water
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Final REPORT

Water Futures and Solutions: Asia 2050

Knowledge and Innovation Support for the Water Financing Program of the Asian Development Bank (RETA 6498)

David WIBERG, Yusuke SATOH, Peter BUREK, Günther FISCHER, Sylvia TRAMBEREND, Taher KAHIL, Martina FLÖRKE, Stephanie EISNER, Naota HANASAKI, Yoshihide WADA, Ed BYERS, Piotr MAGNUSZIEWSKI, Luzma Fabiola NAVA, William COSGROVE, Simon LANGAN, Angelika SCHERZER
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Executive Summary

The Water Futures and Solutions Initiative (WFaS) is a cross-sector, collaborative global project whose objective is to improve human well-being through water security. To that end, it uses applied systems analysis to develop scientific evidence and identify water-related policies and management practices consistently across scales and sectors. The approach adopted is a stakeholder-informed, scenario-based assessment of water resources and water demand that uses ensembles of state-of-the-art socioeconomic and hydrological and climate models. These are used to examine possible futures, and test solutions that are not only feasible today but can be sustainable and robust across a range of possible futures and associated uncertainties. This report aims to present new knowledge on the current situation and water futures of Asia.

Possible Water Futures for Asia

WFaS has developed a set of scenarios of Asian water futures that have been quantified and assessed using a multi-model approach. These water-relevant future scenarios are based on water-use narratives that extend the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) developed by a large global scientific community over several years for the assessments of the Intergovernmental Panel on Climate Change (IPCC). The advantage of using these multi-disciplinary scenarios is to ensure consistency and facilitate comparison among the different sectoral scenarios. The scenarios assume different paths of socioeconomic change and varying degrees of climatic change. These scenarios are: ***Sustainability*** scenario (resulting in low challenges with respect to sustainability, mitigation, and adaptation); ***Middle of the Road*** scenario (intermediate challenges); and ***Regional Rivalry*** scenario (high challenges). The main findings of this analysis are summarized as follows:

- **Population and GDP**: Asia’s total population is estimated at 3.8 billion in 2010. Future projections indicate considerable changes to Asia’s population in the coming decades. It will range between 4.3 and 5.1 billion in the 2050s (+14% to +33% relative to the 2010), and between 3 and 5.8 billion in the 2100s (-24% and +53% relative to the 2010), depending on the scenario used. Specifically, total population will continue to increase through to 2100 under the *Regional Rivalry* scenario, while it will peak at 2040 and 2050, respectively, under the *Sustainability* and the *Middle of the Road* scenarios, respectively. Unlike in the population scenarios, GDP per capita will increase in all combinations of scenarios and regions, although possible decreases in total GDP will occur in some regions such as East Asia and Advanced Economies, all of which have implications for water use and demand.

- **Food**: Food consumption in Asia will continue to increase, although there are notable differences among Asian sub-regions. Food energy intake is estimated at an average of 2750 kilocalories per capita per day (kcal/capita/day in 2010, ranging from less than 2500 kcal/capita/day in South Asia (e.g., Bangladesh, India, Pakistan) to more than 3000 kcal/capita/day in East Asia (i.e., China). The projected food energy intake in 2050 ranges between 2900 and 3270 kcal/capita/ day for the different scenarios. The number of people at risk of hunger in Asia is estimated at 510 million in 2010s but is expected to fall, with hunger being practically eliminated by 2080 under both the *Sustainability* and the *Middle of the Road* scenarios. Only under the *Regional Rivalry* scenario does the number of people at risk of hunger stagnate at about 400 million. All scenarios project increases in cereal production (24-29%), irrigated areas (11-12%), and irrigation water requirements (14-18%) by 2050 compared to 2010s.

- **Energy:** Energy demand in Asia is expected to further increase in the coming decades, from 4990 million tons of oil equivalent (Mtoe) in 2010s to 8380 Mtoe in 2040 (taken from the central scenario of the 2015 World Energy Outlook). Non-OECD Asian countries drive all the growth in primary energy demand in the region. Their demand is expected to increase by up to 80% in 2040 compared to 2010s, while OECD Asian countries will reduce their demand by up to 13% in the same period. Primary energy demand in Asia for all fuel types grows. By 2040 oil and coal collectively remain the most important sources of energy in Asia, although their share of the energy mix decreases by up to 27%. The share of renewable energy including hydropower and biofuels grows by up to 12%, natural gas by up to 5%, and nuclear power by up to 10%. These changes will have important implications for the water demand of the energy sector.

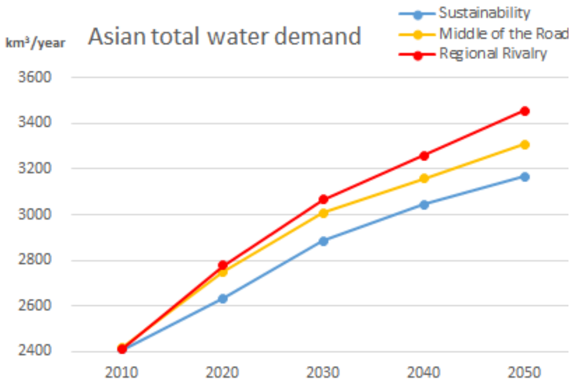

Figure 0-1: Total Asian water demand

- **Water demand:** Current Asian total water demand is estimated at 2410 km^3/year and projected to be between 3170 to 3460 km^3/year in 2050 (an increase of 30-40%) under the three scenarios considered, with industrial and domestic demand growing much faster than agricultural demand. Under the *Middle of the Road* scenario, the share of agricultural demand will decrease from 80% in the 2010s to 60% in the 2050s, while the share of industrial and domestic demand will increase from 20% in the 2010s to 40% in the 2050s, this is summarized in Fig. 0-1. At the regional scale and during the early half of the 21st century, South Asia and East Asia remain the largest water users in the continent in all sectors. In Central and West Asia, significant rises in agricultural demand are also expected. At country level, China and India have the largest demand, followed by Pakistan, Indonesia, and Uzbekistan. Industrial and domestic demands are increasing rapidly with high growth rate in Mongolia, Singapore, Georgia, and Papua New Guinea, driven by their intense socioeconomic growth. Due to the need to improve agricultural productivity, a growth in water demand occurs jointly with an increase in fertilizer use. All this will likely impair water quality and damage valuable water-dependent ecosystems, their functioning as well as services produced, if no adequate abatement measures are designed and implemented.

- **Available surface water resources per capita:** South Asia and East Asia show the lowest water availability per capita in Asia in the 2010s, followed by Central and West Asia. Demographic changes are expected to impact on water availability per capita by the 2050s, with reductions in per capita availability expected in South Asia, Southeast Asia, Central and West Asia, and Pacific Asia during the first half of the 21st century under all scenarios considered. In the second half of the 21st century, water availability per capita in these regions is expected to decrease in the *Regional Rivalry* scenario, but increase in the *Sustainability* and *Middle of the Road* scenarios. In contrast, water availability per capita in East Asia and Advanced Economies will grow in the second half of the 21st century. At the country level, Pakistan, Afghanistan, India, Singapore, and China will have the lowest water availability per capita in Asia.

- **Groundwater resources:** Groundwater use in Asia totals 464 km^3/year in the 2010s. The largest abstractions are taking place in India, China, and Pakistan, followed by Japan, Bangladesh, Uzbekistan, and Georgia. Abstractions in the first three countries account for 86% of total abstractions in Asia. In many countries, groundwater abstraction has already exceeded recharge, leading to the over-exploitation and degradation of important aquifer systems. Growing water requirements leads to considerable growth in demand for groundwater, amounting to 645 km^3/year by the 2050s, a 39% increase over current levels.

Figure 0-2: Potential population under severe water scarcity in 2050 – *Middle of the Road* scenario

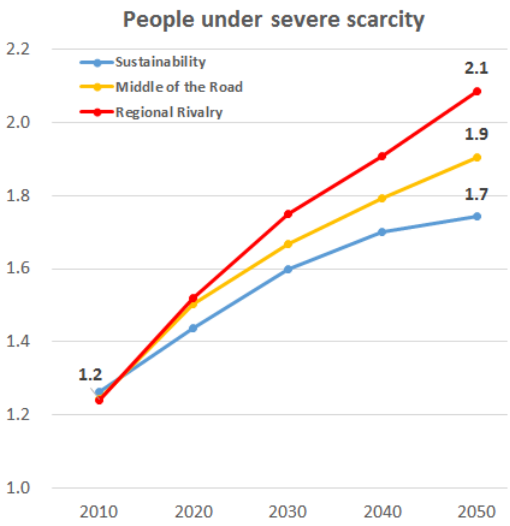

Figure 0-3: People under severe water scarcity in three scenarios

- **Variability of surface water resources:** Surface water availability in Asia has strong seasonal variability. Overcoming the impacts of the dry seasons is already a great challenge for Asian countries. The assessment reveals that droughts will become more severe for most Asian countries in coming decades. In particular, rapid increases in the recurrence, longevity, and severity of drought spells in Central and West Asia, East Asia, and southern Australia are expected. Adding to this challenge, a large increase in flood frequency is projected for all regions in Asia, except Central and West Asia.

- **Water scarcity:** Many countries in Asia, including Armenia, Uzbekistan, Afghanistan, and Pakistan, already experience pervasive water scarcity conditions. The maximum seasonal water scarcity indicator (climatologically driest month) shows that at present almost all of Central and West Asia, China, South Asia, and parts of Southeast Asia suffer from severe water scarcity for at least one month per year. Future projections indicate that the areas 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 severely water scarce areas will increase under all scenarios considered, from 1.2 billion to a range of 1.7-2.1 billion, which represents approximately 40% of Asia's future population (Fig. 0-3). The largest share of affected people will be mainly in South Asia, followed by East Asia as depicted in Fig. 0-2.

- **Hydro-economic analysis:** The hydro-economic analysis quantitatively assesses countries or regions, based on their severity of water challenges and coping capacity. Six Asian countries with a combined population of 1.5 billion people are currently water-stressed (both rich and poor economies), with six or seven countries expected to be water-stressed in the 2050s, depending on the scenario considered. Consequently, a population of between 1.9 and 3.4 billion (about 34-73% of Asia's total population) will be under severe water stress in the 2050s. Furthermore, Pakistan, Afghanistan, and Azerbaijan remain the most vulnerable countries in Asia, as they will be both highly stressed and maintain low adaptive capacity under all scenarios. The number of people living in those three countries will total between 323 and 450 million people, representing up to 9% of Asia's total population (Fig. 0-4).

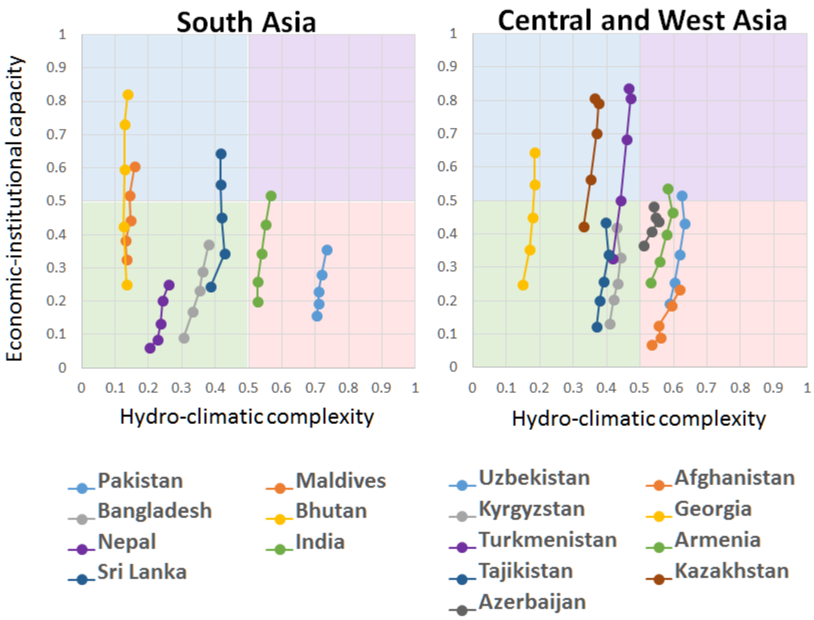

Figure 0-4: Hydro-economic analysis

The results of this report, indicate that Asia currently faces multiple and complex water challenges that will intensify in the future. This will likely hinder economic development, threaten food and energy security, and damage valuable ecosystems. Improved water policies and governance structures, and the adoption of more innovative technological interventions, will offer the best likely solutions. However, managing the water sector alone is no longer sufficient, since water integrates across scales and other sectors that all use and have an influence on increasingly scarce water resources. Consistent solution portfolios need to be identified that work across economic sectors and scales of management. Furthermore, as we cannot manage what we cannot measure, information gathering, generation, and sharing must also be improved. This report provides essential knowledge to inform and guide policymakers in the design and implementation of water solution portfolios. The information provided includes estimates of water supply by source, water variability and occurrence of extreme events, water demand, and hydro-economic classification under various up-to-date socioeconomic and climate scenarios. To improve water, energy, and food security, sustain human well-being, and ensure sustainable development, the identification of portfolios of solutions that work together synergistically in different regions will be the focus of continuing work within the WFaS Initiative and in future reports.

1 Introduction

"Water is a precious resource, crucial to realizing the sustainable development goals, which at their heart aim to eradicate poverty." UN Secretary-General Ban Ki-moon (21th January 2016, Davos)

Changing and growing Asian water demand

Asia is the largest and most populous of the world's continents. It comprises 30% of the world's land area and is home to 60% of its population. It also has the highest population growth rate today, having almost quadrupled during the 20th century and projected to grow substantially in the coming decades. Asia's share in the global economy in 2015 was about 30% in terms of GDP. Economic growth in some Asian countries has outpaced that of many global economies in recent years. Nevertheless, there are large differences between Asian countries, which number some of the poorest in the world. Asian GDP is projected to continue growing, but with different growth rates across various countries. Furthermore, there is increasing evidence that the global water cycle is changing due to global warming (IPCC 2012). The hydrological cycle is also intensifying, with wetter regions generally becoming wetter and drier regions becoming even drier. These supply side changes in the hydrological cycle can have large impacts on future water availability and quality in Asia.

The combination of these socioeconomic and climatic changes will put additional pressures on water, food, and energy systems. Analyses of these aspects of global change will provide evidence to stakeholders and policymakers to support their understanding of the future water challenges; it will guide the design and implementation of sound policy interventions, alternative institutions and governance, best management practices, and innovative technological solutions.

Asian water assessment within the Water Futures and Solutions Initiative (WFaS)

At present, it is universally accepted that sustainable management of water, food, and energy are central to 21st century development challenges. These sectors are tightly linked. The consideration of the linkages among resources is becoming essential for the assessment of water futures. Thus, comprehensive assessments with consistent assumptions across sectors are needed.

In order to provide scientific input to support stakeholder dialogue and decision making, the Water Futures and Solutions Initiative (WFaS) develops multi-model global water scenarios, consistent with scenarios for other sectors. This is undertaken with the aim of analyzing the water-food-energy-climate nexus and identifying future hotspots of water insecurity and related impacts on human well-being. The present study investigates future developments in climatic change in three main water-use sectors: industrial, domestic, and agriculture and focuses on how developments in these sectors affect water supply and demand balances, and related water security, into the future.

1.1 Purpose of the report

The purpose of this report is to assess and depict possible Asian water futures, applying the latest climate and socioeconomic change scenarios based on a multiple-model analysis. Multi-model analysis is used to better understand uncertainty and to provide an indication of the scientific confidence with respect to some of the important conclusions. Better understanding of the current and future availability of water resources is essential for sound development in a changing world. To cope with expected global changes, it is necessary to identify options and find appropriate pathways for achieving development goals, including those of the 2030 Agenda for Sustainable Development, in an effective, efficient, and robust manner. This report discusses why, where, when, and how greatly water resources will be endangered in Asian countries under expected climatic and socioeconomic changes. To reveal water futures in Asia, WFaS has produced a series of projections in a stepwise manner. Here, WFaS presents the latest knowledge obtained by its "fast-track" analysis. This report assumes the Asian Development Bank (ADB) as its main audience and aims to use the analysis to provide scientific expertise for the Bank's work, such as the Asian Water Development Outlook (AWDO) 2016.

1.2 WFaS scenario approach

One of the primary tasks of WFaS has been to develop global scenarios of water potentials and stressors, their interdependencies across the different sectors and at the climate-water-food-energy-ecosystem nexus. From this, investigate the potential impacts on human well-being and Earth ecosystems, as well as on the services that these ecosystems provide. The work provides input to the development of an integrated approach of the water-food-energy-climate-environment nexus and identifying future hotspots of water insecurity and related impacts on human well-being, in particular food and energy security. Where water insecurity is viewed as an imbalance between water supply and demand, combined with the risks of extremes and the lack of capacity of social systems to cope. WFaS has projected these components and assessed Asian water scarcity and security both at present and under future scenarios. How will socio-hydrological conditions in Asia change in the next 50 years? Where will be the hotspots of water insecurity? How serious will water insecurity be?

1.3 Regional categories

This report uses the Asia-Pacific six-region categorization of the Asian Water Development Outlook (Fig. 1-1) (ADB, 2013). The regions cover the whole Asia-Pacific region and comprise 39 countries (Table 1-1). Within the report, the regions are referred to by their abbreviations set out in Table 1-1. Assessments at three levels of spatial scale are provided in this report; regional, country, sub-country scale (i.e., the grid scale of models used in this work). Some small islands are not reflected in the results because the highest spatial resolution of the models used is at 0.5^ox 0.5^o grid (approximately 50km x 50km at the equator).

1.4 Structure of the report

Section 2 gives the detail of the three fundamental principles of the WFaS futures analysis approach. In summary, these are: a) the construction of "water" scenarios based on the Shared Socioeconomic Pathways (illustrated in Fig. 21) (O'Neill et al. 2014; 2015); b) the development of a hydro-economic classification to describe different conditions pertaining water security; and c) the use of a multi-modeling approach to understand the uncertainties and limitations of the modeling assessment.

Section 3 shows results for four sectors of the "nexus." It describes the socioeconomic change in terms of population and gross domestic product (GDP) in purchasing power parity (PPP) (section 3.1). The results of a "fast-track" assessment conducted on the energy (section 3.2) and food (section 3.3) sectors are given. The main emphasis is on water demand (section 3.4) and water supply (section 3.5). Section 3.6 on water security looks at the imbalance between supply and demand and describes the shift over time of countries in the hydro-economic classification. Section 4 gives an outlook, discussing possible water solutions that will be the focus of the next steps of WFaS and section 5 concludes with a summary.

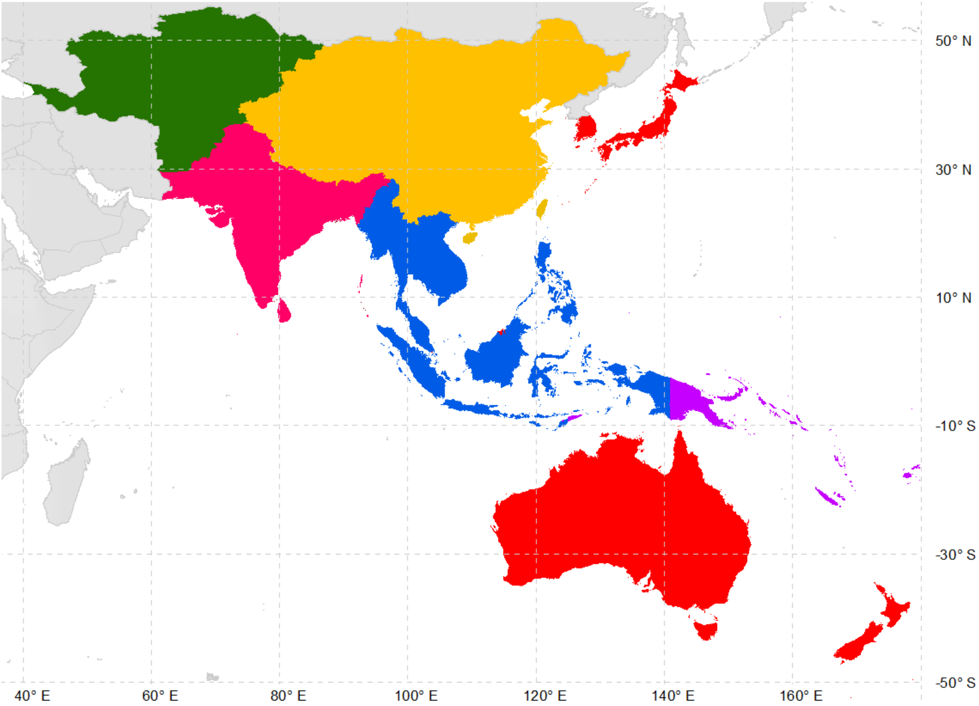

Figure 1-1: Region categories

Table 1-1 Region categories[1]

Advanced economies

- Australia
- Singapore
- New Zealand
- Republic of Korea
- Brunei Darussalam
- Japan

Southeast Asia

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

East Asia

- China
- Mongolia

Central and West Asia

- Uzbekistan
- Afghanistan
- Kyrgyzstan
- Georgia
- Turkmenistan
- Armenia
- Tajikistan
- Kazakhstan
- Azerbaijan

South Asia

- Bangladesh
- Bhutan
- India
- Maldives
- Nepal
- Pakistan
- Sri Lanka

Pacific

- Tonga
- Papua New Guinea
- Vanuatu
- Samoa
- Solomon Islands
- Timor-Leste
- Fiji

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[1] Palau, Micronesia, Niue, Nauru, Marshall Islands, Tuvalu, Cook Islands, and Kiribati are not included in this study because the spatial resolution of simulated data is approximately 50km x 50km.

2 WFaS Futures Analysis Approach

2.1 Building water scenarios

Scenario-based approaches are an important method for exploring uncertainty in future dimensions of environmental conditions, which are intrinsically interlinked with socioeconomic developments. WFaS uses global and consistent scenario analysis as a strategic planning method for exploring coherent alternative hypothetical futures aimed at developing robust pathways toward water security. These different perspectives of integrative future developments support decision making by providing rational information as a sound basis for action. Good scenarios are ones that explore the possible, not just the probable – and that provide a relevant challenge to the conventional wisdom of their users, helping them to prepare for the major changes ahead (Magnuszewski et al. 2013).

Water domain futures are determined by a wide range of specific dimensions of nature (climate change, land use, water resources, ecosystems), society (demography, governance, values and lifestyles), and economy (water use for agriculture, households, energy, and manufacturing, driven by a combination of economic development and technology).

A key element of this study is to have and develop qualitative scenarios for Asia across sectors, embedded in global narratives. To the extent possible, these quantify future water resource potentials vis-à-vis water demand and use. To aid in developing indicators for water security we develop and include in the scenario analysis a hydro-economic classification of water challenges (see section 2.3). We broadly define water security as people's ability to cope with water-related risks that potentially threaten their well-being.

In a quantitative analysis, based on the scenarios, WFaS employs an ensemble of three state-of-the-art Global Water Models (Wada et al. 2016) which require information about both climate and socioeconomic change to project future water supply and demand. To produce a consistent set of new global water scenarios, the WFaS Initiative coordinates its work with other ongoing scenario efforts in the context of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (Moss et al. 2010). This includes the greenhouse gas emissions scenarios of the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011), completed in 2012 to provide input that is essential for climate modelers. The spatial and seasonal patterns of future climate change estimated by climate models must be complemented by socioeconomic and ecological data needed by the other climate change research groups, namely, Integrated Assessment Modelers, and the Impacts, Adaptation, and Vulnerability communities. In response to this, the climate change research community converged on five new projections, termed the Shared Socioeconomic Pathways (SSPs),

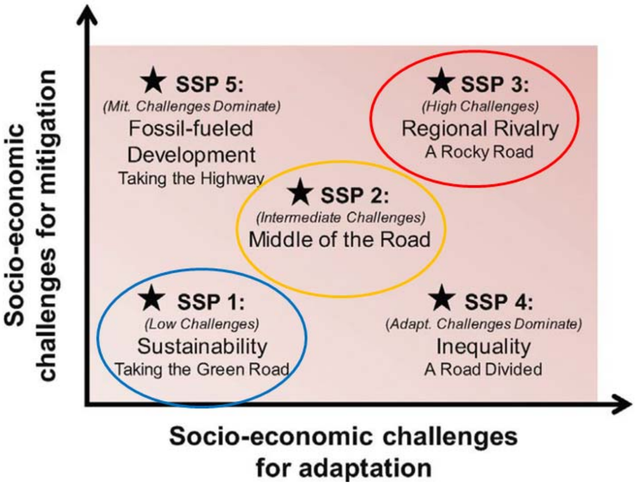

Figure 2-1: The Shared Socioeconomic Pathways (SSPs) representing different combinations of challenges to climate mitigation and adaptation.
Source: (O'Neill et al. 2015)

illustrated in Fig. 2-1 (O'Neill et al. 2014; 2015). In WFaS the SSP storylines, already the result of a multi-year community effort across sectors, have been extended by adding relevant critical dimensions affecting water availability and use. Despite the potential offered by globally consistent, integrated scenario analysis, very few assessments have yet used the SSPs to assess the impacts of global change on water resources (e.g., Hanasaki et al. 2013; Arnell and Lloyd-Hughes 2014).

A first WFaS "fast-track" assessment was conducted to build on existing quantifications of climate scenarios[2] based on the RCPs from the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Warszawski et al. 2014; Frieler et al. 2012). The rate of climate change in these scenarios is characterized by four RCPs. These define pathways of different amounts of radiative forcing up to 2100, ranging from RCP 2.6 to RCP 8.5 (see Box 1). General Global Circulation Models (GCM) experiments investigate the climate response to the RCPs. ISI-MIP applied climate change from five[3] GCMs (Table 2-4) for the calculation of diverse climate change impacts, including results such as daily runoff, from Global Hydrological Models (GHM).

For the IPCC Fifth Assessment Report, the research community agreed on a new parallel analytical process (Moss et al. 2010), building on the concept that a range of socioeconomic and technological development scenarios (as exemplified by the five SSPs) can contribute to a range of climate scenarios (as exemplified by the four RCPs). This has resulted in a new scenario matrix architecture (van Vuuren et al. 2014) combining the RCPs and SSPs. The research community[4] is currently developing Integrated Assessment Models to explore conditions for potential combinations of RCPs and SSPs that could develop in the real world.

In consultation with researchers studying feasible RCP-SSP combinations during the WFaS project group meeting in October 2013 (WFaS 2013) and subsequently, WFaS is employing the following RCP/SSP combinations for its "fast-track" scenario assessment, using the higher bounds of climate change impacts:

- "*Sustainability*" scenario (building on SSP1 together with RCP 4.5)
- "*Middle of the Road*" scenario (SSP2-RCP 6.0)
- "*Regional Rivalry*" scenario (SSP3-RCP 6.0)

To test the approach, the "fast-track" assessment was confined to three scenarios. In December 2015 the international community[5] agreed that the global goal will be to maintain global temperature increase to under 2˚C, which corresponds closely to an RCP of 2.6. If this target is achieved, some of the climate change impacts could be milder than those described in this report. For comparison, other scenario studies have used the combinations SSP1-RCP 2.6, SSP3-RCP 6.0, and SSP5-RCP 8.5[6] (Veldkamp et al. 2016, following Winsemius et al. 2015).

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[2] Distributed by the Coupled Model Intercomparison Project (CMIP), see http://cmip-pcmdi.llnl.gov/cmip5/

[3] The GCMs were selected because their results are bias-corrected and reported globally for a 0.5 by 0.5 decimal degree grid (about 50x50 km grids)

[4] See https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about

[5] http://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

[6] Current insight suggests that RCP 8.5 (i.e., the most extensive radiative forcing) is only feasible in combination with SSP5. The two studies explored this combination as their third scenario.

Box 1: Representative Concentration Pathways (RCPs)

The Representative Concentration Pathways (RCPs) are named according to the target level of radiative forcing (2.6, 4.5, 6.0, and 8.5 W/m^2, respectively) for the year 2100.

The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents, relative to pre-industrial values [Moss et al. 2010; van Vuuren et al. 2011].

The RCPs include:

- A mitigation scenario leading to a very low forcing level (RCP 2.6), which aims to limit the increase of global mean temperature to less than 2°C by 2100.
- A stabilization scenario (RCP 4.5) in which total radiative forcing is stabilized before 2100 through the use of technologies and strategies for reducing greenhouse gas emissions.
- Another stabilization scenario (RCP 6.0) in which total radiative forcing is stabilized after 2100. Both RCP 4.5 and 6.0 aim to limit the increase of global mean temperature to less than 4°C by 2100.
- A very high emission scenario (RCP 8.5) which is characterized by soaring greenhouse gas emissions over time, leading to high greenhouse gas concentration levels. Global mean temperature increases by nearly 6°C by 2100.

2.2 Water-extended Shared Socioeconomic Pathways (SSPs)

The SSPs include both a qualitative component, in the form of a narrative on global development, and a quantitative component that includes numerical pathways that are particularly useful for use in other studies. Box 2 provides an excerpt of the summary SSP storylines. They include demography, economic development, human development, technology, lifestyle~~s~~, environment and natural resources, and policy and institutions. For a subset of SSP elements, tables of qualitative assumptions were developed to describe the relative direction and magnitude of changes in these elements.

Quantification of individual variables for each SSP are an ongoing effort of the research community with results available at the IIASA SSP database portal.[7] Final projections for population and economic development, including demography (population by age, sex, and education), urbanization and economic development (GDP), are available for all scenarios.

Although the SSPs were developed by the climate change community with a focus on the key elements of climate policy, the five SSPs offer the possibility of experimentation by a wide range of researchers by extending the “original” SSPs in various dimensions (O’Neill et al. 2015). WFaS has responded to this by extending the SSP storylines with narratives for water use developed in collaboration with a group of water planners and stakeholders from around the world together with the scientific consortium of WFaS. The qualitative assessment of water narratives for each SSP (Appendix A) provided the basis for the quantification of selected variables required for the global water models (see section 2.5).

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[7] https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about#intro

Box 2: Shared Socioeconomic Pathways (SSPs)

SSP1: Sustainability – Taking the green road

“The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society.”

SSP2: Middle of the road

“The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds but without fundamental breakthroughs.”

SSP3: Regional rivalry – A rocky road

“A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline.”

SSP4: Inequality – A road divided

“Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, lowtech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions.”

SSP5: Fossil-fueled development – Taking the highway

“Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups.”

Source: (O'Neill et al. 2015)

2.3 Hydro-economic classification

The WFaS Initiative develops global scenarios of water potentials and stressors, their interdependencies across different water sectors (the climate-water-food-energy-ecosystem nexus), and across spatial scales. A global assessment is imperative because of the increasing importance of global drivers such as climate change, population growth and rapid urbanization, economic globalization, and safeguarding biodiversity. All of which are interrelated with the water domain. Maintaining a global perspective while providing necessary regional detail that recognizes the current spatial diversity of water-related challenges and possible future developments, is key for water scenario development. However, applying different scenario assumptions at every location would produce unjustifiable complexity and make results hard to interpret in a meaningful way. The quantitative scenario assessment here goes beyond globally uniform assumptions of important scenario drivers by developing a classification system for countries and watersheds describing different conditions pertaining to water security, water insecurity, and related challenges (Fischer et al. 2015). Countries or watersheds facing similar water security challenges and with similar capacity can then be assumed to experience similar rates of change in development, although each will still have its own unique path based on its own current development trends.

This objective requires the development of a system of classification for countries and watersheds describing different conditions pertaining to water challenges). The concept of water security is complex to define because it has different dimensions or facets. First, security needs to be understood as a relative concept (i.e., an imbalance between "supply" and "demand" that varies according to local conditions). Second, water security and water scarcity are fundamentally dynamic. For example, water scarcity intensifies with increasing demand from users and with the decreasing quantity and quality of the resource. However, water scarcity can be reduced when appropriate response options are put in place. In this spirit, we follow recently adopted frameworks for a risk-science perspective, which define water security in terms of societies' adaptation or coping capacity in terms of water-related challenges (Grey et al. 2013), for example, freshwater variability (Hall et al. 2015).

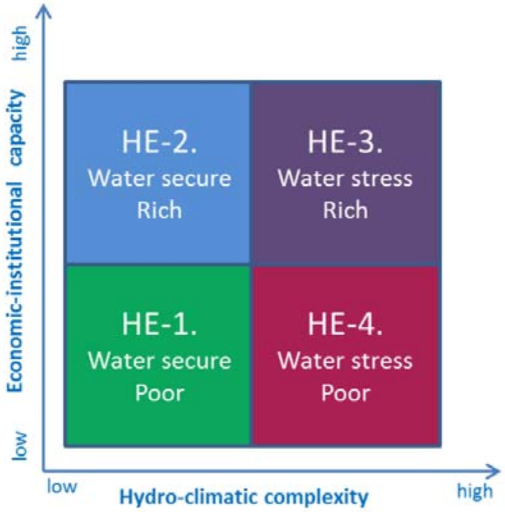

Figure 2-2: Conceptual framework of hydro-economic classification

For this purpose, we define a hydro-economic classification consisting of two broad dimensions representing:

1. **Economic and institutional capacity** to address water challenges (y-dimension in Fig. 2-2)
2. Magnitude and complexity of challenges related to the management of available water resources; that is, **hydrologic challenge/complexity** (x-dimension in Fig. 2-2)

As watersheds and their inherent water challenges extend beyond national boundaries, the hydro-economic classification should also be applicable to both the country level and the watershed unit. To be useful in WFaS the classification approach must meet three basic principles:

1. Produce a small number of distinct classes that differentiate countries in terms of (current and future) water challenges, the capacity they have to act, and the urgency and priorities they are likely to assign to finding water solutions
2. Use variables/indicators that are not only available for past years but can also be computed for future periods and scenarios
3. Apply an approach that is flexible, transparent, and can be refined/tailored to reflect stakeholder priorities, needs, and interests

For the classification, each major dimension is measured by a normalized composite index, computed from a set of relevant sub-indicators (see Fischer et al. 2015). In this way countries/regions will be located in a two-dimensional space representing different human-natural water development challenges and levels of water security. The selection of indicators for each dimension has been extensively discussed in the WFaS consortium, including at a stakeholder meeting in the context of the WFaS Scenario Focus Group (Magnuszewski et al. 2013; Pound et al. 2013).

Hydrologic complexity

For the x-dimension, hydrologic complexity, four indicators of water challenge are used:

(i) *Total renewable water resources per capita* (in m^3/person/year) as a measure for water availability

(ii) *Runoff variability* expressed by the coefficient of variation of simulated monthly runoff for a 30-year period showing both inter- and intra-annual variability of water resources

(iii) The ratio of annual water withdrawal to total renewable water resources (scalar fraction) as a proxy for relative *intensity of water use*

(iv) The dependency ratio, or the share of external (from outside national boundaries) to total renewable water resources as a measure of the *dependency of external water resources*.

Data sources used in the “fast-track” analysis include the AQUASTAT database of the UN FAO (variables i, iii, and iv) and a model-ensemble of six hydrological models calculated from ISI-MIP (Warszawski 2014). All variables can be computed for future periods using hydrological models based on selected climate change scenarios.

Economic/institutional coping capacity

For the y-dimension, we have selected one indicator, namely GDP per capita (in constant PPP dollars per capita) as a measure of economic strength and financial resources available for investing in risk management. Country-level GDP per capita for future periods is readily available in the SSP database. Several additional indicators have been discussed and were explored for potential inclusion in a compound indicator to proxy economic-institutional coping capacity.

The World Bank publishes annual data in The Worldwide Governance Indicators (WGI) project,[8] which reports on six broad dimensions of governance, including composite indicators for:

- Voice and accountability
- Political stability and absence of violence
- Government effectiveness
- Regulatory quality
- Rule of law
- Control of corruption

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[8] See www.govindicators.org

The WGI relies exclusively on perception-based governance data sources, drawing from the private sector (e.g., Gallup World Poll, Global Competitiveness Report), non-governmental organizations (e.g., Global Integrity, Reporters Without Borders), and selected public sector organizations (e.g., CPIA[9] of the World Bank, EBRD[10] Transition Report).

Other potential indicators include

i) The Human Development Indicator (HDI) from the United Nations Development Program and its recent extension the inequality-adjusted HDI
ii) The Corruption Perception index (CPI) from "Transparency International," a non-profit, non-governmental organization
iii) The University of Notre Dame Global Adaptation Index (ND-GAIN[11]) which summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. In particular the latter includes a few indicators related to economic-institutional coping capacity
iv) The Fragile State Index (FSI[12]) comprising 12 indicators or drivers of state failure published since 2005 by the think-tank, Fund for Peace and the journal *Foreign Policy*.

The level of education is a more general indicator of proxy socioeconomic coping capacity than has been suggested, for example, in the context of climate change (Lutz et al. 2014) and natural disasters (Butz et al. 2014).

The reservoir capacity per capita proxies mitigation potential of storage for two key elements of water challenges: floods and droughts resulting from climatic variability. The Global Reservoirs and Dams Database (GRanD[13]) records data for 6862 reservoirs (Lehner et al. 2011).

In the context of scenario analysis, it is important to note that only future projections of GDP per capita and education have been calculated in the SSP database. For all other potential indicators, expert-driven assumptions, depending on scenario narrative, would be required for future estimates.

The WFaS core group (including experienced experts on governance) initially selected the Common Perception Index (CPI) together with GDP per capita to represent economic-institutional coping capacity. However, it is worth noting that there is generally a strong correlation between GDP per capita and the CPI. Thus, CPI would hardly impact scenario outcomes.

A high-level stakeholder meeting in the WFaS Scenario Focus Group recommended simplification of the y-dimension to be represented only by the indicator GDP per capita. GDP was felt to be the most recognizable and understandable representative of economic strength and available financial resources for investing in risk management. The CPI was perceived as not adding value and having an ambiguous meaning across nations, while its data sources were criticized as perception-based and subjective only. The stakeholders further recommended exploring the potential of adding a third dimension to the 2-dimensional space of the Hydro-Economic Classification scheme.

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[9] **C**ountry **P**olicy and **I**nstitutional **A**ssessment

[10] **E**uropean **B**ank for **R**econstruction and **D**evelopment

[11] See http://index.gain.org

[12] See http://fsi.fundforpeace.org

[13] See http://www.gwsp.org/products/grand-database.html

Against this background, WFaS selected GDP per capita for its "fast-track" analysis, as GDP per capita has been projected into the future in the SSP scenarios and, for all countries, there is a strong positive correlation between GDP per capita and many of the other indicators potentially contributing to institutional capacity (e.g., education, CPI, reservoir capacity per capita, WGI). Thus, by using per capita GDP as a proxy for a broader socioeconomic perspective (i.e., economic and institutional coping capacity), WFaS uses an existing and well known path. We argue that changing the indicator is not justified at this point in time. Firstly, the theoretical underpinning and narrative to explain the other indicators in terms of positive or negative effects on institutional effectiveness and potential to cope with risks is weak. Next, there are major differences of opinion among experts regarding the definition of many of the above-discussed indicators (e.g., corruption, fragile states, regulatory quality). Finally, there is a lack of broad stakeholder agreement on the usefulness and importance of other possible indicators, and on the relative weightings that they should be given if combined in an index.

In conclusion, the selected variables for the x-dimension as proxy for hydrologic complexity were perceived by the WFaS consortium and its stakeholders to be generally comprehensive and useful. They also recognized the importance of an appropriate indicator on the y-dimension to proxy a country's or watershed's economic and institutional coping capacity to increase resilience against challenges arising from high levels of hydrological complexity. When hydrology is complex, access to investments is undoubtedly a prerequisite for building resilience. Depending on location-specific circumstances, a combination of infrastructure (e.g., reservoirs), insurance (e.g., against drought losses), technology (e.g., desalination, improved irrigation schemes), and monitoring (e.g., for flood warnings) all require initial investments. Yet, institutions, management, and governance are crucial for making resilience effective by prioritizing often scarce financial resources. For example, even when reservoirs and monitoring are in place, strong governance of upstream and downstream management is essential in cases of flooding. Other inherently governance-dependent resilience options include transparency and data sharing (both on ground- and surface water), monitoring of human water use across sectors (agriculture, households, and industry), legal aspects of access to water, and establishing supranational watershed commissions.

2.4 Summary of scenario assumptions for WFaS "fast-track"

Following the procedures described above, the water scenario assessment framework extends the SSP storylines with water narratives developed in collaboration with a group of water planners from around the world and the WFaS scientific consortium. The framework makes use of available climate projections[14] based on the RCPs, and socioeconomic developments based on the SSPs, to develop a set of quantitative water projections. These climate and socioeconomic pathways are being analyzed in a coordinated multi-model assessment process involving sector and integrated assessment models, water demand models, and different global hydrological models.

While the socioeconomic variables of the SSPs are normally best quantified at the spatial scale of countries, climate change variables including runoff require calculations at the grid-cell level. We employ estimates of monthly runoff using an ensemble of six hydrological models developed in the ISI-MIP project. Consistent with the first estimates of the Integrated Assessment Model (IAM) community, the WFaS "fast-track" water scenarios currently build on three RCP-SSP combinations (SSP1 and RCP4.5, SSP2

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[14] Distributed by the Coupled Model Intercomparison Project (CMIP), see http://cmip-pcmdi.llnl.gov/cmip5/

and RCP6.0, SSP3 and RCP6.0) (see above 2.1). These scenarios cover the diagonal in the SSP scenario matrix in Fig. 2-1, and are therefore a reasonably good representation of the scenario space.

Table 2-1 presents a comprehensive overview of the important quantitative scenario assumptions and underlying data sources applied in the "fast-track" multi-model water assessment. Scenario assumptions are generally deployed at the country level for each scenario. Assumptions for technological and structural changes consider, in addition to the respective SSP scenario narrative, a country's exposure to hydrological challenges and economic-institutional coping capacity (i.e., its position in the HE-classification described above [Table 2-2]). Thus scenario assumptions, such as rates of technological and structural change, have been made for countries or basins within the same H-E class. The Industrial sector comprises energy and manufacturing. Positive technological change improves water use efficiency and thereby decreases water use intensity in the industrial and domestic water use sectors. Annual water use efficiency change rates are estimated for each combination of scenario and H-E class, using a range of historically observed technological change rates (Flörke et al. 2013). Technological change rates are assumed to be similar in the industrial and domestic sectors.

Structural changes in manufacturing lead to water use changes according to the structure of a country's economy. Although the WFaS "fast-track" does not explicitly consider structural change in the manufacturing sector due to a lack of information on sector-specific GDP (i.e., share in agriculture, manufacturing, service), it is at least partly reflected in the results because Gross Value Added (GVA) in the manufacturing sector is an input variable for one of the water models used, namely, WaterGAP (Table 2.5). Structural change in the electricity sector is represented by the replacement rates of power plants with more efficient systems, as the vast majority of water use in this sector is for cooling at thermal power plants. Change in the domestic water use sector is indicated by the number of people and behavioral changes. Structural change in the domestic sector is represented by a gradual 20% reduction in domestic water use intensity by 2050 for SSP1 due to behavioral changes.

Consistent spatial land use and agricultural scenarios, indicating areas of new or increased irrigation and reflecting socioeconomic change, are now being developed using the FAO/IIASA Global-Agro-Ecological

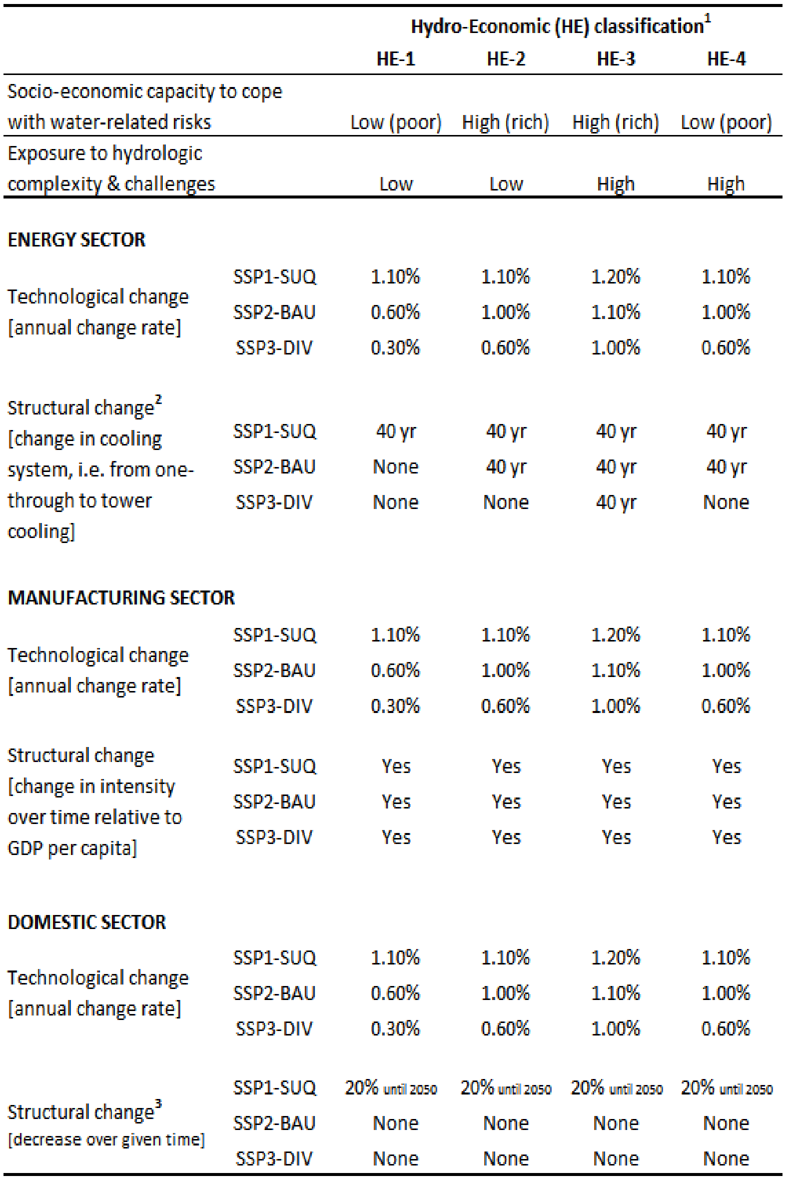
Table 2-1: Assumptions applied in the WFaS "fast-track" scenario runs

WFaS "fast track" scenario	**SSP1 Sustainability**	**SSP2 Middle of the Road**	**SSP3 Regional Rivalry**
Population	SSP1 (IIASA-VIC v9)	SSP2 (IIASA-VIC v9)	SSP3 (IIASA-VIC v9)
Urban population	SSP1 (NCAR)	SSP2 (NCAR)	SSP3 (NCAR)
GDP	SSP1 (OECD[1] v9)	SSP2 (OECD v9)	SSP3 (OECD v9)
Value added in manufacturing[2] scenario related to GEO-4	SSP1 & UNEP-GEO4 "Sustainability First"	SSP2 & UNEP-GEO4 "Markets First"	SSP3 & UNEP-GEO4 "Security First"
Energy consumption (KTOE)[3]	SSP1-RCP4.5 (Message)	SSP2-RCP6.0 (Message)	SSP1-RCP6.0 (Message)
Electricity production (GWh)[3]	SSP1-RCP4.5 (Message)	SSP2-RCP6.0 (Message)	SSP3-RCP6.0 (Message)

[1] OECD Env-Growth Model.

[2] This is only required for WaterGAP. The share of manufacturing gross value added in total GDP is taken from the UNEP GEO4 Driver Scenarios distributed by International Futures (pardee.du.edu).[3] Preliminary results (October 2013) from IIASA – MESSAGE-MACRO model consistent with population and GDP projections for each SSP. The MESSAGE model (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) generated results for 23 regions, which were disaggregated to country level using the distribution of population and GDP from the SSP database hosted at IIASA

Table 2-2: 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
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

[1] The HE classification calculates for each country a compound indicator (values 0–1) for socioeconomic capacity to cope with water-related risks (economic-institutional capacity) and their exposure to hydrologic challenges and complexity (hydrological complexity). In this way each country was located in a two-dimensional space and grouped into four HE classes termed HE-1 to HE-4. [2] When economies have sufficient investment potential (HE-2 and HE-3) or the societal paradigm strives for resource-efficient economies (SSP1) we assume power plants to be replaced after a service life of 40 years by plants with modern water-saving tower-cooled technologies.[3] Only in SSP1 (Sustainability Scenario), do we assume by 2050 a 20% reduction in domestic water use intensity due to behavioral change,

Zones (GAEZ) modeling system (Fischer et al. 2007; 2012). They provide future crop area distribution and improvements in irrigation efficiency. More details on the entire process of scenario development is presented elsewhere (Tramberend et al. 2015).

2.5 Multi-model assessment

This initiative has developed a spatial-temporal quantitative assessment of future water resource availability based on a multi-model assessment framework. The multi-model approach is increasingly used in futures assessments because ensemble averages provide more robust projections than individual models and avoid drawing conclusions from individual outliers (Dankers et al. 2014; Schewe et al. 2014; Wada et al. 2013). The approach is used to better understand the uncertainty and limitations of the modeling, while providing a degree of confidence in the results in cases where models are in agreement. The set of models used provides estimates of water supply and demand with selected combinations of future scenarios globally at 0.5°x 0.5° spatial resolution. The emissions scenarios of the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011) are applied as climate scenarios, and the socioeconomic assumptions are designed to be consistent with the Shared Socioeconomic Pathways (SSPs) (O'Neill et al. 2013). Associated quantifications of developments in other sectors, such as energy and agriculture, are provided by sector models and integrated assessment models working with the same SSPs.

Results presented in this report are based primarily on three leading global hydrological models (GHMs) [H08 (Hanasaki et al. 2013), WaterGAP (Flörke et al. 2013, Müller-Schmied et al. 2014), and PCR-GLOBWB (van Beek et al. 2011, Wada et al. 2014)] which can estimate both water supply and demand for the agricultural, industrial (including energy), and domestic sectors. Concerning runoff and discharge data, the models MPI-HM (Hagemann et al. 2003; Stacke et al 2012) and WBM (Vörösmarty et al. 1998; Wisser et al. 2010) were also applied. Table 2.3 below details the models used in this quantification of available water supply and demand. These GHMs were forced with five general circulation models (GCMs) which provide meteorological conditions (Table 2.4). The atmospheric forcing data set was compiled and made available by the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Warszawski et al. 2014). In total, this study made use of 25 and 15 ensemble member (5 GCMs x 5 or 3 GHMs) projections for water supply and demand estimation, respectively.

Although all GHMs use the same input data for the natural hydrological part (i.e., water supply estimation), they require different input for their estimation of water demand due to the diversity of methods applied in reflecting such a diverse socioeconomic development process. Table 2.5 and Table 2.6 present drivers and parameters for estimation of industrial and domestic water demands, respectively, in the models used. Each of the three applies different parameterizations and uses different input data for the future period. One major difference among GHMs, for example, is the representation of water use in the industrial sector. H08 and PCR-GLOBWB determine water use for an aggregate industry sector, but WaterGAP separates water use for thermal electricity production and the manufacturing industry. Furthermore, while H08 downscales country level representative values into grid scale according to population distributions, PCR-GLOBWB and WaterGAP downscale with urban area data. For consistency in this analysis, water demands estimated by H08 were re-downscaled using the same urban area information as the other models.

Table 2-3: Global Hydrological Models (GHMs) used in this study

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	United States

Table 2-4: General Circulation Models (GCMs) used in this study

GCM	Resolution	Institute	Nation
HadGem2-ES	192 x 145	Met Office Hadley Centre	UK
IPSL-CM5A-LR	96 x 96	Institut Pierre-Simon Laplace	France
GFDL-ESM2M	144 x 90	NOAA Geophysical Fluid Dynamics Laboratory	United States
MIROC-ESM-CHEM	Gaussian 128 x 64	JAMSTEC, AORI, University of Tokyo, NIES	Japan
NorESM1-M	144 x 96	Norwegian Climate Centre	Norway

Table 2-5: Drivers and parameters for estimation of industrial water demand

	Manufacturing water demand		**Thermal electricity production water demand**	
GHM	**Drivers**	**Parameter**	**Drivers**	**Parameter**
WaterGAP	Manufacturing gross value added (GVA)	Manufacturing structural water use intensity [1]	Thermal electricity production	water use intensity[1]

WaterGAP:
Industrial WD = Manufacture WD +
Thermal electricity production WD

	Industrial water demand	
GHM	**Drivers**	**Parameter**
H08	Electricity production	Industrial water intensity [2]
PCR-GLOBWB	GDP Electricity production Energy consumption Household consumption	Industrial water consumption [2]

[1] Data from national statistics
[2] Data from AQUASTAT
Base year: 2005

Table 2-6: Drivers and parameters for estimation of domestic water demand

	Domestic water demand	
GHM	**Drivers**	**Parameter**
WaterGAP	National population GDP per capita Population density	Domestic water intensity [1]
H08	Population	Municipal water intensity [2]
PCR-GLOBWB	GDP Electricity production Energy consumption Household consumption Population density	Per capita domestic water use

[1] Data from national statistics
[2] Data from AQUASTAT
Base year: 2005

2.6 Uncertainty of water supply and demand

This analysis applies a multi-model approach with 5 GCMs together with 5 and 3 GHMs, a total of 25 and 15 ensemble members, to estimate water supply and demand, respectively.

Available surface water resources

Model biases are inevitable, thus we use a multi-model approach for greater confidence in model results and to estimate uncertainty due to any bias. Fig. 2-3a shows time series of precipitation for each region based on 5 GCMs and Fig. 2-3b shows runoff simulated by the 25 scenario ensembles. Shading in Fig 2-3 illustrates uncertainty ranges, and solid lines are ensemble means. Although showing the uncertainty complicates the message, it is informative to demonstrate that significant uncertainty that sometimes exists compared to the trend from the whole ensemble.

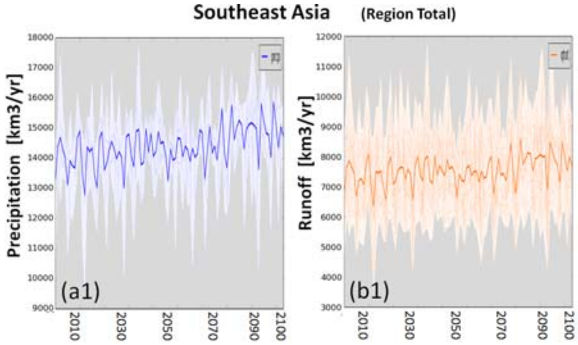


Figure 2-3: Uncertainty in precipitation and runoff:

a) Precipitation b) Runoff (*Middle of the Road* scenario, region total). Lines show ensemble mean of 5 GCMs and 3 GHMs and shades are uncertainty range.

Water demand

The results produced from our first global water use model intercomparison showed a remarkable difference among the three global water models (H08, PCR-GLOBWB, and WaterGAP) used in the WFaS "fast-track" analysis. Fig. 2-4 shows for the largest water consumer countries, three kinds of water demand (agricultural, industrial, and domestic sectors). Each model presents three water scenarios. Although assumptions on socioeconomic, technological, and structural change were harmonized, ensemble projections of water use for the first half of the 21st century showed large variation between the models. The spread was much larger in the industrial sector than the domestic sector. Due to lack of consistent databases of the quantities, qualities, and locations of water demands over time and of the water-related technologies applied, the models use simplified approaches for estimating the water demand of each sector. The approaches used vary, as each model tries to balance the relative unavailability of data with the need for reasonable scenario projections. Although there is a high degree of variability across models and scenarios, almost all projections indicate consistently increasing trends in future industrial and domestic water uses.

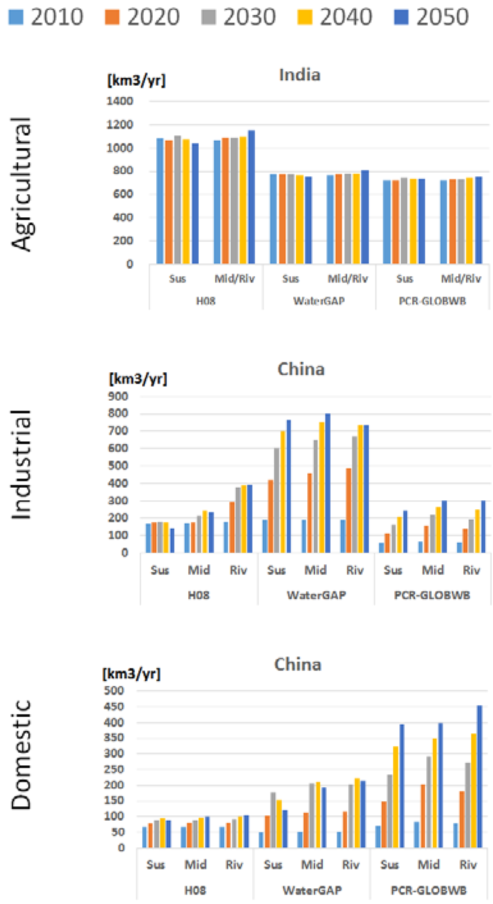


Figure 2-4 **:** Multi-GHM comparison of each water demand – example of the largest water consumer countries in each sector

Despite potential model and data limitations, the WFaS initiative provides an important step beyond earlier work by providing more realistically accounting for the nature of human water use behavior in the 21st century and identifying associated uncertainties. Results in this report are ensemble means, an approach that works well in detecting long-term and relatively large trends.

2.7 The importance of a nexus approach

The water, food, and energy resource systems are inextricably linked. These resources are crucial inputs to economic production and they provide valuable ecosystem services to humans. Secure, reliable, and affordable access to all these resources is critical to basic survival, as well as ongoing economic development at all scales and in every region of the world. The energy sector depends on significant amounts of water: primarily withdrawals for power generation, for running hydropower turbines and the cooling of thermal power stations; for fuel extraction, processing, and transportation; and increasingly for growing biofuels. Similarly, energy is essential for water extraction from both surface and subsurface sources, conveyance and delivery to users, and treatment. Furthermore, energy is used in the agro-forestry sector for fertilizer production, irrigation, cultivating and harvesting crops, and drying and processing products. The agricultural sector is the largest user of water worldwide, mainly for irrigation purposes. Finally, land resources are required for agriculture-, energy-, and water-related activities, primarily for the cultivation of food, feed, fiber, and bioenergy, and also for setting up water and energy facilities. Choices made in one sector can translate to increased risks and harmful effects in another, but they can also generate co-benefits. This linked relationship is commonly known as the water-food-energy nexus.

The next few decades will see an intensification of multiple challenges at the nexus of water, food, and energy. These challenges include growing demands for water, food, and energy, driven by several socioeconomic changes. At the same time, water, food, and energy systems in many countries will be put under growing pressure by increasingly complex interactions, the exhaustion of low-cost supply options, and the impacts of climate change. Jointly, these challenges may compromise the reliability of existing operations and hinder future development. The challenges will be most acute in countries undergoing accelerated transformation and rapid economic growth, or those in which a large proportion of the population lacks access to modern services, such as in many Asian countries (WWAP 2014). However, these least-developed cases also offer opportunities for better planning of long-term nexus dependencies.

The projected future increase of energy demand, coupled with the relative change in the mix of energy production technologies, will likely substantially increase water demand and impair water quality. Global water withdrawals for energy are projected to rise by 20% through 2035, with consumption escalating dramatically by 85%. This will largely be driven by the shift toward higher efficiency power plants with more advanced cooling systems (that reduce water withdrawals but increase consumption), and increased production of biofuels. These changes will be more pronounced in Asia, with withdrawals and consumption increasing by about 50% and 100%, respectively (IEA 2012). Moreover, the future water demands of irrigation, municipal, industrial, and environmental uses are also expected to increase (Wada et al. 2016). This is likely to worsen water scarcity conditions already prevalent in many regions and to increase competition for water across sectors and regions.

At the same time, climate change impacts are highly likely to lead to a more constrained future in many regions around the world. Climate change will likely increase temperature and evapotranspiration, and modify precipitation patterns. Many regions around the world, including Southeast Asia, will suffer reductions in water resource availability and an increase in the occurrence and intensity of extreme events such as droughts and heatwaves. Hydropower and thermal power, the dominant electricity-generating technologies in the world, are especially vulnerable to increased water temperature, diminished water availability, and extreme events (van Vliet et al. 2016). These changes in energy supply can subsequently raise energy prices and result in disruptions.

Energy demand for water supply and treatment is also expected to increase as a consequence of the growing demand for water, driven by growth in population and wealth, and the shrinking water availability resulting from climate change impacts. As clean freshwater becomes scarcer, energy use per unit of water produced often grows as capital and energy are substituted for services previously mainly provided by natural capital. For instance, many of the measures aimed at addressing water scarcity such as water transfer and trading between distant regions, groundwater pumping from deeper aquifers, the use of unconventional water resources (e.g., treated wastewater and desalination), and the shift toward more-efficient irrigation technologies (e.g., sprinkler and drip systems) require considerable amounts of energy with consequences for greenhouse gas emissions and climate change (WWAP 2014). For example, desalination requires an order of magnitude more energy than standard drinking-water treatment (King et al. 2008). Meanwhile, hydropower projects can improve both energy and water security, but have implications for both terrestrial and aquatic ecosystems through flow alteration and habitat loss (Vörösmarty et al. 2010).

Bioenergy production can help mitigate climate change and alleviate energy security concerns, but can also have negative impacts on food production and prices, water use, and biodiversity, if not restricted to non-irrigated marginal or abandoned cropland (Chaturvedi et al. 2013). Food production can be expanded through cropland expansion and intensification (Schmitz et al. 2014), but these strategies will have impacts on natural ecosystems and result in greater water and energy use, and impaired water quality.

Despite these interdependencies, water, food, and energy policies are rarely integrated, and have been so far addressed in isolation within sectoral boundaries. Decision makers often remain ill-informed about the importance of integration and nexus thinking. The lack of integration in resource assessments and policymaking leads to inconsistent strategies and inefficient use of resources. Part of the reason for this is that the spatial scales of concern to water, food, and energy-supply managers are usually quite different. Energy providers are rarely focused on regions as small as a city, or town, or basin that water utility managers and farmers are responsible for. Water utility managers of local municipalities and farmers are not likely to feel obliged to take into account the production of electricity or gasoline hundreds of kilometers away that they may eventually use (Cosgrove and Loucks 2015). Another reason is pricing asymmetries. While energy and food are priced in competitive markets, water supplies are often sold at an administered price because of several physical and institutional barriers. Good examples are irrigators who pay a fixed price per unit of use to an irrigation district, or homeowners who buy water from a public or private water utility at a set price. Therefore, resource use decisions may not accurately reflect the economic value of water.

Sustainable management of water, food, and energy resource systems should be conducted using integrated approaches that are based on a broader systems perspective (Liu et al. 2015). These approaches strive to identify the linkages and interactions among sectors to better understand the synergies and trade-offs involved in meeting future resource demands of both human and natural systems in a sustainable way. The ultimate objective is to identify solutions that capitalize on potential synergies and co-benefits, minimize counterproductive policies and investments, and ensure that humanity remains within planetary boundaries. Although a fully integrated model and assessment of nexus feedbacks is beyond the scope of this assessment, the question of how water constraints will affect food production, energy production, access to water, and ecosystem health are of particular interest.

3 Results for the Asian Region

3.1 Socioeconomic change

This chapter presents population growth (Fig. 3-1) and changes in GDP (PPP) (Fig. 3-2) in Asia according to the three WFaS scenarios. This data is available in five-year time step from the Shared Socioeconomic Pathways database hosted by IIASA.[15]

3.1.1 Population growth

The results shown here are from the IIASA Population Program. KC and Lutz (2014) applied the methods of multi-dimensional mathematical demography and projected national populations based on alternative assumptions on future fertility, mortality, migration, and educational transitions that correspond to the five SSPs.

Every scenario projects large population increases in the next few decades (Fig. 3-1). In the *Regional Rivalry* scenario, Asian total population continues to increase indefinitely. Conversely, in the *Sustainability* and *Middle of the Road* scenarios, Asian total population peaks at 2040 and 2050, respectively. Asia's total population was about 3.8 billion in 2010. Compared to current levels, it is expected to increase in the ranges of 114-133% by the 2050s and 76-153% by the 2100s.

Table 3-1 provides a more detailed breakdown of the regional figures for the population under the different scenarios. For instance, in the *Sustainability* scenario, South Asia will reach its highest population in around 2050, while in the *Middle of the Road* scenario this will happen around 2065, though this South Asia peak is happening at a later stage in these scenarios than the peak of the whole. The *Regional Rivalry* scenario shows a continuous increase in population. In East Asia, where China is dominant, all scenarios project a decreasing trend with peaks between2020 to 2030. Unlike other regions, the Advanced Economies have the lowest population under the *Regional Rivalry* scenario and the highest population under the *Sustainability* scenario through the 2010s to the 2050s. The increasing trends through to the end of the 21st century of Central and Western Asia, Southeast Asia and Pacific Asia under the *Regional Rivalry* scenario until are also distinctive, as most combinations of scenarios and regions have their peak in the middle of the 21st century. The total population ranking among regions remains almost unchanged through all scenarios, but the population of Central and West Asia will become larger than that of the Advanced Economies in the *Regional Rivalry* scenario and the *Middle of the Road* scenario around the 2050s and the 2070s, respectively, due to population decrease in the Advanced Economies.

Within the 21st century, many countries in Asia are expected to peak in population, particularly under the *Sustainability* and *Middle of the Road* scenarios. Three countries have already peaked in population (Armenia [1990], Georgia [1990], and Japan [2010]) and two countries are expected to peak in the near future (China [2020-2030], Republic of Korea [2020-2030]). By 2050 the populations of 23 countries will peak under the *Sustainability* scenario, compared to 17 countries under the *Middle of the Road* scenario and 6 countries under the *Regional Rivalry* scenario, respectively, in the same timeframe. Appendix B1 provides a detailed table of the number of population per country for the years 2015, 2030, 2050 and 2100 for all three scenarios.

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[15] IIASA Shared Socioeconomic Pathways database: https://tntcat.iiasa.ac.at/SspDb

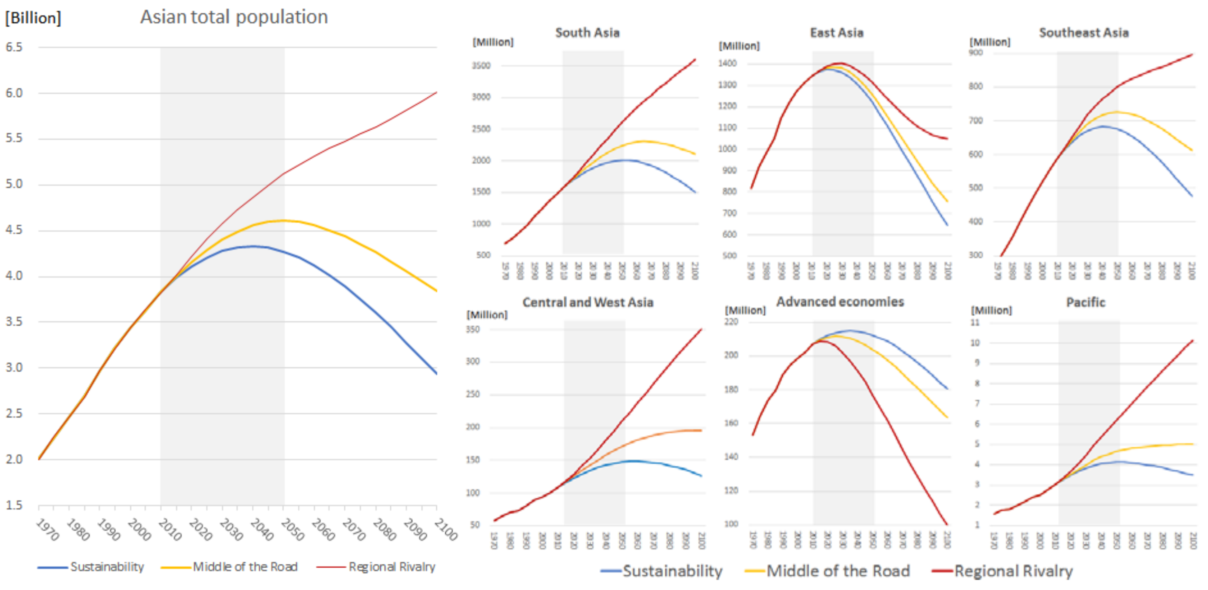

Figure 3-1: Change in population

Table 3-1: Population changes at national level

[10^3 people]		Reference 2010	Sustianability			Middle of the Road			Regional Rivalry		
			Maximum	Increase	Peak Year	Maximum	Increase	Peak Year	Maximum	Increase	Peak Year
Central and West Asia	Afghanistan	31412	66815	113%	2080	111717	256%	2100	222907	610%	2100
	Kazakhstan	16026	19336	21%	2050	21286	33%	2070	25835	61%	2100
	Kyrgyzstan	5334	6217	17%	2040	6753	27%	2050	9226	73%	2100
	Tajikistan	6879	8077	17%	2040	8755	27%	2050	14620	113%	2100
	Turkmenistan	5042	6011	19%	2045	6521	29%	2055	8034	59%	2100
	Uzbekistan	27445	32032	17%	2040	34759	27%	2050	49370	80%	2100
	Armenia	3092	3544		1990	3544		1990	3544		1990
	Azerbaijan	9188	10972	19%	2045	11717	28%	2050	13796	50%	2100
	Georgia	4352	5460		1990	5460		1990	5460		1990
East Asia	China	1341335	1371064	2%	2020	1383430	3%	2025	1399601	4%	2030
	Mongolia	2756	3441	25%	2050	3821	39%	2060	5332	93%	2100
Pacific Asia	Fiji	861	916	6%	2025	946	10%	2035	1286	49%	2100
	Samoa	183	183	0%	2015	183		2010	340	86%	2100
	Solomon Islands	538	880	64%	2065	1100	104%	2085	1535	185%	2100
	Timor-Leste	1124	1789	59%	2055	2503	123%	2100	6071	440%	2100
	Tonga	104	107	3%	2020	108	4%	2025	209	101%	2100
	Vanuatu	240	396	65%	2065	493	106%	2085	708	196%	2100
South Asia	Bangladesh	148692	175779	18%	2040	190671	28%	2050	259595	75%	2100
	Bhutan	726	1123	55%	2060	1310	80%	2075	1727	138%	2100
	India	1224614	1543020	26%	2050	1757775	44%	2065	2686574	119%	2100
	Maldives	316	432	37%	2060	480	52%	2065	606	92%	2100
	Nepal	29959	46770	56%	2065	57217	91%	2080	102100	241%	2100
	Pakistan	173593	250792	44%	2060	316605	82%	2085	550589	217%	2100
Southeast Asia	Cambodia	14138	16864	19%	2045	18658	32%	2055	26768	89%	2100
	Indonesia	239871	273067	14%	2040	286223	19%	2045	307692	28%	2060
	Lao PDR	6201	7890	27%	2050	8973	45%	2060	13186	113%	2100
	Malaysia	28401	41477	46%	2065	48296	70%	2080	68100	140%	2100
	Myanmar	47963	50187	5%	2025	51855	8%	2035	57358	20%	2100
	Philippines	93261	127064	36%	2055	150743	62%	2080	250596	169%	2100
	Thailand	69122	73419	6%	2030	75042	9%	2035	78532	14%	2100
	Viet Nam	87848	101033	15%	2040	105686	20%	2045	113176	29%	2055
Advanced Economies	Australia	22268	46667	110%	2100	43353	95%	2095	28373	27%	2055
	Brunei Darussalam	399	652	64%	2065	732	84%	2075	884	122%	2100
	Japan	126536	126536		2010	126536		2010	126536		2010
	New Zealand	4368	7576	73%	2100	7150	64%	2095	5163	18%	2045
	Republic of Korea	48184	50563	5%	2030	49953	4%	2030	49103	2%	2020
	Singapore	5086	7851	54%	2065	8202	61%	2075	7382	45%	2095

3.1.2 Growth of GDP and GDP per capita (PPP)

WFaS future scenarios include GDP growth (PPP) as well as population. Unlike the population scenarios, GDP continues to increase in almost every combination of scenario and region (Fig. 3-2). Exceptional instances of falling GDP are in East Asia under the all three scenarios (peaking at: 2065 in the Sustainability scenario, 2095 in the *Middle of the Road* scenario, 2055 in the *Regional Rivalry* scenario) and the Advanced Economies countries under the *Regional Rivalry* scenario (peaking at 2045). East Asia currently has the highest share of Asian GDP (PPP). But, every socioeconomic scenario projects that, with time, East Asia will be overtaken by South Asia. For instance, the earliest that GDP in South Asia exceeds that of the East Asia is in 2068 in the *Sustainability* scenario. The Advanced Economies, which is the second most dominant sector in the 2010s, will be overtaken by Southeast Asia and by South Asia in around 2040 and 2020, respectively. The scenario further indicates that by 2050, East Asia will have increased its GDP 4- to 5-fold compared to the current Advanced Economies. One of the determining factors influencing this strong growth in GDP in these three regions is the especially strong economic development of China, India, and Indonesia. Compared to their current states, China's and India's GDPs see 7.5- and 10-fold increases by their peaks in 2050, respectively, under the *Sustainability* Scenario.

Average incomes, represented by GDP per capita (lines with human symbols in the figure), are projected to increase continuously (Fig. 3-2). Even where GDP peaks (solid lines), for instance in East Asia under the *Sustainability* scenario, GDP per capita continues to rise. At the country level, almost all combinations of countries and scenarios indicate continuous growth in GDP per capita through to 2100. The only exceptions are three countries under the *Regional Rivalry* scenario, namely Kazakhstan, Turkmenistan, and Singapore. Appendix B2 and Appendix B3 provide tables of country GDP and GDP per capita for the three scenarios.

The Hydro-Economic Classification (section 2.3) uses GDP per capita as an index to evaluate “economic coping capacity” in terms of water risks. Countries are categorized into four classes to quantify their hydro-economic class. Fig. 3-3 shows the economic coping capacity in the 2010s and the 2050s under the *Middle of the Road* scenario. In the 2050s Afghanistan, Nepal, and Myanmar are in a low class; they will require higher levels of financial support due to their high hydro-climatic complexity and low coping capacity. Their hydro-climatic complexity is presented in the next section.

Overall, water demand grows with increasing population and income. Apart from well-managed conditions with effective and efficient development plans, water laws, and/or water-saving technologies, more rapid social growth results in higher water security risks. Thus new insights into our possible futures, considering both climate and socioeconomic change, are urgently needed.

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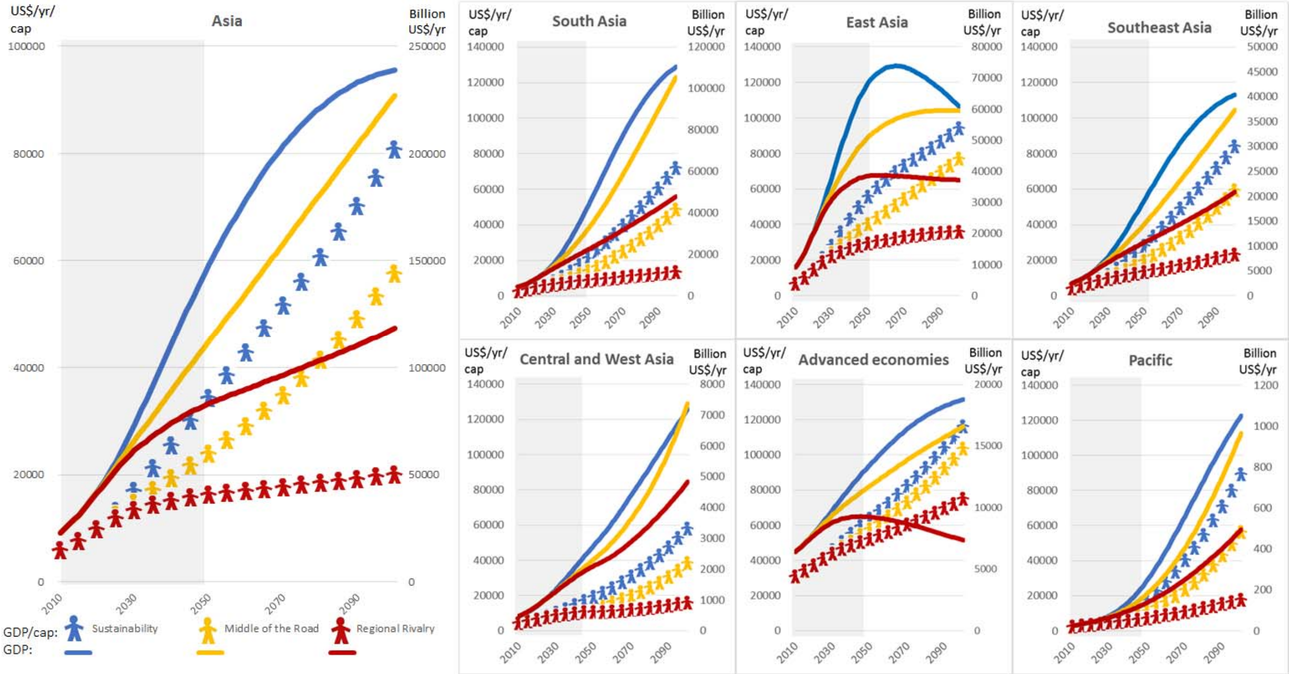
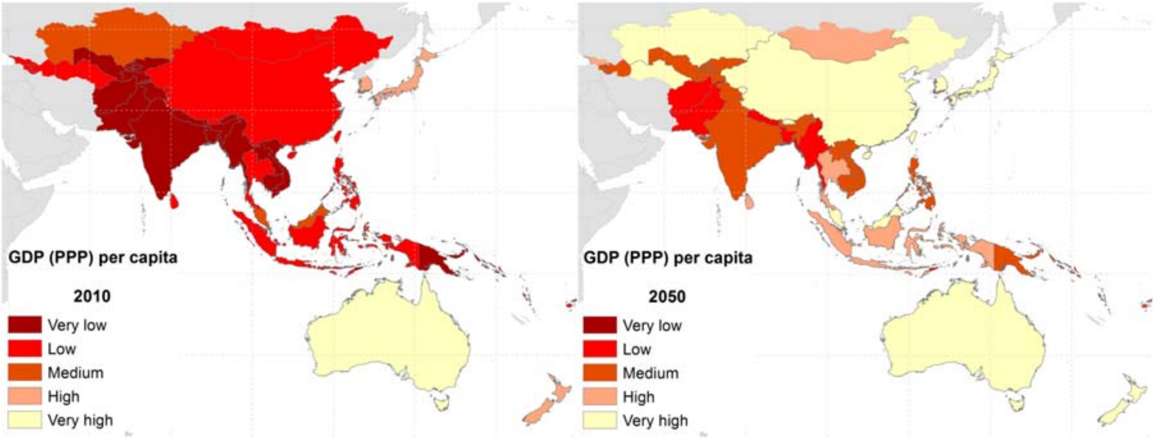


Figure 3-2: Change in GDP per capita and GDP (PPP)

Solid lines and the right axis shows GDP. Lines with human symbols and the left axis are for GDP per capita



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

Figure 3-3: Quantifying “economic capacity” for hydro-economic classification: GDP per capita in the 2010s and the 2050s (*Middle of the Road* scenario)

3.2 Energy system development/scenarios

3.2.1 Energy demand and security

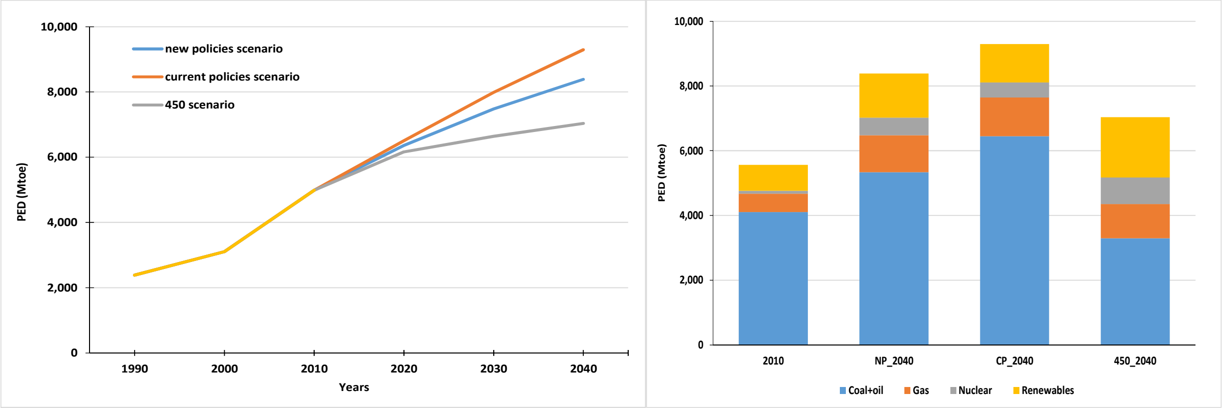
Energy demand in Asia has experienced rapid growth in recent years, accounting for 70% of the growth in global energy consumption since 2000. This demand has especially increased in large emerging economies such as China and India, driven primarily by economic and population growth. From 2000 to 2010, the primary energy demand of Asia grew at 5% per annum, from 3100 million tons of oil equivalent (Mtoe) to 4990 Mtoe. Consequently, Asia's share in the world's total primary energy demand reached 40% in 2010, up from 30% in 2000 (ADB 2013a). Energy demand in Asia has become the major driving force of world demand for energy, with major consequences for energy security, financial and energy markets, and environmental sustainability, both regionally and globally.

Energy security has emerged as a critical issue in Asia in recent years, due to the increasing demand and competition for energy resources in the region, the fear of resource depletion in the near future, and concerns about the impacts of climate change. While Asia is the largest energy-producing region in the world, with almost 30% of global production in 2013, the region is a net energy importer, as its internal demand is growing faster than its production (IEA 2015a). Self-sufficiency, a simplified indicator of energy security, has declined over the last few years. Self-sufficiency is currently greater than 0.7 in almost all Asian countries, but it is expected to be less than 0.5 in 2035 for the majority. This means that in 2035, domestic resources will meet less than 50% of annual energy requirements (Fueyo et al. 2014).

3.2.2 Energy system development and scenarios

Future energy and climate policies play a powerful role in determining the degree of growth in energy demand and the choice of energy supply mix. According to the 2015 World Energy Outlook (WEO-2015), primary energy demand in Asia will increase by about 50% between 2013 and 2040 to reach 8380 Mtoe under the central scenario of WEO-2015 (*new policies scenario*) (Fig. 3-4) (IEA 2015b). This demand represents almost half of the projected global demand. The average rate of growth in primary energy demand continues to increase over time until 2030 compared to the current situation, and slows down by 2040. The reasons are the possible deceleration of economic and population growth, coupled with the implementation of energy efficiency policies and the shift toward low-carbon technologies, especially in one of the WEO-2015 scenarios that is a pathway to the 2 °C climate goal (450 scenario), aimed at increasing energy use efficiency and mitigating climate change (New policies and 450 scenario).

Non-OECD Asian countries drive all of the growth in Asia's primary energy demand, with their demand expected to increase by up to 80% by 2040 compared to current demands. Conversely, OECD Asian countries reduce their demands by up to 13% by 2040. The most important energy users in Asia are China, India, Japan, and some southeastern countries including Indonesia, Thailand, Malaysia and Philippines. China's primary energy demand grows by one-third, to exceed 4000 Mtoe in 2040, being the most important energy consumer in the world. India becomes the world's number one source of energy demand growth, with two-and-a-half-times higher demand by 2040 compared to current levels. Primary energy demand in Japan falls by 12% by 2040, to around 400 Mtoe. Primary energy demand in southeast Asia is expected to rise by 80%, as the regional economy more than triples in size.



New policies scenario: includes the policies and measures that affect energy markets and that had been adopted as of mid-2015, and also takes into account other relevant intentions that have been announced, even where the precise implementing measures have yet to be fully defined. ***Current policies scenario***: considers only those policies for which implementing measures had been formally adopted as of mid-2015 and makes the assumption that these policies persist unchanged. ***450 scenario***: assumes a set of policies that ensure an emissions trajectory consistent with stabilization of the GHG concentration after 2100 at around 450 parts per million. PED: primary energy demand, NP_2040: new policies scenarios in 2040, CP_2040 = Current policies scenario in 2040, 450_2040: 450 scenario in 2040.

Figure 3-4: Primary energy demand in Asia under the different WEO-2015 policy scenarios (left) and primary energy demand by fuel type in Asia in 2010 and 2040 (right)

Primary energy demand in Asia for all fuels grows through to 2040 (Fig. 3-4). The share of renewable energy, natural gas, and nuclear energy grows considerably, while for oil and coal it slows with time, especially under the 450 scenario. Although by 2040 oil and coal collectively remain the most important sources of energy in Asia, their share of the energy mix decreases across the three scenarios. For instance, the 450 scenario assumes the largest decrease from 74% in 2013 to 47% in 2040. On the other hand, the share of renewable energy grows from 14% in the base year to 27% in the forecasted year. In line with climate stabilization targets, the scenarios include substantial energy conversion and end-use efficiency improvements, technological advances such as carbon capture and storage, and negative emissions through land-use change and bioenergy with carbon capture. Emissions capture and carbon pricing in these scenarios are fundamental to reconciling these uses of fossil fuels with climate stabilization.

A recent study completed within WFaS by van Vliet et al. (2016) shows that climate change will reduce the existing power plant capacities of both hydropower and thermal power in most regions worldwide. Hydropower, which currently generates 14% of total electricity production in Asia, is expected to experience in the order of a 3% reduction in annual usable capacity in both the 2020s and the 2050s. Annual thermal power usable capacity, which currently generates 76% of Asian electricity production, is expected to decrease by around 3% in the 2020s and by up to 8% in the 2050s. It should also be noted that these annualized reductions in usable capacity do not reflect the severity of impacts that may be experienced during more severe drought events. Future work will also consider the consequence of dry years and drought events in relation substantial reductions in usable capacity of both hydropower and thermal power, over shorter periods, with possible impacts for electricity prices and energy security.

3.3 Food and Agriculture Development

The World Food Summit of 1996 defined food security as existing “when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life.” Commonly, the concept of food security is defined as including both physical and economic access to food that meets people's dietary needs as well as their food preferences. It has become increasingly complex and challenging to achieve food security. Particularly, under the impact of rapidly rising population numbers, fast economic growth, changing consumption patterns, volatile international trade, growing demand for non-food uses such as biofuels, and environmental change.

Economic growth and food security have been mutually reinforcing throughout the history of development. However, earlier experiences suggest that food insecurity cannot be fully eradicated by economic growth alone. In recent decades, strong growth has played a crucial role in the decline of poverty and undernourishment, but food insecurity still persists in many countries and regions around the world. This means that to achieve food security, increasing food production is necessary but not sufficient. In addition to enhancing the resource base and increasing land productivity, achieving food security also entails ensuring equitable distribution of food, particularly to: countries and people where there is a food deficit; reduce distortions and barriers in global food markets; and avoiding unnecessary wastage of food at all levels from field to fork.

The economies of developing Asia and the Pacific grew an average 7.6% per year between 1990 and 2010, far exceeding the 3.4% global average growth. Fig. 3-5 shows the projected population and economic growth in the three development pathways analyzed in this study. While population in Asia and the Pacific peaks mid-century in two of the three development pathways (4.4 billion people around 2040 in the *Sustainability* scenario and 4.7 billion people around 2050 in the *Middle of the Road* scenario), population numbers continue growing throughout the simulation period in the *Regional Rivalry* scenario and exceed 5.6 billion people in 2080, compared to 3.9 billion in 2010. The scenarios portray strong economic growth in Asia and the Pacific region, at average annual GDP growth rates of 5% over the period 2010-2050 (*Sustainability* scenario), 4.3% (*Middle of the Road* scenario), and 3.5% (*Regional Rivalry* scenario). This results in average annual per capita GDP growth rates for the 40 years to 2050 of 4.7%, 3.8%, and 2.8% respectively (Fig. 3-5).

Growing wealth and population numbers have both been driving the rising demand for more protein-rich food and better nutrition. As land suitable for crop production is limited, especially in South and East Asia, the growth in food demand and production has strong implications for the intensity of production, with respect both to required yield increases and enhanced multi-cropping. Asia’s share in global food consumption, measured in food calories consumed, has been increasing in the last two decades. Consumption per capita in Asia and the Pacific went up from 2379 kilocalories per capita per day (kcal/capita/day) in 1990 to 2665 kcal/capita/day in 2009, with higher average annual increases than the increase in global per capita consumption observed over the same period. Yet despite this rapid increase, per capita consumption in the region remained below the global average of 2800 kcal/capita/day and far below European and North American average per capita consumption of more than 3400 kcal/capita/day (ADB 2013).

Based on the demographic and economic macro-drivers in Asia outlined above, scenario simulations with IIASA’s World Food System (WFS) model (e.g., Fischer 2011; Fischer et al. 2009) and the Global Agro-Ecological Zones (GAEZ) model (Fischer et al. 2012; Fischer et al. 2007) indicate that food consumption in

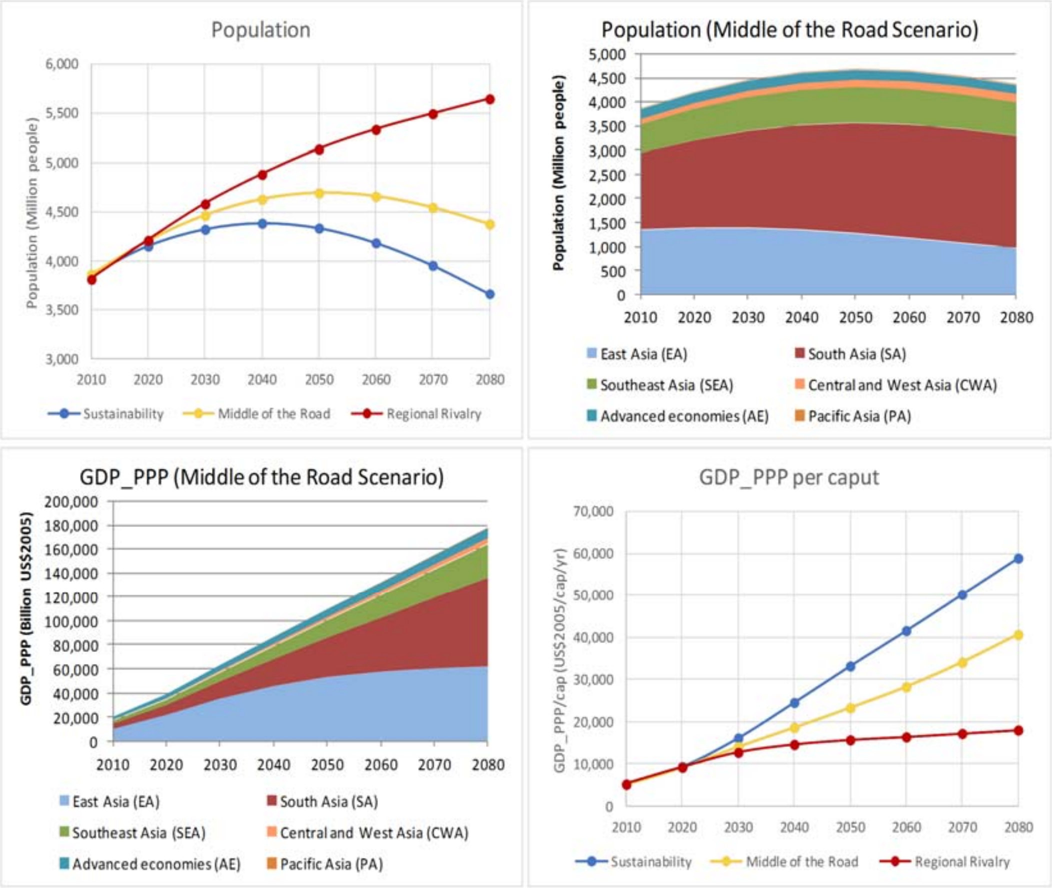


Figure 3-5: Major drivers of food system development in Asia under the different Shared Socioeconomic Pathways (SSPs)

Asia will continue to increase, although there are notable differences among Asian regions. Food energy intake in the WFS model is estimated at an average 2750 kcal/cap/day in 2010, with a range from less than 2500 kcal/cap/day in South Asia (e.g. Bangladesh, India, Pakistan) to more than 3000 kcal/cap/day in East Asia (i.e., China). The projected food energy intake in 2050 reaches levels between 2850 kcal/cap/day (*Regional Rivalry* scenario) and 3345 kcal/cap/day (*Sustainability* scenario), and in 2080 respectively 2935 to 3600 kcal/cap/day (i.e., comparable to the current energy intake levels in Western Europe and North America). This change over time is shown graphically in Fig. 3-6.

Total cereal utilization in 2010 in the Asia and Pacific region simulated in the WFS model – including food, feed, industrial use, seed use and waste – amounts to 960 million tons.[16] In 2050 scenario results fall in the range of 1195 million tons of cereals (*Sustainability* scenario) to 1260 million tons (*Regional Rivalry* scenario). In 2080 the range of scenario results widens, from a low of 1150 million tons of cereals to a high estimate of 1400 million tons. The cereal self-sufficiency ratios for the Asia and Pacific region shown in Figure 2 indicate that the high level of regional self-reliance (more than 95% simulated in 2010) may fall

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[16] The Asia and Pacific region formed by the countries and regional groups as used in the WFS model and shown in Figure 2 necessitates some differences from the ADB definition by including in the estimates Korea DPR and excluding Afghanistan, Mongolia and countries in Central Asia.

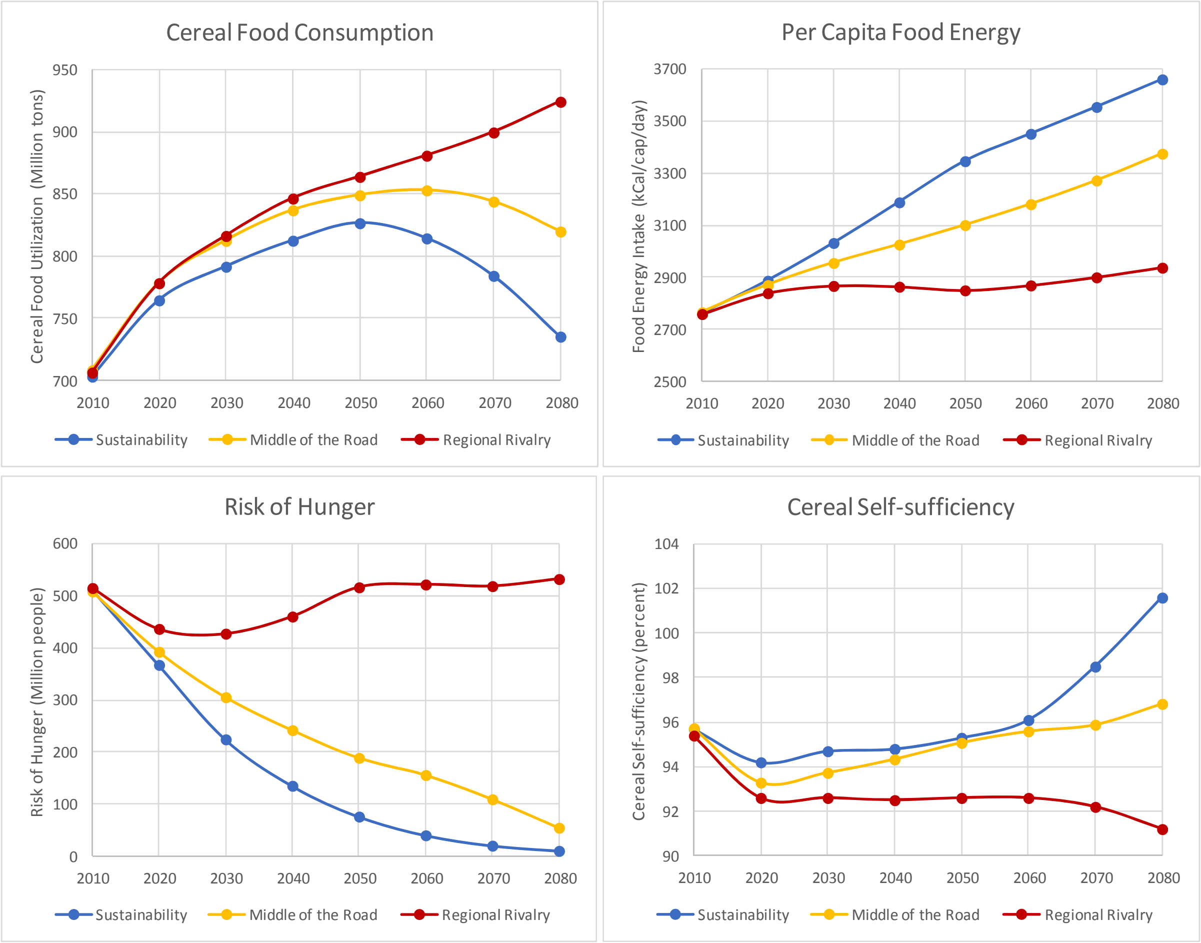

Figure 3-6: Selected Indicators of food system development in Asia under the different Shared Socioeconomic Pathways (SSPs)

initially until 2030 but would likely recover thereafter. In the *Sustainability* scenario the regional cereal self-sufficiency ratio in 2080 reaches about 100% thanks to net cereal exporters in the region such as Australia, New Zealand, and Thailand.

The number of people at risk of hunger in the Asia and Pacific region estimated for 2010 amounts to 510 million. This number is rapidly reducing in two development pathways, and hunger is practically eliminated by 2080. Yet under the *Regional Rivalry* scenario, economic development is insufficient to end hunger and the estimated number of people at risk of hunger stabilizes at about 500 million (Fig. 3-6).

The strong income and population growth in Asia and the consequent rise in food demand will put additional pressures on land, water, energy resources, as well as the environment. Results of the WFS and GAEZ model simulations indicate a further increase in the use of cultivated land (i.e., arable land and land under permanent crops) in Asia from a total of 534 million hectares in 2010 to reach between 536 and 564 million hectares under the different development scenarios by 2050, and between 511 and 569 million hectares in 2080 (Fig. 3-7). In the *Sustainability* and *Middle of the Road* scenarios the peak of

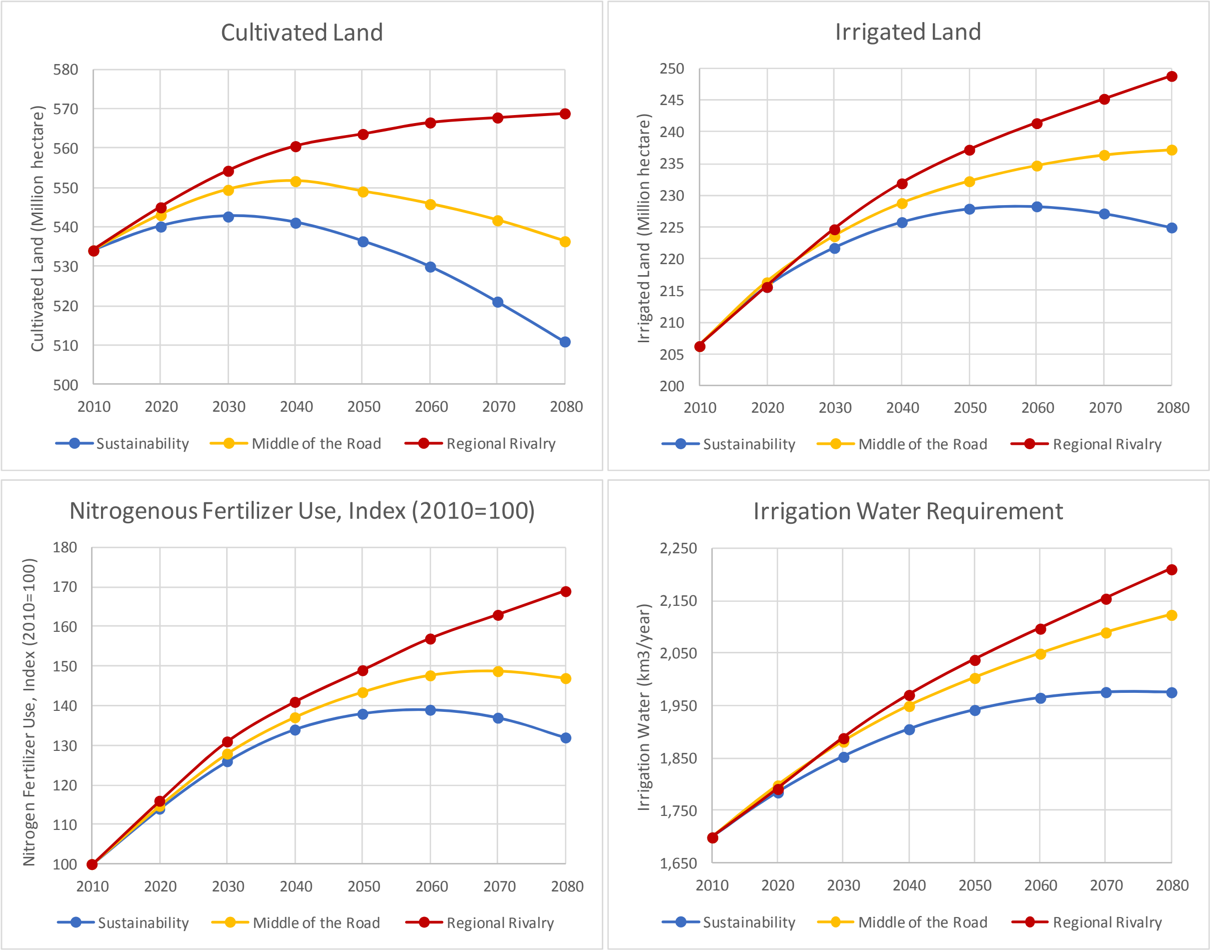

Figure 3-7: Evolution of cultivated land, area equipped with irrigation, cereal production, and total irrigation water requirement in Asia under the different Shared Socioeconomic Pathways (SSPs)

cultivated land use is reached around 2040 and use of cultivated land subsequently decreases. In the *Regional Rivalry* scenario, due to continued population growth and slower economic development, the use of arable land continues to increase until the end of the simulation period in 2080, approaching a level of about 570 million hectares (Fig. 3-7), that is, some 35 million hectares (or 6.5%) more than in 2010.

The increase of cultivated land is modest compared to simulated production changes. Projected cereal production in the three analyzed scenarios is up by 24-27% in 2050 compared to 2010 and by 30-36% in 2080. Total crop production in the developing Asia and Pacific region (at FAO international dollar (I$) of 2005 constant international prices of 2004-2006) increases by 30-36% in 2050 (relative to 2010) and by 46-50% in 2080 compared to 2010. For livestock production the projected increases in developing Asia and Pacific region are even higher, namely, 53-64% in 2050, and 82-110% in 2080.

Table 3-2 summarizes selected indicators of crop production growth across different scenarios. Note, there is only minimal change in total cultivated land extent. Production increases in all scenarios as a function of production intensification, that is, substantial increases of output per unit of cultivated land. While this is possible and achievable due to existing yield gaps (actual versus potential) in developing Asia,

Table 3-2: Indicators of crop production growth in the Asia and Pacific region across scenarios

	Change relative to level in 2010 (percent change)		
	2030	2050	2080
Crop production (constant int. 2005$)	17 – 21	30 – 36	46 – 50
Cultivated land	2 – 4	0 – 6	-4 – 7
Land equipped with irrigation	7 – 9	10 – 15	9 – 21
Irrigation water requirement	9 – 11	14 – 20	15 – 30
Nitrogenous fertilizer use	26 – 31	38 – 49	32 – 69
Output intensity*	13 – 19	23 – 36	37 – 57

* Output intensity represents a generalized measure of yield and is calculated as the value of crop production (in constant I$ of 2005) per hectare of cultivated land.

it cannot be taken as given and will require major efforts by the countries. Cropland intensification, if not regulated and managed well, will increase the risk of environmental damage. Intensification inevitably means higher application and use of nutrients, other agro-chemicals, water, and energy. All of which may result in pollution and may cause over-exploitation of water resources to meet irrigation requirements. This is particularly the case in the already intensively farmed areas of South and East Asia, where there is a potential that this will further increase the risks of groundwater over-exploitation and environmental degradation. For instance, in the *Middle of the Road* scenario, projected use of nitrogenous fertilizers in 2050 in the Asia and Pacific region is 43% higher than in 2010 and 47% higher in 2080. The range of outcomes indicates increases of 38% (*Sustainability*) to 49% (*Regional Rivalry*) in 2050 and of 32-69% in 2080.

For irrigated land it is projected there will be an increase from 206 million hectares in 2010 to about 228 to 237 million hectares in 2050, and between 225 and 249 million hectares in 2080 (Fig. 3-7). This implies that the *Middle of the Road* irrigation as a proportion of total cultivated land in the region, increases from 38.6% in 2010 to 42.3% in 2050 and 44.2% in 2080.

Future irrigation water requirements estimates based on changes in irrigated areas projected in the WFS scenario simulations and the multi-model ensemble mean of irrigation requirements per unit area suggest significant increases. For the year 2010 we obtained an estimate of irrigation water use in the Asia and Pacific region amounting to 1700 km^3/yr. Keeping the irrigation system efficiency parameters at base year level, the irrigation water requirements calculated for 2050 were in the range of 1940 km^3/yr (*Sustainability* scenario) to 2040 km^3/yr (*Regional Rivalry* scenario), and in 2080 ranging from 1975 km^3/yr to 2210 km^3/yr or 16% to 30% above the level in 2010 (see, Fig. 3-7).

Climate change and the increase in irrigated land combine in the scenario projections to increase crop irrigation water requirements, as detailed in Table 3-2. Climate change impacts on irrigation requirements are more pronounced at higher latitudes such as in the East Asia and Central and West Asia regions. In

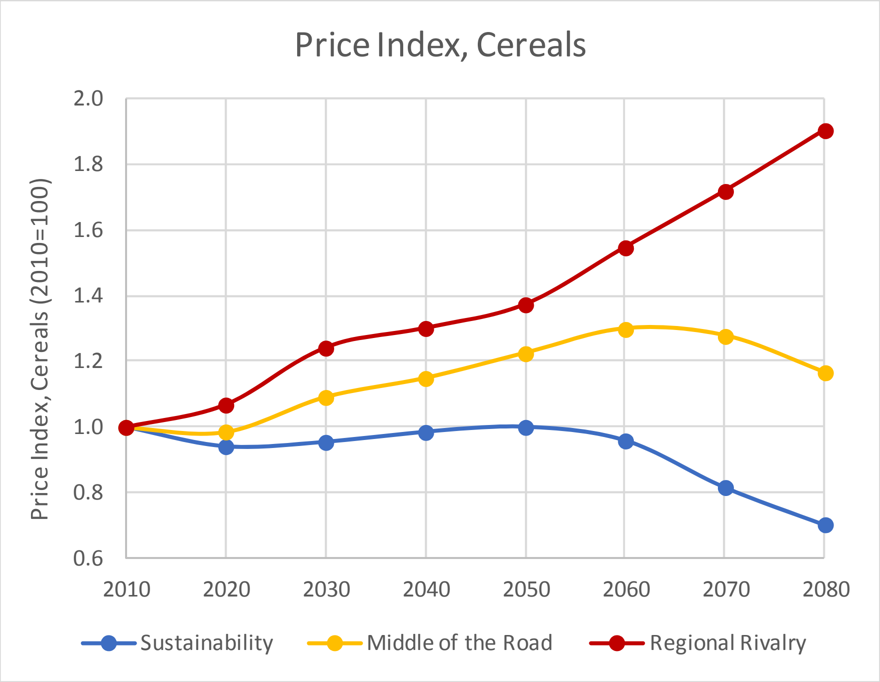

Figure 3-8: Cereal price index (2010=100) under the different SSP scenarios

the Advanced Economies region the irrigated area gradually decreases under all three development pathways which approximately balances the increases in irrigation water requirements induced by climate change.

The results summarized in Table 3-2 indicate an aggregate impact of climate change on irrigation water requirements due to warming and changes in precipitation in 2030 of 2.0% (in the *Sustainability* scenario based on RCP 4.5) to 2.7% (in RCP 6.0). In 2050 the climate change impacts fall into a range of 3.9% to 5.3%, and in 2080 the range becomes 6.9% to 9.3%. In comparison, cultivated land equipped with irrigation in 2050 is 10.4% to 14.8% above the level in 2010, and by 8.9% to 20.5% in 2080.

When combining climate change and land use change impacts, the estimated increase of irrigation water use in the Asia and Pacific region becomes 14.3% to 19.9% in 2050 and 16.3% to 30.1% in 2080. As noted before, these estimates are calculated assuming at basin level an overall irrigation system efficiency as in the base year 2010. Model estimates and data on crop water requirements and irrigation water withdrawal provided in FAO (2012) indicate an overall system efficiency expressed as a water requirement ratio (i.e., the ratio of estimated crop irrigation water requirements over irrigation water withdrawal) for the Asia and Pacific region of 58%. In the FAO study, irrigation water withdrawal in Asia and Pacific region accounted for about 13% (in 2005) of the region’s total renewable freshwater resources, yet with very large differences across Asian basins.

The world food system model used for scenario analysis in this study that links the various national and regional geographical components by means of a world market, uses the mechanism that international market clearing prices are computed to equalize global demand with supply, subject to, among other constraints and national budget constraints on a yearly basis. The index of cereal prices generated in each scenario is shown in Fig. 3-8.

The cereal price index can be interpreted as a stress indicator of the world food system. Under the *Sustainability* scenario, cereal prices remain initially quite stable. A clear downward trend occurs beyond mid-century, coinciding with the decline of world population numbers in this scenario. In the *Middle of the Road* scenario cereal prices increase modestly until mid-century and start falling as global population stabilizes. Price development in the *Regional Rivalry* scenario signals that meeting food demand is becoming increasingly difficult under this scenario. Rising prices in the global food market add to the risk of hunger in this *Regional Rivalry* world.

3.4 Water demand

Water demand is calculated for all three scenarios based on three global GHMs and five GCMs. Asian total water demand was about 2400 km^3/year around 2010, and all scenarios indicate consistent increases of approximately 30-40% (Fig. 3-9). Note that results shown in this section are the mean of the 15 ensemble members for the *Middle of the Road* scenario, which represents the intermediate path among the three scenarios. Detailed country and regional numbers for the *Sustainability* and *Regional Rivalry* scenario are given in Appendix C. Also, that the projection of agricultural water demand presented has not included socioeconomic assumptions that is, technological and farming practice change, such as change of irrigation area and improvement of irrigation efficiency. For instance, irrigation area is fixed to that of the year 2000. However, this estimate also gives good insights into future change under global warming. WFaS has been developing future scenarios of these agricultural factors, and will release further projections in the next phase of work.

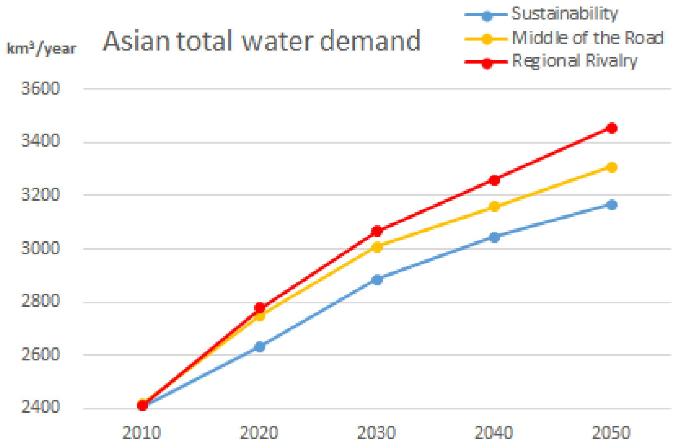

Figure 3-9: Asian total water demand

Table 3-3: Total water demand (*Middle of the Road* scenario)

	Middle of the Road			Change Rate	
	2010	2030	2050	2030	2050
East Asia	726	1088	1217	50%	68%
South Asia	1135	1267	1386	12%	22%
Southeast Asia	260	308	340	18%	31%
Central and West Asia	179	220	239	23%	33%
Advanced economies	118	126	127	7%	7%
Pacific	0.5	0.7	1.1	49%	122%
Asian Total	2418	3009	3310	24%	37%

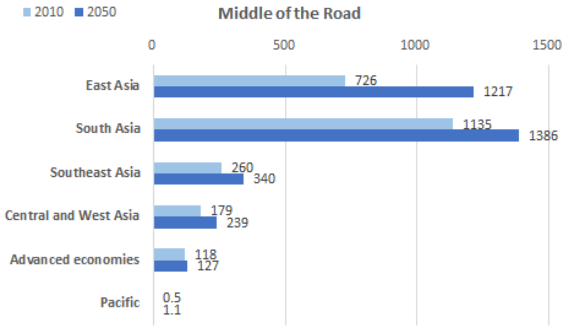

Figure 3-10: Regional water demand in 2010s and 2050s [km^3/year]

Table 3-4: Ranking of total water demand (Country level, *Middle of the Road* scenario)

	Total water demand						**Increase rate**			
Rank	**2010**		**2030**		**2050**		**2030**		**2050**	
1	India	764	China	1086	China	1214	Georgia	106%	Mongolia	174%
2	China	725	India	882	India	965	Singapore	93%	Singapore	172%
3	Pakistan	304	Pakistan	309	Pakistan	332	Mongolia	90%	Georgia	170%
4	Indonesia	74	Indonesia	95	Indonesia	103	Papua New Guinea	59%	Papua New Guinea	157%
5	Thailand	67	Thailand	75	Thailand	82	China	50%	Solomon Islands	105%
6	Japan	60	Uzbekistan	64	Uzbekistan	71	Fiji	49%	Fiji	103%
7	Uzbekistan	53	Viet Nam	61	Viet Nam	66	Samoa	49%	China	68%
8	Viet Nam	52	Japan	57	Bangladesh	65	Tonga	47%	Bhutan	65%
9	Bangladesh	49	Bangladesh	56	Japan	56	Solomon Islands	45%	LPDR	61%
10	Afghanistan	37	Afghanistan	41	Afghanistan	45	Armenia	40%	Armenia	60%

[km^3/year]

Table 3-3 provides a time series of each region's total water demand for the *Middle of the Road* scenario. Total water demand includes industrial, domestic, and agricultural water demands. Asian total water demand is 2418 km^3/year in the 2010s. South Asia is the largest water consumer (47%), followed by East Asia (30%). Fig. 3-10 shows that water demand will increase in all Asian regions by 31 to 43% by 2050, for a total demand of 3167 to 3459 km^3/year. The increase in rate of water demand growth will be greatest in East Asia. In East and South Asia the biggest growth in water demand will take place in the 2030s-2050s, while other regions' water demands will increase more during the 2010s-2030s. The timing of this rapid growth is important.

A more detailed explanation of sector and country level water demand is presented in section 3.3.

This assessment did not specifically investigate water quality issues. But crop area expansion and increased crop production necessitates increased fertilizer use. This, in addition to increased water demand from the domestic and industrial sectors, might adversely impact water quality if no countermeasures are taken into account. In a subsequent second phase, this would, hopefully be investigated in a bit more detail.

Water demand change by sector

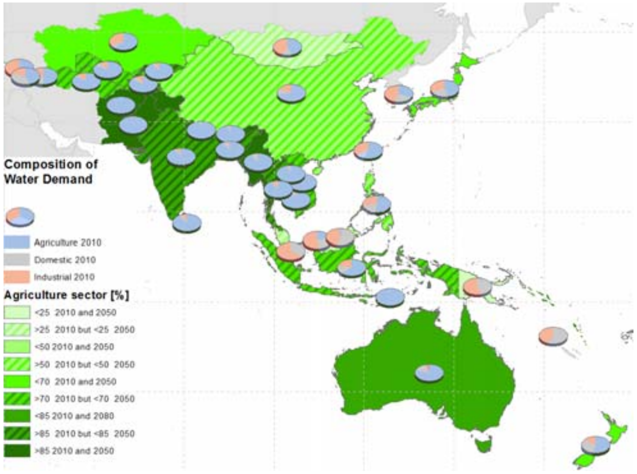

Figure 3-11: Composition of water demand by sector in 2010 and declining of the agricultural component till 2050

It is essential that Asian water assessments consider the share that each different sector has on total water demand, as each sector's contribution varies by country and it will change in the future. Fig. 3-11 presents the composition rate of water demand among the three different sectors and the decreasing share of the agriculture sector through to 2050. In countries (illustrated with stripes), the share of agricultural water demand will decrease due to growth of the other two sectors. Even for the largest water- consuming countries, India and China, it is expected that share of agricultural water demand will decline. Sector-specific water demands at the regional level are presented in Fig. 3-12. Table 3-5 provides the temporal evolution of each water demand. These projections show that water demand will increase in each region and every sector until the 2050s. Table 3-6 introduces a national ranking of water demand and increase rate in Asia and countries' demand. In the 2050s, under the *Middle of the Road* scenario, all regions except Advanced Economies and Pacific Asia will see a large growth in the industrial and domestic sectors, with East Asia having the most growth. The agricultural sector will increase in all region by 3-5%.

Agricultural sector

Regional: This study estimates that Asia's agricultural water demand in the 2010s is 1939 km^3/year, and will increase by +5.4% in the 2050s. South Asia is the biggest water consumer in Asia, and South Asia will keep its top rank in the future, with both the highest absolute amount and the highest rate of change (Fig. 3-11). The demands are approximately two to three times those of East Asia and five times those of Southeast Asia, depending on the scenario.

National: The ranking of large water consumer countries remains almost the same in the future, as shown in Table 3-6. India, China, and Pakistan show an order of magnitude greater agricultural water requirements than others due to their large irrigation area, with Indian agricultural water demand the largest. A ranking of countries by the rate of change in demand, however, gives another perspective. The ranking of countries by their rate of change fluctuates considerably more. This fluctuation stems primarily from the influence of projected decadal or longer climate variability. Though the variability could shift several years, according to this projection, for example, irrigation water demand in Pakistan in the 2030s is 1.1% less compared with the 2010s but it will be 4.7% more in the 2050s. Another noteworthy feature here is that India and China, which originally had larger water demands, will remain highly ranked in rate of change.

Considering Asia as a whole, the agricultural sector is responsible for 80% of total water demand in the 2010s. But there are some countries where industrial and domestic sectors account for a larger share than the agricultural sector in terms of water demand, such as Republic of Korea, Georgia, and Armenia (Fig. 3-11).

Regarding the rate of growth, industrial and domestic water demand are much larger than that of agriculture. In our estimation, the share of total water demand of these two sectors together will increase from 20% (in the 2010s) to 38% (in the 2050s) under the *Middle of the Road* scenario. In the cases of both industrial and domestic water demand, East Asia requires the most water although this region does not have the highest agricultural demand.

Table 3-5: Regional water demand of three sectors [km^3/year]

(a) Agricultural water demand

[km^3/year]	Middle of the Road			Change Rate	
	2010	2030	2050	2030	2050
East Asia	513	519	543	1.1%	5.7%
South Asia	1038	1051	1099	1.2%	5.8%
Southeast Asia	190	192	194	1.4%	2.4%
Central and West Asia	140	145	148	3.7%	5.3%
Advanced economies	58	59	61	1.8%	4.2%
Pacific	0.1	0.1	0.1	2.1%	7.2%
Asian Total	1939	1967	2044	1.4%	5.4%

(b) Industrial water demand

[km^3/year]	Middle of the Road			Change Rate	
	2010	2030	2050	2030	2050
East Asia	145	373	443	157%	205%
South Asia	45	91	121	104%	172%
Southeast Asia	41	56	72	35%	76%
Central and West Asia	28	52	60	88%	116%
Advanced economies	32	37	36	16%	13%
Pacific	0.2	0.3	0.4	34%	83%
Asian Total	291	610	734	109%	152%

(c) Domestic water demand

[km^3/year]	Middle of the Road			Change Rate	
	2010	2030	2050	2030	2050
East Asia	67	196	231	191%	243%
South Asia	52	125	166	141%	220%
Southeast Asia	29	60	74	105%	153%
Central and West Asia	11	22	31	96%	175%
Advanced economies	28	30	30	7%	6%
Pacific	0.2	0.3	0.5	99%	252%
Asian Total	188	433	532	131%	183%

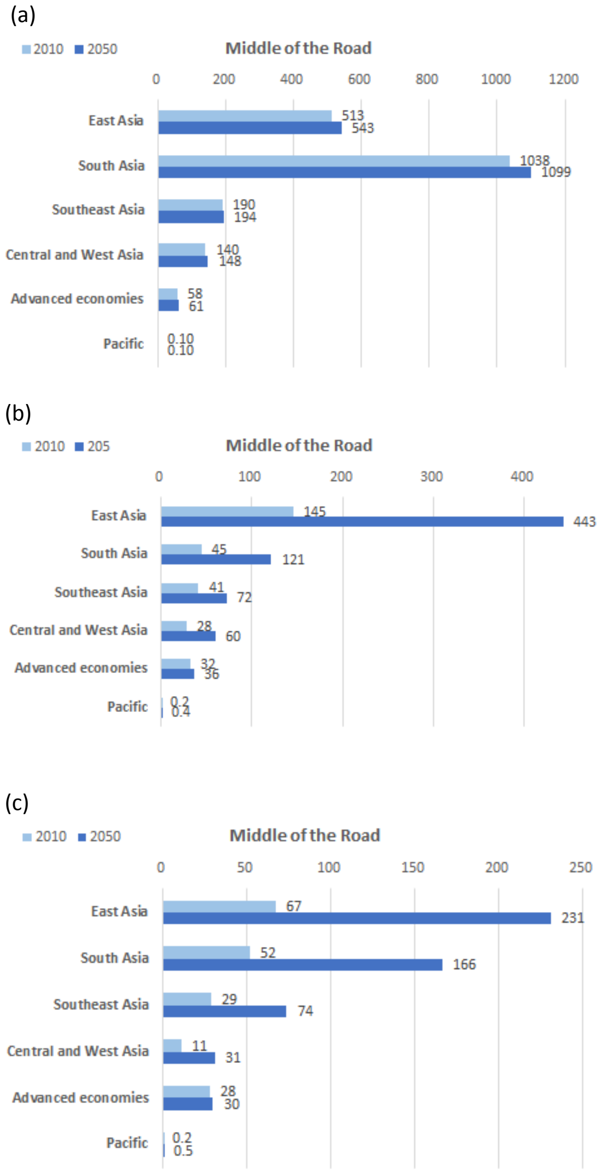

Figure 3-12: Regional water demand by sector [km^3/year]. (a) Agricultural, (b) industrial and (c) domestic water demand. Absolute value in 2050 and 2010, (*Middle of the Road* scenario)

Industrial sector

Regional: Industrial water demand is projected to increase in every region in Asia (Fig. 3-11), currently estimated at 291 km^3/year in the 2010s, and growing by to +152% in the 2050s. The growth of industrial water demand in East Asia and South Asia is estimated to be about +205% and +172%, respectively. While Southeast Asia has a larger absolute industrial water demand than Central and West Asia, growth rates in these latter regions will be higher.

Table 3-6: Ranking of water demand for each sector by country in 2050 (“*Middle of the Road*” scenario)

(a) Agricultural water demand

	Total water demand						Increase rate			
Rank	**2010**		**2030**		**2050**		**2030**		**2050**	
1	India	684	India	700	India	729	Georgia	13.8%	Georgia	19.6%
2	China	513	China	518	China	542	Armenia	8.5%	Armenia	14.1%
3	Pakistan	294	Pakistan	291	Pakistan	308	Azerbaijan	8.0%	Azerbaijan	9.6%
4	Thailand	59	Thailand	60	Thailand	61	Kazakhstan	5.4%	Timor-Leste	7.2%
5	Indonesia	48	Indonesia	49	Indonesia	50	Kyrgyzstan	4.5%	India	6.6%
6	Bangladesh	44	Uzbekistan	45	Uzbekistan	45	Mongolia	4.3%	Australia	6.6%
7	Uzbekistan	43	Bangladesh	44	Bangladesh	45	Tajikistan	4.0%	Kazakhstan	6.6%
8	Viet Nam	41	Viet Nam	41	Viet Nam	41	Uzbekistan	3.8%	Mongolia	6.1%
9	Afghanistan	37	Afghanistan	37	Afghanistan	38	Turkmenistan	3.2%	China	5.7%
10	Japan	27	Japan	27	Japan	28	Australia	3.0%	Kyrgyzstan	5.3%

[km^3/year]

(b) Industrial water demand

	Total water demand						Increase rate			
Rank	**2010**		**2030**		**2050**		**2030**		**2050**	
1	China	145	China	372	China	442	Bhutan	1032%	Bhutan	2140%
2	India	38	India	77	India	103	Afghanistan	510%	Nepal	1330%
3	Japan	18	Indonesia	19	Indonesia	25	Nepal	424%	Afghanistan	861%
4	Indonesia	17	Republic of Korea	16	Japan	16	LPDR	329%	LPDR	555%
5	Republic of Korea	11	Japan	16	Uzbekistan	16	Sri Lanka	207%	Cambodia	405%
6	Kazakhstan	8	Kazakhstan	15	Kazakhstan	16	Timor-Leste	175%	Sri Lanka	399%
7	Philippines	7	Uzbekistan	13	Thailand	15	Turkmenistan	167%	Timor-Leste	368%
8	Azerbaijan	6	Viet Nam	10	Republic of Korea	15	Georgia	158%	Bangladesh	330%
9	Uzbekistan	6	Thailand	10	Viet Nam	13	China	157%	Georgia	256%
10	Thailand	6	Turkmenistan	8	Turkmenistan	10	Mongolia	134%	Turkmenistan	230%

[km^3/year]

(c) Domestic water demand

	Total water demand						Increase rate			
Rank	**2010**		**2030**		**2050**		**2030**		**2050**	
1	China	67	China	196	China	230	Bhutan	426%	Solomon Islands	765%
2	India	42	India	105	India	133	LPDR	324%	Afghanistan	705%
3	Japan	15	Indonesia	27	Indonesia	29	Timor-Leste	262%	Bhutan	692%
4	Indonesia	10	Japan	14	Philippines	18	Solomon Islands	242%	LPDR	655%
5	Republic of Korea	7	Philippines	11	Pakistan	17	Mongolia	236%	Mongolia	586%
6	Viet Nam	6	Pakistan	10	Japan	13	Turkmenistan	216%	Cambodia	489%
7	Philippines	6	Viet Nam	10	Bangladesh	12	Afghanistan	205%	Nepal	487%
8	Pakistan	6	Republic of Korea	8	Viet Nam	12	Sri Lanka	192%	Turkmenistan	381%
9	Australia	5	Bangladesh	7	Uzbekistan	10	China	191%	Bangladesh	268%
10	Uzbekistan	3.8	Uzbekistan	7	Republic of Korea	8	Indonesia	169%	Papua New Guinea	266%

[km^3/year]

National: The results in Table 3-6 show substantial growth rates, indicating that industrial water demand will continue to rise in many Asian countries linked to their rapid growth. China requires and will keep requiring the largest quantities of industrial water resources. India is second and the rank order is unaltered in the future. Only Japan and Azerbaijan show reductions in demand.

Domestic sector

Regional: Similar to the other two sectors, domestic water demands will grow in each region and have the largest growth rate. Asia’s industrial water demand in the 2010s is estimated at 188 km^3/year, and to

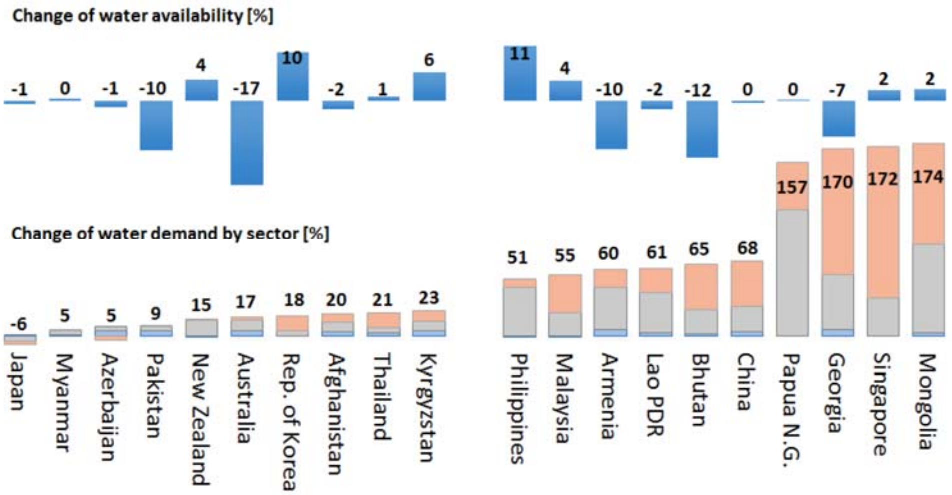

Figure 3-13: Percent change in water supply (top) and total water demand (bottom) (blue: agriculture; gray: domestic; red: industry) from 2010 to 2050 with greatest increasing and declining countries

grow by up to +183% in the 2050s. In five out of six regions, the growth is between 153%-252% for the same period. Domestic water demand in East Asia will be more than three times higher in the 2050s. Domestic water demands in Southeast Asia and Central and West Asia are almost equal to that of the Advanced Economies in the 2010s, but their water demand will surpass that of the Advanced Economies by the 2050s. This is because Advanced Economies' domestic water demand will peak in the 2040s and decline thereafter, while Southeast Asia and Central and West Asia show steady growth.

National: Domestic water demand is projected to increase in all Asian countries except Japan, and will more than double in 18 countries. China and India have the largest domestic water demands due to their larger populations with demand growth of +242% and +216% by the 2050s. Unlike in other countries, demand is not expected to grow in South Korea and domestic water demand will slowly decrease in Japan. The lower overall growths in the Advanced Economies are due to the demand contraction of Japan.

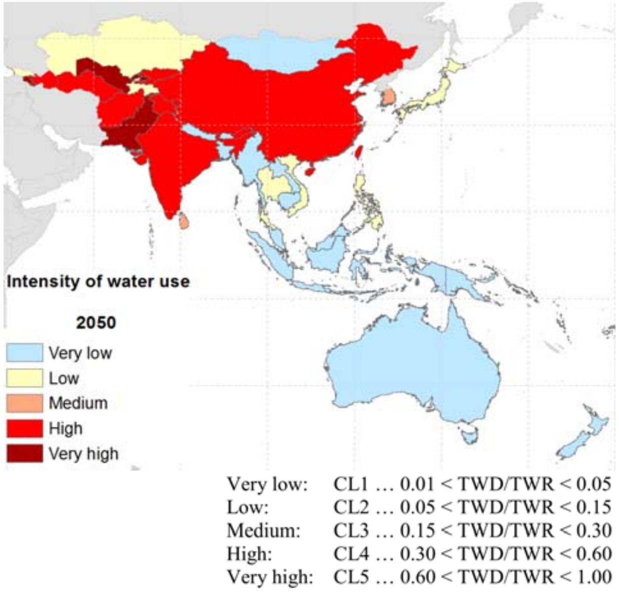

Figure 3-14: Quantifying "hydrological complexity" for hydro-economic classification: Intensity of water use – *Middle of the Road* Scenario

Fig. 3-13 sums up the development for the ten countries with the lowest and highest relative changes in water demand by the 2050s, compared with the percentage change in water supply. The highest changes in total water demand are in Mongolia, Singapore, Georgia, and Papua New Guinea due to their rapid socioeconomic growth, reflected by increasing industrial and domestic water demands.

The ratio of annual water demand to total renewable surface water resources is used as a proxy for the "intensity of water use." It is another indicator to assess the hydrologic complexity. This indicator for Pakistan, Uzbekistan, and Armenia is in the highest class (Fig. 3-14), indicating significant imbalance between water demand and supply.

3.5 Water supply

As described in this assessment, population change is a fundamental factor to be considered in the fair allocation of water resources, as finite water resources need to be shared. Through the WFaS initiative, both surface water and groundwater resources have been estimated. This analysis defines that surface water is composed of runoff within a region or country and inflow through river networks. The population dataset this study applies is based on Jones and O'Neill (2013), which downscaled and gridded the Shared Socioeconomic Pathways (SSPs) introduced earlier in this report.

3.5.1 Surface water resources availability

Asian total and regional aspects

First, we present an impact assessment of climate change at regional level, followed by a more local-scale discussion. Although a regional-scale analysis may ignore the heterogeneity of water resources and may conceal some local-scale water issue, this section focuses on regional aspects, a macroscopic perspective that also provides highly valuable insights that are worth considering. [17]

Fig. 3-15 presents a time series of the projected regional total surface water resources from 2010 to 2090, showing macroscopic behavior of future water availability in Asia. Note that these values are 10-year averages because projected climate variability differs among models. Available surface water resources are plotted with solid lines (km^3/year), while the lines with human symbols depict available surface water resources per capita [m^3/year/cap]. In interpreting these figures, note that changes in available surface water resources reflect the impacts of climate change, while changes in available surface water resources per capita reflect the impacts of both climate and population change.

Total available surface water resources

For available surface water resources, long-term changes can be identified within limits of uncertainty, particularly around decadal variability.

In the long term, most regions show trends of increasing surface water resource availability under the applied scenarios, while only Central and West Asia and Advanced Economies show decreasing trends under the *Middle of the Road* and the *Regional Rivalry* scenarios. Under the *Sustainability* scenario, four out of six regions (South Asia, East Asia, Southeast Asia, Advanced Economies) show increases in surface water resource availability in the 2050s compared with the present. Three of the same six regions (East

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[17] Note that the water future scenario of WFaS applies two climate scenarios, the *Middle of the Road* scenario and the *Regional Rivalry* scenario, both of which use same climate scenario. A climate scenario used for these two scenarios has greater climate change impacts than that in the *Sustainability* scenario.

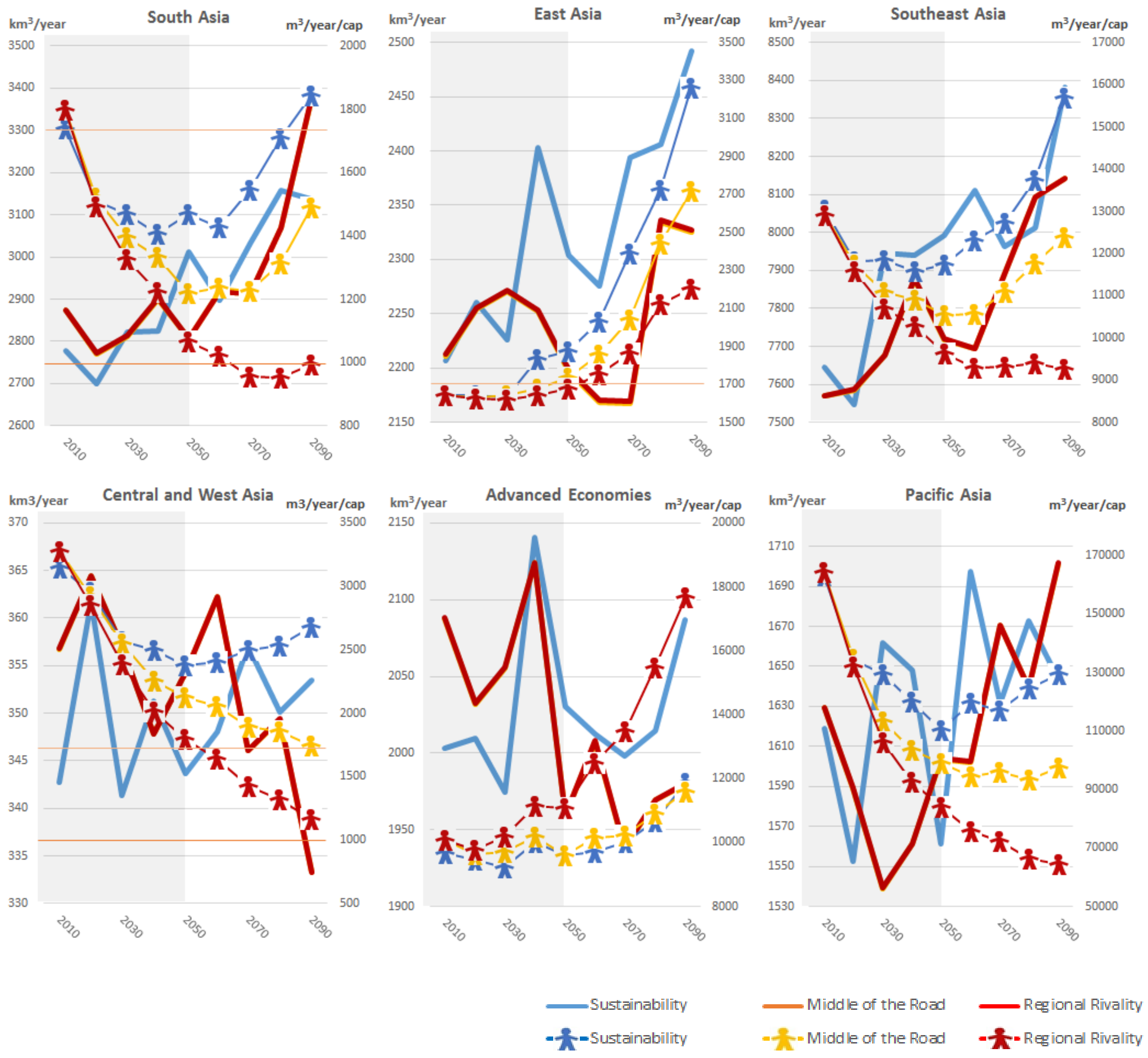


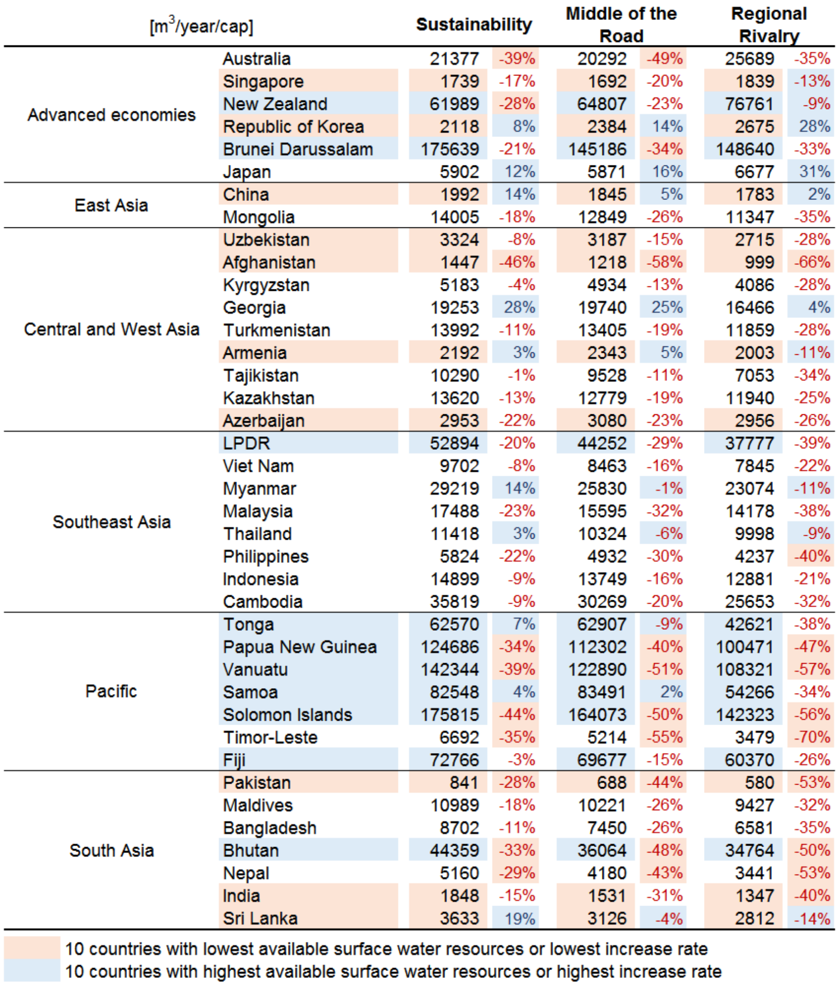
Figure 3-15: Total available surface water resources [km³/year] and available surface water per capita [m³/year/cap] at regional scale. Orange colored horizontal lines are threshold of Falkenmark indicator; No stress [>1700 m³/yr/cap], stress [1000-1700 m³/yr/cap], scarcity [500-1000 m³/yr/cap] and absolute scarcity [<500 m³/yr/cap]

Asia, Southeast Asia, Advanced Economies) indicate an increased total surface water availability under the *Middle of the Road* and the *Regional Rivalry* scenarios.

Available surface water resources per capita

The three scenarios indicate that available surface water resources per capita will decrease significantly in four out of six regions (South Asia, Southeast Asia, Central and West Asia, and Pacific Asia) during the first half of the 21st century. For instance, available surface water resources per capita decreases by almost half up to the 2050s under the *Regional Rivalry* scenario in these regions. Under the *Regional Rivalry* scenario and in Central and West Asia under the *Middle of the Road* scenario, per capita availability continues to decrease into the second half of the 21st century. However, under the *Sustainability* scenario

Table 3-7: Ranking of available surface water by country in the 2050s



[m^3/year/cap]		Sustainability		Middle of the Road		Regional Rivalry	
Advanced economies	Australia	21377	-39%	20292	-49%	25689	-35%
	Singapore	1739	-17%	1692	-20%	1839	-13%
	New Zealand	61989	-28%	64807	-23%	76761	-9%
	Republic of Korea	2118	8%	2384	14%	2675	28%
	Brunei Darussalam	175639	-21%	145186	-34%	148640	-33%
	Japan	5902	12%	5871	16%	6677	31%
East Asia	China	1992	14%	1845	5%	1783	2%
	Mongolia	14005	-18%	12849	-26%	11347	-35%
Central and West Asia	Uzbekistan	3324	-8%	3187	-15%	2715	-28%
	Afghanistan	1447	-46%	1218	-58%	999	-66%
	Kyrgyzstan	5183	-4%	4934	-13%	4086	-28%
	Georgia	19253	28%	19740	25%	16466	4%
	Turkmenistan	13992	-11%	13405	-19%	11859	-28%
	Armenia	2192	3%	2343	5%	2003	-11%
	Tajikistan	10290	-1%	9528	-11%	7053	-34%
	Kazakhstan	13620	-13%	12779	-19%	11940	-25%
	Azerbaijan	2953	-22%	3080	-23%	2956	-26%
Southeast Asia	LPDR	52894	-20%	44252	-29%	37777	-39%
	Viet Nam	9702	-8%	8463	-16%	7845	-22%
	Myanmar	29219	14%	25830	-1%	23074	-11%
	Malaysia	17488	-23%	15595	-32%	14178	-38%
	Thailand	11418	3%	10324	-6%	9998	-9%
	Philippines	5824	-22%	4932	-30%	4237	-40%
	Indonesia	14899	-9%	13749	-16%	12881	-21%
	Cambodia	35819	-9%	30269	-20%	25653	-32%
Pacific	Tonga	62570	7%	62907	-9%	42621	-38%
	Papua New Guinea	124686	-34%	112302	-40%	100471	-47%
	Vanuatu	142344	-39%	122890	-51%	108321	-57%
	Samoa	82548	4%	83491	2%	54266	-34%
	Solomon Islands	175815	-44%	164073	-50%	142323	-56%
	Timor-Leste	6692	-35%	5214	-55%	3479	-70%
	Fiji	72766	-3%	69677	-15%	60370	-26%
South Asia	Pakistan	841	-28%	688	-44%	580	-53%
	Maldives	10989	-18%	10221	-26%	9427	-32%
	Bangladesh	8702	-11%	7450	-26%	6581	-35%
	Bhutan	44359	-33%	36064	-48%	34764	-50%
	Nepal	5160	-29%	4180	-43%	3441	-53%
	India	1848	-15%	1531	-31%	1347	-40%
	Sri Lanka	3633	19%	3126	-4%	2812	-14%

🟥 10 countries with lowest available surface water resources or lowest increase rate
🟦 10 countries with highest available surface water resources or highest increase rate

in South Asia and under the *Middle of the Road* scenario in Southeast Asia, the trend of decreasing per capita surface water resources reverses to a trend of rising availability in the second half of the 21st century. Thus these regions will experience the least per capita water resources around middle of the 21st century. As a result, it is likely that the water futures of these four regions worsen toward the 2050s, compared to the present situation. Conversely, in East Asia and Advanced Economies there is a trend of growing per capita surface water resources, albeit with a small reduction in the early stages of the 21st century. This is linked to expected reductions in population in these regions and relatively stable and improved water futures compared to the other regions mentioned above.

Available surface water resources per capita in East, South, Central, and West Asia is in general significantly less than other Asian sub-regions. These available surface water resources per capita are utilized for one of the most widely used measures of water stress, called "The Falkenmark Indicator" (Falkenmark 1989). Based on the per capita water availability, the water conditions in an area can be categorized as: no stress (> 1700 m^3/year/cap); stress (1000-1700 m^3/year/cap); scarcity (500-1000 m^3/year/cap); and absolute scarcity (< 500 m^3/year/cap). Although the Falkenmark indicator at regional or country level may conceal smaller scale water scarcity, it can be a good proxy to obtain an insight about impact of population growth on water security. According to the definition of the Falkenmark Indicator, East Asia is categorized into "stress" in the first half of the 21st century under all three scenarios. However, available surface water resources per capita of this region are projected to increase, mainly due to falling population (see Fig. 3-1), changing this regions to "no stress" by around middle of the 21st century in all scenarios. Under the *Sustainability* scenario, East Asia will move into "no stress" by the 2040s. In contrast, South Asia is categorized as "no stress" in the 2010s but, as the available surface water resources per capita decrease in this region, it will move into the "stress" category during the 2020s-2060s under all scenarios. Furthermore, worsening conditions in South Asia will move it into "scarcity" category in second half of the 21st century under the *Regional Rivalry* scenario. Although available surface water resources per capita in Central and West Asia are classified as under "no stress" in every scenario applied during the first half of the 21st century, under worsening conditions it will move into "stress" under the *Regional Rivalry* scenario in the second half of 21st century. It is worth mentioning that these transition timing changes in trend as well as timings from one category to another, suggest important periods for decision making in every aspect of water management.

Differences between available surface water resources and available surface water resources per capita in each figure show the impacts of population change. Fig. 3-15 presents some examples of opposing trends between available surface water resources and available surface water resources per capita. For instance, South Asia shows an increasing trend in available surface water resources but a decreasing trend in available surface water resources per capita under every scenario because of a significant population growth. Thus it is assumed that socioeconomic change, like population, is vitally important for the water resources assessment.

Country level aspects

Table 3-7 presents available surface water resources per capita for the 2050s at country level and the ratio of change (change compared with 2010s divided by amount in 2010s) for each scenario (a decrease in change rate is marked in red). The table shows that, compared with the 2010s, out of 39 countries, available surface water resources per capita will be lower in 29 countries in the 2050s under the *Sustainability* scenario, 33 countries under the *Middle of the Road* scenario, and 35 countries under the *Regional Rivalry* scenario.

Ranking countries by per capita surface water availability results in a few changes among the scenarios. The red and blue marker (Table 3-7) indicates the top 10 countries with the lowest and highest surface water resources per capita and their rate of increase. In particular, Pakistan, Afghanistan, India, Singapore, and China tend to have the least surface water resources per person. The Falkenmark Indicator categorizes Pakistan as under "water scarcity" in all three scenarios. Afghanistan is categorized as under either "water scarcity" or "stress" in all three scenarios. Afghanistan also shows an ever-decreasing trend through all scenarios. India is categorized in "stress" in two scenarios. Analysis reveals that these reductions in per capita surface water resources are largely due to population growth because the total water resources are not expected to change significantly.

The detailed time series of available surface water resources per capita for each country is presented in Appendix D. As mentioned in the description on the regional results above, periods of inflection from a decreasing to an increasing trend are of importance here as well. Though there are discrepancies among scenarios for each country, these provide information on possible developments in those countries' water future. In conclusion, water stress and scarcity tends to increase in areas where surface water resources

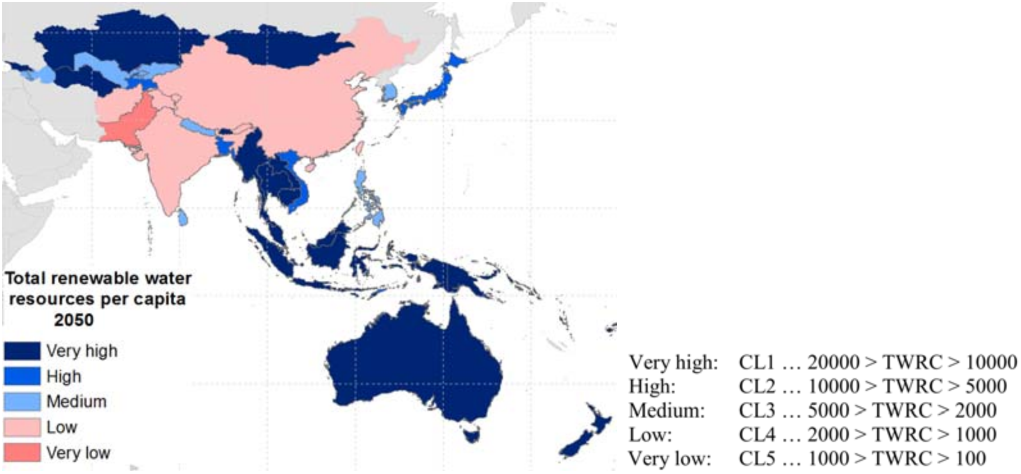


Figure 3-16: Quantifying "hydrological complexity" for hydro-economic classification: Total renewable surface water resources per capita – *Middle of the Road* scenario

per capita are already lacking, as shown by the decreasing availability of per capita surface water resources in Table 3-7. This is partly due to the reduction of total surface water resources as a result of climate change, yet predominantly driven by population growth.

Another country-level analysis is presented here, as mentioned in Section 2.3. To express the hydrologic complexity for the hydro-economic classification, four indicators of water challenge are used. "*Total renewable water resources per capita"* (in m^3/year/cap) is used as a measure for water availability for the first indicator and shown in Fig 3-16 for the case of the *Middle of the Road* scenario. Very low levels of 100-1000 m^3/cap/year mean an extreme low availability of water resources per capita. Pakistan is categorized under the lowest level. China, Afghanistan, and India are categorized under low level between 1000-2000 m^3/cap/year. By the 2030s, it is expected that Pakistan will shift from a low to a very low level and Afghanistan will move from medium to low level. India will shift from medium to low level in the 2020s. It worth mentioning that this indicator looks neither at seasonal effects of total renewable water resources (e.g., dry seasons) nor at regional variability within countries (e.g., China, Australia), while another applied indicator '*surface water variability'* does include seasonal variability.

Sub-country Considerations

The finer spatial distribution of population, the available surface water resources and available surface water resources per capita should also be taken into consideration because these variables have large heterogeneity within countries. Fig. 3-17 (1) displays the mean value during the 2010s and (2-4) display the changes between the 2010s and 2050s under three scenarios, though available surface water resources has yearly-decadal variability. Fig. 3-17 suggests that there are a very large number of areas where surface water resources per capita will decline at sub-national or local level. It must be noted that macro-scale water resources assessment at national or larger scales can overlook critical smaller-scale changes. For example, although Table 3-7 clearly shows that China's per capita surface water resources will increase by 2050 and China is classified "no stress" under every scenario at country level. Fig. 3-17 indicates that there are many areas where the water situation will be worse, in particular, around highly

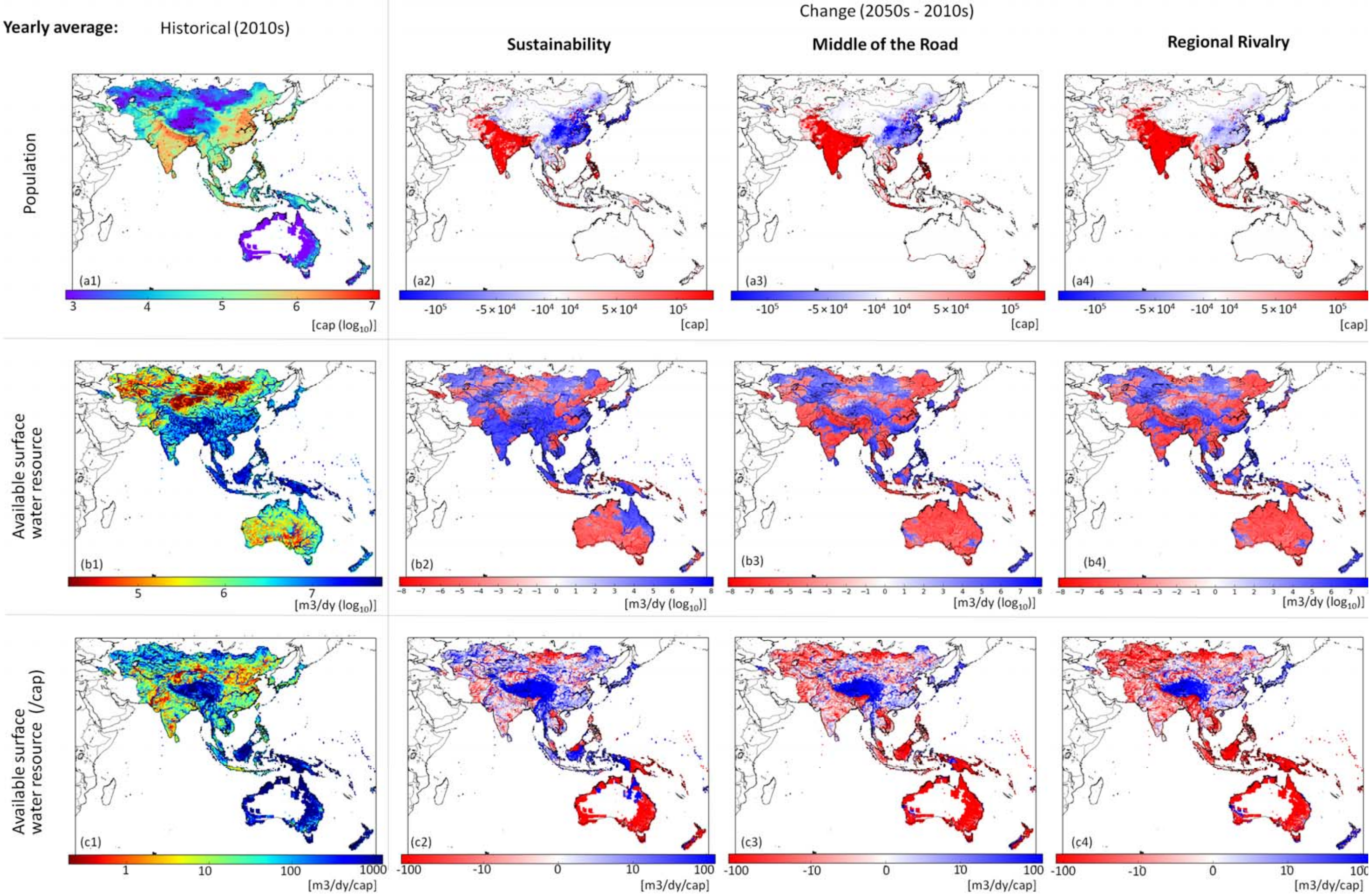


Figure 3-17: Population [cap] (Upper) ,yearly available surface water resource [m^3/day] (Middle) , yearly available surface water resource per capita [m^3/day/cap] (Lower). Left column is historical value (the 2010s) and others are difference between the 2050s and the 2010s for each global change scenarios.

[m3/year/cap] is used for the Falkenmark index but this map utilizes [m3/day/cap] because we discuss not only yearly average but also dry periods during the year in Fig3-17;

(no stress [> 4.66 m^3/day/cap], stress [2.74-4.66 m^3/day/cap], scarcity [1.34-2.74 m^3/day/cap] and absolute scarcity [< 1.34 m^3/day/cap])

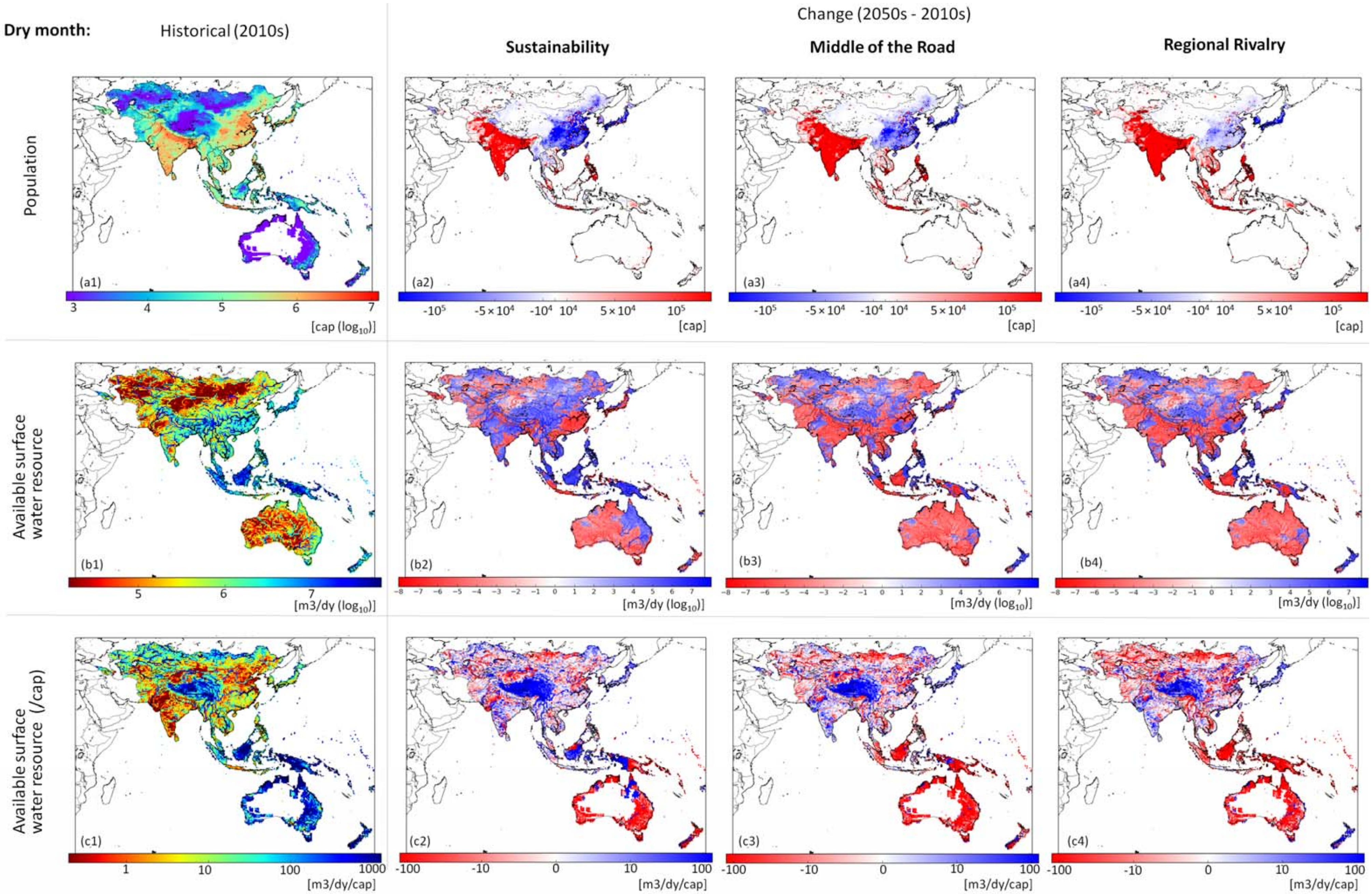


Figure 3-18: Population [cap] (Upper) , available surface water resource [m^3/day] (Middle) , available surface water resource per capita [m^3/day/cap] (Lower) about the driest month.
(the Falkenmark index: no stress [> 4.66 m^3/day/cap], stress [2.74-4.66 m^3/day/cap], scarcity [1.34-2.74 m^3/day/cap] and absolute scarcity [< 1.34 m^3/day/cap])

populated areas. As available surface water resources per capita have high spatial variability, regions with lower available surface water resources per capita are subsequently scattered throughout the regions. As a result, in the 2010s comparatively large regions with low available surface water resources per capita can be found around northeastern and northwestern China, in the region from eastern Pakistan to northeastern India, southern India, eastern India along the Ganga River, and in the region from Turkmenistan to Uzbekistan. Furthermore, per capita surface water resources are lower in larger cities depicted as singular tiny red-orange dots in Fig. 3-17.

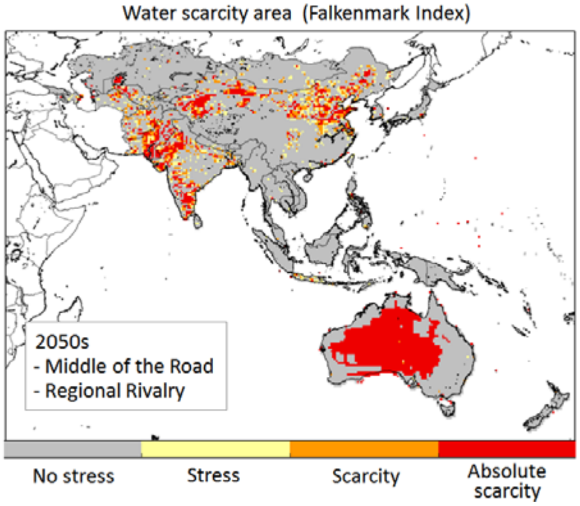


Figure 3-19: Water scarcity area (Falkenmark Index)

Fig. 3-19 illustrates the spatial distribution of water scarcity areas in the 2050s as scored by the Falkenmark Indicator. The above-mentioned regions are categorized under "absolute scarcity" and marked in red, though country and regional level analyses do not reveal these hotspots of water scarcity shown as "absolute scarcity." Among these regions, northeastern China, regions from eastern Pakistan to northern and southern India have large populations and relatively low available surface water resources, and are therefore the most water scarce areas in Asia. An area across Turkmenistan to Uzbekistan and northwestern China is hydrologically dry, while the population is relatively low. Eastern India along the Ganga River has abundant water resources but has less available surface water resources per capita due to high population density. Similarly, large cities tend to be water scarce due to their large populations even if they are not located in hydrologically dry areas. This indicates again that the balance between water resources and population is critical. Below, the key changes relevant to per capita surface water resources at sub-country scale are highlighted.

Population

Differences in population between the 2010s and the 2050s are illustrated in Fig 3-17 (a). South Asia and East Asia, which currently have quite high populations, both exhibit significant, yet opposing trends. Darker red (blue) indicates large increases (decreases) by more than 100,000 people within any particular area the scale of which is around 50km by 50km. India, eastern Pakistan, and large parts of Afghanistan, Bangladesh, and southern Nepal are expected to continue experiencing a significant population growth through all scenarios. In South Asia, large population increases are expected in the Philippines, Malaysia, Mongolia, Papua New Guinea, and Oceania in all scenarios. On the other hand, s are likely to decrease in large parts of eastern China, Japan, and the Republic of Korea. However, populations in metropolitan areas in China grow with continuing urbanization. Concentration of populations in larger cities is expected, which can lead to less surface water resources per capita. These changes, which are consistent among scenarios, can be considered as very likely. In contrast, there are regions such as Southeast Asia (Myanmar, Thailand, Vietnam, and Indonesia) and northern Pakistan in which population trends differ obviously depending on the scenario.

Annual available surface water resources

A comparison of the annual available surface water resources between the 2010s and the 2050s is presented in Fig. 3-17 (b). A consistent decrease among three scenarios are found in regions around Georgia, Azerbaijan and Armenia, regions around Kazakhstan, Turkmenistan and Uzbekistan, southern Pakistan, northern India, regions around east Kazakhstan, northern China and western Mongolia, eastern China, regions in Indochina, a part of Indonesia, and Australia. Most of the regions mentioned are currently arid or semi-arid regions and are likely to become even drier. The *Middle of the Road* and the *Regional Rivalry* scenarios indicate significantly decreasing available surface water resources over Asia as compared to the *Sustainability* scenario. In the *Middle of the Road* and the *Regional Rivalry* scenarios, Afghanistan, the central part of Pakistan, central, southern, and northeastern India, Nepal, Bhutan, eastern China (Nanjin etc.), central Japan, and northeastern Australia are also expected to become drier in the 2050s.

Annual available surface water resources per capita

A change in available surface water resources per capita that can be explained by a combination of changes in population and available surface water resources is presented in Fig. 3-17 (c). In all scenarios, available surface water resources per capita will significantly decrease in a region over the western part of Turkmenistan, Uzbekistan, and Kazakhstan, a region from Afghanistan to the southern part of Pakistan, central eastern India, Lao PDR, western Mongolia, Malaysia, the Philippines, and parts of central eastern China. Japan and Korea show consistent increases, primarily because of declining populations, toward the 2050s. Considering the Falkenmark Indicator, an almost similar spatial distribution can be observed, but an expansion of the “scarcity” category in a region from Afghanistan to a part of Pakistan is also notable.

In the driest month

Asia has clear seasonal variability and the need to respond to drier periods of the year. Fig. 3-18 is similar to Fig. 3-17 but presents data for the driest month (minimum of the average of each month in a 10- year time series) in order to assess seasonal variation. Even though this analysis considers terrestrial water storage that can mitigate seasonal variability, such as snowpack, base flow, and reservoirs, it is evident that there is a larger extent of dry areas in Fig. 3-17. Future work on options will have to cope with seasonal water shortage by well-designed storage management

In the *Regional Rivalry* scenario (Fig. 3-17 [b]), the red color indicates regions where the driest month will likely become drier, indicating that drought will be an increasing concern. In dry months, spatial distributions of change are more scattered than those of the annual averages. Figure 3.16 shows, (compared to the annual changes in per capita water resource availability which are widespread), changes in per capita availability are more heterogeneous when the dry months are considered. However, in some small areas within river basins, such as in Afghanistan and Pakistan, large parts of Central and western Asia, central-east India, parts of China and Vietnam, western Mongolia, Indonesia, and Australia, available surface water resources in the driest month are consistently expected to decrease in all three scenarios.

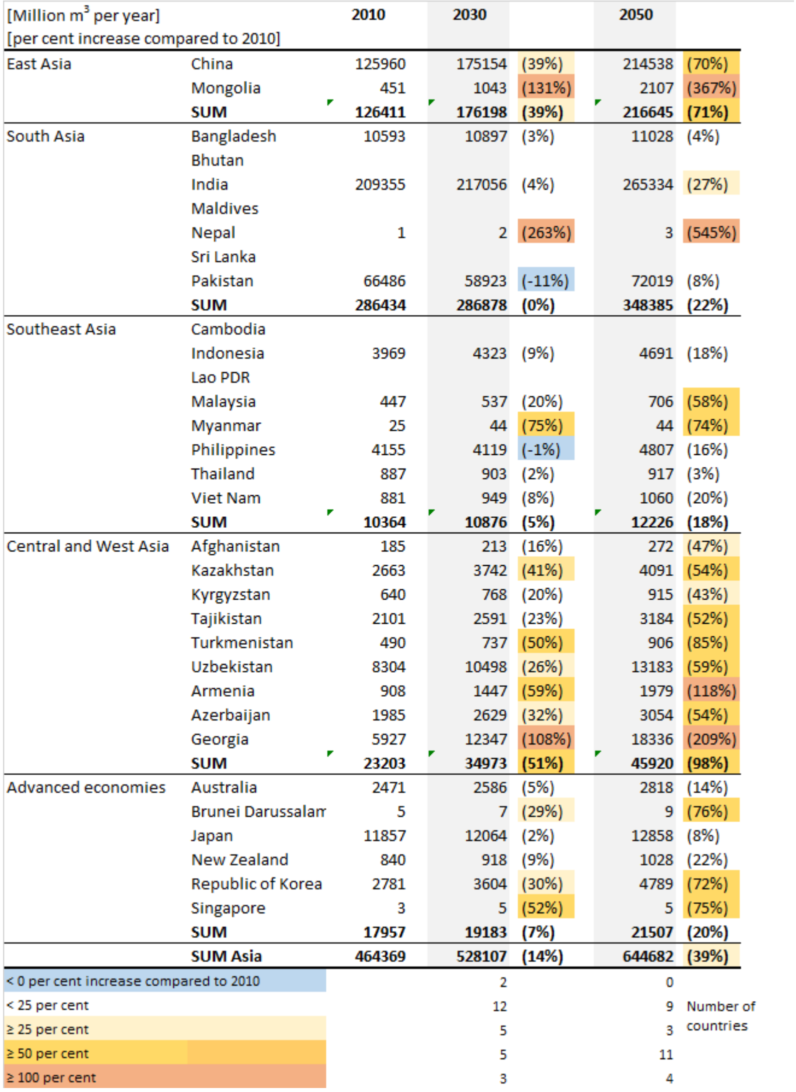
3.5.2 Groundwater use

When surface water is insufficient to satisfy demands during the dry seasons and dry years, groundwater serves as the main alternative source of water for irrigation. Globally, irrigated agriculture is the largest abstractor and predominant consumer of groundwater resources. Groundwater resources supply one-third of the world's irrigated area, and approximately 60% of them are in Asia (Siebert et al., 2010).

Of the three WFaS global hydrological models, only PCR-GLOBWB can project groundwater abstraction. An example of the case for the *Middle of the Road* scenario is presented here.

Table 3-8 presents country-level groundwater abstraction (million m^3 per year) and its changes in 2030 and 2050. Results indicate that groundwater abstractions in Asia in the 2010s amount to 464 km^3/year. The largest groundwater abstractions take place in India, China, and Pakistan, followed by Japan, Bangladesh, Uzbekistan, and Georgia. Abstractions in these countries represent 86% of the total abstraction in Asia.

Table 3-8**:** Country-level characteristics of ground water abstraction
(*Middle of the Road* scenarios)



[Million m^3 per year] [per cent increase compared to 2010]		**2010**	**2030**		**2050**	
East Asia	China	125960	175154	(39%)	214538	(70%)
	Mongolia	451	1043	(131%)	2107	(367%)
	SUM	**126411**	**176198**	**(39%)**	**216645**	**(71%)**
South Asia	Bangladesh	10593	10897	(3%)	11028	(4%)
	Bhutan					
	India	209355	217056	(4%)	265334	(27%)
	Maldives					
	Nepal	1	2	(263%)	3	(545%)
	Sri Lanka					
	Pakistan	66486	58923	(-11%)	72019	(8%)
	SUM	**286434**	**286878**	**(0%)**	**348385**	**(22%)**
Southeast Asia	Cambodia					
	Indonesia	3969	4323	(9%)	4691	(18%)
	Lao PDR					
	Malaysia	447	537	(20%)	706	(58%)
	Myanmar	25	44	(75%)	44	(74%)
	Philippines	4155	4119	(-1%)	4807	(16%)
	Thailand	887	903	(2%)	917	(3%)
	Viet Nam	881	949	(8%)	1060	(20%)
	SUM	**10364**	**10876**	**(5%)**	**12226**	**(18%)**
Central and West Asia	Afghanistan	185	213	(16%)	272	(47%)
	Kazakhstan	2663	3742	(41%)	4091	(54%)
	Kyrgyzstan	640	768	(20%)	915	(43%)
	Tajikistan	2101	2591	(23%)	3184	(52%)
	Turkmenistan	490	737	(50%)	906	(85%)
	Uzbekistan	8304	10498	(26%)	13183	(59%)
	Armenia	908	1447	(59%)	1979	(118%)
	Azerbaijan	1985	2629	(32%)	3054	(54%)
	Georgia	5927	12347	(108%)	18336	(209%)
	SUM	**23203**	**34973**	**(51%)**	**45920**	**(98%)**
Advanced economies	Australia	2471	2586	(5%)	2818	(14%)
	Brunei Darussalam	5	7	(29%)	9	(76%)
	Japan	11857	12064	(2%)	12858	(8%)
	New Zealand	840	918	(9%)	1028	(22%)
	Republic of Korea	2781	3604	(30%)	4789	(72%)
	Singapore	3	5	(52%)	5	(75%)
	SUM	**17957**	**19183**	**(7%)**	**21507**	**(20%)**
	SUM Asia	**464369**	**528107**	**(14%)**	**644682**	**(39%)**
< 0 per cent increase compared to 2010			2		0	
< 25 per cent			12		9	Number of countries
≥ 25 per cent			5		3	
≥ 50 per cent			5		11	
≥ 100 per cent			3		4	

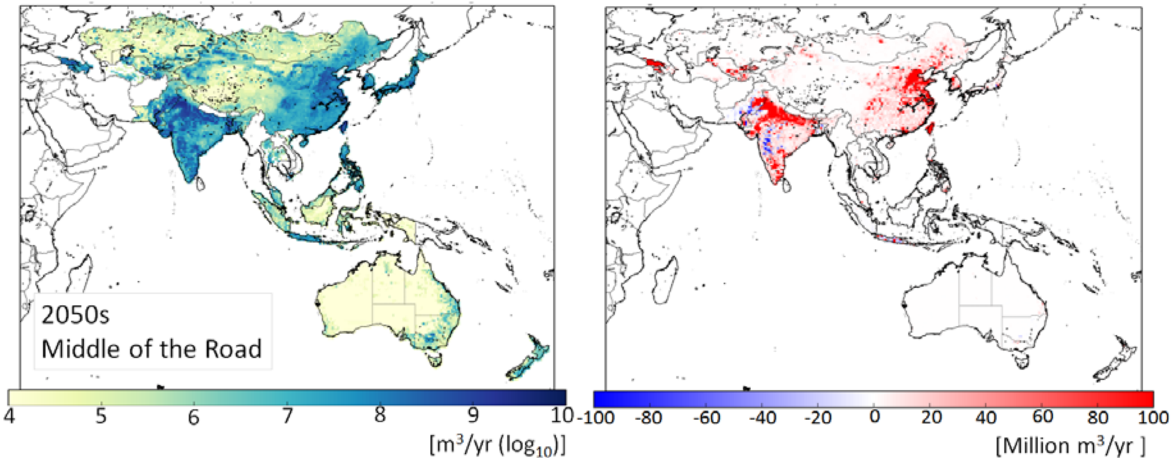


Figure 3-20: Groundwater abstraction in 2050s (left) and its increase compared with 2010s (right).

Fig. 3-20 shows the spatial distribution of groundwater abstraction in the 2050s and its increase compared to the 2010s. In the 2050s, all countries show an increase in groundwater abstraction in combination with an increase in water demand. In total, 645 km^3/year of groundwater will be used in Asia, an increase of 39% compared to 2010.[18] India, China, and Pakistan will remain the top three consumers of groundwater in the 2050s. Total abstraction in these three countries will be 545 km^3/year. The increase in groundwater use is also considerable in Georgia, Uzbekistan, and Republic of Korea. The change in countries such as Nepal, Mongolia, and Armenia will be insignificant.

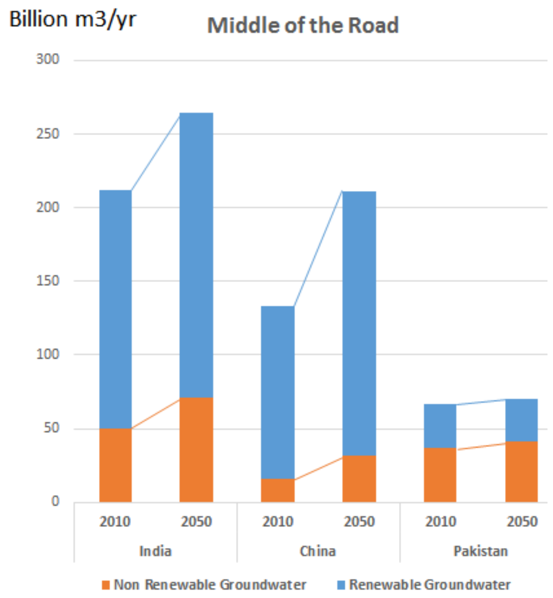


Figure 3-21: Groundwater abstraction in India, China and Pakistan

Recently, many studies have identified rapid aquifer depletion in many regions across the world, due to over-exploitation (i.e., abstraction exceeding recharge). Over-exploitation leads to a number of problems, such as shallow wells running dry, pumping costs increasing, wetlands drying out, reductions in stream and river flows, and increases in contamination. Furthermore, over-exploitation leads to aquifer compaction, resulting in permanent loss of storage capacity. Because groundwater depletion occurs when abstraction exceeds recharge, nonrenewable groundwater, that is, over-exploitation, is calculated as the difference between recharge and abstraction. Fig. 3-21 shows groundwater in India, China, and Pakistan, with the orange-colored portion indicating groundwater. Respectively, 24%, 12%, and 55% of their groundwater abstractions are nonrenewable in the 2010s. Although the absolute amount of groundwater abstractions in Pakistan is the smallest, the proportion

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[18] Note that this projection also assumes constant irrigation area at year 2000 in the future. It is considered that groundwater demand may be larger due to expansion of irrigation area.

of its nonrenewable groundwater component is the most predominant. Besides these three countries, the ratio of nonrenewable groundwater in total groundwater abstraction is high in Georgia, Armenia, and Uzbekistan. Asia, in particular South and East Asia, is the prominent groundwater consumer. From a sustainability viewpoint, it is clear that some Asian countries abstract too much groundwater. And it is expected that Asian groundwater use will increase further in the future. The estimates shown in Fig. 3-20 do not take into account the fact that groundwater depletion may reach critical points, where groundwater levels fall too steeply or readily available groundwater resources are exhausted in regions currently suffering from severe depletion. Thus, interpreting these findings, it is obvious that a decent understanding of the status of use and the purposes of different uses, clear policy guidance, and focused local actions are required to make better use of groundwater resources.

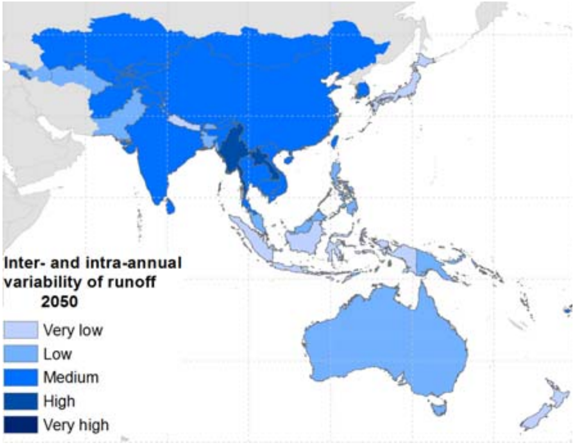
3.5.3 Variability of surface water resources

3.5.3.1 Inter- and intra-annual variability

Surface water resource variability, as a measure for inter- and intra-annual variability of runoff and inflow, is used as a second indicator to express the hydrologic complexity using five classes (see below and Fig. 3-22). For this indicator we used a 10-year time series of total monthly runoff averages across the participating hydrological models to calculate the respective coefficient of variation for each country. For the Asian monsoon regions with their strong seasonal variability, signals of yearly variability tend to be concealed by seasonal variability.

3.5.3.2 Water-related disasters

It is widely known that global warming is intensifying the hydrological cycle, resulting in longer dry periods and more intense precipitation (IPCC, 2012). Water disasters represent extreme variability, and disaster risks reduce water security. This section briefly introduces perspectives on future drought and flood in Asia. Both cases apply the most severe climate change scenario because



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

Figure 3-22: Quantifying "hydrological complexity" for hydro-economic classification: Inter- and intra annual variability of runoff – *Middle of the Road* scenario

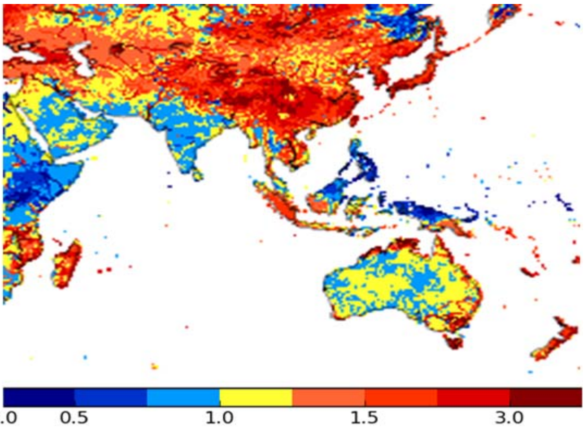


Figure 3-23: Impact of climate change on drought in Asia (Ratio of number of drought days per year. Blue: decreasing days of drought condition. Yellow-red: increasing days of drought condition. 1980-1999 vs 2080-2099)

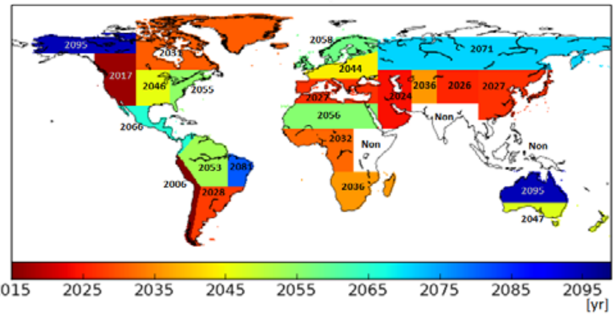


Figure 3-24: Timing at which regional averages of drought days deviate from historical experience range

using the most extreme condition helps to detect and assess water disasters trends and connections.

Hydrological drought

Fig. 3-23 shows the ratio of the number of days of drought per year in the last 20 years of the 20th and 21st centuries (Satoh et al., 2015). If the ratio is more than 1.0 in a grid, the number of drought days is increasing. The 20th percentile climatological drought in the historical base period (1980-1999) was applied as the threshold of drought detection. Drought will be more severe over most of Asia except India, a southern part of Pakistan, Philippines, and parts of Australia. There are some regions in which the number of days of drought will double. Furthermore, the timing at which future drought deviates from the historical range and never returns within a timespan to 2100, was estimated. This point indicates the time left to prepare for a new regime of unprecedented drought (Fig. 3-23). Overall, Central and West Asia, East Asia, and southern Australia will cross these thresholds during first half of the 21st century. As the time left for these regions to prepare for long-term change is short, strategic planning and prompt action are required.

Flood

Fig. 3-25 presents the flood return period in the 21st century for discharge corresponding to the 20th century's one-in-100-year flood (Hirabayashi et al. 2013). An ensemble of projections demonstrates a large increase in flood frequency in Southeast Asia and Peninsular India. This means that severe flood is occurring more often than ever before. For example, near Madras, India (dark-blue color in Fig. 3-25) a flood with the probability of occurrence of 0.01 per year in the 20th century will have a probability of occurrence of 0.2 per year in the 21st century. This study investigated specifically large basins including the Indus, Ganges, Brahmaputra, Mekong, Huanghe, Changjiang, and Murray-Darling River. In all of them, the ensemble projection indicates more severe floods to be expected in the future. Particularly, the so-called 100-year flood occurs more often than once in ten years in the Ganges, Brahmaputra, and Murray-Darling River.

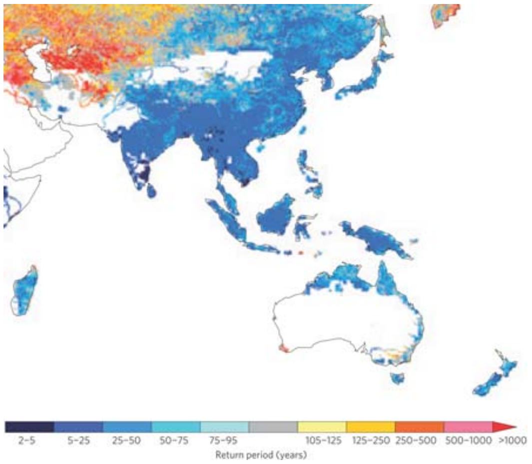


Figure 3-25: (a) Multi-model median return period in 21C for discharge corresponding to the 20C 100-year flood
Red: a 100-year flood will occur less often
Blue: a 100-year flood will occur more often

3.5.4 Transboundary dependency of water resources

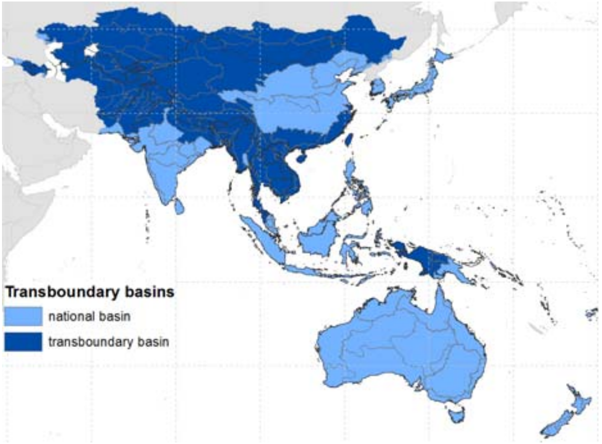


Figure 3-26: Transboundary basin in the Asia Pacific region

About 40% of the world's population lives in and around river and lake basins that comprise two or more countries, and over 90% lives in countries that share basins. These 263 transboundary lakes and river basins cover nearly one-half of the Earth's land surface and account for an estimated 60% of global freshwater flows (UN-Water, 2008). In the Asia Pacific region, 86 out of 191 basins (based on Global Runoff Data Centre 2004) are transboundary catchments. They account for 55% of the total basin area, with Australia, India, Indonesia and China contributing mainly to national basins (see Fig. 3-26). Of the total population in Asia of around 3.7 billion people (Jones and O'Neill 2013), 60% live in national basins.

Water dependency ratio

The water dependency ratio is defined by FAO (2010) as the proportion of renewable water resources that originate outside the border of a country and is therefore an indicator of the level to which a country depends on its neighbors for water resources. A country with a ratio of 100% receives all its renewable water from upstream countries.

In contrast to the historical ratio given by FAO AQUASTAT, here the indicator was calculated using 5 different GCMs and 5 different GHMs as meteorological forcing, which also makes it possible to investigate projections to 2050. The water dependency ratio does not include groundwater use, possible allocation of water to downstream countries, or any water footprint calculation.

Fig. 3-27 shows the percentage of total renewable water resources originating from outside the country, clearly depicting three main areas of water dependency in Asia: Central Asia and Pakistan, Bangladesh, and the northern part of Southeast Asia. The main transboundary river basins in Asia are the Syr Darya, Amu Darya, Indus, the Ganges–Brahmaputra river system and the Mekong. Especially Turkmenistan (Amu Darya Basin) and Bangladesh (Ganges–Brahmaputra) are highly dependent on upstream riparian countries. The dependency ratio also does not change significantly between now and 2050.

The water dependency ratio does not take the total water demand into account. It is solely based on the water supply and does not

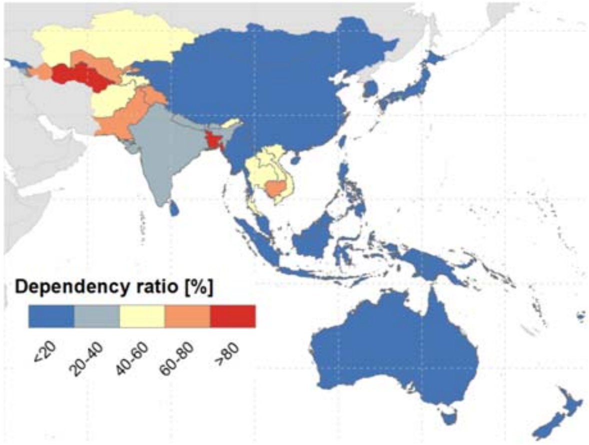


Figure 3-27: Dependency ratio 2010 (definition based on FAO AQUASTAT)

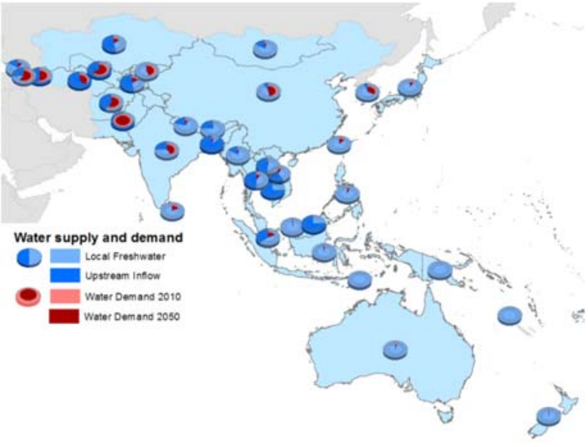


Figure 3-28: Water supply and demand

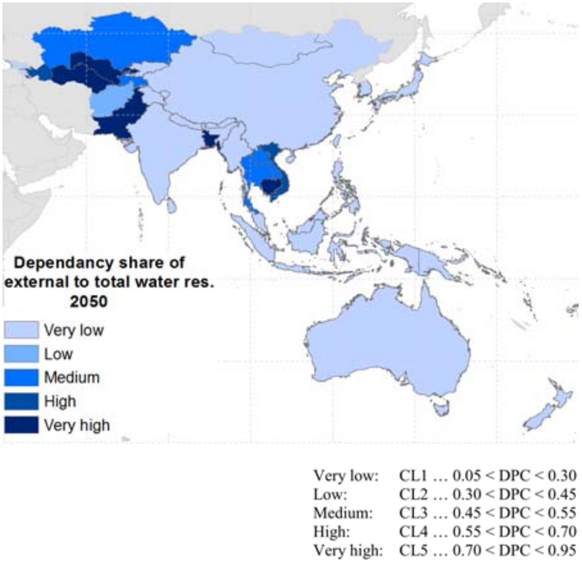


Figure 3-29: Quantifying "hydrological complexity" for hydro-economic classification: Dependency share of external to total renewable water resources

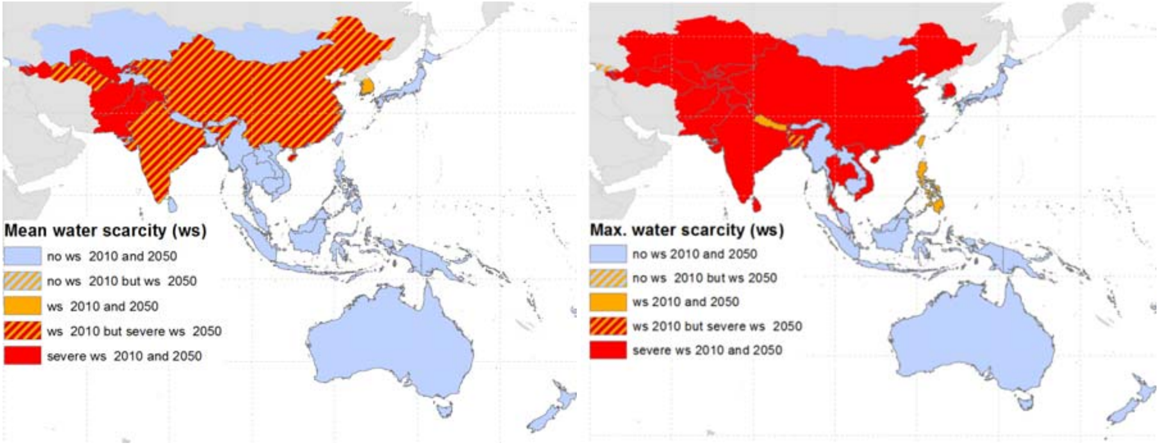


Figure 3-30: Mean water scarcity (left) and water scarcity based on the climatological driest month (right) at country scale

indicate if the local (by country) freshwater is sufficient for the total water demand. The water dependency index does account for how much of the total water demand has to be provided by inflow from upstream countries. Fig 3-29 shows the per country split between local freshwater and upstream inflow as blue pie charts. The red pie shows the share of total water demand (light red 2010, dark red 2050). For example, the water demand of China is almost half of the water supply in 2050 but it can be supplied by local freshwater resources. On the other hand, Turkmenistan has a water dependency ratio of almost 90% (2010) and 92% (2050) and is in need of upstream inflow to fulfill its water demand. Pakistan's water demand is as high as the existing available water from local freshwater (27%) and upstream inflow (73%).

The dependency ratio, or the share of external (from outside national boundaries) to total renewable water resources, is used as a measure of the dependency of external water resources. It is the fourth indicator to assess the hydrologic complexity. Fig 3-29 shows this indicator in five classes with Central Asia, Pakistan, Bangladesh, and the northern part of Southeast Asia.

3.6 Water security

3.6.1 Water scarcity - Imbalance between supply and demand

Today, in many regions in Asia, withdrawals exceed local renewable water resources, resulting in groundwater mining (e.g., Northwest Indo-Gangetic Plain), land subsidence (e.g., Northern Beijing Plain), and saltwater intrusion (e.g., Mekong Delta, Shandong Province). Severe water scarcity has led to major infrastructure investments and plans for large-scale water transfers (e.g., China's South-North Water Transfer Project, several existing and proposed transfer schemes in India). Securing Asia's water future against the background of climate change and growing water demands has been recognized as a key challenge for sustaining security throughout the region (Asia Society, 2009).

The integrated WFaS modeling has assessed future imbalances between water supply and demand. We use the water resources vulnerability index, defined as the ratio of total annual withdrawals for human use to total available surface water resources. Regions are considered water-scarce if annual withdrawals are between 20-40% of annual supply, and as severely water-scarce if withdrawals exceed 40% (Raskin et al. 1997). Fig. 3-30 highlights changes in water scarcity between 2010 and 2050 at the country level in terms of water-scarce ("ws"; 20-40% threshold) regions and severely water-scarce ("severe ws"; i.e., annual withdrawals are more than 40% of available water resources, often termed the "critical ratio") regions. Annual aggregations may disguise potential seasonal challenges of water

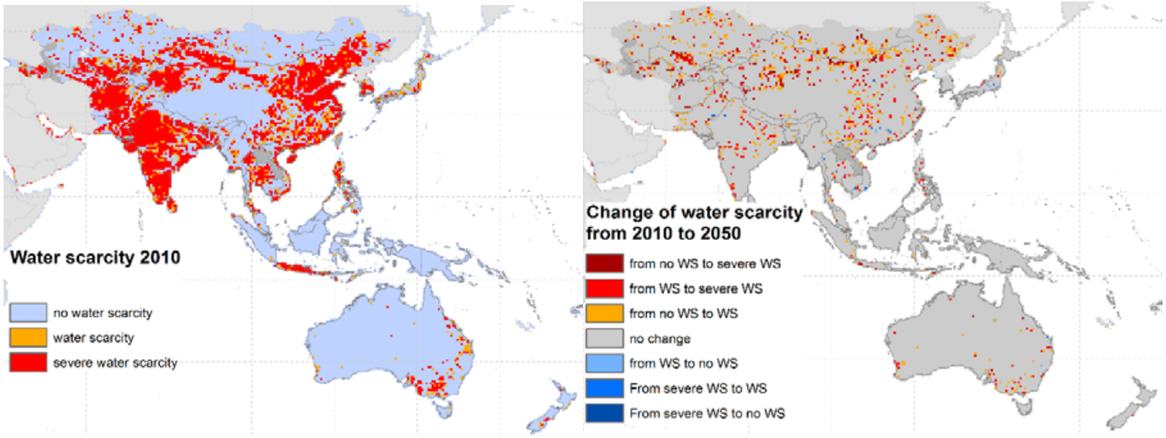


Figure 3-31: Water scarcity based on the climatological driest month at grid scale

scarcity. Thus water scarcity index has been calculated for both annual mean and driest month, based on annual water resources and demand (Fig. 3-30, left) and calculated for the climatologically driest month in the particular year (Fig. 3-30, right).

While Armenia, Uzbekistan, Afghanistan, and Pakistan already suffer from severe water scarcity, a much larger area will be affected by 2050 including India, China, and Turkmenistan (Fig. 3-30, left). In terms of the maximum seasonal water scarcity (climatologically driest month, Fig. 3-30 right) large areas in West, Central, East, and South Asia, including China and India, already suffer from severe water scarcity for at least one month of the year, and will continue to do so in the 2050s.

Fig. 3-31 shows grid-scale maps of water scarcity based on the climatologically driest month (seasonal effect) in the 2010s (left) and changes between the 2010s and the 2050s. Severely water-scarce areas occur in northwest and northeast China, central-eastern China, some urban areas along coasts in China, part of Thailand, Vietnam, Java, southeastern Australia, large parts of India and Pakistan, Afghanistan, Uzbekistan, and Turkmenistan in the 2010s. At a grid level, large parts of Asia are classified into severe water scarcity including highly populated areas. These areas require further investigation and appropriate measures to alleviate scarcity. By 2050 severe water scarcity will further expand across Asia. Hotspots of major changes and high levels of scarcity between 2010 and 2050 include Turkmenistan, parts of west and central China, and central India, as well as Indonesia and Australia.

Potential population exposed to future severe water scarcity

Combining the development of population with the WFaS scenario analysis on water scarcity reveals an increasing number of people in Asia are exposed to conditions of severe water scarcity through to 2050. The spatially explicit analysis based on grid-cell data, highlights for each country in Asia, the amount of population exposed to severe water scarcity by 2010, 2030, and 2050 for the three WFaS scenarios. Appendix E highlights these results for the country level including the percentage of population in each country exposed to severe water scarcity. Fig. 3-32 presents a comprehensive summary of the analysis shown in Appendix E.

All three scenarios feature an increasing population living in conditions of severe water scarcity, from 1.2 billion in 2010 to 1.7 to 2.1 billion people in 2050 (Fig. 3-10). In each scenario, by 2050, as much as 40% of population may be affected by severe water scarcity. Albeit, depending on management and the adaptation potential of the individual, not all those people living in a grid cell classified as severe water scarcity will be affected by detrimental impacts of water scarcity. However results indicate the large amount of population that could potentially be affected by living in areas of severe water scarcity. Below, we present a more detailed discussion of the *Middle of the Road* scenario.

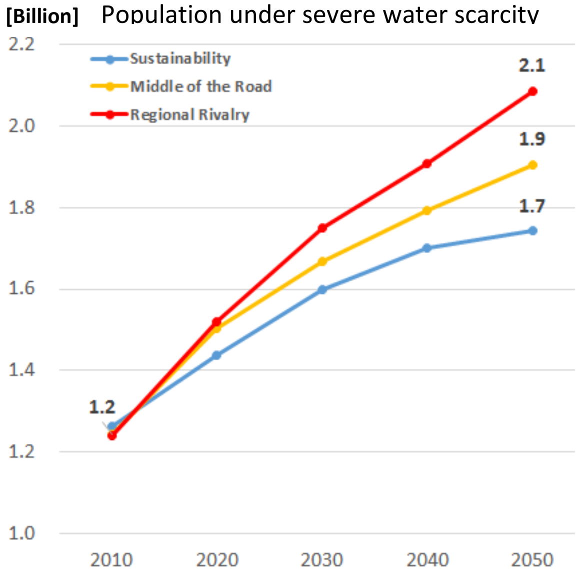


Figure 3-32: population under severe water scarcity in three scenarios

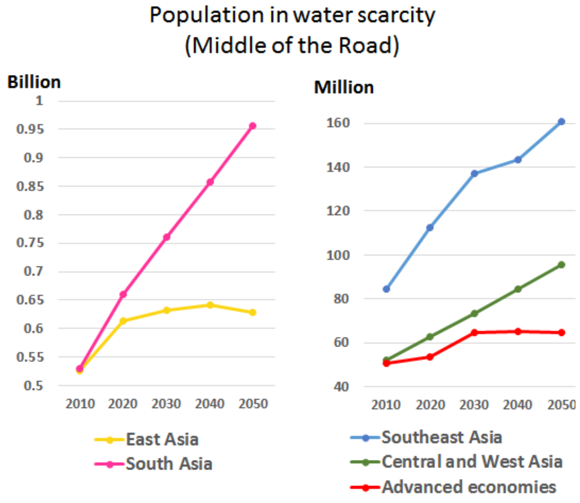


Figure 3-33: Change in the number of people under severe water scarcity (*Middle of the Road* scenario)

Fig. 3-33 presents regional plots for the *Middle of the Road* scenario, and Table 3-9 provides country results. Water scarcity indices in the Pacific region are always below the threshold of severe water scarcity and are therefore exempt from the results in Fig. 3-33 and Table 3-9. In the 2050s, approximately 1.9 billion people, which will be 40% of the Asian population at the time, live in areas with severe water scarcity. Throughout 2050 South Asia's population living in areas of severe water scarcity is continuously increasing, reaching almost 1 billion by 2050. While East Asia has the second largest population expected, this peaks during the 2040s and shows a decreasing trend until the 2050s. This is mainly related to China's population peaking around the 2030s. Only in countries from Advanced Economies does the number of people exposed to water scarcity until 2050 remain fairly stable.

South Asia: The majority (about two-thirds) of the population in South Asia affected by scarcity live in India, followed by Pakistan and Bangladesh. All three show an increasing trend in exposed population.

East Asia: China shows a rapidly increasing number of people affected by water scarcity during the 2020s and 2030s, hitting a peak during the 2040s, and then decreasing throughout the 2050s.

Southeast Asia: More than half of Southeast Asia's population living in water-scarce areas are in Indonesia, where after 2030 about one-third of the population is exposed to water scarcity. This is followed by the Philippines which also shows an increasing trend in people exposed to water scarcity. In Thailand and Vietnam about 10% of the population lives in water-scarce areas with almost no increases over time. In Malaysia after the 2030s, the number of people exposed to water scarcity increases rapidly. In Lao PDR, Myanmar, and Cambodia only a small (possibly no) people are projected to experience water scarcity.

Central and West Asia: Seven countries, Armenia and Georgia excluded, indicate increases in scarcity. Afghanistan will have the most people under water scarcity, followed by Kazakhstan and Turkmenistan. The number of people living in water scarcity in these regions is projected to continue growing rapidly.

Table 3-9: Country-level characteristics of change of the number of people under severe water scarcity [million].
(Middle of the Road scenario)

[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	

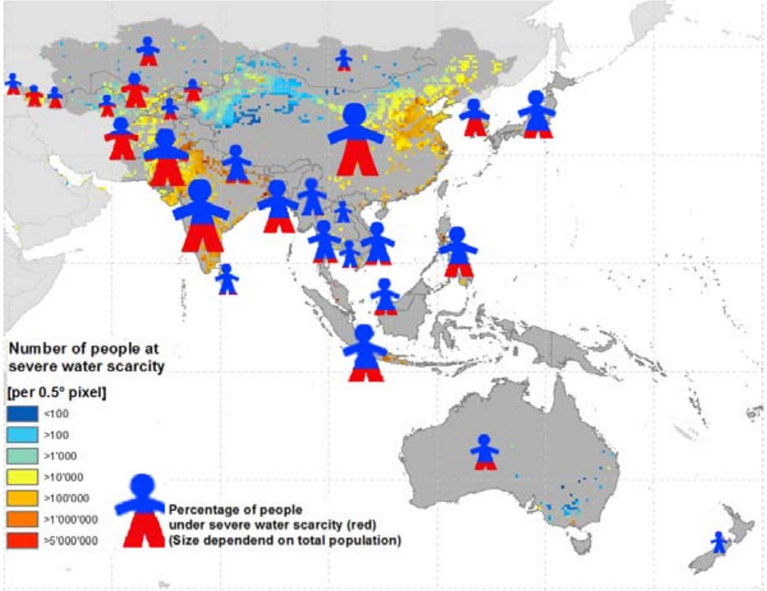


Figure 3-34: Potential population under severe water scarcity in 2050 – *Middle of the Road* scenario

Advanced Economies: While Australia and New Zealand show increasing trends, Japan and the Republic of Korea will hit their peak during the 2030s and decrease thereafter.

As shown in Table 3-9, the top five countries in terms of people living in areas affected by water scarcity in 2050 are India (730 million), China (627 million), Pakistan (157 million), Indonesia (93 million) and Bangladesh (62 million), together accounting for about one third of Asia's population in 2050. Countries with a decreasing trend in people exposed to water scarcity after 2030 include China, Japan, Republic of Korea, Azerbaijan, and Georgia.

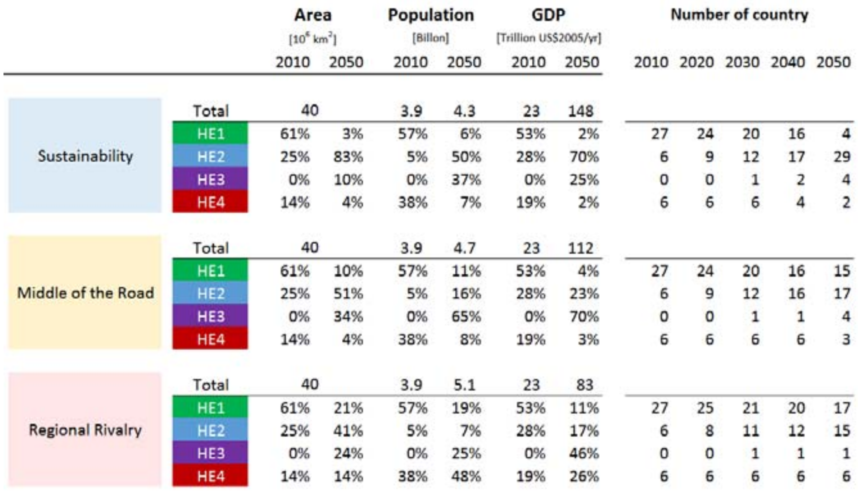
The map in Fig. 3-34 presents the regional distribution of the areas classified as severe water scarcity by 2050, including both the amount of population living in each water-scarce grid-cell and the percentage of people in a particular country living in these water-scarce areas. For example, in Australia just over half of the population (58%, see Table 3-9) reside in water-scarce areas, mainly in southeastern Australia. In China as much as 76% of the population, albeit mainly living on the coast and in the northeast of the country. A large number of people will be facing water scarcity especially throughout central eastern China, India, and Pakistan. Large urban conglomerates such as Tokyo, Seoul, and Busan, many urban areas along China's coastline, Manila, Ha Noi, Ho Chi Minh, Bangkok, Jakarta and Bandung, Kabul, and Tashkent have large populations that will be affected. A full overview of all three scenarios is given in Appendix E.

3.6.2 Hydro-economic classification change

Country-level analysis

In the above analysis, the water scarcity indicator has been discussed as one sub-indicator (biophysical) of the x-axes (hydro-climatic challenges). Equally important are the economic, Hydro-economic (HE) classification, a key metric applied in WFaS for the evaluation of water security (see section 2.3). The HE classification places countries or watersheds in a two-dimensional space where the x- and y-axes proxy water challenges and economic-institutional coping capacity, respectively. Development of the other three indicators of the x-axes have been discussed above, namely, renewable water resources per capita (see 3.5.1), variability in runoff (3.5.3), and dependency of external water resources (3.5.4).

Table 3-10: Change in area, population and GDP in each Hydro-economic class. Comparison between 2000s, 2010s, and 2050s



		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
Sustainability	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
Middle of the Road	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
Regional Rivalry	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

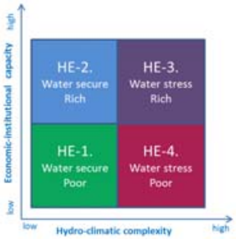
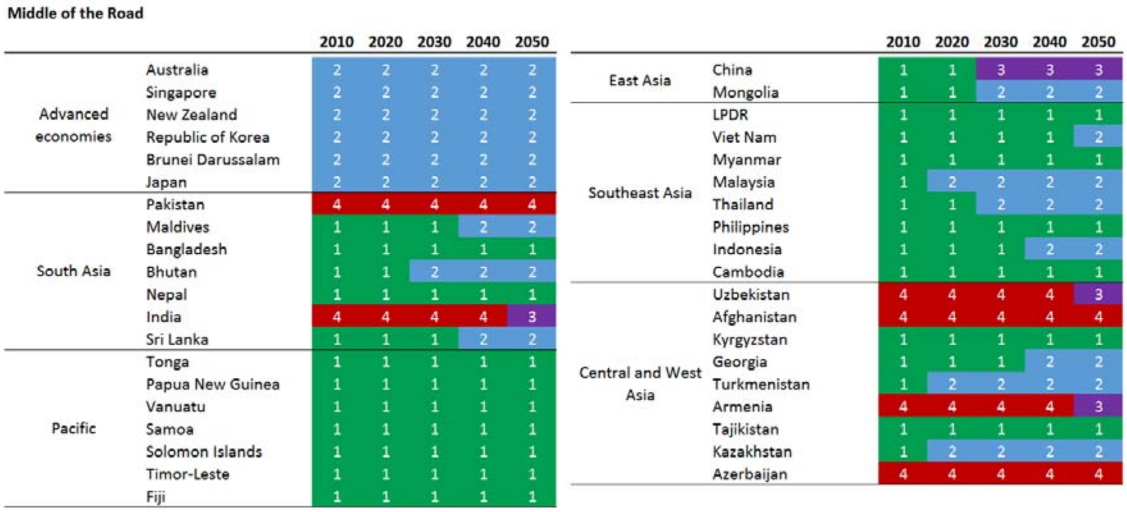


Table 3-11: Shifts in hydro-economic class at national scale



Middle of the Road

		2010	2020	2030	2040	2050
Advanced economies	Australia	2	2	2	2	2
	Singapore	2	2	2	2	2
	New Zealand	2	2	2	2	2
	Republic of Korea	2	2	2	2	2
	Brunei Darussalam	2	2	2	2	2
	Japan	2	2	2	2	2
South Asia	Pakistan	4	4	4	4	4
	Maldives	1	1	1	2	2
	Bangladesh	1	1	1	1	1
	Bhutan	1	1	2	2	2
	Nepal	1	1	1	1	1
	India	4	4	4	4	3
	Sri Lanka	1	1	1	2	2
Pacific	Tonga	1	1	1	1	1
	Papua New Guinea	1	1	1	1	1
	Vanuatu	1	1	1	1	1
	Samoa	1	1	1	1	1
	Solomon Islands	1	1	1	1	1
	Timor-Leste	1	1	1	1	1
	Fiji	1	1	1	1	1
East Asia	China	1	1	3	3	3
	Mongolia	1	1	2	2	2
Southeast Asia	LPDR	1	1	1	1	1
	Viet Nam	1	1	1	1	2
	Myanmar	1	1	1	1	1
	Malaysia	1	2	2	2	2
	Thailand	1	1	2	2	2
	Philippines	1	1	1	1	1
	Indonesia	1	1	1	2	2
	Cambodia	1	1	1	1	1
Central and West Asia	Uzbekistan	4	4	4	4	3
	Afghanistan	4	4	4	4	4
	Kyrgyzstan	1	1	1	1	1
	Georgia	1	1	1	2	2
	Turkmenistan	1	2	2	2	2
	Armenia	4	4	4	4	3
	Tajikistan	1	1	1	1	1
	Kazakhstan	1	2	2	2	2
	Azerbaijan	4	4	4	4	4

In the 2050s, 35 countries, excluding New Zealand, Japan, Vanuatu, and the Solomon Islands, will be experiencing more severe conditions than at present. Of these, 27 countries show consistently increasing hydro-climatological complexity (x-axis). However, economic-institutional capacity will improve in every country (Fig. 3-35). Table 3-10 presents a comprehensive summary of the distribution of area, population, and GDP across the four hydro-economic classes for the different scenarios. Results are based on the HE-classification of individual countries in Asia. Six countries will be in HE-3 and seven in HE-4 in the 2050s, with 44-73% of Asian total population.

The time series shown in Table 3-11 are for the *Middle of the Road* scenario. In this scenario, for example, in the 2010s six countries with a population of 1.5 billion (Uzbekistan, Afghanistan, Armenia, Azerbaijan, Pakistan, and India) are in HE-4 (high water challenge due to high hydro-climate complexity and low adaptation capability), while no countries are currently in HE-3 (high water challenge and high coping capacity). However, by the 2050s, seven countries are attributed to HE4 or HE3 totaling 3.4 billion people (73% of Asian population).

Under the scenarios used, significant levels of economic growth (i.e., increasing GDP) in all countries are predicted. This results in an upward shift along the y-axes moving more countries into classes HE-2 and HE-3. Depending on actual implementation of this increased economic strength, this should increase the countries' coping capacity for adaptation and risk management related to water challenges, even though poverty and inequality in these countries may remain. For example, the shift of Uzbekistan, Armenia, and India into HE-3 in the 2050s reduces the population in HE-4 to 379 million (8% of Asian total). Our analysis suggests that three countries will remain in HE4 (Pakistan, Afghanistan and Azerbaijan) throughout the period.

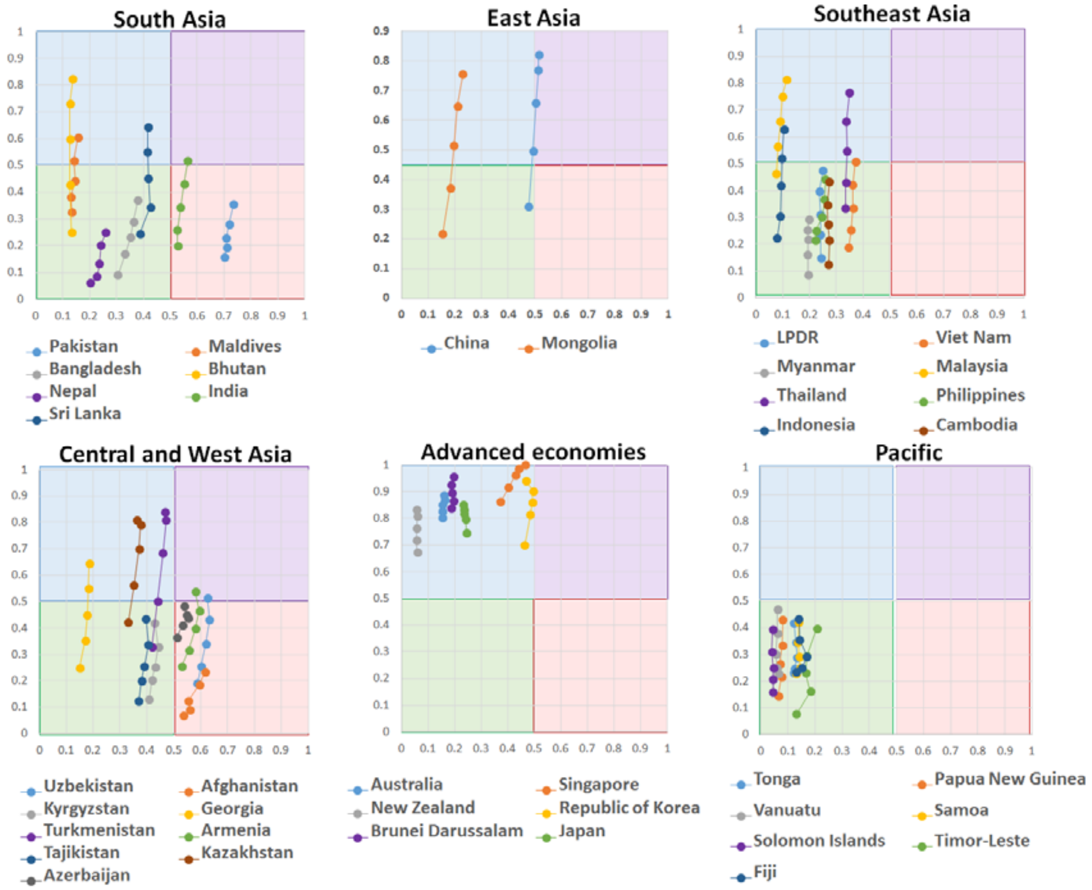


Figure 3-35: Hydro-economical change at country level – *Middle of the Road* scenario

They should preferentially receive financial support, as their coping capacity may remain lower while also facing higher hydrological complexity over time. China will shift from HE1 into HE3 as of 2030, significantly increasing the total Asian population living in the quadrant classified as HE-3 (3 billion by 2050). Although the hydrological-climatic challenges of China will increase over time, its capacity to cope with water challenges are expected to increase substantially. Finally, Fig. 3-35 presents the trajectory of the HE-indicator in the two-dimensional space for each country under Middle of the Road scenario. Regardless of the scenario analyzed and although paths differ for the countries with high hydrological-climatic complexity discussed above, all countries except China and Sri Lanka shift into the same HE category by 2050.

Basin level analysis

Table 3-12: Areas, population, and GDP in 15 Asian large basins
(The Middle of the Road scenario)

Population ranking 2010	Basin	Area [10^3 km^2]	Population [Millioin]			GDP [10^9 US$]		
			2010	2020	2030	2010	2030	2050
1	Ganges - Bramaputra	1673	701	880	995	701	880	995
2	Yangtze	1792	396	399	360	396	399	360
3	China Coast	642	371	390	365	371	390	365
4	Indus	868	195	261	314	195	261	314
5	Java - Timor	218	157	183	192	157	183	192
6	Ziya He, Interior	340	135	143	134	135	143	134
7	Huang He	832	131	137	126	131	137	126
8	Japan	369	125	121	113	125	121	113
9	Sabarmati	524	105	136	158	105	136	158
10	Philippines	295	99	131	154	99	131	154
11	Xun Jiang	414	92	95	88	92	95	88
12	Krishna	276	91	115	132	91	115	132
13	Godavari	315	76	96	109	76	96	109
14	Mekong	807	69	77	77	69	77	77
15	Amur	2076	68	70	64	68	70	64

Finer-scale analyses highlight water challenges more clearly, as both hydrological and socioeconomic conditions have high spatial variability within a country (Fig. 3-36). The same hydro-economic analysis was applied to river basins in Asia, and results for 40 basins (see Fig. 3-36) in the Middle of the Road scenario are presented in this section. Table 3-12 presents the socioeconomic data for the 15 most populous river basins in 2010. Fig. 3-36 (a) presents the main result of the hydro-economic classification from the 2000s to the 2050s. Additionally, the x-axis of Fig. 3-36 (b)-(d) shows the normalized index of per capita surface water resource, water use intensity, and monthly variability of runoff, respectively. These figures describe changes in each index that contribute to the integrated index in Fig. 3-36 (a). Note that the points in each trajectory for each basin are for the 2010s, 2030s, and 2050s, with the 2000s also included for reference.

Thirty-one of a total of 40 basins were classified as HE-3 or HE-4 (i.e., higher water challenge in the 2050s). Hydro-climatic complexity is expected to increase in all basins except those in Japan (Fig. 3-36 a). For example, hydro-climatic complexity in the Krishna, Bo Hai and China Coast basins is expected to increase, despite already high complexity in the 2010s. Changes in the x-axis at the basin scale analysis are more significant than that of the country-scale analysis. When it comes to the integrated index (Fig. 3-36 a), focusing on HE-4, the basins can be categorized into three types. Twenty-nine out of 40 basins will experience HE-4 at least once during the period and will subsequently reach HE-3 in the 2050s (Group B). Ten basins in Group B will be in HE-4 from the 2010s to the 2040s and will narrowly turn into HE-3 in the 2050s. Four basins move from HE-1 in the 2010s to HE-3 in the 2050s, via HE-4. However, four basins – Amu Darya, Indus, Ganges-Bramaputra, and Sabarmati – will remain in HE-4 over the entire period through to the 2050s (Group A). Sabarmati, in particular, in the west of India, scores highest on water challenge among the 40 basins. It must also be emphasized that the Ganges-Bramaputra and Indus, which have the first and fourth largest populations of all Asian basins, will remain in HE-4. Although their GDP per capita will increase, they will remain classified as low coping capacity basins.

Of the three indexes that make up the x-axis, per capita surface water resource (Fig. 3-36 b) and water use intensity (Fig. 3-36 c) exhibit larger changes and are thus more dominant than external dependency (Fig. 3-36 c). Of these, water use intensity contributes most to the hydro-climatic complexity score and thus has the largest impact on this hydro-economic analysis. Chinese basins provide good examples of this. It is expected that scores of per capita surface water resources in Chinese basins will rise through to the 2050s because population growth in them will peak around the 2030s and decrease thereafter. However, the integrated indicators for these Chinese basins show ever-increasing trends due to rapid growth in water use intensity (e.g., Bo Hai Basin). Our projection indicates that water demand will steadily keep increasing even if it is in a basin with already-high hydro-climatic complexity. Countermeasures must be taken to solve this growing imbalance between water demand and supply. The result indicates that mitigation of water use intensity must be a key priority in solving water issues. The following chapter comprehensively discusses possible water solutions.

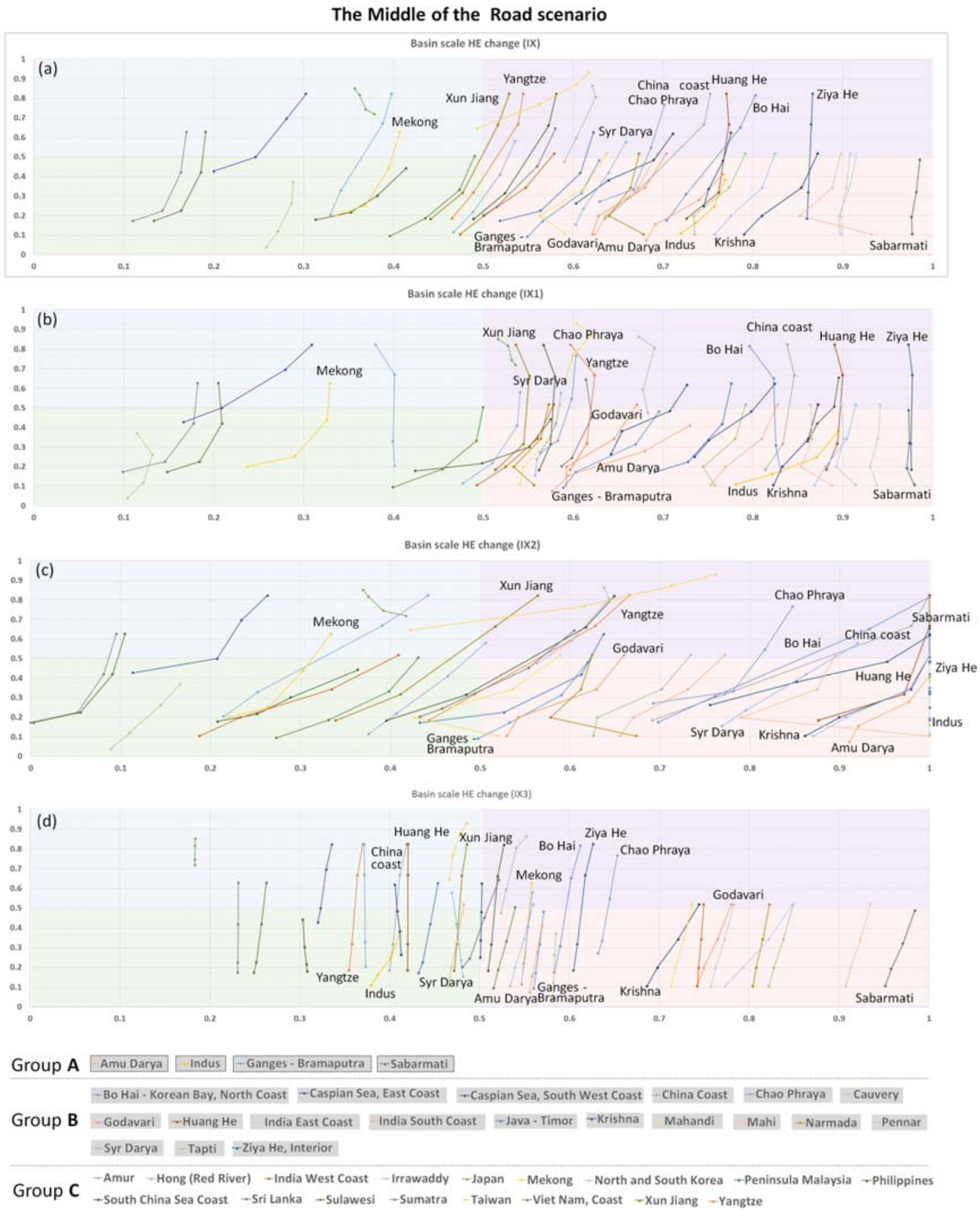


Figure 3-36: Change in hydro-economic class at basin scale in the Middle of the Road scenario. (a) x-axis is integrated index. (b) x-axis is index 1 about per capita available surface water resources. (c) x-axis is index2 about water use intensity. (d) x-axis is index 3 about monthly variability of runoff. Because this is basin scale result, index 4 about external dependency is not presented here. Group A: Basins which are classified as HE4 throughout period. Group B: Basins which are categorized in HE4 at least once during the period. Group C: Basins which does not pass through HE4 until the 2050s.

4 Outlook - Uncovering water solutions

4.1 Policy responses for coping with growing water scarcity

In this section we assess the outcomes and tradeoffs of the different policies used in several countries based on a literature review. However, we do not provide recommendations on specific policies to address the growing water scarcity in Asia. This is the focus of continuing work within the WFaS initiative.

Many Asian countries face important water scarcity challenges, which will be aggravated in the coming decades by economic and population growth and climate change impacts. The water problems of the future will continue to become increasingly complex, as competition for limited resources intensifies, and will become more and more intertwined with other sectors like agriculture, energy, and the environment. Policy interventions are needed to address the multiple future water challenges. The objective of implementing water policies is to balance freshwater supplies with demand in a way that ensures water availability that is adequate in both quantity and quality.

Policymakers possess a wide range of instruments to address the multiple future water challenges, but all of them entail financial and social costs. Current evidence, however, suggests that the benefits of many policy options validate their costs. For instance, practitioners of disaster management such as droughts and floods indicate that, to reduce the impact of a disaster, it is typically more cost-effective to invest in disaster risk reduction measures than to provide emergency relief measures once the disaster has occurred. *The Stern Review* has, documented several examples of the economic feasibility of water policy interventions to address climate change impacts in a number of countries (Stern 2007).

Water policies are typically divided into supply-side measures and demand-side measures. Supply-side measures aim at increasing water supply by using new sources of water to meet growing water demand. Historically, the focus for most countries worldwide in addressing water challenges has been to consider supply-side measures through the construction of large infrastructures for storing, moving, and treating water (Gleick 2003). These infrastructures have played a key role in sustaining economic growth (Sadoff et al. 2015). However, as engineering solutions have become increasingly limited and expensive, demand-side measures have become more common. In addition, some supply-side measures entail negative environmental impacts, and they may also be inconsistent with climate change mitigation because they involve high energy consumption and cause greenhouse gas emissions (Bates et al. 2008). Unlike supply expansion, demand management avoids water scarcity by promoting water efficiency and conservation. It relieves scarcity by making greater use of existing supplies, reducing demand, or altering the timing of demands, all of which can avoid the need for new supplies. Demand management aims to squeeze more beneficial use out of existing supplies in several ways (Brooks, 2003).

It should be mentioned that there is no unique classification of measures and what can be considered as being part of one category is, in some cases, subject to debate. Most of the solutions reported in the literature to date include planned measures, which require deliberate policy decisions and investment, in contrast to autonomous measures, which occur spontaneously among individuals, triggered by natural and human changes. Water solutions can be both proactive and reactive. Proactive measures aim at avoiding damage due to water scarcity (e.g., avoiding restrictions in water supply and groundwater over-exploitation). Reactive measures, on the other hand, help to deal with damage once it has occurred (e.g., regeneration of employment and assistance to farmers after extreme events). Measures can be also classified as short-run or long-run interventions depending on the economic life of capital investment.

Water resource management approaches around the world are changing significantly. These changes include a shift away from depending mainly on finding new sources of supply to address perceived new demands toward a growing emphasis on incorporating environmental values into water policy, a reemphasis on meeting basic human needs for water services, and a decoupling between economic growth and water use (Gleick 2000). It is recognized that the solution to such problems calls for an integrated approach. Integrated water resource management is formally defined by the Technical Advisory Committee of Global Water Partnership as the coordinated development and management of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of valuable ecosystems. From an economic stance, integrated management embraces the principle that water supplies and demands can be managed jointly in the search for the least-cost and sustainable mix of measures to avoid scarcity. With proper planning, it can be achieved at a lower cost than either demand management or supply expansion alone (Ward 2012).

Most water experts agree that infrastructural modifications require supply and demand management form the core of the water sector strategy to confront climate change. However, when designing water policy interventions, the demand side, less attention has been devoted to the institutional aspects of water management, which play a crucial role in determining the adaptive capacity of basins. Water institutions are defined as encompassing all the water-related laws, organizations, networks, and coalitions that govern the whole range of water-related activities (Saleth and Dinar 2004). While water technologies and management capabilities will play a direct role in climate change adaptation, water institutions will play an indirect but indispensable role in providing the economic incentives and organizational basis for the adoption of existing technologies and management options, as well as the development of new ones. Moreover, water institutions will perform an important role in determining the overall social impacts of a change in water availability, as well as the distribution of gains and losses across different stakeholders.

Tables 4-1 and 4-2 provide a summary of the water policy intervention alternatives to address water scarcity problems, including institutional measures based on a literature review. The tables identify the stakeholders that should be involved in the decision-making and implementation processes for each intervention, and present a further classification of the interventions that could guide policymakers in prioritizing between them.

4.2 Different pathways for managing water scarcity

Countries around the world have opted for different pathways to address water scarcity and to achieve sustainable water use. We review here the outcomes and tradeoffs of some of these pathways. We present results from different locations based on the literature review. It may be possible for many Asian countries to implement such pathways.

Rising concerns in the European Union about water scarcity and droughts led the European Commission to propose in 2007 a set of policy measures to address these issues (EC 2007). The most important measures are enforcing the full recovery of the costs of water services, considering additional water supply infrastructure, and fostering the adoption of water-efficient technologies and practices. The water pricing policy advocated by the European Water Framework Directive aims at recovering the full cost of water services including the resource and environmental costs, following the polluter-pays principle (EC, 2012). The objective of this policy is to encourage the efficient use of water resources and to assure the financial viability of water supply agencies, which could guarantee their operation without the need of public subsidies.

Water pricing to achieve water conservation has been the subject of continuous debate among researchers, stakeholders, and policymakers since the 1990s. Generally, it seems that water pricing could achieve gains in efficiency in urban and industrial water networks as shown in many studies including Hanemann (1998), and more recent studies such as Roibas et al. (2007) and Grafton et al. (2015). However, Perez-Urdiales et al. (2016) indicate the existence of non-discretionary uses of water that are not sensitive to price changes. To reduce these uses, non-pricing policies such as education programs, retrofit subsidies, and public information campaigns should be applied. Reynaud (2013) indicates that residential water demand is inelastic with respect to water price, but not perfectly so. This means that a price increase will have only a limited impact on water consumption. The author suggests that price increases should be combined with non-pricing policies to induce more water conservation.

In contrast, irrigation water pricing is a politically and socially sensitive issue, in particular where economies are dependent on irrigation. In many cases, the issue of who should be responsible for the costs of irrigation development is not straightforward (Cornish et al. 2004). It is often indicated that farmers should bear the full supply costs, including capital investment, depreciation, and annual O&M costs. However, one string of the literature finds that irrigation water pricing has limited effects on water conservation and involves disproportionate costs to farmers (Cornish et al. 2004, Kahil et al. 2016). Bakker (1999) indicates that irrigation water is used for many purposes other than irrigating crops, and ignoring these benefits will result in a serious underestimation of the benefits available from the volume of water that is diverted for irrigation. For instance, consumers have benefited from irrigation development in terms of lower cereal prices. Especially in developing countries, there are millions of indirect beneficiaries who benefit at least as much as farmers. Food prices are usually kept artificially low and urban consumers should be willing to subsidize irrigation development through taxation. In contrast, Tsur et al. (2004) indicate that water pricing could achieve an efficient allocation of irrigation water without damaging farmers' benefits as long as the pricing policy guarantees that all or part of the revenue collected by water agencies remains in the area and is reinvested in improving water use efficiency. Although pricing and recovery of irrigation water costs are important policy objectives, several preconditions must be satisfied before it can be implemented effectively. These preconditions include an adequate political and legal framework; institutional and administrative resources capable of implementing and enforcing the policy; and water distribution infrastructure providing the level of control and measurement required Cornish et al. (2004).

Improving water use efficiency has also become a policy objective in the European Union and in many other countries around the world. Different technological options are available to improve water use efficiency such as the adoption of efficient irrigation systems, improvement of pipelines and lining canals, and the adoption of low-flow showers and toilets in cities. Many studies analyze the adoption of efficient irrigation systems. They find that these efficient systems enable a reasonably uniform distribution of water across a field and good control on the depth of application compared to surface irrigation. Moreover, the use of efficient irrigation systems seems to be profitable because it reduces land abandonment, facilitates the adoption of diversified and high-value cropping patterns, and improves crop yield (Perry et al. 2014). However, contrary to widespread expectations, improving irrigation water use efficiency may increase water depletion at basin level through enhanced crop evapotranspiration and reduction of return flows. These flows contribute to instream flow and groundwater replenishment that could be essential for downstream consumption and environmental uses (Huffaker 2008). Experts suggest that irrigation efficiency gains should be accompanied by a set of regulatory measures on water allocations or irrigation areas to prevent the unintended effects (Ward and Pulido-Velazquez 2008).

In many basins around the world, the sharing of water is governed by administrative rules dictating who receives how much, depending on overall supply. These rules may not properly reflect the value of water across users and uses, and may be more damaging for certain water users than for others. In recent decades, the water market approach to allocate water has been gaining ground in some parts of the world, for example, Australia and Chile. Water markets increase water use efficiency, avoid the development of new costly water resources, and achieve significant welfare gains by reallocating water from lower to higher value uses (Dinar et al. 1997).

The Murray-Darling Basin (MDB) in Australia is at present the most active water market in the world, and during the drought of 2002–2012, this market generated benefits in the range of several hundred million to 1 billion US dollars per year (Kirby et al. 2014). A challenge to water markets are the third-party effects such as environmental impacts. Water markets reduce streamflows because previously unused water allocations are traded and also because gains in irrigation efficiency at parcel level reduce drainage and return flows to the environment downstream (Howe et al. 1986; Qureshi et al., 2010). Another worrying effect is the large surge in groundwater extractions, as shown in the last drought in the MDB. Groundwater extractions between 2002 and 2007 were seven times above the allowed limits placed on groundwater users (Blewett 2012). These environmental impacts reduce the benefits of trading and increase adaptation costs. For instance, water authorities in Australia are implementing very expensive public programs on infrastructure upgrading investments and environmental water buyback, in order to recover water for the environment in the MDB (Wheeler et al. 2014).

Most developed countries have invested heavily in infrastructure, such as construction of reservoirs, desalination of saline water, reusing treated wastewater, and groundwater development and use in order to ensure their water security, often starting early on their path to growth. These developed nations are now relatively water-secure. However, most of the world’s developing countries still do not have enough water infrastructure and remain relatively water-insecure (Vörösmarty et al. 2010).

The option of building reservoirs is limited by silting and lack of available runoff to fill the reservoirs. Most of the cost-effective and viable sites for reservoirs in developed countries have been identified and used, and the remaining sites are not cost-effective. Furthermore, environmental concerns and restrictions have strongly limited the potential for additional reservoir construction throughout the world (Gleick 2003). However, many developing countries such as Bangladesh, Nepal, and Vietnam lack adequate water storage capacity (Brown and Lall 2006). The future development of new water storage infrastructures should consider the full set of costs and benefits for different water users and uses including ecosystems needs.

Table 4-1: Water supply-side interventions.

Measures	Purpose/Specific actions	Involved stakeholders	Long-term	Short-term	Planned	Autonomous	Proactive	Reactive
Development of water storage and retention infrastructures	Enhancing existing storage capacity and/or building new storage facilities (dams, pond and tanks, aquifers, soil moisture, natural wetlands) to increase water supply for downstream uses, reducing the risks of extreme events such as droughts and floods, and producing hydropower	Government Development and funding agencies Experts Basin authority Industries Irrigation districts Environmental NGOs	X		X		X	
Rainwater harvesting	Collecting and storing rainwater for reuse	Farmers and irrigation districts Households Government Water utilities		X	X	X	X	
Groundwater development and use	Increasing water availability in normal years and mitigation of fluctuations in surface water supply in drought years, conjunctive use of surface and ground waters	Farmers and irrigation districts Industries Basin authority Experts Government Environmental NGOs	X	X	X	X	X	X
Treatment and use of wastewater	Removing pollutants from wastewater and reusing it for different purposes depending on the treatment level	Water utilities Industries Government Environmental NGOs Development and funding agencies Experts	X		X		X	X
Desalination	Removing salts from saline water to produce freshwater	Government Development and funding agencies Environmental NGOs Experts Basin authority	X		X		X	X
Inter-basin transfer	Moving water from water-abundant regions to water-scarce regions through man-made conveyance schemes	Government Basin authority Development and funding agencies Environmental NGOs Farmers and irrigation districts Industries Households	X		X		X	X

Table 4-2: Water demand-side and institutional interventions

Measures	Purpose/Specific actions	Involved Stakeholders	Long-term	Short-term	Planned	Autonomous	Proactive	Reactive
Demand-side measures								
The adoption of efficient water technologies	Increasing water use efficiency and water productivity through the use of efficient irrigation technologies (sprinkler and drip) and retrofit of water devices in houses and the implementation of special public programs promoting their adoption	Farmers and irrigation districts Households Government Basin authority Development and funding agencies Experts Media	X		X	X	X	X
Land use planning and management	Promoting water saving and best management practices such as crop residue management, conservation tillage, irrigation metering and scheduling, deficit irrigation, water recycling in fields, conversion to rain-fed agriculture, change in crop pattern and cropping intensity, and use of drought-tolerant and early-maturing varieties	Farmers and irrigation districts Government Basin authority Development and funding agencies Experts		X	X	X		X
River basin planning and management	Setting limits on water extractions, efficient and fair allocation rules, clear property rights, adjustment of operation rules, extreme event management plans	Basin authority Farmers and irrigation districts Industries Households Environmental NGOs Government Experts	X	X	X		X	X
Raising awareness	Information, education, and communication	Government Environmental NGOs Experts Media Development and funding agencies Civil society	X	X	X	X	X	X
Institutional interventions								
Institutional development and best governance practices	Formulation of laws and regulations, support of decentralized management, participative and transparent decision making, stakeholder involvement, conflict resolution mechanisms, enforcement mechanisms, networking and coalitions, capacity building, social and community support, extreme event committees to coordinate efforts, special laws for extreme events	Government Basin authority Development and funding agencies Farmers and irrigation districts Households Industries Environmental NGOs Civil society Media Experts	X	X	X		X	X
Use of economic instruments	Subsidies for the adoption of efficient technologies, environmental taxes, water pricing, water markets, virtual water trade, payments for ecosystem services, insurance schemes, financial risk management, recovery schemes	Government Basin authority Farmers and irrigation districts Industries Households Development and funding agencies Water utilities Experts		X	X		X	X
Information collection, analysis and transfer	Monitoring, forecast and warning systems, expert know-how, simulation models, decision support systems, farm advisory, research	Government	X	X	X	X	X	X

Drawing on lessons from previous failures to estimate the real costs of these projects could be useful in this regard. Considering more ecosystem-friendly forms of water storage, such as natural wetlands and soil moisture, could in certain areas be more cost-effective and sustainable than traditional infrastructure such as dams (OECD 2016).

Desalination of saline water is an expensive and energy-intensive option that is available to municipalities because the cost can be passed on to the consumer. This option is used in many developed country settings such as Australia, Israel, United States, the Gulf countries, and some Mediterranean countries. The environmental concerns with respect to desalination relate to the disposal of the brine and the energy used in the process. Desalination is generally not an available option for agriculture because of the high cost of water along with the volume of water required for production. However, desalination costs have dropped significantly in recent decades due to technological advances (Gaffour et al. 2013). This has increased the attractiveness of desalination to policymakers as a means of addressing water supply shortages in all sectors, including agriculture.

Treated municipal wastewater has also become a viable option for both municipal and agricultural uses in many countries in Europe and in the United States (Schwabe et al. 2013). Tertiary treated wastewater is being used for groundwater recharge and subsequently municipal water supply. Secondary, and in some cases tertiary (e.g., Spain) treated wastewater has become a source of water for irrigated agriculture adjacent to large municipalities. Secondary treated wastewater is also being used for groundwater recharge to replenish aquifer systems used for irrigated agriculture. Given the rate of urban population growth in all countries, this source of water is likely to increase. In addition to managing the buildup of salts and nutrients in soils, there is the challenge of moving water from the source to the end use as the energy cost of pumping water can be excessive. An interesting example of wastewater treatment and reuse can be found in Singapore, where wastewater is recovered and treated to drinking water quality. Treated wastewater presently meets 30% of Singapore's water needs, with plans to triple volumes by 2060.

Groundwater is an increasingly important water supply source globally, brought about by the adoption of pumping technologies with falling costs. However, significant negative impacts are already occurring in many basins worldwide where extraction rates are well above recharge. An illustration is the finding that a third of the world biggest groundwater systems are in distress (Richey et al. 2015). Therefore, the use of groundwater resources during drought spells and under future climate change scenarios requires the design of adequate regulations that protect groundwater systems and assure their sustainable use.

It is necessary to select a portfolio of policies that integrates both supply- and demand-side measures supported by well-functioning water institutions in order to achieve efficient, sustainable, and equitable outcomes. Some policy interventions may be excessively costly, may not lead to the intended benefits, may result in harmful and perhaps unintended impacts upon people and the environment, or may close off more beneficial future investment opportunities. A successful policy in one setting does not necessarily work in other settings because water policies are driven by a complex interaction of multi-layer and path-dependent influences, with policy reforms building up on many previous waves of institutional reform.

The future work of WFaS will incorporate supply- and demand-side measures into comprehensive portfolios of policy recommendations, quantify their benefits and their trade-offs under the alternative scenarios based on the Shared Socioeconomic Pathways and Representative Concentration Pathways, and test their robustness to establish the scenarios under which they produce improved results.

5 Conclusion

The Water Futures and Solutions (WFaS) initiative has produced a set of consistent and comprehensive projections for possible water futures in Asia. To carry out this assessment, new narratives of water use were established as an extension of the *Shared Socioeconomic Pathways*, giving three future scenarios; the *Sustainability* scenario, the *Middle of the Road* scenario and the *Regional Rivalry* scenario. Focusing on the near future to the 2050s, WFaS assessed how these water futures change over time, using a multi-model projection with 15 ensemble members (five General Circulation Models x three Global Hydrological Models). Subsequently, the impacts of socioeconomic and climatic changes on water security were assessed through the development of a hydro-economic classification system that aggregates indicators of hydrological challenges and adaptation capacities.

The assessment indicates that the impacts of socioeconomic change on water resources are significant. Expected and required growth in food and energy production, driven by population growth and economic development, will increase demands on water resources. WFaS projects that water demand in the agriculture, industrial, and domestic sectors will increase between 30% and 40% in the next decades throughout the three future scenarios considered. Industrial and domestic water demand will grow much more rapidly than agricultural demand, although agriculture will remain the dominant water demand sector.

At regional level, South Asia and East Asia are presently the top two water-consuming regions. Agricultural water demand is largest in South Asia, while industrial and domestic water demand are largest in East Asia, a trend expected to continue. At country level, China and India have the largest total water demand, followed by Pakistan, Indonesia, and Uzbekistan. Water availability per capita is expected to decrease in South Asia, Southeast Asia, Central and West Asia, and Pacific Asia during the early half of the 21st century under all scenarios considered. These reductions are tightly linked to population growth as well climate change impacts.

Pakistan, Afghanistan, India, Singapore, and China will have the lowest water availability per capita in Asia. In some parts of these countries such as northeastern China, eastern Pakistan, northern, southern, and eastern India along the Ganga River, parts of Turkmenistan and Uzbekistan, and northwestern China, the pressures will be even higher due to the spatial variability of water resources, high population density, and urbanization. National strategies and management to cope with these growing pressures are needed. Furthermore, Uzbekistan, Turkmenistan, Cambodia, Pakistan, Bangladesh, Brunei Darussalam, Azerbaijan, and Vietnam will depend on water delivery from upstream countries, thus requiring cooperative transboundary water management.

Groundwater abstractions in Asia cover an important share of water demand. The largest abstractions occur in India, China, and Pakistan, accounting for 86% of Asian total groundwater abstractions. In many countries over-exploitation is occurring, with groundwater abstractions already exceeding recharge rates in some areas, leading to degradation of important aquifer systems. Currently, 25% of total groundwater abstractions in India, China, and Pakistan originate from non-renewable groundwater resources. By the 2050s, groundwater abstractions in Asia will be 30% higher than 2010s levels, with the share of non-renewable groundwater use increasing to 30%.

Finally, this report assesses the imbalance between surface water supply and demand under the three different scenarios. Many areas of Asia are already under severe water scarcity and these areas will further expand in the future. All three scenarios indicate a 40% of population living in severely water-scarce areas by the 2050s. These areas include northwest, northeast, central-eastern, and some coastal urban areas of China, parts of Thailand, Vietnam, Java, and southeastern Australia, and large parts of India, Pakistan, Afghanistan, Uzbekistan, and Turkmenistan.

Our hydro-economic classification, which categorizes countries based on their hydro-climatic complexity and economic-institutional capacity to manage water risks, was performed for all countries in Asia. This analysis shows that six or seven countries, both rich and poor, will be "water-stressed" in the 2050s; depending on the scenario, this affects 34-73% of Asia's total population (up to 3.4 billion in 2050) who will be in the water-stress category. Additionally, Pakistan, Afghanistan, and Azerbaijan remain the most vulnerable countries in Asia, as they will be highly stressed and have low adaptive capacity under all scenarios.

Furthermore, results in this report conclude that the next few decades will see an intensification of multiple challenges at the nexus of the water, food, and energy sectors. These challenges include growing demands for all three nexus resources. Simultaneously, these resources will be put under growing pressure by complex cross-sector interactions, the exhaustion of low-cost supply options, and climate change impacts. The different sectors of the nexus are inextricably linked, but water, food, and energy policies are typically addressed separately within sectoral boundaries. The results of this study point to the need for an integrated approach based on a broader systems perspective capable of addressing the management of water, food, and energy systems from a cross-cutting perspective. Although a fully integrated model and assessment of nexus feedbacks is beyond the scope of this assessment, this report underlines that understanding and managing the cross-sectoral impacts of socioeconomic behavior, as well as climate changes, is crucial for water security, and suggests that water constraints will affect all socioeconomic development.

Policymakers in Asia possess a wide range of policy instruments to address the multiple future water challenges. Water policies are typically divided into: supply-side measures, which seek to increase supply by finding new sources of water; demand-side measures, which promote water efficiency and conservation; and the adoption of best governance practices and well-functioning institutions. All of these instruments entail financial and social costs that need to be considered when designing future water adaptation strategies to socioeconomic and climatic changes. This report presents a review of some of the pathways chosen by different countries to address water scarcity and achieve sustainable water use. They include careful investment in water infrastructure, an improvement of water-use efficiency, the design of effective institutions, and the use of economic instruments for improved allocation of scarce water resources among competing uses.

Consistent solution portfolios that work across sectors and scales of management will need to be identified. Regional and local options must be applied within the context of global communications and markets and the development paths of other countries and regions. To determine how these external factors may influence their choices, their robustness can be tested by modifying local scenarios to see if they produce improved results under all global scenarios. Identifying solution portfolios that work together synergistically in different regions to improve water, energy, and food security, human well-being, and the sustainability of development projects is the focus of continuing work of the WFaS initiative and of future reports.

References

Arnell, N. and Lloyd-Hughes, B., 2014. The global-scale impacts of climate change on water. Climatic Change, Volume 122, pp. 127-140.

Asian Development Bank (ADB), 2013. Asian Water Development Outlook 2013. Measuring Water Security in Asia and the Pacific. ADB. Manila.

Asian Development Bank (ADB), 2013a. Energy outlook for Asia and the Pacific. ADB. Manila.

Asian Development Bank (ADB), 2013b. Food security in Asia and the Pacific. Publication No. RPT135848-2. ADB. Manila.

Asia Society, 2009. Asia's Next Challenge: Securing the Region's Water Future

Bakker, M., 1999. Valuing the multiple uses of water. In M. Bakker, R. Barker, R. Meinzen- Dick & F. Konradsen, eds. Multiple uses of water in irrigated areas: a case study from Sri Lanka, pp. 26–30. SWIM Paper 8. Colombo, IWMI. (available at http: //www.cgiar.org/iwmi/pubs/SWIM/).

Bates, B.C., Kundzewicz, Z.W., Wu, S. and Palutikof, J.P., 2008. *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, Switzerland.

Blewett, R., 2012. Shaping a Nation. A Geology of Australia; Geoscience Australia-ANU Press: Canberra, Australia.

Brooks, D.B., 2003. Another Path Not Taken: A Methodological Exploration of Water Soft Paths for Canada and Elsewhere. Report to Environment Canada. Friends of the Earth Canada, Ottawa, ON.

Brown C. and Lall U., 2006. Water and economic development: The role of variability and framework for resilience. Natural Resources Forum 30: 306-317.

Butz W.P., Lutz W. and Sendzimir J (Eds), 2014. Special Feature, "Education and Differential Vulnerability to Natural Disasters. Ecology and Society.

Chaturvedi, V., Hejazi, M., Edmonds, J., Clarke, L., Kyle, P., Davies, E. and Wise, M., 2013. Climate mitigation policy implications for global irrigation water demand. Mitigation and Adaptation Strategies for Global Change, Volume 20, pp. 1-19.

Cornish, G., Bosworth, B., Perry, C. and Burke, J., 2004. Water Charging in Irrigated Agriculture. An Analysis of International Experience; FAO Water Report No. 28: Rome, Italy.

Cosgrove, W. and Loucks, D., 2015. Water management: Current and future challenges and research directions. Water Resource Research, Volume 51, pp. 4823–4839.

Dankers, R., Arnell N. W., Clark, D. B., Falloon, P. D., Fekete, B. M. , Gosling, S. N., Heinke, J.,Kim, H., Masaki, Y.,Satoh, Y., Stacke, T., Wada, Y. and Wisser, D.,2014. First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble, Proc. Natl. Acad. Sci. USA, 111(9), 3257–3261, doi:10.1073/pnas.1302078110, Global Climate Impacts: A Cross-Sector, Multi-Model Assessment Special Feature.

Dellink, R., J. Chateau, E. Lanzi and Magné, B., 2015. Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change. DOI: http://dx.doi.org/10.1016/j.gloenvcha.2015.06.004

Dinar, A.; Rosegrant, M. and Meinzen-Dick, R., 1997. Water Allocation Mechanisms: Principles and Examples. Policy Research Working Paper No. WPS 1779; World Bank: Washington, DC, USA.

European Commission (EC), 2007. Communication from the Commission to the Council and the European Parliament, "Addressing the challenge of water scarcity and droughts in the European Union", Brussels, 18.07.07, COM(2007) 414 final.

European Commission (EC), 2012. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Blueprint to Safeguard Europe's Water Resources; COM(2012) 673 Final; European Commission: Brussels, Belgium.

Falkenmark, M., 1989. The massive water scarcity threatening Africa-why isn't it being addressed. Ambio 18, no. 2 (1989): 112-118.

FAO, 2010. AQUASTAT online database, Total renewable water resources, The Food and Agriculture Organization of the United Nations, Rome, Italy

FAO, 2012. Irrigation water requirement and water withdrawal by country. Available online at: http://www.fao.org/nr/water/aquastat/water_use_agr/IrrigationWaterUse.pdf

Fischer, G., Tubiello, F. N., van Velthuizen, H. and Wiberg, D., 2007. Climate change impacts on irrigation water requirements: Effects of mitigation, 1990-2080. Technological Forecasting and Social Change (Special Issue: Greenhouse Gases - Integrated Assessment), 74(7):1083-1107

Fischer, G., Hizsnyik, E., Prieler, S., Shah, M. and van Velthuizen H.T., 2009. Biofuels and Food Security. Final Report to Sponsor: The OPEC Fund for International Development (OFID), Vienna, Austria

Fischer, G., 2011. How can climate change and the development of bioenergy alter the long-term outlook for food and agriculture. In: Looking Ahead in World Food and Agriculture: Perspectives to 2050, P Conforti (ed.), FAO, Rome, Italy pp.95-155.

Fischer, G., Nachtergaele, F., Prieler, S., Teixeira, E., Toth, G., van Velthuizen, H. Verelst, L. and Wiberg, D., 2012. Global Agroecological Zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO

Fischer, G., Hizsnyik, E., Tramberend, S. and Wiberg, D., 2015. Towards indicators for water security - A global hydro-economic classification of hydrological challenges and socioeconomic coping capacity. IIASA Interim Report IR-15-01. International Institute for Applied Systems Analysis. Laxenburg.

Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F. and Alcamo, J., 2013. Domestic and industrial water uses of the past 60 years as a mirror of socioeconomic development: A global simulation study. Global Environmental Change, Volume 23, pp. 144-156.

Frieler, K., Meinshausen, M., Mengel, M., Braun, N. and Hare, W., 2012. A scaling approach to probabilistic assessment of regional climate change. Journal of Climate. Volume 25, Issue 9, May 2012, Pages 3117-3144

Fueyo, N., Gomez, A. and Dopazo, C., 2014. Energy security, sustainability, and affordability in Asia and the Pacific. ADB Economics Working Papers Series NO. 401. ADB. Manila.

Ghaffour N., Missimer T. and Amy G., 2013. Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. Desalination 309: 197-207.

Gleick, P.H., 2000. The changing water paradigm: A look at twenty first century water resources development. *Water International* 25.1: 127–138.

Gleick P.H., 2003. Global freshwater resources: soft-path solutions for the 21st century. Science 302, 1524-1528.

Global Runoff Data Centre, 2004. WMO Subregion / Global Runoff Data Centre. Koblenz, Germany: Federal Institute of Hydrology (BfG).

Grafton, Q., Chu, L. and Kompas, T., 2015. Optimal water tariffs and supply augmentation for cost-of-service regulated water utilities. Utilities Policies 34: 54-62.

Grey, D., Garrick, D., Blackmore, D., Kelman, J. Muller and M. Sadoff, C.W., 2013. Water Security in one blue planet: Twenty-first century policy challenges for science. Phil. Trans. R. Soc., pp. 371. 20120406. DOI: 10.1098/rsta.2012.0406

Hall, J.W., D. Grey, D. Garrick, F. Fung, C. Brown, S.J. Dadson, and Sadoff, C.W., 2014. Water security: Coping with the curse of freshwater variability. *Science* (Washington, DC) 346(6208):429–430. doi:10.1126/science.1257890

Hagemann, S. and L. Dümenil Gates, 2003: Improving a subgrid runoff parameterization scheme for climate models by the use of high resolution data derived from satellite observations Clim. Dyn. 21, pp. 349-359

Hanasaki, N., S. Fujimori, T. Yamamoto, S. Yoshikawa, Y. Masaki, Y. Hijioka, M. Kainuma, Y. Kanamori, T. Masui, K. Takahashi, and Kanae, S., 2013. A global water scarcity assessment under Shared Socioeconomic Pathways - Part 2: Water availability and scarcity. Hydrology and Earth System Sciences, 2013. 17(7): p. 2393-2413.

Hanemann, W., 1998. Determinants of Urban Water Use. In Urban Water Demand Management and Planning; Bauman, D., Boland, J., Hanemann, W., Eds.; McGraw-Hill: New York, NY, USA, 1998.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H. and Kanae, S., 2013. Global flood risk under climate change, Nature Climate Change, 3, 816-821, doi:10.1038/NCLIMATE1911, 2013

Howe, C., Schurmeier, D., Shaw, W. 1986. Innovative Approaches to Water Allocation: The Potential for Water Markets. Water Resources Research 22, 439–449.

Huffaker, R. 2008. Conservation potential of agricultural water conservation subsidies. Water Resources Research 44, 1–8.

International Energy Agency (IEA), 2012. Water for energy: Is energy becoming a thirstier resource? Excerpt from the World Energy Outlook 2012. IEA.

International Energy Agency (IEA), 2015a. Energy balances of non-OECD countries. IEA Statistics. OECD/IEA. Paris.

International Energy Agency (IEA), 2015b. World Energy Outlook 2015. OECD/IEA. Paris.

IPCC: Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change

Jones, B. and O'Neill, B., 2013. Historically grounded spatial population projections for the continental United States, Environmental Research letters, doi:10.1088/1748-9326/8/4/044021

Kahil, M.T., Albiac, J., Dinar, A., Calvo, E., Esteban, E., Avella, L. and Garcia-Molla, M. 2016. Improving the Performance of Water Policies: Evidence from Drought in Spain. *Water 8,* 34.

KC, S. and Lutz, W., 2014. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change.

King, C.W., Holman, A.S. and Webber, M.E., 2008. Thirst for energy. Nature Geoscience Volume 1(5):pp. 283-286.

Kirby, M., Bark, R., Connor, J., Qureshi, E. and Keyworth, S., 2014. Sustainable irrigation: How did irrigated agriculture in Australia's Murray-Darling Basin adapt to the Millennium drought? Agricultural Water Management 145, 154–162.

Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P., 2008. High resolution mapping of the world's reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas. Map 81: GRanD Database (V1.0). Available online at http://atlas.gwsp.org

Liu, J., Mooney, H., Hull, V., Davis, S.J., Gaskell, J., Hertel, T., Lubchenco, J., Seto, K.C., Gleick, P., Kremen, C. and Li, S., 2015. Systems integration for global sustainability. Science, Volume 347(6225).

Lutz, W., Muttarak, R., Striessnig, E., 2014. Universal education is key to enhanced climate adaptation. *Science* 346(6213):1061-1062.

Magnuszewski, P., Wiberg D., Cosgrove, W., Fischer, G., Flörke, M., Hizsnyik, E., Pahl-Wostl, C., Segrave, A., Toth, G., Tramberend, S., van Vliet, M., Yillia, P. and Zeller, D., 2015. Conceptual framework for scenarios development in the Water futures and Solutions project. IIASA Interim Report IR-15-011. International Institute for Applied Systems Analysis (IIASA). Laxenburg.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P. and Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. Nature 463:747-756.

Müller Schmied, H., Eisner, S., Franz, D., Wattenbach, M., Portmann, F. T., Flörke, M., and Döll, P., 2014. Sensitivity of simulated global-scale freshwater fluxes and storages to input data, hydrological model structure, human water use and calibration, Hydrol. Earth Syst. Sci., 18, 3511-3538, doi:10.5194/hess-18-3511-2014.

OECD 2016. Mitigating Droughts and Floods in Agriculture: Policy Lessons and Approaches, OECD Studies on Water, OECD Publishing, Paris.

O'Neill, B., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R. and van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Climatic Change, 122(3), pp. 387-400.

O'Neill, B., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M. and Solecki, W., 2015. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change.

Pérez-Urdiales, M., García-Valiñas, M.A. and Martínez-Espiñeira, R., 2016. Responses to Changes in Domestic Water Tariff Structures: A Latent Class Analysis on Household-Level Data from Granada, Spain. Environmental and Resource Economics 63: 167-191.

Perry, C., Wichelns, D. and Steduto, P. (2014). The myth that "water efficiency" will eradicate hunger and poverty. Waterfront 4, 10.

Pound D., Hardcastle K., Magnuszewski P., Yillia P.T. and Hizsnyik E., 2013. Water Futures and Solution: World Water Scenarios Initiative, Scenario Focus Group Workshop 1, 4-6 November 2013, Workshop outputs Word for Word Report, IIASA WFaS report.

Qureshi, M., Schwabe, K., Connor, J. and Kirby, M., 2010. Environmental water incentive policy and return flows. Water Resources Research 46 (4), W04517.

Raskin, P., Gleick, P., Kirshen, P., Pontius, G. and Strzepek, K. 1997. Water Futures: Assessment of Long-range Patterns and Prospects. Stockholm, Sweden: Stockholm Environment Institute, 1997.

Reynaud, A. 2013. Assessing the impact of price and non-price policies on residential water demand: a case study in Wisconsin. International Journal of Water Resources Development, 29 (3): 415–433.

Richey, A., B. Thomas, M. Lo, J. Reager, J. Famigliettti, K. Voss, S. Swenson and Rodell, M., 2015. Quantifying renewable groundwater stress with GRACE. Water Resources Research, 51, doi:10.1002/2015WR017349

Roibás, D., García-Valiñas, M.A., and Wall, A. 2007. Measuring welfare losses from interruption and pricing as responses to water shortages: an application to the case of Seville. Environmental and Resource Economics 38(2):231–243.

Sadoff, C.W., Hall, J.W., Grey, D., Aerts, J.C.J.H., Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., Kelman, J., McCornick, P., Ringler, C., Rosegrant, M., Whittington, D. and Wiberg, D., 2015. Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth, University of Oxford, UK, 180pp.

Saleth, R.M. and Dinar, A., 2004. The Institutional Economics of Water: A Cross- Country Analysis of Institutions and Performance, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Satoh Y., Yoshimura K., Pokhrel Y., Kim H. and Oki T., 2015. The shift in onset of unprecedented hydrological drought as a response to different levels of global warming, EGU2015-13348, European Geosciences Union

Schewe, J., Heinke, J., Gerten, G., Haddeland, I., Arnell, N.W., Clark, D.B., Dankers, R., Eisner, S., Fekete, B., Colón-González, F. J., Gosling, S. N., Kim, H., Liu, S. N., Masaki, Y., Portmann, F. T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L. and Kabat, P., 2014. Multi-model assessment of water scarcity under climate change, Proc. Natl. Acad. Sci. USA, 111(9), 3245–3250, doi:10.1073/pnas.1222460110, Global Climate Impacts: A Cross-Sector, Multi-Model Assessment Special Feature.

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G.C., Fujimori, S., Gurgel, A., Havlik, P., Heyhoe, E., d'Croz, D.M., Popp, A., Sands, R., Tabeau, A., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A. and Valin, H., 2014. Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. Agricultural Economics, Volume 45(1): pp. 69-84.

Schwabe, K., Albiac, J., Connor, J., Hassan, R. and Meza, L. (Eds.) 2013. Drought in arid and semi-arid regions: A multi-disciplinary and cross-country perspective. Springer, Dordrecht.

Stacke, T., and S. Hagemann, 2012: Development and validation of a global dynamical wetlands extent scheme. Hydrol. Earth Syst. Sci., 16, 2915-2933

Stern, N., 2007. *The Economics of Climate Change: The Stern Review*, Cambridge, UK: Cambridge University Press.

Tramberend, S., Wiberg, D., Wada, Y., Flörke, M., Fischer, G., Satoh, Y., Yillia, P. van Vliet, M., Hizsnyik, E., Nava Jimenéz, L.F. and Blokker, M., 2015. Building Global Water Use Scenarios, IIASA Interim Report IR-15-014. International Institute for Applied Systems Analysis (IIASA). Laxenburg.

Tsur, Y., Dinar, A., Doukkali, R. and Roe, T., 2004. Irrigation water pricing: Policy implications based on international comparison. Environment and Development Economics 9, 735–755.

UN-Water, 2008. Transboundary Waters: UN-Water Thematic Paper Sharing Benefits, Sharing Responsibilities. UN-Water Thematic Paper.

United Nations World Water Assessment Programme (WWAP), 2014. The United Nations World Water Development Report 2014: Water and Energy. Paris, UNESCO.

Van Beek, L. P. H., Wada, Y., and Bierkens, M. F. P., 2011. Global monthly water stress: I. Water balance and water availability, Water Resour. Res., 47, W07517, doi:10.1029/2010WR009791

van Vliet, M., Yearsley, J., Ludwig, F., Vögele, S., Lettenmaier, D. and Kabat, P., 2012. Vulnerability of US and European electricity supply to climate change. Nature Climate Change, Volume 2, pp. 676-681.

van Vliet, M., Wiberg, D., Leduc, S. and Riahi, K., 2016. Power-generation system vulnerability and adaptation to changes in climate and water resources. Nature Climate Change DOI: 10.1038/NCLIMATE2903

van Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J. and Rose, S.K., 2011. The representative concentration pathways: an overview. Climatic Change, 109(1), pp. 5-31.

Veldkamp, T. I. E., Wada, Y., Aerts, J.C.J.H. and Ward, P.J., 2016. Towards a global water scarcity risk assessment framework: incorporation of probability distributions and hydro-climatic variability. Environmental Research Letters 11(2): 024006.

Vörösmarty, C. J., Peterson, B. J., Lammers, R. B., Shiklomanov, I. A. and Shiklomanov, A.I., 1998. A regional, electronic Hydrometeorlogical data network for the pan-Arctic Region.

Vörösmarty, C., McIntyre, P., Gessner, M., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S., Sullivan, C., Liermann, C. and Davies, P., 2010. Global threats to human water security and river biodiversity. Nature 467, 555–561.

Wada, Y., Wisser, D., Eisner, S., Flörke, M., Gerten, D., Haddeland, I., Hanasaki, N., Masaki, Y., Portmann F. T., Stacke, T., Tessler, Z. and Schewe, J., 2013. Multimodel projections and uncertainties of irrigation water demand under climate change, Geophys. Res. Lett., 40, 4626–4632, doi:10.1002/grl.50686.

Wada, Y., Wisser, D., and Bierkens, M. F. P., 2014. Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources, Earth Syst. Daynam., 5, 15-40, doi:10.5194/esd-5-15-2014.

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y., van Vliet, M., Yillia, P., Ringler, C., Burek, P. and Wiberg, D., 2016. Modeling global water use for the 21st century: Water Futures and Solutions (WFaS) initiative and its approaches. Geoscientific Model Development, Volume 8, pp. 6417–6521.

Ward F. and Pulido-Velazquez M., 2008. Water conservation in irrigation can increase water use. PNAS 105 (47): 18215-18220.

Ward, F., 2012. Cost–benefit and water resources policy: a survey. Water Policy 14: 250-280.

Warszawski, L., K. Frieler, V. Huber, F. Piontek, O. Serdeczny, and Schewe, J., 2014. The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): Project framework. Proc. Natl. Acad. Sci. USA, 111, 9, 3228-3232, doi: 10.1073/pnas.1312330110.

Water Futures and Solutions (WFaS), 2013. Project Group Meeting, 30 Sep – 2 Oct 2013, Laxenburg, Austria, Report, IIASA.

Wheeler, S., Loch, A., Zuo, A. and Bjornlund, H., 2014. Reviewing the adoption and impact of water markets in the Murray–Darling Basin. Australia. Journal of Hydrology 518, 28–41.

Winsemius, H.C., Aerts, J.C.J.H., van Beek L.P.H., Bierkens, M.F.P., Bouwman, A., Jongman, B., Kwadijk, J., Lucas, P.,van Vuuren, D.P. and Ward, P.J., 2015. Global drivers of future river flood risk Nat. Clim. Change. doi:10.1038/nclimate2893

Wisser, D., Fekete, B. M., Vörösmarty, C. J. and Schumann, A. H., 2010. Reconstructing 20th century global hydrography: A contribution to the Global Terrestrial Network-Hydrology (GTN-H). Hydrology and Earth System Sciences, 14(1),1-24. European Geophysical Society, doi:10.5194/hess-14-1-010

Appendices

Appendix A1: WFaS water storylines and implications for industrial water use

SSP1: Sustainability – Taking the green road

Elements of the SSP storyline relevant for the ENERGY sector

- Reduced overall energy demand over the longer term
- Lower energy intensity, with decreasing fossil fuel dependency
- Relatively rapid technological change is directed toward environmentally friendly processes, including energy efficiency, clean energy technologies; favorable outlook for renewables - increasingly attractive in the total energy mix
- Strong investment in new technologies and research improves energy access
- Advances in alternative energy technologies

Implications for electricity water use intensity

- Reduction in energy demand will substantially decrease the demand for water from the energy sector, even if world population, primary energy production, and electricity generation were to increase
- A shift away from traditional biomass toward less consuming energy carriers, as well as changing energy mix in electricity generation could lead to water savings
- A favorable outlook for renewables will cause big structural and efficiency shifts in the choice of technology with variable consequences for water use intensity and efficiency, depending on the renewable type. For example, an expanding output of biofuels will lead to a rise in water consumption, whereas a shift toward photovoltaic solar power or wind energy will lead to a decrease in water use intensity
- Higher energy efficiency could translate into a relatively lower water demand, improvements in water quality, following high standards that commit industry to continually improving environmental performance
- Overall, structural and technological changes will result in decreasing water use intensities in the energy sector. For example, the widespread application of water-saving technologies in the energy sector will significantly reduce the amount of water used not only for fuel extraction and processing but also for electricity generation

Elements of the SSP storyline relevant for the MANUFACTURING sector

- Improved resource-use efficiency
- More stringent environmental regulations
- Rapid technological change is directed toward environmentally friendly processes
- Research and technology development reduce the challenges of access to safe water
- Risk reduction and sharing mechanism

Implications for manufacturing water use

- The importance of the manufacturing sector in the overall economy decreases further due to the increasing importance of the non-resource-using service sector
- Manufacturing industries with efficient water use and low environmental impacts are favored and increase their competitive position against water intensive industries
- Enhanced treatment, reuse of water, and water-saving technologies; widespread application of water-saving technologies in industry

SSP2: Middle of the road

Elements of the SSP storyline relevant for the ENERGY sector

- Continued reliance on fossil fuels, including unconventional oil and gas resources
- Stabilization of overall energy demand over the long run
- Energy intensity declines, with slowly decreasing fossil fuel dependency
- Moderate pace of technological change in the energy sector
- Intermediate success in improving energy access for the poor

Implications for electricity water use intensity

- Reliance on fossil fuels may lead to only minor structural and efficiency shifts in technology
- Stabilization of overall energy demand over the long run will lead to little or no change in water demand for fuel extraction, processing, and electricity generation
- A decline in energy intensity will lower water demand
- A moderate pace in technological change will cause minor structural and efficiency shifts in technology and ultimately water use intensity

will change only slightly
- Weak environmental regulation and enforcement trigger only slow technological progress in water use efficiencies
- Regional stress points will increase globally. Power generation in regional stress points will likely have to deploy more and more technologies fit for water-constrained conditions to manage water-related risks, although this can involve trade-offs in cost, energy output, and project siting.
- In general, if historic trends remain the same, water use intensities will continue to decrease in the most developed regions. However, there will be slow progress in Africa, Latin America, and other emerging economies

Elements of the SSP storyline relevant for the MANUFACTURING sector

- The SSP2 World is characterized by dynamics similar to historical developments
- Moderate awareness of environmental consequences from natural resource use
- Modest decline in resource-intensity
- Consumption oriented toward material-growth
- Technological progress but no major breakthrough
- Persistent income inequality (globally and within economies)

Implications for manufacturing water use

- Manufacturing GVA further declines in relative terms
- Moderate and regionally different decreases in manufacturing water use intensities
- Following historic trends water use intensities further decrease in the most developed regions but less progress in Africa, Latin America and other emerging economies
- Weak environmental regulation and enforcement trigger only slow technological progress in water use efficiencies

SSP3: Regional Rivalry – A rocky road

Elements of the SSP storyline relevant for the ENERGY sector

- Growing resource intensity and fossil fuel dependency
- Focus on achieving energy and food security goals within own region
- Barriers to trade, particularly in the energy resource and agricultural markets
- Use of domestic energy results in some regions increases heavy reliance on fossil fuels
- Increased energy demand driven by high population growth and little progress in efficiency.

Implications for electricity water use intensity

- Barriers in trade may trigger slow technological progress in water use efficiencies. A moderate pace in technological change will cause minor structural and efficiency shifts in technology and ultimately water use intensity will change only slightly.
- Reliance on fossil fuels may lead to only minor structural and efficiency shifts in technology
- An increase in energy intensity will increase water demand whereas little progress in efficiency would trigger increased water demand as energy use intensifies
- Weak environmental regulation and enforcement hamper technological progress in water use efficiencies; hence very low progress in water-saving technologies.

Elements of the SSP storyline relevant for the MANUFACTURING sector

- Low priority for addressing environmental problems
- Resource-use intensity is increasing
- Low investment in education and technological development
- Persistent income inequality (globally and within economies)
- Weak institutions and global governance

Implications for manufacturing water use

- Manufacturing GVA in relative terms (% of GDP) declines more slowly than historic trends
- Weak environmental regulation and enforcement hamper technological progress in water use efficiencies
- Very low progress in water-saving technologies
- Water use intensities increase only marginally, primarily in the most developed regions

Appendix A2: WFaS water storylines and implications for domestic water use

SSP1: Sustainability – Taking the green road

Elements of the SSP storyline relevant for the DOMESTIC sector

- Inequality reduction across and within economies
- Effective and persistent cooperation and collaboration across the local, national, regional, and international scales and between public organizations, the private sector, and civil society within and across all scales of governance
- Resource use efficiency optimization associated with urbanizing lifestyles
- Changing consumption and investment patterns
- Civil society helps drive the transition from increased environmental degradation to improved management of the local environment and the global commons
- Research and technology development reduce the challenges of access to safe water
- Emphasis on promoting higher education levels, gender equality, access to health care and to safe water, and sanitation improvements.
- Investments in human capital and technology lead to a relatively low population
- Better-educated populations and high overall standards of living confer resilience to societal and environmental changes with enhanced access to safe water, improved sanitation, and medical care

Implications for domestic water use intensity

- Management of the global commons will slowly improve if cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society is enhanced
- A demographic transition to lower population levels can be achieved if education and health investments are increased
- Inequality can be reduced both across and within countries if development goals are achieved
- Sustainability relies on increasing environmental awareness in societies around the world
- Industrialized countries support developing countries in their development goals by providing access to human and financial resources and new technologies

SSP2: Middle of the road

Elements of the SSP storyline relevant for the DOMESTIC sector

- Moderate awareness of the environmental consequences of choices when using natural resources
- There is relatively weak coordination and cooperation among national and international institutions, the private sector, and civil society to address environmental concerns
- Education investments are not high enough to rapidly slow population growth
- Access to health care and safe water and improved sanitation in low-income countries makes steady progress
- Gender equality and equity improve slowly
- Consumption is oriented toward material growth, with growing consumption of animal products
- Conflicts over environmental resources flare when and where there are high levels of food and/or water insecurity
- Growing energy demand lead to continuing environmental degradation

Implications for domestic water use intensity

- Weak environmental awareness triggers slow achievement of water security and progress in water use efficiencies.
- Lack of cooperation and collaboration on the part of global and national institutions slows progress toward achieving sustainable development goals
- Growing population and intensity of resource lead to environmental systems degradation
- Lower education investments do not promote slow population growth
- Access to health care, safe water, and sanitation services is affected by population growth and heterogeneities within countries
- Conflicts over natural resources access and corruption hamper the effectiveness of development policies.

SSP3: Regional Rivalry – A rocky road

Elements of the SSP storyline relevant for the DOMESTIC sector

- Societies become more skeptical about globalization
- Countries show weak progress in achieving sustainable development goals
- Environmental policies have a very little importance. Serious degradation of the environment becomes critical
- Cooperation among organizations and institutions is weak. Their leadership is highly questionable
- Low investments in education and in technology increase socioeconomic vulnerability
- Growing population and limited access to health care, safe water, and sanitation services challenge human and natural systems

- Gender equality and equity remain stable
- Consumption is material-intensive and economic development remains stratified by socioeconomic inequalities

Implications for domestic water use intensity

- Countries are pushed to focus on domestic issues.
- National and regional security issues foster stronger national policies to secure access to water resources and sanitation services
- Consumption is primarily material-intensive and water use important.
- A move toward sustainable development goals will lead to authoritarian forms of government and consequently to a rise in social awareness of water uses
- Water security and environmental system health are triggered by high levels of water consumption and limited development of human capital
- National rivalries between the countries in a certain region weaken progress toward sustainable development goals and increase competition for natural resources

Appendix A3: WFaS water storylines and implications for agricultural water use

SSP1: Sustainability – Taking the green road

In SSP1 the world is gradually moving toward sustainability.

- Sustainability concerns; more stringent environmental regulation implemented
- Rapid technological change
- Energy efficiency and improved resource efficiency
- Relatively low population growth; emphasis on education
- Effective institutions
- Wide access to safe water
- Emphasis on regional production
- Some liberalization of agricultural markets
- Risk reduction and sharing mechanisms in place

The above general tendencies of development in the SSP1 world can be interpreted as having the following agriculture-/irrigation-related implications:

- Improved agricultural productivity and resource use efficiency
- Quite rapid reduction of prevailing yield gaps toward environmentally sustainable and advanced technology yield levels
- Improving nutrition with environmentally benign diets and lower per capita consumption of livestock products
- Enforced limits to groundwater over-exploitation
- Large improvements in irrigation water use efficiency
- Reliable water infrastructure and water sources
- Enhanced treatment and reuse of water
- Concern for pollution reduction and water quality, implying widespread application of precision farming and nutrient management
- Risk management and related measures implemented in order to reduce and spread yield risks

SSP2: Middle of the road

In SSP2 the world is the world is progressing along past trends and paradigms.

- Most economies are politically stable
- Markets are globally connected but function imperfectly
- Slow progress in achieving development goals of education, safe water, health care
- Technological progress but no major breakthrough
- Modest decline in resource use intensity
- Population growth levels off in second half of century
- Urbanization proceeds according to historical trends
- Consumption is oriented toward material growth
- Environmental systems experience degradation
- Significant heterogeneities exist within and across countries
- Food and water insecurity remain in areas of low-income countries
- Barriers to entering agricultural markets are reduced only slowly
- Moderate corruption slows effectiveness of development policies

The SSP2 world is characterized by dynamics similar to historical developments. This would imply continuation of agricultural growth paths and policies, continued protection of national agricultural sectors, and further environmental damages caused by agriculture:

- Modest progress of agricultural productivity
- Slow reduction in yield gaps especially in low-income countries
- Increasing per capita consumption of livestock products with growing incomes
- Persistent barriers and distortions in international trade of agricultural products
- No effective halt to groundwater over-exploitation
- Some improvements in water use efficiency, but only limited advances in low-income countries
- Some reduction in food insecurity due to trickle down of economic development
- Food and water insecurity remain as problems in some areas of low-income countries
- No effective measures to prevent pollution and degradation by agricultural practices; environmental risks caused by intensive application of fertilizers and agro-chemicals, and intensive and concentrated livestock production systems
- Only moderate success in reducing climate risks and vulnerability

SSP3: Regional rivalry

In SSP3, world development is stagnating.

- Growing concerns about globalization and focus on national/regional issues and interests
- Markets (agriculture, energy) are protected and highly regulated
- Global governance and institutions are weak
- Low priority for addressing environmental problems
- Slow economic growth
- Low investment in education and technology development
- Poor progress in achieving development goals of education, safe water, health care
- Increase in resource use intensity
- Population growth low in developed, high in developing countries; overall large increase
- Urbanization proceeds slowly; disadvantaged continue to move to unplanned settlements
- Serious degradation of environmental systems in some regions
- Large disparities within and across countries
- Weak institutions contribute to slow development

Development in the SSP3 world will lead to manifold problems in food and agriculture, with implications for irrigation development and water challenges, characterized by:

- Poor progress with agricultural productivity improvements in low-income countries due to lack of investment and education
- Widespread lack of sufficient investment and capacity for yield gap reduction in developing countries
- Growing protection of national agricultural sectors and increasing agricultural trade barriers. Low priority to halt environmental degradation caused by agriculture (erosion, deforestation, poor nutrient management, water pollution, and exploitation)
- Widespread pollution and deterioration of ecosystems
- Continued deforestation of tropical rainforests
- Only modest improvements of irrigation water use efficiency
- Persistent over-exploitation of groundwater aquifers
- Widespread lack of access to safe water and sanitation
- Unreliable water and energy supply for agricultural producers
- Food and water insecurity persist as major problems in low-income countries
- High population growth and insufficient development leave behind highly vulnerable human and environmental systems

Appendix B1: Population growth in Asian countries under three water scenarios

Population	**(x 10^3)**	**2015**			**2030**			**2050**			**2100**		
Region	**Nation**	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry
Central and West Asia	Afghanistan	35400	35819	36501	46740	51895	58542	59470	75343	100617	64083	111717	222907
	Kazakhstan	16850	16924	16963	18471	19000	19332	19336	20829	22016	15206	19706	25835
	Kyrgyzstan	5608	5641	5680	6107	6340	6752	6143	6753	7885	4349	5916	9226
	Tajikistan	7246	7284	7380	7969	8270	9243	7948	8755	11324	5773	7904	14620
	Turkmenistan	5316	5344	5373	5869	6087	6368	5975	6511	7266	4246	5641	8034
	Uzbekistan	28826	28979	29183	31528	32758	34808	31733	34759	40459	22077	29609	49370
	Armenia	3087	3092	3112	2988	3045	3174	2739	2884	3185	1760	2287	3275
	Azerbaijan	9854	9916	9933	10766	11086	11248	10882	11717	12280	7718	10301	13796
	Georgia	4248	4250	4285	3852	3887	4121	3211	3279	3833	1679	2040	3587
East Asia	China	1361023	1364053	1366395	1357272	1377723	1399601	1218805	1255265	1309802	643590	754132	1046138
	Mongolia	2946	2962	2980	3296	3421	3582	3441	3776	4240	2617	3588	5332
Pacific Asia	Fiji	889	892	901	916	941	1019	863	927	1129	561	731	1286
	Samoa	183	183	188	177	179	219	157	162	257	99	120	340
	Solomon Islands	597	603	605	741	781	820	858	975	1093	757	1079	1535
	Timor-Leste	1242	1245	1275	1562	1653	1951	1778	2055	3063	1659	2503	6071
	Tonga	106	106	108	106	108	128	98	103	155	65	81	209
	Vanuatu	265	267	268	329	346	364	383	433	488	347	482	708
South Asia	Bangladesh	156312	157092	158213	171986	178646	189031	174209	190671	219321	121533	161613	259595
	Bhutan	791	795	796	958	993	1002	1098	1205	1261	903	1218	1727
	India	1299391	1307169	1317281	1456612	1520626	1607984	1543020	1714611	1982470	1130900	1569457	2686574
	Maldives	338	339	340	391	405	417	428	462	499	349	428	606
	Nepal	32648	32862	33265	39624	41711	45156	45493	51376	62478	39612	55129	102100
	Pakistan	188327	189826	191529	223809	237241	255167	248623	286349	344119	212164	313968	550589
Southeast Asia	Cambodia	14905	14984	15091	16490	17141	18185	16777	18552	21407	11966	16750	26768
	Indonesia	250492	251286	252238	269532	276373	284606	269183	285495	306167	181589	225099	292127
	Lao PDR	6607	6653	6697	7542	7900	8383	7890	8820	10177	5752	8231	13186
	Malaysia	30623	30764	30864	36303	37589	38804	40702	44257	48324	36236	46853	68100
	Myanmar	49132	49373	49615	49997	51771	54055	45996	49842	55271	27725	37927	57358
	Philippines	100272	100907	101763	116546	121997	131217	126597	141441	169729	107025	146627	250596
	Thailand	70931	71069	71174	73419	74762	75608	69647	72819	75903	42664	53830	78532
	Viet Nam	92182	92487	92848	99879	102453	105418	99196	105136	112919	64030	78087	108516
Advanced economies	Australia	24072	23994	23773	29643	29180	26735	36758	35501	28303	46667	43331	23149
	Brunei Darussalam	437	439	439	539	551	547	632	672	674	543	686	884
	Japan	126226	125974	125441	121852	119931	115121	112489	107482	94848	84432	74738	45661
	New Zealand	4618	4613	4578	5424	5379	5014	6376	6232	5157	7576	7132	4072
	Republic of Korea	49102	49030	48868	50563	49953	48258	48569	46390	41397	34680	30152	18632
	Singapore	5608	5564	5549	6686	6637	6365	7617	7632	6886	6656	7627	7371

Appendix B2: GDP growth in Asian countries under three water scenarios

GDP (PPP)	**Billion US$2005/yr**	**2015**			**2030**			**2050**			**2100**		
Region	Natino	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry
Advanced economies	Australia	941.6	940.7	929.6	1490.9	1435.0	1295.8	2444.3	2131.3	1559.3	4898.4	4248.3	1691.0
	Singapore	321.9	322.2	318.9	483.0	482.9	448.5	577.1	593.1	482.1	463.4	616.0	466.1
	New Zealand	125.4	125.3	124.4	176.9	170.5	158.6	296.4	259.6	198.3	678.9	664.6	283.1
	Republic of Korea	1597.6	1595.6	1590.3	2641.3	2542.6	2393.9	3695.9	3421.9	2748.4	4289.1	4177.6	1923.9
	Brunei Darussalam	20.8	21.0	20.9	31.8	32.2	29.8	46.4	49.0	38.2	54.8	84.5	58.2
	Japan	4130.6	4122.9	4104.9	5022.8	4764.4	4509.9	6437.0	5319.2	4212.8	8410.1	6795.3	2933.2
East Asia	China	13852.4	13882.1	13904.5	38292.5	33582.3	31120.3	68441.8	50967.5	38452.5	60660.5	59184.7	37012.2
	Mongolia	17.7	17.8	17.9	60.2	53.4	49.3	147.6	119.0	91.6	231.6	279.0	211.8
Central and West Asia	Uzbekistan	108.5	109.2	110.0	269.2	253.1	242.5	635.3	526.1	423.0	1165.1	1301.3	1053.2
	Afghanistan	47.6	48.2	48.7	109.6	101.9	101.9	456.7	314.4	264.8	3708.0	3490.8	1621.1
	Kyrgyzstan	14.1	14.2	14.3	31.6	29.7	29.3	84.7	70.6	61.5	200.3	231.5	202.5
	Georgia	27.2	27.3	27.5	54.3	47.9	46.6	101.4	75.6	65.0	136.0	140.2	130.3
	Turkmenistan	54.8	55.2	55.5	149.7	158.0	152.4	265.3	289.6	283.1	265.5	369.2	408.9
	Armenia	18.1	18.2	18.3	31.6	29.0	28.7	57.0	43.6	38.3	76.4	75.8	64.2
	Tajikistan	17.7	17.8	18.0	45.2	39.4	39.6	135.0	94.1	83.5	297.5	314.0	270.1
	Kazakhstan	239.1	240.3	240.7	539.5	515.2	521.3	853.9	751.3	759.9	965.3	1073.4	862.3
	Azerbaijan	91.3	91.7	91.9	128.9	126.2	126.9	182.7	155.3	128.4	379.7	381.6	225.2
Southeast Asia	LPDR	20.9	21.1	21.2	59.1	53.5	51.6	167.0	119.2	93.0	422.3	420.5	233.5
	Viet Nam	333.1	334.4	335.6	861.6	787.2	745.5	2091.5	1602.4	1255.9	4094.5	4047.2	2515.3
	Myanmar	91.5	92.0	92.4	214.4	187.8	179.2	501.7	304.4	224.2	1044.4	703.2	287.9
	Malaysia	473.0	475.2	476.9	941.2	903.3	864.7	1853.7	1683.4	1399.8	3444.0	4002.3	3155.7
	Thailand	649.8	651.2	652.0	1399.7	1298.9	1184.0	2899.3	2389.5	1679.0	4416.4	4836.2	2849.3
	Philippines	413.8	416.7	419.9	871.8	818.9	783.5	2340.1	1802.9	1388.7	7535.0	7450.8	4754.9
	Indonesia	1262.3	1266.8	1271.2	3417.5	3045.0	2843.9	9086.7	6335.0	4534.4	18550.5	14987.2	6619.4
	Cambodia	38.3	38.6	38.8	102.6	92.9	88.8	291.7	204.2	156.5	891.4	816.3	417.2
Pacific	Tonga	0.5	0.5	0.5	0.7	0.7	0.7	1.5	1.2	1.2	4.0	3.9	4.0
	Papua New Guinea	23.5	23.8	23.8	53.1	50.0	47.4	176.9	132.2	98.6	731.9	690.6	346.4
	Vanuatu	1.1	1.1	1.2	2.5	2.3	2.1	8.2	5.8	4.3	36.7	32.9	15.9
	Samoa	0.8	0.8	0.8	1.2	1.2	1.2	2.4	1.9	2.0	5.2	5.7	6.0
	Solomon Islands	1.7	1.7	1.7	4.1	3.7	3.4	13.1	9.5	6.9	50.4	50.6	24.5
	Timor-Leste	2.3	2.3	2.3	7.5	6.7	6.8	32.1	20.4	16.8	182.5	138.3	71.7
	Fiji	3.9	4.0	4.0	6.2	6.0	5.8	14.0	11.3	9.2	39.3	42.3	25.1
South Asia	Pakistan	487.5	492.2	496.1	1017.3	967.9	915.8	3134.4	2479.5	1759.9	12060.3	13333.7	6186.1
	Maldives	2.8	2.8	2.8	5.1	4.9	4.7	11.2	9.3	7.6	22.8	24.6	16.0
	Bangladesh	299.6	301.6	303.3	841.0	750.7	707.6	2636.7	1754.1	1236.3	7746.9	6975.5	3207.8
	Bhutan	5.6	5.7	5.7	21.1	20.0	17.8	56.6	51.0	35.0	115.5	145.7	80.2
	Nepal	39.2	39.5	39.9	95.6	85.3	78.6	380.2	237.6	156.7	2062.9	1642.2	675.7
	India	4978.7	5017.0	5047.2	13287.6	12207.7	11288.5	36896.7	27538.5	18892.2	87096.5	81989.5	36935.6
	Sri Lanka	132.2	133.0	133.3	310.9	294.8	276.8	688.9	563.9	411.1	1276.5	1430.0	742.7

Appendix B3: Growth in GDP per capita in Asian countries under three water scenarios

GDP per capita (PPP)	US$2005/yr/cap	2015			2030			2050			2100		
Region	Natino	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry	Sustainability	Middle of the Road	Regional Rivalry
Advanced economies	Australia	38981.4	940.7	929.6	50159.7	1435.0	1295.8	66797.3	2131.3	1559.3	118201.2	4248.3	1691.0
	Singapore	59643.3	322.2	318.9	80143.7	482.9	448.5	90486.6	593.1	482.1	106957.7	616.0	466.1
	New Zealand	27186.0	125.3	124.4	33329.5	170.5	158.6	49042.3	259.6	198.3	105035.0	664.6	283.1
	Republic of Korea	32680.0	1595.6	1590.3	52528.9	2542.6	2393.9	76440.4	3421.9	2748.4	134299.3	4177.6	1923.9
	Brunei Darussalam	48619.5	21.0	20.9	64172.2	32.2	29.8	85485.9	49.0	38.2	130677.3	84.5	58.2
	Japan	32779.8	4122.9	4104.9	41045.5	4764.4	4509.9	56606.7	5319.2	4212.8	109313.2	6795.3	2933.2
East Asia	China	10213.7	13882.1	13904.5	28166.3	33582.3	31120.3	55892.6	50967.5	38452.5	94195.2	59184.7	37012.2
	Mongolia	6037.8	17.8	17.9	18348.7	53.4	49.3	43186.0	119.0	91.6	88669.3	279.0	211.8
Central and West Asia	Uzbekistan	3798.1	109.2	110.0	8733.8	253.1	242.5	20838.9	526.1	423.0	55000.0	1301.3	1053.2
	Afghanistan	1343.1	48.2	48.7	2298.2	101.9	101.9	7526.0	314.4	264.8	56716.2	3490.8	1621.1
	Kyrgyzstan	2545.7	14.2	14.3	5340.0	29.7	29.3	14657.4	70.6	61.5	49899.1	231.5	202.5
	Georgia	6435.5	27.3	27.5	14361.0	47.9	46.6	32613.5	75.6	65.0	83554.3	140.2	130.3
	Turkmenistan	10390.1	55.2	55.5	25911.6	158.0	152.4	45654.5	289.6	283.1	64713.2	369.2	408.9
	Armenia	5942.8	18.2	18.3	11035.2	29.0	28.7	23175.0	43.6	38.3	56662.8	75.8	64.2
	Tajikistan	2476.6	17.8	18.0	5970.5	39.4	39.6	19001.0	94.1	83.5	61160.2	314.0	270.1
	Kazakhstan	14304.3	240.3	240.7	29697.9	515.2	521.3	45577.0	751.3	759.9	66743.3	1073.4	862.3
	Azerbaijan	9507.3	91.7	91.9	12430.4	126.2	126.9	17689.6	155.3	128.4	53784.3	381.6	225.2
Southeast Asia	LPDR	3185.3	21.1	21.2	7958.5	53.5	51.6	21815.8	119.2	93.0	75881.3	420.5	233.5
	Viet Nam	3634.2	334.4	335.6	8677.3	787.2	745.5	21293.2	1602.4	1255.9	66740.3	4047.2	2515.3
	Myanmar	1878.4	92.0	92.4	4351.0	187.8	179.2	11216.1	304.4	224.2	39613.9	703.2	287.9
	Malaysia	15522.3	475.2	476.9	26217.5	903.3	864.7	46549.6	1683.4	1399.8	100792.9	4002.3	3155.7
	Thailand	9187.5	651.2	652.0	19017.4	1298.9	1184.0	41294.0	2389.5	1679.0	103330.4	4836.2	2849.3
	Philippines	4118.1	416.7	419.9	7297.5	818.9	783.5	17630.7	1802.9	1388.7	65127.0	7450.8	4754.9
	Indonesia	5057.6	1266.8	1271.2	12635.7	3045.0	2843.9	33521.4	6335.0	4534.4	101005.2	14987.2	6619.4
	Cambodia	2597.9	38.6	38.8	6437.1	92.9	88.8	18533.9	204.2	156.5	81399.9	816.3	417.2
Pacific	Tonga	4306.7	0.5	0.5	6901.2	0.7	0.7	16527.8	1.2	1.2	65423.3	3.9	4.0
	Papua New Guinea	3149.8	23.8	23.8	5853.1	50.0	47.4	17362.1	132.2	98.6	86560.5	690.6	346.4
	Vanuatu	4298.5	1.1	1.2	7485.7	2.3	2.1	21488.7	5.8	4.3	107070.6	32.9	15.9
	Samoa	4262.1	0.8	0.8	6958.3	1.2	1.2	16055.6	1.9	2.0	57532.7	5.7	6.0
	Solomon Islands	2847.9	1.7	1.7	5570.4	3.7	3.4	15567.8	9.5	6.9	68591.0	50.6	24.5
	Timor-Leste	1845.3	2.3	2.3	4923.5	6.7	6.8	19014.1	20.4	16.8	116232.0	138.3	71.7
	Fiji	4440.1	4.0	4.0	6929.9	6.0	5.8	17124.7	11.3	9.2	73818.5	42.3	25.1
South Asia	Pakistan	2593.8	492.2	496.1	4516.8	967.9	915.8	12427.3	2479.5	1759.9	55670.2	13333.7	6186.1
	Maldives	8285.0	2.8	2.8	13095.0	4.9	4.7	26565.8	9.3	7.6	78332.5	24.6	16.0
	Bangladesh	1918.8	301.6	303.3	4838.3	750.7	707.6	14840.1	1754.1	1236.3	62138.3	6975.5	3207.8
	Bhutan	7136.0	5.7	5.7	21835.7	20.0	17.8	50476.6	51.0	35.0	122359.1	145.7	80.2
	Nepal	1207.2	39.5	39.9	2450.7	85.3	78.6	8629.7	237.6	156.7	55801.7	1642.2	675.7
	India	3850.7	5017.0	5047.2	9107.7	12207.7	11288.5	23798.2	27538.5	18892.2	76505.4	81989.5	36935.6
	Sri Lanka	6156.7	133.0	133.3	13837.3	294.8	276.8	31625.4	563.9	411.1	85752.9	1430.0	742.7

Appendix C: WFaS Water demand

Time series of national total water demand

		Sustainability			Middle of the Road			Regional Rivalry		
	[km^3/year]	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
Advanced economies	Australia	28	30	31	27	30	32	27	30	33
	Singapore	1.3	2.0	2.5	1.3	2.5	3.5	1.3	2.6	3.6
	New Zealand	3.0	3.2	3.5	3.0	3.4	3.4	3.0	3.6	3.7
	Republic of Korea	26	29	28	26	33	31	26	31	30
	Brunei Darussalam	0.3	0.2	0.1	0.3	0.4	0.4	0.3	0.4	0.4
	Japan	59	53	52	60	57	56	60	58	57
	SUM	117	118	117	118	126	127	118	126	127
East Asia	China	723	1018	1145	725	1086	1214	723	1122	1275
	Mongolia	0.8	1.4	1.8	0.8	1.6	2.3	0.8	1.8	2.7
	SUM	724	1019	1146	726	1088	1217	724	1123	1278
Central and West Asia	Uzbekistan	53	63	76	53	64	71	53	65	77
	Afghanistan	38	41	46	37	41	45	37	41	45
	Kyrgyzstan	9.4	10.4	11.5	9.3	10.5	11.3	9.3	10.6	11.9
	Georgia	2.9	5.7	7.8	3.1	6.4	8.4	3.0	6.2	9.2
	Turkmenistan	22	26	27	22	29	33	22	28	30
	Armenia	3.2	4.3	5.6	3.4	4.7	5.4	3.3	4.8	5.9
	Tajikistan	8.1	9.1	11.4	8.1	9.3	10.5	8.1	9.5	11.6
	Kazakhstan	25	30	30	26	35	37	26	34	35
	Azerbaijan	16	16	16	17	20	18	16	19	19
	SUM	177	205	231	179	220	239	178	217	245
Southeast Asia	LPDR	2.9	3.8	4.7	2.9	3.9	4.7	2.9	3.9	5.1
	Viet Nam	52	57	62	52	61	66	52	63	70
	Myanmar	21	21	22	21	22	22	21	22	23
	Malaysia	10	11	12	10	13	16	10	14	18
	Thailand	67	72	77	67	75	82	67	76	82
	Philippines	27	29	38	27	33	41	27	34	47
	Indonesia	74	86	91	74	95	103	74	98	110
	Cambodia	4.5	4.8	5.6	4.5	4.8	5.6	4.5	4.9	5.4
	SUM	258	286	312	260	308	340	260	317	361
Pacific	Tonga	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Papua New Guinea	0.3	0.4	0.8	0.3	0.5	0.8	0.3	0.5	0.9
	Vanuatu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Samoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Solomon Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Timor-Leste	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2
	Fiji	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
	SUM	0.5	0.6	1.1	0.5	0.7	1.1	0.5	0.8	1.2
South Asia	Pakistan	302	313	326	304	309	332	304	312	340
	Maldives	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bangladesh	49	55	63	49	56	65	49	56	65
	Bhutan	0.4	0.6	0.7	0.4	0.6	0.7	0.4	0.6	0.7
	Nepal	8.0	8.8	10.6	7.9	8.7	10.5	7.9	8.7	9.9
	India	765	869	948	764	882	965	764	896	1019
	Sri Lanka	9	11	12	9	11	13	9	12	13
	SUM	1133	1258	1360	1135	1267	1386	1134	1285	1448
	Asia SUM	2409	2886	3167	2418	3009	3310	2415	3070	3459

Time series of national agriculture water demand

	[km^3/year]	Sustainability			Middle of the Road			Regional Rivalry		
		2010	2030	2050	2010	2030	2050	2010	2030	2050
Advanced economies	Australia	22	23	23	22	22	23	22	22	23
	Singapore	0	0	0	0	0	0	0	0	0
	New Zealand	2	2	2	2	2	2	2	2	2
	Republic of Korea	8	8	9	8	8	8	8	8	8
	Brunei Darussalam	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
	Japan	27	27	28	27	27	28	27	27	28
	SUM	59	60	61	58	59	61	58	59	61
East Asia	China	522	536	560	513	518	542	513	518	542
	Mongolia	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	SUM	522	536	560	513	519	543	513	519	543
Central and West Asia	Uzbekistan	44	45	46	43	45	45	43	45	45
	Afghanistan	37	38	39	37	37	38	37	37	38
	Kyrgyzstan	8	9	9	8	9	9	8	9	9
	Georgia	1	1	1	1	1	1	1	1	1
	Turkmenistan	18	19	19	18	19	19	18	19	19
	Armenia	1	2	2	1	2	2	1	2	2
	Tajikistan	7	7	7	7	7	7	7	7	7
	Kazakhstan	17	18	18	17	18	18	17	18	18
	Azerbaijan	9	9	10	9	9	9	9	9	9
	SUM	142	147	151	140	145	148	140	145	148
Southeast Asia	LPDR	3	3	3	3	3	3	3	3	3
	Viet Nam	41	41	41	41	41	41	41	41	41
	Myanmar	19	19	19	19	19	19	19	19	19
	Malaysia	2	2	2	2	2	2	2	2	2
	Thailand	59	59	61	59	60	61	59	60	61
	Philippines	14	13	14	14	15	14	14	15	14
	Indonesia	48	48	49	48	49	50	48	49	50
	Cambodia	4	4	4	4	4	4	4	4	4
	SUM	190	190	193	190	192	194	190	192	194
Pacific	Tonga	0	0	0	0	0	0	0	0	0
	Papua New Guinea	0	0	0	0	0	0	0	0	0
	Vanuatu	0	0	0	0	0	0	0	0	0
	Samoa	0	0	0	0	0	0	0	0	0
	Solomon Islands	0	0	0	0	0	0	0	0	0
	Timor-Leste	0	0	0	0	0	0	0	0	0
	Fiji	0	0	0	0	0	0	0	0	0
	SUM	0	0	0	0	0	0	0	0	0
South Asia	Pakistan	293	299	305	294	291	308	294	291	308
	Maldives	0	0	0	0	0	0	0	0	0
	Bangladesh	44	45	45	44	44	45	44	44	45
	Bhutan	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Nepal	8	8	8	8	8	8	8	8	8
	India	688	706	689	684	700	729	684	700	729
	Sri Lanka	8	8	8	8	8	8	8	8	8
	SUM	1040	1066	1055	1038	1051	1099	1038	1051	1099
	Asia SUM	1954	1998	2020	1939	1967	2044	1939	1967	2044

Time series of national domestic water demand

		Sustainability			Middle of the Road			Regional Rivalry		
	[km^3/year]	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
Advanced economies	Australia	4.4	5.8	7.0	4.5	6.3	7.1	4.5	6.5	8.0
	Singapore	0.3	0.5	0.7	0.3	0.6	0.8	0.3	0.6	1.0
	New Zealand	0.8	1.1	1.2	0.9	1.1	1.3	0.9	1.2	1.4
	Republic of Korea	6.7	7.2	7.0	6.9	8.2	8.2	6.9	8.3	9.0
	Brunei Darussalam	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Japan	15.2	12.7	12.0	15.5	13.7	12.6	15.4	14.3	13.8
	SUM	27.5	27.3	28.1	28.1	30.0	29.9	28.0	31.0	33.3
East Asia	China	62.9	166.0	202.1	67.2	195.5	229.8	65.5	189.6	258.1
	Mongolia	0.1	0.4	0.7	0.1	0.4	0.8	0.1	0.4	0.9
	SUM	63.0	166.3	202.8	67.3	195.9	230.6	65.6	190.0	259.0
Central and West Asia	Uzbekistan	3.7	5.9	10.0	3.8	6.9	10.0	3.8	7.3	13.1
	Afghanistan	0.4	1.3	4.2	0.5	1.4	3.7	0.5	1.4	3.9
	Kyrgyzstan	0.5	0.7	1.2	0.5	0.9	1.3	0.5	0.9	1.6
	Georgia	0.8	1.6	2.3	0.8	1.8	2.4	0.8	1.8	2.7
	Turkmenistan	0.8	1.7	2.1	0.9	2.7	4.1	0.8	2.5	3.7
	Armenia	1.1	1.7	2.5	1.2	2.0	2.5	1.1	2.0	2.8
	Tajikistan	0.5	0.9	1.8	0.5	1.1	1.6	0.5	1.1	2.1
	Kazakhstan	1.1	1.8	1.9	1.1	2.3	2.8	1.1	2.2	2.7
	Azerbaijan	1.6	2.2	2.4	1.9	2.9	2.5	1.8	2.7	3.0
	SUM	10.4	17.7	28.4	11.2	22.0	30.9	10.9	21.8	35.5
Southeast Asia	LPDR	0.2	0.6	1.2	0.2	0.7	1.2	0.2	0.7	1.5
	Viet Nam	5.7	8.1	10.6	5.9	9.7	11.9	5.9	10.3	14.6
	Myanmar	1.6	1.9	2.2	1.7	2.2	2.4	1.7	2.3	2.8
	Malaysia	2.7	3.4	3.9	2.8	4.1	5.0	2.8	4.4	6.2
	Thailand	2.6	4.6	5.0	2.6	5.2	5.7	2.6	5.5	6.8
	Philippines	5.7	9.7	15.9	5.8	10.6	17.9	5.8	10.6	21.2
	Indonesia	9.8	23.2	23.1	10.0	26.8	28.8	9.9	28.0	34.5
	Cambodia	0.1	0.3	0.6	0.1	0.3	0.8	0.1	0.3	0.6
	SUM	28.3	51.7	62.4	29.1	59.6	73.7	28.9	61.9	88.2
Pacific	Tonga	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Papua New Guinea	0.1	0.3	0.6	0.1	0.3	0.5	0.1	0.3	0.6
	Vanuatu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Samoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Solomon Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Timor-Leste	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Fiji	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUM	0.2	0.3	0.6	0.2	0.3	0.5	0.2	0.3	0.6
South Asia	Pakistan	5.5	9.8	15.2	5.6	10.3	17.3	5.6	10.6	19.5
	Maldives	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bangladesh	3.3	7.1	10.9	3.4	7.5	12.4	3.3	7.4	13.5
	Bhutan	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
	Nepal	0.3	0.7	1.9	0.3	0.7	1.8	0.3	0.8	1.5
	India	40.6	94.4	143.4	42.1	105.0	133.0	41.7	110.7	184.7
	Sri Lanka	0.5	1.3	1.3	0.5	1.5	1.6	0.5	1.6	1.9
	SUM	50.2	113.3	172.9	51.9	125.1	166.2	51.4	131.2	221.4
	Asia SUM	179.6	376.7	495.3	187.8	432.9	531.9	185.0	436.2	638.1

Time series of national of industrial water demand

		Sustainability			Middle of the Road			Regional Rivalry		
	[km^3/year]	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
Advanced economies	Australia	1.1	1.2	1.2	1.2	1.6	1.9	1.2	1.7	1.6
	Singapore	1.0	1.5	1.7	1.0	1.9	2.7	1.0	1.9	2.6
	New Zealand	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.7	0.7
	Republic of Korea	10.8	13.6	12.1	11.3	16.4	14.8	11.1	14.7	12.2
	Brunei Darussalam	0.2	0.2	0.0	0.2	0.3	0.3	0.2	0.3	0.3
	Japan	16.8	13.6	12.0	17.8	16.4	16.1	18.2	16.9	15.3
	SUM	30.4	30.7	27.6	32.0	37.1	36.3	32.3	36.3	32.7
East Asia	China	138.5	316.3	382.3	144.9	372.2	442.4	145.0	413.8	475.1
	Mongolia	0.3	0.6	0.7	0.4	0.8	1.1	0.3	1.0	1.4
	SUM	138.8	316.9	383.0	145.2	373.1	443.5	145.4	414.8	476.5
Central and West Asia	Uzbekistan	5.9	11.9	19.9	6.4	12.8	16.1	6.2	13.0	18.6
	Afghanistan	0.3	2.1	2.8	0.3	2.1	3.3	0.3	2.0	3.5
	Kyrgyzstan	0.5	0.8	1.3	0.5	1.0	1.3	0.5	1.1	1.6
	Georgia	1.2	3.1	4.4	1.4	3.6	5.0	1.3	3.5	5.5
	Turkmenistan	2.5	5.3	5.2	2.9	7.7	9.6	2.7	6.7	7.7
	Armenia	0.6	1.0	1.4	0.7	1.1	1.2	0.7	1.2	1.4
	Tajikistan	0.7	1.1	2.4	0.8	1.3	1.8	0.8	1.4	2.5
	Kazakhstan	7.0	9.9	9.8	8.4	15.1	16.0	8.1	13.9	14.3
	Azerbaijan	5.2	5.0	4.5	6.4	7.7	5.9	6.0	7.1	6.7
	SUM	24.0	40.2	51.7	27.9	52.4	60.1	26.7	50.0	61.8
Southeast Asia	LPDR	0.1	0.5	0.8	0.1	0.5	0.8	0.1	0.5	0.8
	Viet Nam	5.3	8.7	10.6	5.5	10.3	12.7	5.5	12.2	14.9
	Myanmar	0.5	0.4	0.6	0.6	0.5	0.6	0.6	0.6	0.7
	Malaysia	5.2	5.6	5.7	5.4	7.1	9.0	5.5	7.8	9.9
	Thailand	5.5	8.4	11.3	5.7	9.8	14.8	5.8	10.7	14.2
	Philippines	6.9	5.8	8.6	7.3	7.7	9.3	7.3	8.6	11.4
	Indonesia	16.0	14.8	18.4	16.5	19.4	24.8	16.7	21.8	25.9
	Cambodia	0.1	0.2	0.6	0.1	0.2	0.5	0.1	0.3	0.4
	SUM	39.7	44.3	56.7	41.3	55.6	72.5	41.6	62.5	78.3
Pacific	Tonga	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Papua New Guinea	0.2	0.1	0.2	0.2	0.2	0.3	0.2	0.3	0.3
	Vanuatu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Samoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Solomon Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Timor-Leste	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
	Fiji	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
	SUM	0.2	0.2	0.4	0.2	0.3	0.4	0.2	0.3	0.5
South Asia	Pakistan	4.3	5.0	6.0	4.5	7.6	6.2	4.6	10.0	12.4
	Maldives	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bangladesh	1.8	2.9	6.8	1.8	4.3	7.9	1.9	4.8	6.6
	Bhutan	0.0	0.1	0.2	0.0	0.1	0.2	0.0	0.1	0.2
	Nepal	0.1	0.3	1.0	0.1	0.3	0.8	0.1	0.3	0.5
	India	36.3	69.2	115.7	37.7	76.9	103.1	38.0	85.6	105.1
	Sri Lanka	0.6	1.5	2.4	0.7	2.1	3.4	0.7	2.2	2.9
	SUM	43.1	78.8	132.1	44.7	91.2	121.5	45.1	103.0	127.7
	Asia SUM	276.3	511.1	651.6	291.3	609.7	734.2	291.3	666.8	777.5

Appendix D: Available surface water resource

		Sustainability			Middle of the Road			Regional Rivalry		
	[km^3/year]	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
Advanced economies	Australia	776	724	782	883	825	731	883	825	731
	Singapore	11	11	11	11	11	11	11	11	11
	New Zealand	375	380	375	369	370	385	369	370	385
	Republic of Korea	95	102	102	101	100	110	101	100	110
	Brunei Darussalam	89	94	95	88	89	91	88	89	91
	Japan	665	670	671	643	668	638	643	668	638
	SUM	2010	1981	2037	2095	2062	1966	2095	2062	1966
East Asia	China	2337	2364	2439	2347	2403	2331	2347	2403	2331
	Mongolia	47	45	48	48	47	48	48	47	48
	SUM	2385	2409	2487	2395	2450	2379	2395	2450	2379
Central and West Asia	Uzbekistan	99	100	101	103	106	107	103	106	107
	Afghanistan	85	95	88	92	100	92	92	100	92
	Kyrgyzstan	29	28	30	30	30	32	30	30	32
	Georgia	66	63	60	69	66	64	69	66	64
	Turkmenistan	80	85	81	83	88	85	83	88	85
	Armenia	7	6	5	7	6	6	7	6	6
	Tajikistan	71	72	73	74	76	77	74	76	77
	Kazakhstan	252	243	255	254	253	258	254	253	258
	Azerbaijan	35	32	30	37	34	34	37	34	34
	SUM	723	724	724	749	758	753	749	758	753
Southeast Asia	LPDR	409	398	405	386	395	382	386	395	382
	Viet Nam	931	940	953	884	914	883	884	914	883
	Myanmar	1226	1296	1307	1249	1264	1256	1249	1264	1256
	Malaysia	646	685	696	648	659	675	648	659	675
	Thailand	766	789	802	757	770	759	757	770	759
	Philippines	697	783	773	658	679	735	658	679	735
	Indonesia	3942	4014	4039	3921	3950	3953	3921	3950	3953
	Cambodia	557	565	564	534	543	533	534	543	533
	SUM	9173	9469	9538	9038	9173	9177	9038	9173	9177
Pacific	Tonga	6	6	6	7	7	7	7	7	7
	Papua New Guinea	1296	1341	1270	1289	1224	1292	1289	1224	1292
	Vanuatu	56	59	54	60	59	53	60	59	53
	Samoa	15	14	12	15	14	14	15	14	14
	Solomon Islands	170	167	148	175	150	159	175	150	159
	Timor-Leste	12	12	11	13	13	11	13	13	11
	Fiji	64	64	60	70	72	68	70	72	68
	SUM	1619	1662	1561	1629	1539	1604	1629	1539	1604
South Asia	Pakistan	202	203	212	213	220	201	213	220	201
	Maldives	4	4	5	4	5	5	4	5	5
	Bangladesh	1451	1441	1546	1504	1427	1458	1504	1427	1458
	Bhutan	48	48	50	50	46	45	50	46	45
	Nepal	217	210	227	221	209	210	221	209	210
	India	2651	2691	2865	2735	2656	2654	2735	2656	2654
	Sri Lanka	64	65	79	68	70	76	68	70	76
	SUM	4638	4661	4984	4795	4632	4649	4795	4632	4649
	Asia SUM	20547	20905	21332	20700	20614	20528	20700	20614	20528

Appendix E: Potential population under severe water scarcity

[Million of people]		Sustainability			Middle of the Road			Regional Rivalry		
(per cent of whole population)		**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
East Asia	China	529 (39%)	627 (45%)	607 (48%)	525 (38%)	631 (45%)	627 (48%)	522 (38%)	648 (45%)	647 (48%)
	Mongolia	0 (1%)	1 (19%)	1 (19%)	0 (1%)	1 (19%)	1 (19%)	0 (1%)	1 (19%)	1 (19%)
	SUM	529 (39%)	627 (45%)	607 (48%)	525 (38%)	631 (45%)	628 (48%)	522 (38%)	649 (45%)	648 (48%)
South Asia	Bangladesh	29 (20%)	55 (33%)	56 (32%)	21 (14%)	57 (32%)	62 (32%)	21 (14%)	59 (32%)	69 (31%)
	Bhutan	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	India	428 (35%)	546 (37%)	632 (41%)	420 (34%)	576 (37%)	730 (42%)	420 (34%)	624 (39%)	836 (42%)
	Maldives	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Nepal	3 (11%)	4 (11%)	5 (12%)	3 (11%)	4 (11%)	5 (12%)	3 (11%)	5 (11%)	7 (12%)
	Sri Lanka	1 (7%)	2 (11%)	1 (5%)	1 (6%)	1 (6%)	1 (6%)	1 (6%)	1 (6%)	2 (6%)
	Pakistan	86 (51%)	119 (54%)	135 (55%)	85 (50%)	123 (53%)	157 (55%)	85 (50%)	131 (52%)	188 (55%)
	SUM	548 (34%)	726 (38%)	829 (41%)	530 (33%)	761 (38%)	957 (42%)	530 (33%)	820 (39%)	1101 (42%)
Southeast Asia	Cambodia	1 (5%)	0 (0%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)
	Indonesia	50 (21%)	76 (28%)	91 (34%)	50 (21%)	85 (31%)	93 (33%)	50 (21%)	84 (30%)	95 (31%)
	Lao PDR	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Malaysia	0 (0%)	0 (0%)	8 (23%)	0 (0%)	0 (0%)	9 (21%)	0 (0%)	7 (20%)	9 (19%)
	Myanmar	1 (2%)	0 (1%)	0 (1%)	0 (1%)	0 (1%)	0 (1%)	0 (1%)	0 (1%)	0 (1%)
	Philippines	15 (17%)	19 (16%)	35 (27%)	15 (17%)	30 (25%)	36 (25%)	15 (17%)	30 (23%)	42 (25%)
	Thailand	8 (11%)	8 (11%)	9 (12%)	8 (11%)	9 (11%)	9 (12%)	8 (11%)	9 (12%)	9 (11%)
	Viet Nam	7 (8%)	11 (12%)	11 (12%)	10 (11%)	12 (12%)	12 (12%)	10 (11%)	12 (12%)	14 (12%)
	SUM	82 (14%)	115 (17%)	156 (23%)	84 (14%)	137 (20%)	161 (22%)	84 (14%)	144 (20%)	170 (21%)
Central and West Asia	Afghanistan	19 (58%)	27 (56%)	37 (61%)	18 (56%)	28 (54%)	46 (60%)	18 (56%)	31 (54%)	56 (60%)
	Kazakhstan	4 (25%)	7 (37%)	7 (39%)	4 (27%)	7 (37%)	8 (38%)	4 (27%)	7 (35%)	8 (35%)
	Kyrgyzstan	4 (54%)	4 (60%)	4 (63%)	3 (54%)	4 (56%)	4 (58%)	3 (54%)	4 (54%)	5 (55%)
	Tajikistan	2 (29%)	2 (31%)	2 (31%)	2 (24%)	2 (29%)	3 (31%)	2 (24%)	3 (32%)	3 (31%)
	Turkmenistan	3 (44%)	3 (49%)	3 (53%)	2 (43%)	4 (52%)	4 (56%)	2 (43%)	4 (51%)	5 (54%)
	Uzbekistan	17 (66%)	19 (68%)	20 (71%)	16 (65%)	20 (66%)	21 (69%)	16 (65%)	21 (66%)	25 (69%)
	Armenia	1 (35%)	2 (73%)	2 (78%)	1 (35%)	2 (71%)	2 (76%)	1 (35%)	2 (70%)	2 (73%)
	Azerbaijan	4 (49%)	5 (53%)	6 (55%)	4 (49%)	6 (54%)	6 (53%)	4 (47%)	5 (52%)	6 (53%)
	Georgia	0 (5%)	0 (5%)	0 (5%)	0 (5%)	0 (5%)	1 (42%)	0 (0%)	0 (5%)	2 (37%)
	SUM	53 (49%)	71 (53%)	83 (57%)	52 (48%)	73 (52%)	95 (57%)	52 (47%)	77 (51%)	111 (56%)
Advanced economies	Australia	2 (7%)	8 (26%)	10 (27%)	2 (8%)	8 (26%)	10 (27%)	2 (8%)	7 (26%)	8 (27%)
	Brunei Darussalam	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Japan	24 (19%)	26 (21%)	26 (23%)	25 (20%)	25 (21%)	25 (23%)	25 (20%)	23 (20%)	20 (21%)
	New Zealand	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (30%)
	Republic of Korea	24 (49%)	25 (49%)	24 (50%)	24 (49%)	25 (50%)	23 (50%)	24 (49%)	24 (50%)	21 (50%)
	Singapore	0 (0%)	0 (0%)	7 (92%)	0 (0%)	7 (90%)	7 (91%)	0 (0%)	7 (89%)	7 (89%)
	SUM	50 (24%)	59 (27%)	68 (32%)	50 (24%)	65 (30%)	65 (31%)	50 (24%)	61 (30%)	57 (32%)
	SUM Asia	1262 (33%)	1599 (37%)	1743 (40%)	1242 (32%)	1667 (37%)	1906 (41%)	1239 (32%)	1751 (38%)	2087 (41%)
< 25 per cent of the population	Number of countries	22	18	16	23	17	16	23	17	15
≥ 25 per cent of the population		12	13	13	12	12	13	12	12	14
≥ 50 per cent of the population		4	7	7	3	8	7	3	8	8
≥ 75 per cent of the population		0	0	2	0	1	2	0	1	1

WATER FUTURES AND SOLUTIONS

The Water Futures and Solutions Initiative (WFaS) is a cross-sector, collaborative global initiative which develops the scientific evidence and applies systems analysis to help identify water-related policies and management practices that work together consistently across scales and sectors with the aim to improve human well-being through enhanced water security.

A stakeholder informed, scenario-based assessment of water resources and water demand, employing ensembles of state-of-the-art socio-economic and hydrological models, test the feasibility, sustainability and robustness of portfolios of options that can be implemented today and can be sustainable and robust across a range of possible futures and associated uncertainties we face.

WFaS includes case studies to zoom in on particular issues and regions, and knowledge sharing networks to share policy, management, and technical solutions that have been effective in the bio-physical and socio-economic contexts to which they have been applied, so they can be assessed for application in similar conditions in other regions.

IIASA
International Institute for Applied Systems Analysis
Schlossplatz 1, A-2361 Laxenburg, Austria
Tel: +43 2236 807 Fax: +43 2236 71313
www.iiasa.ac.at