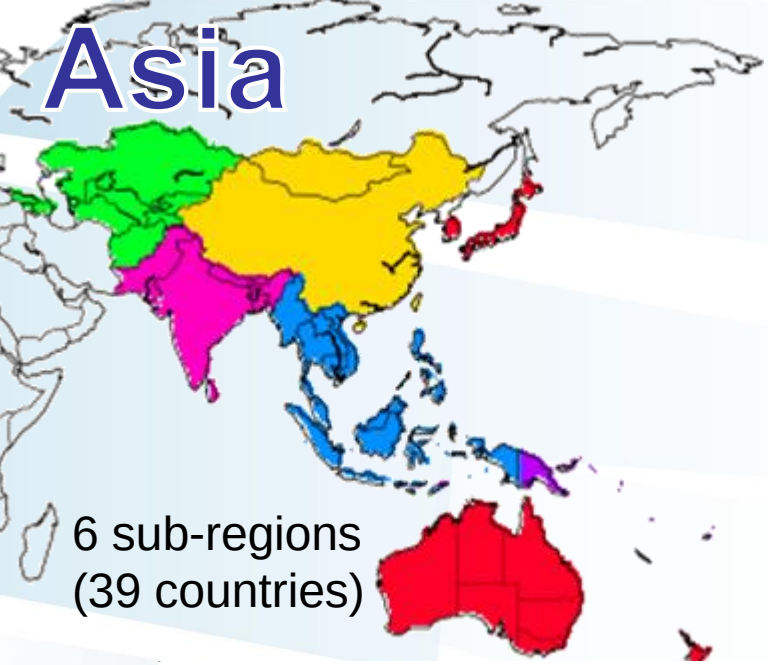
Asia



6 sub-regions
(39 countries)

Advanced economies (AE)
- Australia
- Brunei Darussalam
- Japan
- New Zealand
- Republic of Korea
- Singapore

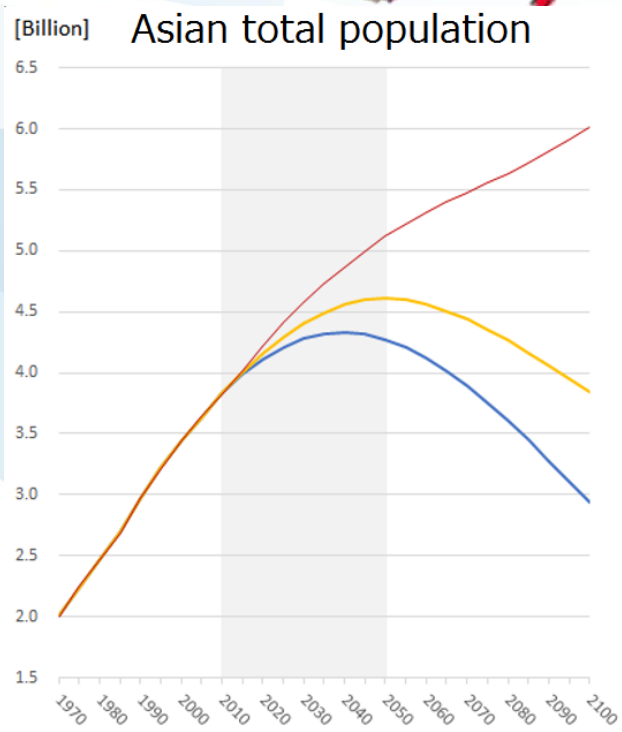
Central and West Asia (CWA)
- Afghanistan
- Armenia
- Azerbaijan
- Georgia
- Kazakhstan
- Kyrgyzstan
- Tajikistan
- Turkmenistan
- Uzbekistan

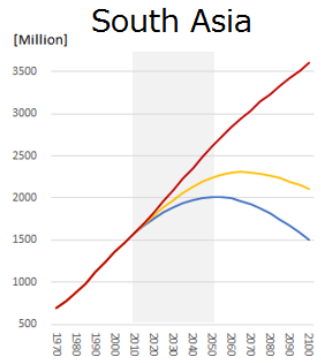
South Asia (SA)
- Bangladesh
- Bhutan
- India
- Maldives
- Nepal
- Pakistan
- Sri Lanka

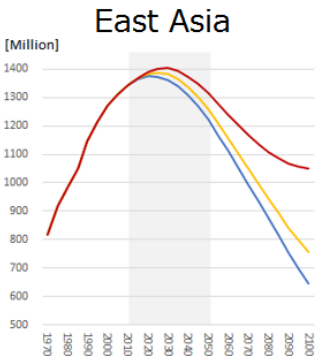
Southeast Asia (SEA)
- Cambodia
- Indonesia
- Lao People s Democratic Republic
- Malaysia
- Myanmar
- Philippines
- Thailand
- Viet Nam

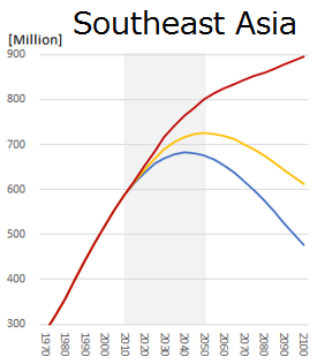
East Asia (EA)
- China
- Mongolia
- Taiwan

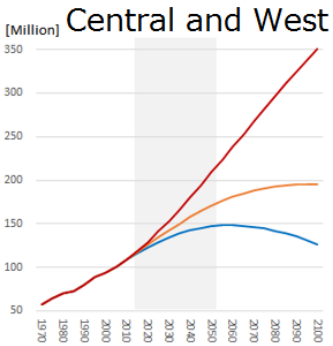
Pacific Asia (PA)
- Cook Islands
- Fiji
- Kiribati
- Marshall Islands
- Micronesia
- Nauru
- Niue
- Palau
- Papua New Guinea
- Samoa
- Solomon Islands
- Timor-Leste
- Tonga
- Tuvalu
- Vanuatu

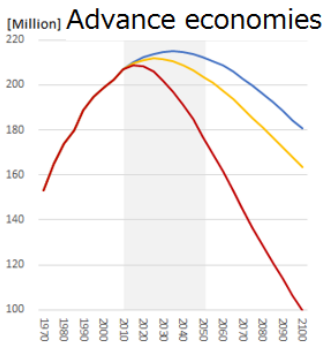


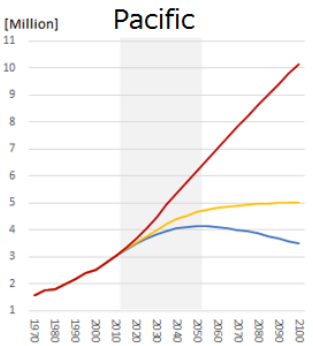












SSP1 SSP2 SSP3

Purpose of this study

Back ground:

- As well as climate change, **these socio-economic change will put additional pressure on water**, food and energy systems
- Assessment of these global change will provide essential knowledges for stakeholders and policy makers
- **But**, **only very few assessments have yet used the Shared Socioeconomic Pathways** (SSPs) **to assess the impacts of global change on water resources** because we need to develop scenarios for water-sector as extension of SSPs to investigate possible water futures

[Hanasaki, et al., 2013, Arnell & Lloyd-Hughes, 2014]

The IIASA Water Futures and Solutions Initiative (WFaS) initiative developed a set of water use scenarios

Purpose:

→ **depict and assess Asian water futures at country and regional scale with a set of new "water scenarios**

WFaS approach

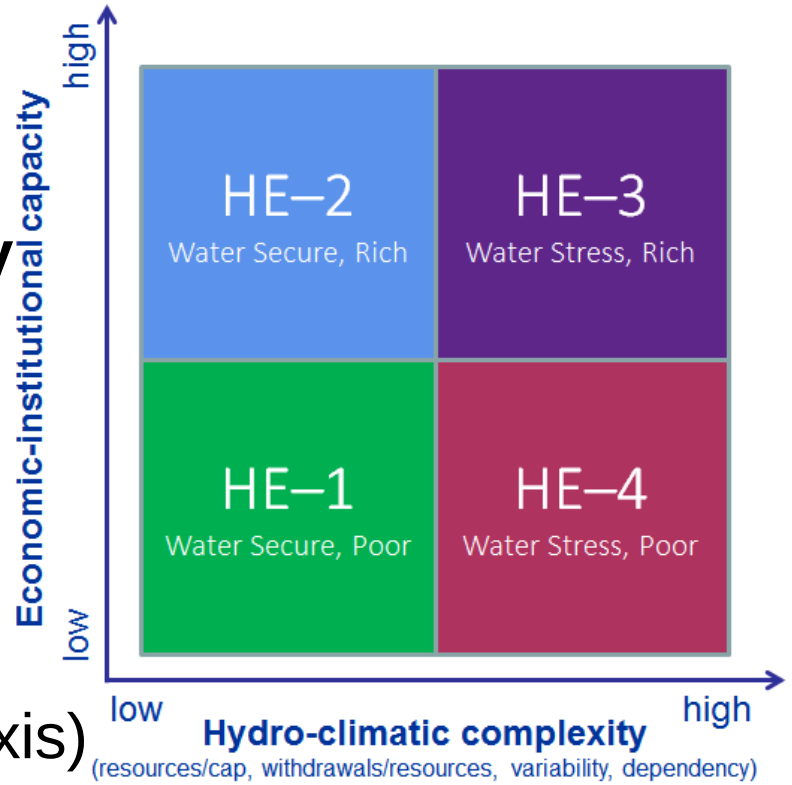
- ✓ **Multi-criteria**
- ✓ **Multi-scenarios**
- ✓ **Multi-models**

✓ **Multi-criteria approach**

Hydro-Economic Classification

***Fischer** et.al. (2015), IIASA Interim Report*

Regions, countries or basins are classified on the basis of two major dimensions;



1. Economic-Institutional Capacity (Y-axis)

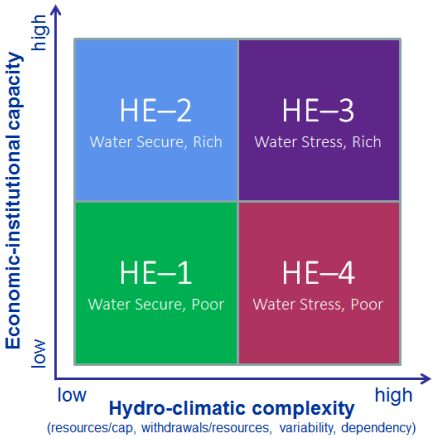
- GDP (in PPP) per capita
- ~~Corruption Perception Index; Educational Achievements~~

2. Hydro-climatic Complexity (X-axis)

- Total renewable surface water resources per capita
- Share of Total Water demand (withdrawal) in total surface water supply
- Coefficient of variation of monthly runoff
- Share of external water resources in total surface water supply

✓ **Multi-criteria approach**

Hydro-Economic Classification



1. Select component indicator variables for X-axis representing a country‘s hydrological complexity
2. Map each indicator variable to respective component index values in interval [0,1]
3. Choose criteria weights wi, i=1,Nx and calculate compound index:

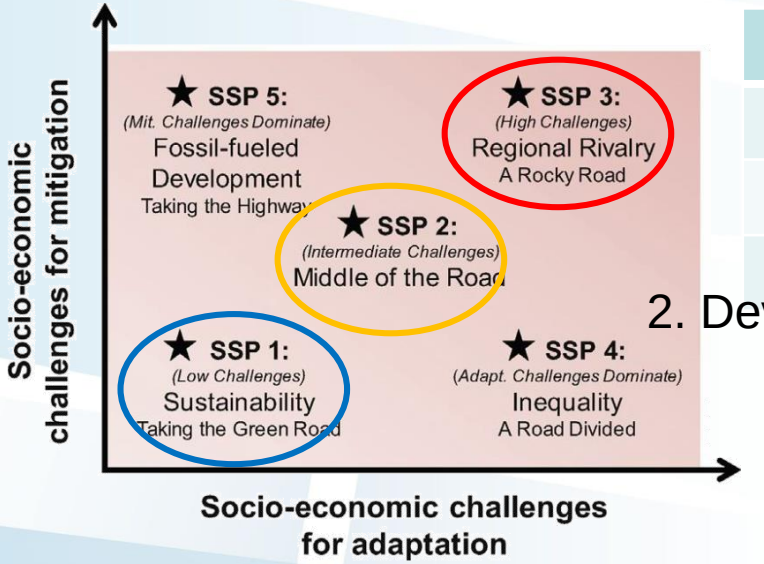
$$IX = \sum_{i=1}^{Nx} w_i X_i \Big/ \sum_{i=1}^{Nx} w_i$$

4. Select component indicator variables for Y-axis representing a country‘s economic-institutional capacity and map to component index values and compound index *IY*
5. Map countries according to X- and Y-dimensions and classify accordingly

✓ **Multi-scenario approach**

WFaS water scenarios

1. Define feasible combination of SSP and RCP



Scenario name	SSP	RCP
Sustainability	SSP1	RCP4.5
Middle of the Road	SSP2	RCP6.0
Regional Rivalry	SSP3	RCP6.0

2. Develop water narratives from SSP assumptions

SSP1: The world is moving toward sustainability

SSP characteristics

- Improved resource use efficiency
- More stringent environmental regulations
- Rapid technological change is directed toward environmentally friendly processes
- Management of global commons improves.

Implications for Manufacturing Water Use:

- Manufacturing industries with efficient water use and low environmental impacts are favored.
- Enhanced treatment, reuse of water, and water-saving technologies;
- Widespread application of water-saving technologies in industry

WFaS initiative
+ stakeholder group

3. Improve the narriatives with HE classification

			L		M		H		M	
		socio-economic capacity	poor		rich		Rich		Poor	
		hydro-climatic complexity	low		low		high		high	
			HE-1		HE-2		HE-3		HE-4	
H	SSP1	Sustainability Quest (SSP dominant)	HL	B	HM	B	HH	A	HM	B
M	SSP2	Business as Usual (SSP as HE)	ML	D	MM	C	MH	B	MM	C
L	SSP3	Fragmentation (HE dominant)	LL	E	LM	D	LH	C	LM	D

4. Set parameters

A	B	C	D	E
1.2%	1.1%	1%	0.6%	0.3%
highest				lowest

✓ **Multi-scenario approach**

WFaS water scenarios

Scenario assumptions for technology and structural change in the industry and domestic sector

		Hydro-Economic (HE) classification[1]			
		HE-1	HE-2	HE-3	HE-4
Socio-economic capacity to cope with water-related risks		Low (poor)	High (rich)	High (rich)	Low (poor)
Exposure to hydrologic complexity & challenges		Low	Low	High	High
ENERGY SECTOR					
Technological change [annual change rate]	SSP1-SUQ	1.10%	1.10%	1.20%	1.10%
	SSP2-BAU	0.60%	1.00%	1.10%	1.00%
	SSP3-DIV	0.30%	0.60%	1.00%	0.60%
Structural change[2] [change in cooling system, i.e. from one-through to tower cooling]	SSP1-SUQ	40 yr	40 yr	40 yr	40 yr
	SSP2-BAU	None	40 yr	40 yr	40 yr
	SSP3-DIV	None	None	40 yr	None
MANUFACTURING SECTOR					
Technological change [annual change rate]	SSP1-SUQ	1.10%	1.10%	1.20%	1.10%
	SSP2-BAU	0.60%	1.00%	1.10%	1.00%
	SSP3-DIV	0.30%	0.60%	1.00%	0.60%
Structural change [change in intensity over time relative to GDP per capita]	SSP1-SUQ	Yes	Yes	Yes	Yes
	SSP2-BAU	Yes	Yes	Yes	Yes
	SSP3-DIV	Yes	Yes	Yes	Yes

		Hydro-Economic (HE) classification[1]			
		HE-1	HE-2	HE-3	HE-4
Socio-economic capacity to cope with water-related risks		Low (poor)	High (rich)	High (rich)	Low (poor)
Exposure to hydrologic complexity & challenges		Low	Low	High	High
DOMESTIC SECTOR					
Technological change [annual change rate]	SSP1-SUQ	1.10%	1.10%	1.20%	1.10%
	SSP2-BAU	0.60%	1.00%	1.10%	1.00%
	SSP3-DIV	0.30%	0.60%	1.00%	0.60%
Structural change[3] [decrease over given time]	SSP1-SUQ	20% until 2050	20% until 2050	20% until 2050	20% until 2050
	SSP2-BAU	None	None	None	None
	SSP3-DIV	None	None	None	None

- Detailed explanation of scenario development process and assumptions can be found in **Wada et al. (2015)**

✓ **Multi-model approach**

A consistent setting of simulations

Water supply : 5 global hydrological model **x 5** forcing (ISI-MIP)
Water demand : 3 global hydrological model (WFaS)

- Global 0.5x0.5 degree (applrox. 50km)
  ⇒ Global -> Asia region
  ⇒ Scale of assessment
  (Asian, Sub-regional, country and sub-country)
- Main analysis period **: the 2010s- the 2050s**

[Warszawski et al. 2014]

GHM	Resolution	Institute	Nation
WaterGAP	0.5° x0.5°	University of Kassel	Germany
H08	0.5° x0.5°	NIES	Japan
PCR-GLOBWB	0.5° x0.5°	University of Utrecht	The Netherlands
MPI-HM	0.5° x0.5°	Max Planck Institute	Germany
WBM	0.5° x0.5°	City College of New York	The United States

Results

1. **Change in water supply**
2. **Change in water demand**
3. **Water scarcity**
   (Imbalance between water demand and supply)
4. **Hydro-economical analysis**

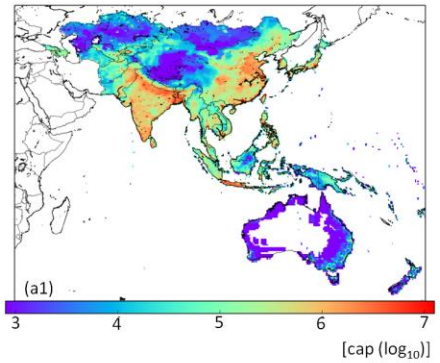
Change in supply side

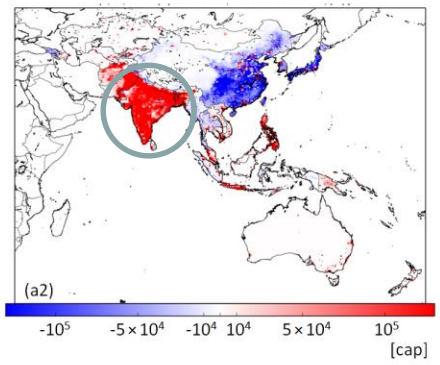
Change (2050s-2010s) (10yr climatology)

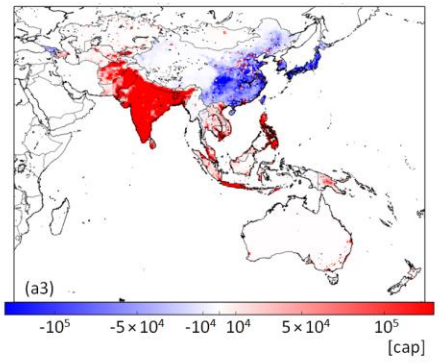
Yearly average

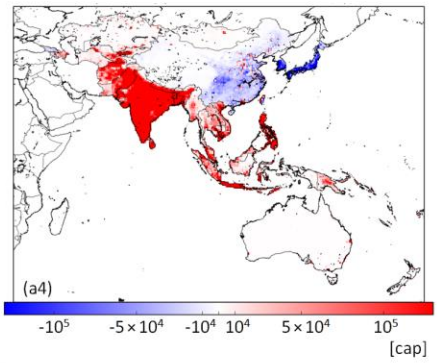
The 2010s	SSP1/RCP4.5 (Sustainability)	SSP2/RCP6.0 (Middle of the Road)	SSP3/RCP6.0 (Regional Rivalry)

Population

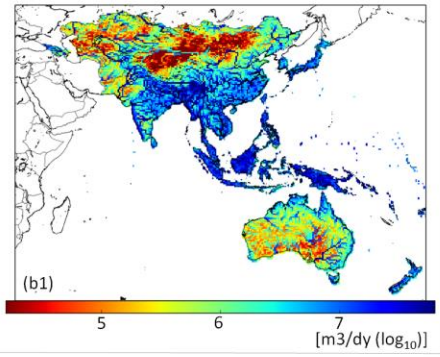


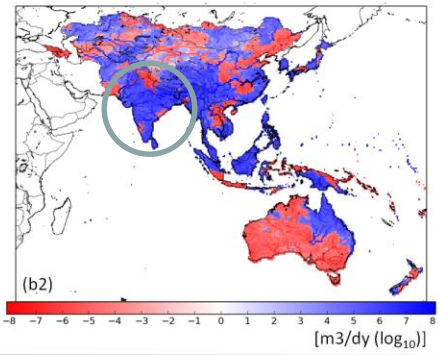


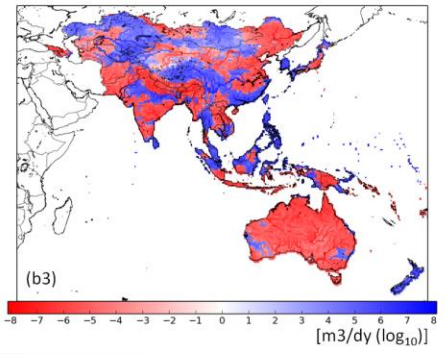


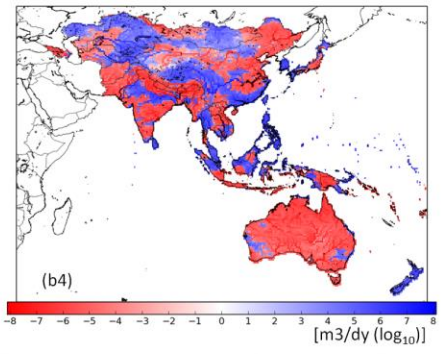


Available surface water resource

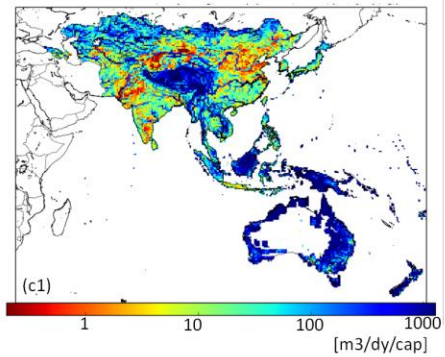


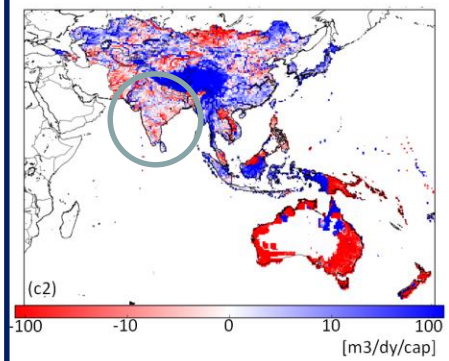


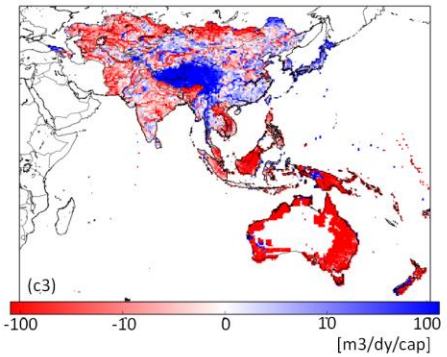


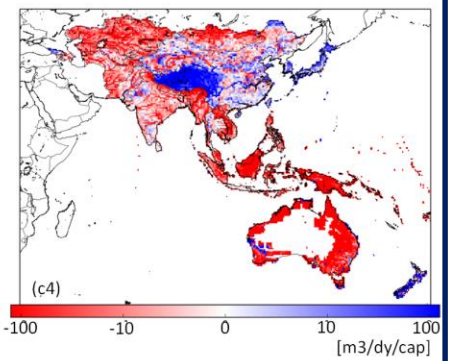


Available surface water resource (/cap)







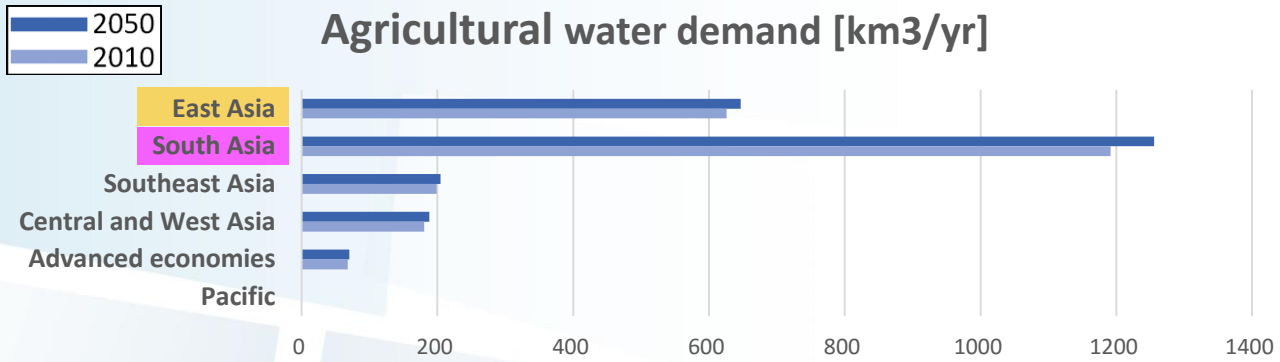


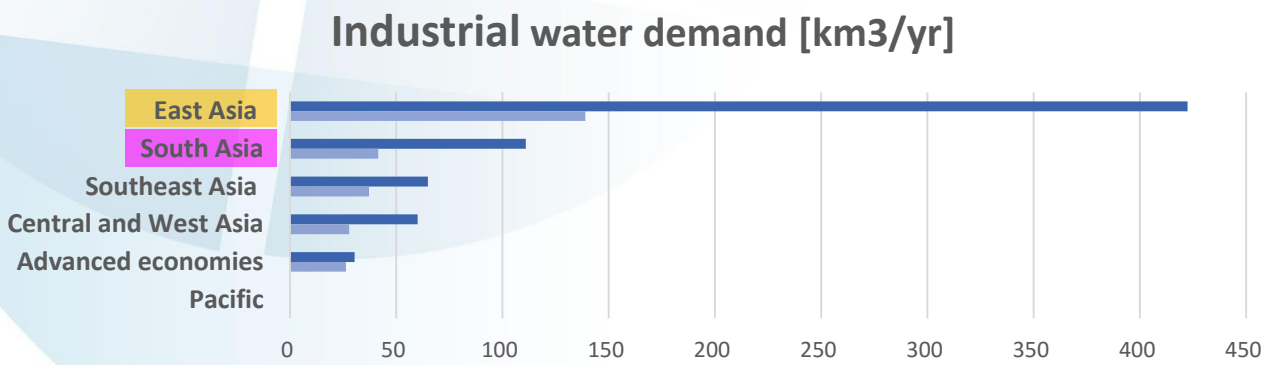
Many regions show decrease in per capita water resource…

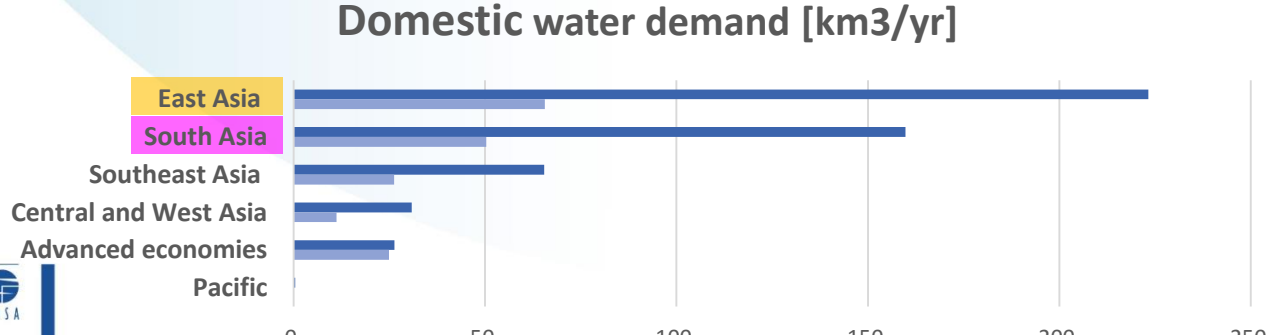
Change in demand side

Asian total water demand in the 2010s is about 2410 km^3/year and was projected that it will be 3170 - 3460 km^3/year (**increase by 30 - 40%**) under the three scenarios

Middle of the Road





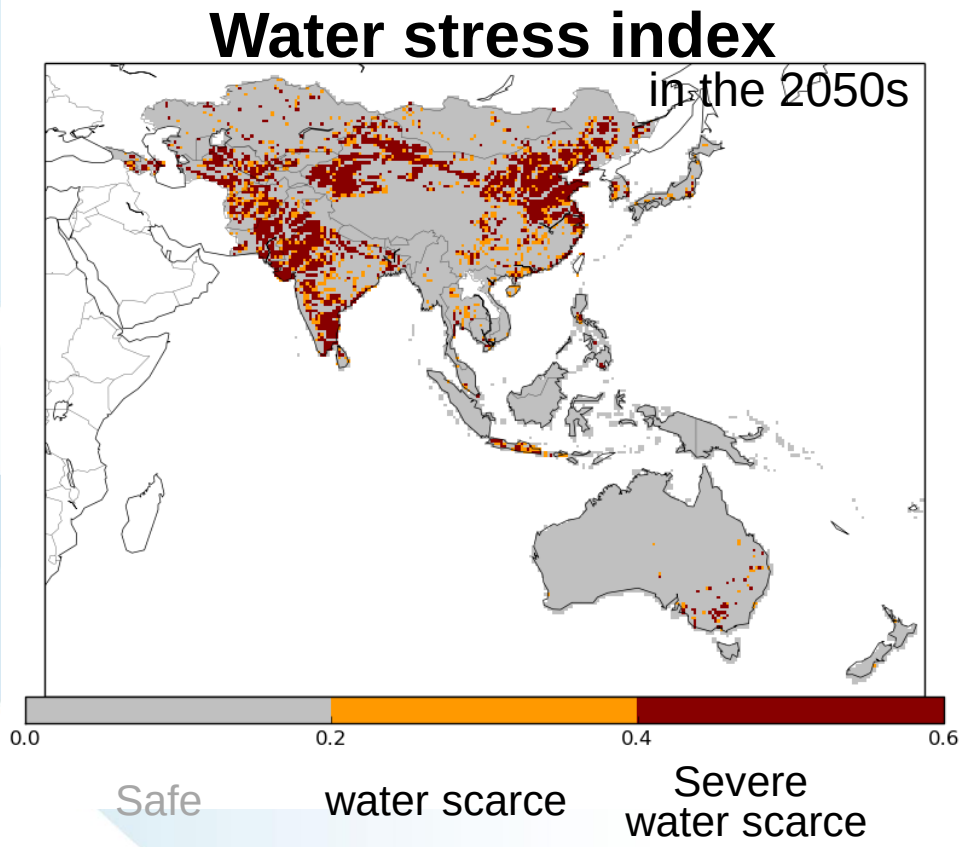


Total water demand (2050s)

Ranking	Country	km^3/yr
1	China	1214
2	India	965
3	Pakistan	332
4	Indonesia	103
5	Thailand	82
6	Uzbekistan	71
7	Viet Nam	66
8	Bangladesh	65
9	Japan	56
10	Afghanistan	45
11	Philippines	41
12	Kazakhstan	37
13	Turkmenistan	33
14	Australia	32
15	Republic of Korea	31
⋮		

Imbalance between demand and supply

Middle of the Road

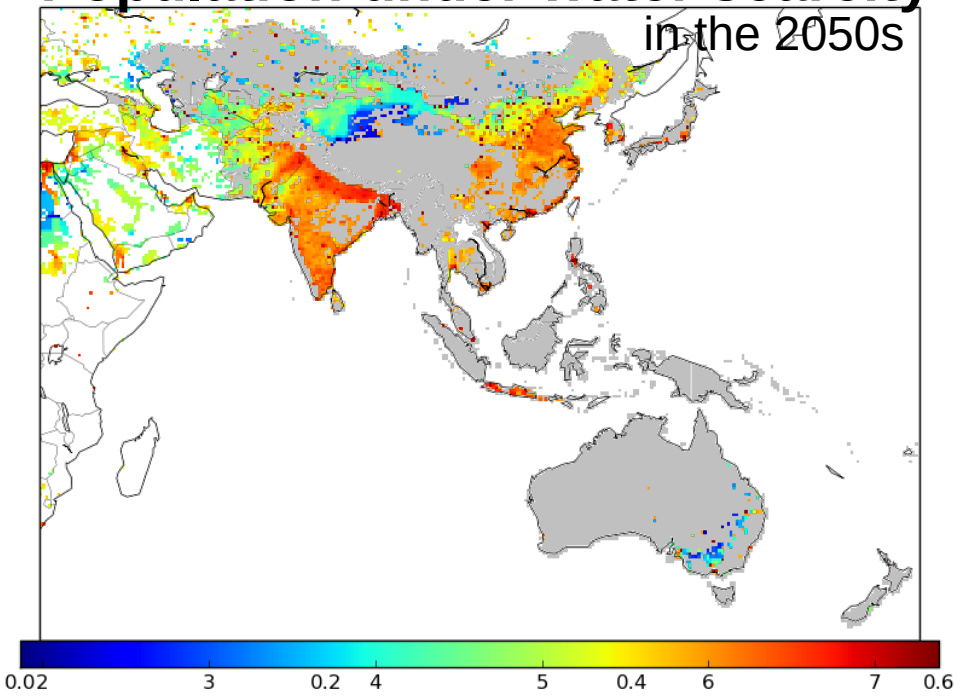


$$\text{Water scarcity index} = \frac{\text{Water demand}}{\text{Available water resource}}$$

Imbalance between demand and supply

Middle of the Road

Population under water scarcity in the 2050s



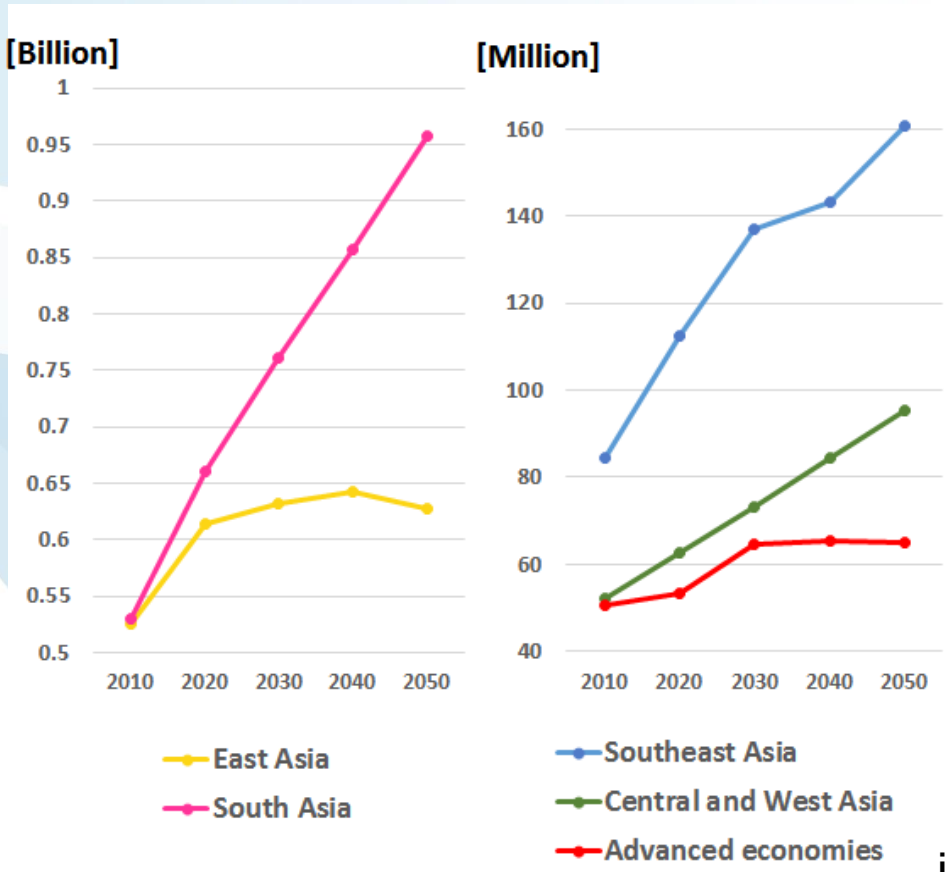
$$\text{Water scarcity index} = \frac{\text{Water demand}}{\text{Available water resource}}$$

[Million of people] (per cent of whole population)		Middle of the Road 2010		2030		2050	
East Asia	China	525	(38%)	631	(45%)	627	(48%)
	Mongolia	0	(1%)	1	(19%)	1	(19%)
	SUM	525	(38%)	631	(45%)	628	(48%)
South Asia	Bangladesh	21	(14%)	57	(32%)	62	(32%)
	Bhutan	0	(0%)	0	(0%)	0	(0%)
	India	420	(34%)	576	(37%)	730	(42%)
	Maldives	0	(0%)	0	(0%)	0	(0%)
	Nepal	3	(11%)	4	(11%)	5	(12%)
	Sri Lanka	1	(6%)	1	(6%)	1	(6%)
	Pakistan	85	(50%)	123	(53%)	157	(55%)
	SUM	530	(33%)	761	(38%)	957	(42%)
Southeast Asia	Cambodia	1	(5%)	1	(5%)	1	(5%)
	Indonesia	50	(21%)	85	(31%)	93	(33%)
	Lao PDR	0	(0%)	0	(0%)	0	(0%)
	Malaysia	0	(0%)	0	(0%)	9	(21%)
	Myanmar	0	(1%)	0	(1%)	0	(1%)
	Philippines	15	(17%)	30	(25%)	36	(25%)
	Thailand	8	(11%)	9	(11%)	9	(12%)
	Viet Nam	10	(11%)	12	(12%)	12	(12%)
	SUM	84	(14%)	137	(20%)	161	(22%)
Central and West Asia	Afghanistan	18	(56%)	28	(54%)	46	(60%)
	Kazakhstan	4	(27%)	7	(37%)	8	(38%)
	Kyrgyzstan	3	(54%)	4	(56%)	4	(58%)
	Tajikistan	2	(24%)	2	(29%)	3	(31%)
	Turkmenistan	2	(43%)	4	(52%)	4	(56%)
	Uzbekistan	16	(65%)	20	(66%)	21	(69%)
	Armenia	1	(35%)	2	(71%)	2	(76%)
	Azerbaijan	4	(49%)	6	(54%)	6	(53%)
	Georgia	0	(5%)	0	(5%)	1	(42%)
	SUM	52	(48%)	73	(52%)	95	(57%)
Advanced economies	Australia	2	(8%)	8	(26%)	10	(27%)
	Brunei Darussalam	0	(0%)	0	(0%)	0	(0%)
	Japan	25	(20%)	25	(21%)	25	(23%)
	New Zealand	0	(0%)	0	(0%)	0	(0%)
	Republic of Korea	24	(49%)	25	(50%)	23	(50%)
	Singapore	0	(0%)	7	(90%)	7	(91%)
	SUM	50	(24%)	65	(30%)	65	(31%)
	SUM Asia	1242	(32%)	1667	(37%)	1906	(41%)
< 25 per cent of the population	Number of countries	23		17		16	
≥ 25 per cent of the population		12		12		13	
≥ 50 per cent of the population		3		8		7	
≥ 75 per cent of the population		0		1		2	

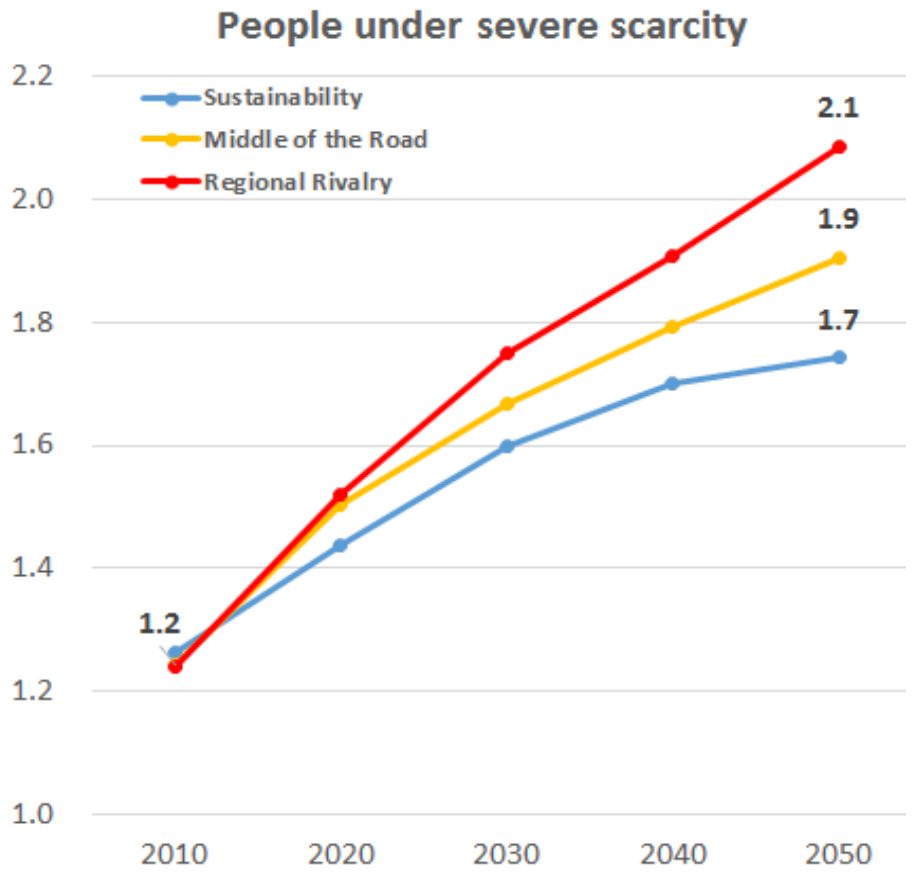
Imbalance between demand and supply

Middle of the Road

Population under water scarcity



Scenario comparison



increase under all scenarios, in the range of 1.7 to 2.1 billion, which represents approximately 40% of Asian total population

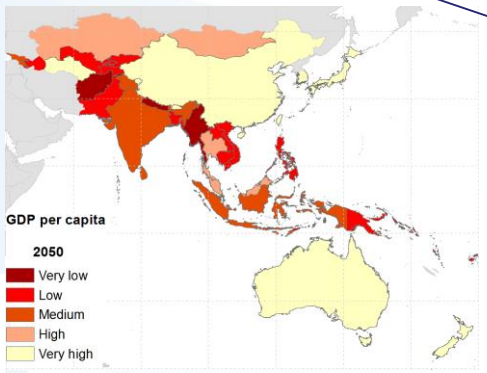
Country level

Hydro-Economic Analysis

in the 2050s

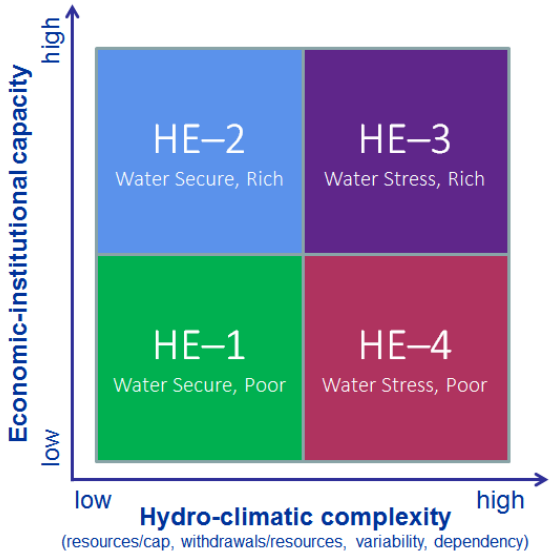
Middle of the Road scenario

Economic-institutional capacity

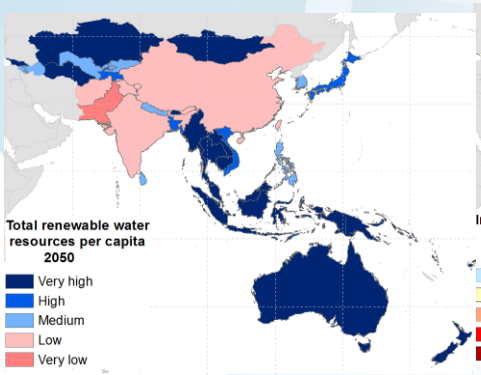


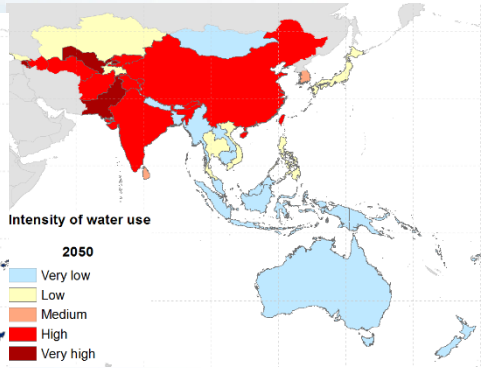
Very low:	CL1 … 3000 > GDPC > 250
Low:	CL2 … 10000 > GDPC > 3000
Medium:	CL3 … 10000 > GDPC > 20000
High:	CL4 … 35000 > GDPC > 20000
Very high:	CL5 … 90000 > GDPC > 35000

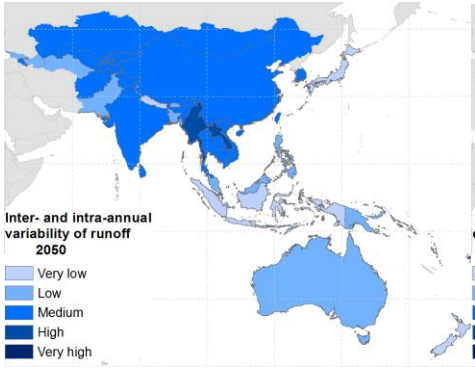
GDP per capita

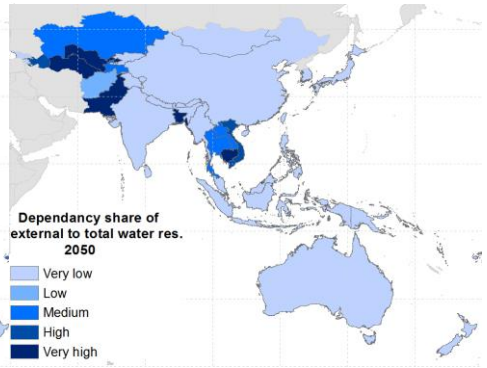


Hydro-climatic complexity









Total renewable surface water resources per cap

Very high:	CL1 … 20000 > TWRC > 10000
High:	CL2 … 10000 > TWRC > 5000
Medium:	CL3 … 5000 > TWRC > 2000
Low:	CL4 … 2000 > TWRC > 1000
Very low:	CL5 … 1000 > TWRC > 100

Intensity of water use

Very low:	CL1 … 0.01 < TWD/TWR < 0.05
Low:	CL2 … 0.05 < TWD/TWR < 0.15
Medium:	CL3 … 0.15 < TWD/TWR < 0.30
High:	CL4 … 0.30 < TWD/TWR < 0.60
Very high:	CL5 … 0.60 < TWD/TWR < 1.00

Inter- and intra annual variability of runoff

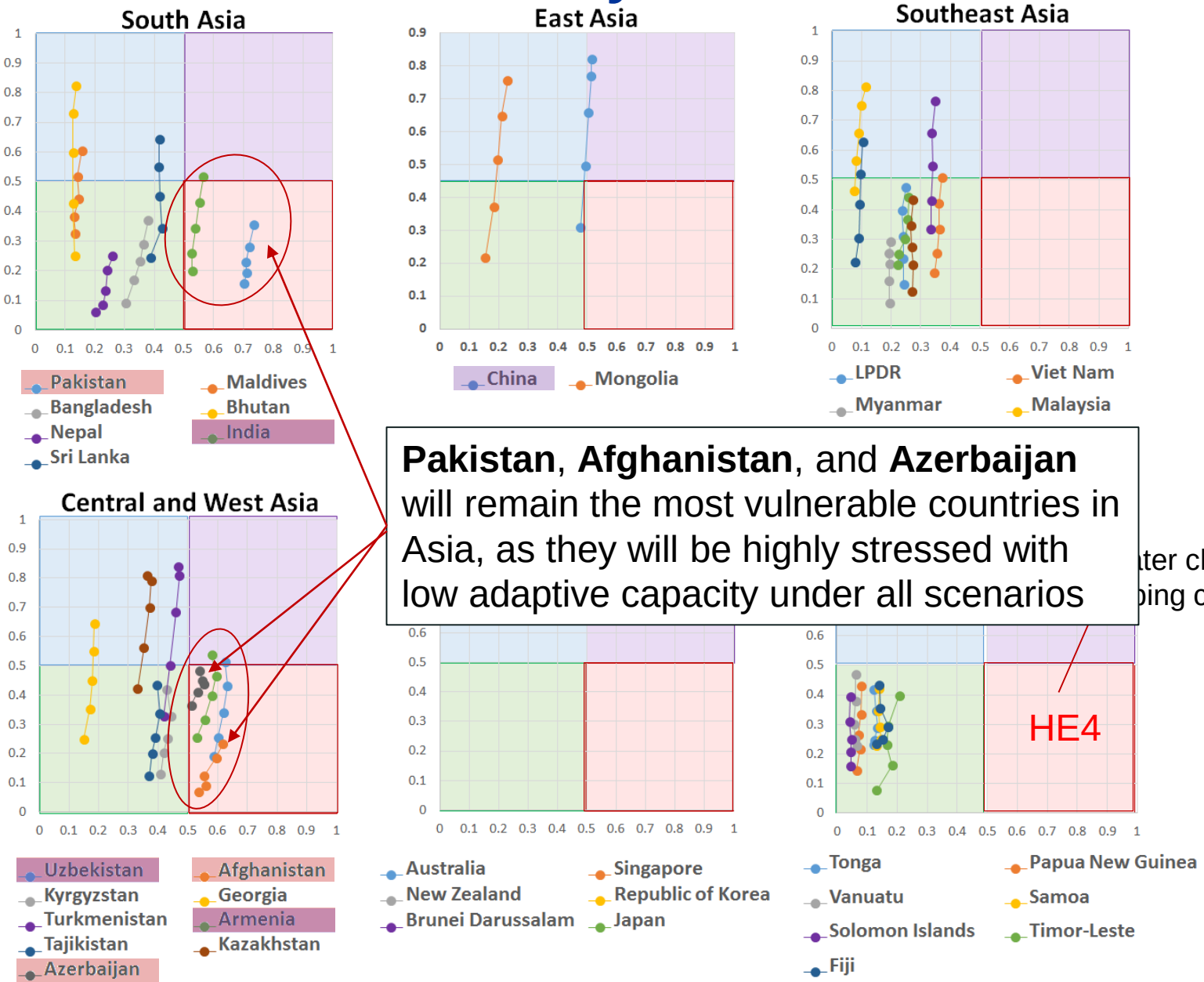
Very low:	CL1 … 0 < CVTWR < 30
Low:	CL2 … 30 < CVTWR < 60
Medium:	CL3 … 60 < CVTWR < 100
High:	CL4 … 100 < CVTWR < 150
Very high:	CL5 … 150 < CVTWR < 225

Dependency share of external water resources

Very low:	CL1 … 0.05 < DPC < 0.30
Low:	CL2 … 0.30 < DPC < 0.45
Medium:	CL3 … 0.45 < DPC < 0.55
High:	CL4 … 0.55 < DPC < 0.70
Very high:	CL5 … 0.70 < DPC < 0.95

Country level

Hydro-Economic Analysis



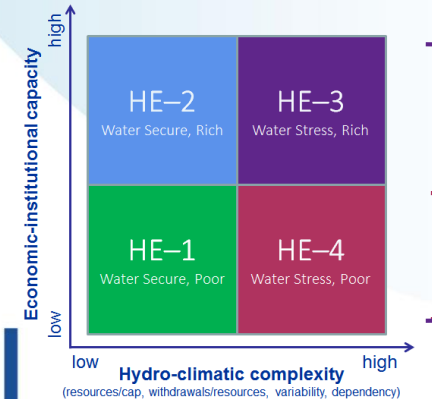
Pakistan, **Afghanistan**, and **Azerbaijan** will remain the most vulnerable countries in Asia, as they will be highly stressed with low adaptive capacity under all scenarios

ter challenge
ping capacity

HE analysis

Scenario comparison

		Area [10^6 km^2]		Population [Billon]		GDP Trillion US$2005/yr		Number of country				
		2010	2050	2010	2050	2010	2050	2010	2020	2030	2040	2050
(SSP1/RCP4.5) Sustainability scenario	Total	40		3.9	4.3	23	148					
	HE1	61%	3%	57%	6%	53%	2%	27	24	20	16	4
	HE2	25%	83%	5%	50%	28%	70%	6	9	12	17	29
	HE3	0%	10%	0%	37%	0%	25%	0	0	1	2	4
	HE4	14%	4%	38%	7%	19%	2%	6	6	6	4	2
(SSP2/RCP6.0) Middle of the Road scenario	Total	40		3.9	4.7	23	112					
	HE1	61%	10%	57%	11%	53%	4%	27	24	20	16	15
	HE2	25%	51%	5%	16%	28%	23%	6	9	12	16	17
	HE3	0%	34%	0%	65%	0%	70%	0	0	1	1	4
	HE4	14%	4%	38%	8%	19%	3%	6	6	6	6	3
(SSP3/RCP6.0) Regional Rivalry scenario	Total	40		3.9	5.1	23	83					
	HE1	61%	21%	57%	19%	53%	11%	27	25	21	20	17
	HE2	25%	41%	5%	7%	28%	17%	6	8	11	12	15
	HE3	0%	24%	0%	25%	0%	46%	0	0	1	1	1
	HE4	14%	14%	38%	48%	19%	26%	6	6	6	6	6



in the 2050s, in HE-3 or HE-4:

- 44-73% of Asian population,
- 27-73% of Asian GDP

Currently in HE-4:

- 38% of Asian population, 19% of GDP

Summary

This study shows that;

- We need feasible future water scenarios in conjunction with SSPs and RCPs
- Socioeconomic change has significant impacts of on water resource management

Water demand:

- Asian total water demand increase between **30 and 40%** under the three scenarios
- At country level, China and India will remain the largest water consumer, followed by Pakistan, Indonesia, and Uzbekistan.

Water scarcity:

- Future projections indicate that the area under severe water scarcity conditions in Asia will grow by the 2050s, to include large parts of India, China, and Turkmenistan.
- The number of people living in area experiencing severe water scarcity will increase under all scenarios considered, in the range of **1.7 to 2.1 billion** (approximately **40%** of Asia's total population).

HE analysis:

- Population between **1.9 and 3.4 billion** (about **44 to 73%** of Asia's total population) will be under high hydro-climatic complexity Complexity (HE3 or HE4) in the 2050s.
- Pakistan, Afghanistan, and Azerbaijan will remain the most vulnerable countries in Asia throughout all three scenarios.

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If we focus our attention on problems, we will find problems.
If we focus our attention on solutions, we will find solutions.