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Water Futures and Solution - Fast Track Initiative (Final Report)

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Working Paper **WP-16-006**

Water Futures and Solution

Fast Track Initiative – Final Report
ADA Project Number 2725-00/2014

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Final REPORT

Water Futures and Solution
Fast Track Initiative

ADA Project Number 2725-00/2014

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Summary

The Water Futures and Solutions Initiative (WFaS) is a cross-sector, collaborative global water project. Its objective is to apply systems analysis, develop scientific evidence and identify water-related policies and management practices, working together consistently across scales and sectors to improve human well-being through water security. The approach is a stakeholder-informed, scenario-based assessment of water resources and water demand that employs ensembles of state-of-the-art socio-economic and hydrological models, examines possible futures and tests the feasibility, sustainability and robustness of options that can be implemented today and can be sustainable and robust across a range of possible futures and associated uncertainties. This report aims at assessing the global current and future water situation.

Possible Water Futures

WFaS has developed a set of scenarios of global water futures, which have been quantified and assessed with a multi-model approach. These water-relevant future scenarios are based on water use narratives that extend the Shared Socio-economic Pathways (SSPs) and Representative Concentration Pathways (RCPs); a set of pathways developed by a large global 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 the consistency 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**: Global total population is estimated at 6.7 billion in 2010. Future projections indicate that Global population is expected to undergo considerable changes in the coming decades. It will range between 8.4 and 9.8 billion in the 2050s and it will range between 7 and 12 billion in the 2100s depending on the scenario. Specifically, total population will continue to increase through 2100 under the *Middle of the Road* scenario, while it will peak at 2050 and 2070 in the *Sustainability* and the *Middle of the Road* scenarios, respectively. Global GDP levels at the end of this century are lowest in the 'Rivalry' scenario (with lowest levels of international co-operation and trade) amounting to around 280 trillion USD. In the 'Sustainability' and '*Middle of the Road*' scenario this increases to 560 and 540 trillion USD. Owing to its large population Asia and Africa are the main drivers for differences across scenarios, especially in the second half of this century.
- **Food:** Globally, average food energy intake in the World Food System model is estimated at 2860 kCal/cap/day in 2010, with regions ranging from less than 2300 kCal/cap/day in Africa to more than 3500 kCal/cap/day in Northern America, Europe and Oceania. The projected per capita food energy intake in 2050 ranges levels between 2950 to 3360 kCal/cap/day depending on the scenario. The number of people at risk of hunger estimated for 2010 amounts to 920 Million, some 13.5% of global population. This number is rapidly decreasing in two development pathways and the share of people at risk of hunger is below 2% of global population by 2080. Only in the *Regional Rivalry* scenario the estimated number of people at risk of hunger stagnates at about 800 Million or some 8.5% of the global population in 2080.

- **Energy:** Global energy demand is expected to further increase in the next decades, from 13600 million tons of oil equivalent (Mtoe) in 2010 to 15200 - 19700 Mtoe in 2040 depending on the scenario of the 2015 World Energy Outlook. This increase will be driven mainly by demand growth in India, China, Africa, the Middle East, and Southeast Asia. The growing demand for power engenders global electricity generation to increase. Global electricity generation is expected to increase significantly from 23318 TWh in 2010 to between 33900 and 43100 TWh in 2040. The contribution of fossil fuels to total electricity generation will decrease from 77% in 2010 to between 29% and 64% in 2040. Generation from renewables grows the fastest, as their costs fall and government support continues, and it increases two to three and a half times, to reach between 11500 and 17800 TWh by 2040. Hydropower remains the largest source of renewables generation, while wind power and solar PV expand rapidly, but from a much lower base. Output from nuclear power plants increases up to 150%.
- **Available surface water resources per capita:** Countries on the Arabic peninsula show the lowest water availability per capita in the 2010s followed by North African countries. Pakistan, China but also Belgium have low water availability per capita. Due to demographic changes, differences in water availability per capita among scenarios become evident by the 2050s. Water availability per capita is expected to decrease in a belt around 10° to 40° northern latitude from Morocco to India during the early half of the 21st century under all scenarios considered. Only a few countries show the opposite trend like Poland which goes from vulnerable in the 2010s to no stress in the 2050s and China which is under water stress now but will be in the category above 1700 m^3/year/cap in two out of three scenarios in the 2050s.
- **Groundwater resource:** Groundwater use globally amounts to 800 km^3/year in the 2010s. The largest abstractions are taking place in India, USA, China, Iran and Pakistan. Abstractions these countries account for 67% of total abstractions worldwide. In many countries, groundwater abstraction has already exceeded recharge, leading to the overexploitation and degradation of important aquifer systems. A worrying issue in the 2050s will be the expected large surge in groundwater abstractions, required to satisfy the increase of water demands, amounting to 1100 km^3/year, a 39% increase compared to current level.
- **Water demand:** It is estimated that global total water demand in the 2010s is about 4600 km^3/year and projected that it will be between 5500 to 6000 km^3/year under the three scenarios considered, with industrial and domestic demand growing much faster than agricultural demand. Under *Middle of the Road* scenario, the share of agricultural demand will decrease from 72% in the 2010s to 59% in the 2050s, while the share of industrial and domestic demand will increase from 18% in the 2010s to 24% in the 2050s. At continental scale, Asia remains the largest water user in the world in all sectors especially for agricultural water use. Significant rises in total water demand are expected to occur in Western, Eastern and Southern Africa, as well as in Southern and Eastern Asia. At country level, India and China have the largest demand, followed by USA, Pakistan and Russia. Domestic demands are rapidly increasing in sub Saharan Countries, driven by their intense socio-economic growth. These changes in water use patterns come together with the potential increase of fertilizers utilization, due to the need to improve agricultural productivity. All of this will likely impair water quality and damage valuable water-dependent ecosystems, if no adequate abatement measures are designed and implemented.
- **Water scarcity:** Many countries including the countries on the Arabic peninsula, North Africa, Cyprus, Armenia, Uzbekistan, Afghanistan and Pakistan are already undergoing pervasive water scarcity conditions. At present almost all countries in belt around 10° to 40° northern latitude from Mexico to China and Western South America, South Africa, South Europe are affected by water scarcity. An increasing number of people will be exposed to conditions of severe water scarcity until 2050. In the 2010s on annual basis 1.9 billion people (27% of the total global population) live in potential severe water scarce areas and in 2050 it will be 2.7 to 3.2 billion depending on the scenario. If monthly variability is taken into account already now 3.6 billion people worldwide (51%) are living in potential severe water scarcity areas at least for one month per year and it will be 4.8 to 5.7 billion in 2050. 73% of the affected people live in Asia (69% in 2050).

- **Hydro-Economic analysis:** 22 countries with combined population of 1.7 billion people are currently water stressed (rich and poor economies remaining water stressed) and 28 to 33 countries expected to be in the 2050s, depending on the scenario considered. Consequently, a population of 3.6 and 4.6 billion (43 to 47% of the World's total population) will be in the two water stress categories in the 2050s. 91 to 96% of the affected population will live in Asia (mainly Southern and Eastern Asia) and 4 to 9% in Africa (mainly Northern Africa). Our analysis reveals that Somalia, Eritrea, Niger, Burkina Faso, Senegal, Yemen, Afghanistan and Pakistan will be the most vulnerable countries globally, as they will be highly stressed with low adaptive capacity under most of the scenarios.

The results indicate that the World currently faces multiple and complex water challenges that are expected to 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 a more innovative technological interventions will offer some solutions. However, managing the water sector alone is no longer sufficient, since water integrates across scales and sectors, which all use and influence increasingly scarce water resources. Consistent solution portfolios need to be identified to work across economic sectors and scales of management. Since we cannot manage what we cannot measure, information gathering, generation, and sharing must also be improved. This report provides essential information to inform and guide policymakers in the design and implementation of water solutions portfolios. The information provided includes estimates of water supply by source, water variability, water demand, and hydro-economic classification under various up-to-date socio-economic and climate scenarios. To improve water, energy, and food security, sustain human wellbeing, and ensure sustainable development, the identification of portfolios of options that work together synergistically in different regions will be the focus of continuing work within the WFaS initiative and future reports.

1 Introduction

Changing and growing global water demand:

The world population is expected around the middle of 21st century to range from 8.4 to 9.8 billion depending on the scenario. GDP is expected to grow globally three to six times till 2050 compared to 2010, although there are and will be large differences among countries. The drastic socio-economic changes will increase pressure on food, energy, and water resources.

There is also increasing evidence that the global water cycle is changing due to global warming. The hydrological cycle is 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. Analysis of these aspects of global change helps understanding the urgent need for swift planning and execution of strategic, reasonable and effective management and countermeasures against deteriorating water security.

Global water assessment within the Water Future and Solutions Initiative (WFaS):

It is now universally accepted that sustainable management of food, energy, ecosystem and water are central parts of the 21st century development challenge and that they are deeply connected with each other. An assessment relevant to water should cover all of these components and consider their linkages, utilizing consistent assumptions across sectors.

For the sake of providing scientific input to support stakeholder dialog and decision making, the Water Future and Solutions Initiative (WFaS) develops consistent multi-model global water scenarios, consistent with scenarios for other sectors, with the aim to analyze the water-food-energy-climate nexus and identify future hotspots of water insecurity and related impacts on human wellbeing. This current study investigates future climatic change developments in three main water use sectors, the industrial, domestic and agricultural sectors, focusing on how the developments in those sectors affect water supply and demand balances, and the related water security, into the future.

1.1 Purpose of this report

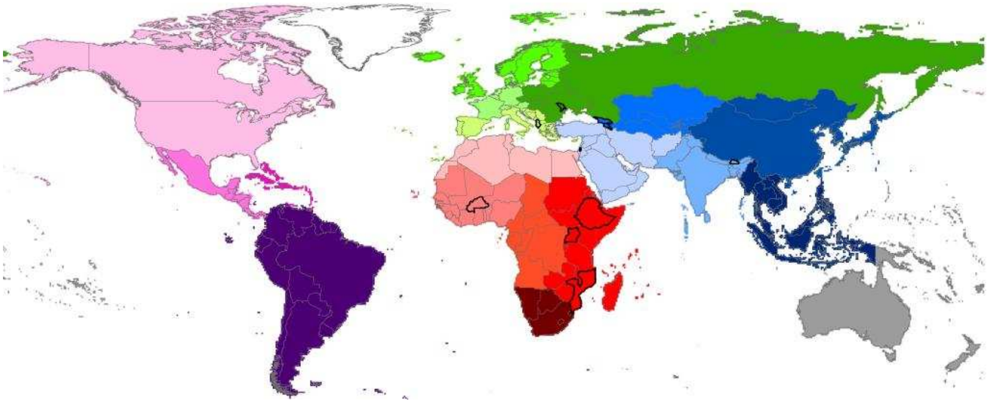
The purpose of this report is to assess and depict possible global water futures, applying the latest climate and socio-economic change scenarios based on multiple-model analysis. Multi-model analysis is used to better understand uncertainty, and provide an indication of the scientific confidence we can provide 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, we need to identify options and find appropriate pathways for achieving the development goals, including Agenda 2030, in an effective, efficient and robust manner. This report discusses where, when, how much and why water resource will be endangered in different regions of the World under expected climate and socio-economic change.

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, the climate-water-food-energy-ecosystem nexus, and the impacts on human wellbeing and earth ecosystems and the services they provide. In the quantitative analysis WFaS develops consistent, multi-model global water scenarios with the aim to analyze the water-food-energy-climate-environment nexus and identify future hotspots of water insecurity and related impacts on human well-being, in particular food and energy security. Water insecurity is an imbalance between water supply and demand, combined with risks of extremes and the coping capacities of social systems, WFaS has projected these components and assessed global water scarcity and security both at present and under possible futures. How will socio-hydrological condition change in next 50 years? Where will be hot-spots of water insecurities? How serious will it be?

1.3 Regional categories used in this analysis

This report uses the composition of regions by the United Nations Statistics Division[1], consisting of six continental regions (Africa, North and Middle America, South America, Asia, Oceania, Europe) and 19 geographical sub-regions listed in Figure 1-1.



Continent	Subregions	
Africa	Northern Africa	🟥
	Western Africa	🟥
	Middle Africa	🟥
	Eastern Africa	🟥
	Southern Africa	🟥
Asia	Western Asia	🟦
	Southern Asia	🟦
	Central Asia	🟦
	Eastern Asia	🟦
	South-Eastern Asia	🟦

Continent	Subregions	
America and Central America	Northern America	🟪
	Central America	🟪
	Caribbean	🟪
South America	South America	🟪
Europe	Western Europe	🟩
	Southern Europe	🟩
	Northern Europe	🟩
	Eastern Europe	🟩
Oceania	Oceania	⬛

Figure 1-1: Regional categories

Assessments at five levels of spatial scale are provided in this report; global, continental, sub-regional, country and sub-country scale (i.e. the grid scale of models). Some small islands are not reflected in the result, because the minimum spatial resolution of the utilized models is 0.5^ox 0.5^o global (approximately 50km x 50km at equator).

We put special emphasis on some of the countries which are the key and priority countries of the Austrian Development Cooperation which are: Albania, Armenia, Bhutan, Burkina Faso, Ethiopia, Moldavia, Mozambique, Uganda and for comparison Austria.

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[1] http://unstats.un.org/unsd/methods/m49/m49regin.htm

2 The Importance of a Nexus Approach

The water, food, and energy resource systems are inextricably linked. These resources are crucial input into 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 needs significant amounts of water withdrawals for power generation, primarily for cooling thermal power plants and running hydropower turbines; 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 the agriculture, energy and water-related activities, primarily for the cultivation of food, feed, fiber, and bioenergy, but 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 socio-economic 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. These challenges can jointly 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 countries (WWAP 2014).

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 one-fifth through 2035, with consumption escalating dramatically by 85%, driven by the shift towards 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 (International Energy Agency 2012). Moreover, 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 condition already prevalent in many regions and to enhance competition for water across sectors and regions.

At the same time, climate change impacts portend 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 will suffer a decrease of water resources availability and an increase of 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. 2012). These changes in energy supply can subsequently rise energy prices and limit access to energy.

Energy demand for water supply and treatment is also expected to increase, as a consequence of the growing demand for water, driven by population and wealth growth, and the shrinking water availability because of climate change impacts. Some of the proposed solutions to address water scarcity embrace water transfer and trading between distant regions, groundwater pumping from deeper aquifers, the use of unconventional water resources such as treated wastewater and desalination, and the shift towards more-efficient irrigation technologies such as sprinkle and drip systems. All these solutions require considerable amounts of energy with consequences for greenhouse gas (GHG) emissions and climate change (WWAP 2014). For example, desalination uses 10-12 times 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 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 policy-making leads to inconsistent strategies and inefficient use of resources. Part of the reason for this is the geographic 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 they need to take into account the production of electricity or gasoline hundreds of kilometers away that they may eventually use (Cosgrove and Loucks 2015).

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 is of particular interest.

3 Future scenarios- WFaS Futures Analysis Approach

3.1 Building water scenarios

Alternative scenarios are an important method for exploring uncertainty in future dimensions of environmental conditions which are intrinsically interlinked socio-economic developments. WFaS employs globally consistent scenario analysis as a strategic planning method for exploring consistent and coherent alternative hypothetical futures ultimately aimed at developing robust pathways towards water security. 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 probably – providing a relevant challenge to the conventional wisdom of their users, and helping them prepare for the major changes ahead (Magnuszewski et al. 2015).

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

A key element of this study is to develop consistent qualitative global scenarios across sectors, embedded in global narratives. To the extent possible they 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 the people's ability to cope with water related risks that potentially threaten their well-being.

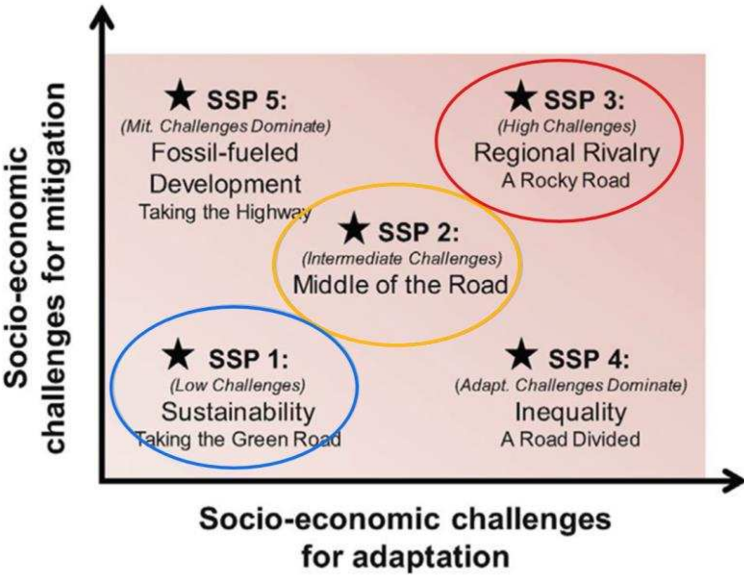

Figure 3-1: The shared socioeconomic pathways (SSPs) representing different combinations of challenges to climate mitigation and adaptation. Source: (O'Neill, et al., 2015)

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) for which information about both climate and socioeconomic change is required to project future water supply and demand. For the sake of a consistent set of new global water scenarios the WFaS initiative coordinates its work with other on-going scenario efforts in the context of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (Moss et al. 2010). This includes the emission 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 that the other climate change research groups, namely the integrated assessment modelers (IAM), and the impacts, adaptation, and vulnerability community need. In response to this the climate change research community converged on new projections, termed Shared Socioeconomic Pathways (SSPs), illustrated in Figure 3-1 (O'Neill et al. 2014, O'Neill et al. 2015). The SSP storylines, already the result of a multi-year community effort across sectors, have in WFaS been extended with 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 builds 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 is characterized by four RCPs. They define pathways of different amounts of radiative forcing until 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 5th assessment report the research community has agreed on a new parallel process (Moss et al. 2010) building on the concept that the four RCPs can be achieved by a diverse range of socio-economic and technological development scenarios outlined in the five SSPs. This results in a new scenario matrix architecture (van Vuuren et al. 2014) combining RCPs and SSPs. The research community[4] is currently performing Integrated Assessment Models (IAM) 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 thereafter WFaS employs the following combinations for its "fast-track" scenario assessment:

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

Another rational for selection of the specific SSP-RCP combinations was that those represent the higher bound of climate change impacts assuming continuation of current mitigation policies. In December 2015 the international community[5] decided that the global goal will be less than a temperature increase of 2˚C, which corresponds closely to an RCP of 2.5. If this target is reached, some of the climate change impacts could be less than described in this paper. Other scenario studies to date 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[1] for the year 2100 (2.6, 4.5, 6.0, and 8.5 W/m^2, respectively).

The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents, and the forcing levels are 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 by employment 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 nearly 6 °C by 2100.

[1] Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report radiative forcing values are for changes relative to preindustrial conditions defined at 1750 and are expressed in Watts per square meter (W/m^2) (IPCC 2007)

3.2 Water extended Shared Socio-Economic Pathways (SSPs)

SSPs include both a qualitative component in the form of a narrative on global development and a quantitative component that includes numerical pathways for certain variables that are particularly useful to have in quantitative form for use in other studies. Box 2 provides an excerpt of the summary SSP storylines. They include demography, economic development, human development, technology, lifestyles, 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.

Quantifications of individual variables for each SSP are an ongoing effort of the research community with results available at the IIASA SSP database portal[7]. At present 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.

SSPs were developed by the climate change community with a focus of the key elements of climate policy. However, the five SSPs were developed to offer the possibility for experimentation by a wide range of researchers for extending the "original" SSP in various dimensions (O'Neill et al. 2015). WFaS has responded to this by extending the SSP storylines (Appendix A) with water narratives for water use developed in collaboration with a group of water planners from around the world and the scientific consortia of WFaS. The qualitative assessment of water narratives for each SSP (Appendix B) provided the basis for the quantification of selected variables required for the global water models (see section 3.5).

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

Box 2: Shared Socioeconomic Pathways (SSP)

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 ..."

Source: O'Neill et al. 2015

3.3 Hydro-economic classification

The WFaS initiative develops global scenarios of water potentials and stressors, their interdependencies across different water sectors (climate-water-food-energy-ecosystem nexus) and across spatial scales. A global assessment is imperative owing to the increasing importance of global drivers such as climate change, population growth and rapid urbanization, economic globalization or safeguarding biodiversity, all of which interrelated with the water domain. Maintaining a global perspective while providing necessary regional detail, which 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, or its reverse, water challenges (Fischer et al. 2015). Countries or watersheds facing similar water security challenges and capacities 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 requires developing a system of classification for countries and watersheds describing different conditions pertaining to water security (or its reverse 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 by users and with the decreasing quantity and quality of the resource. It can further decrease when the right 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 (Grey et al. 2013) to water related challenges, for example freshwater variability (Hall et al. 2014).

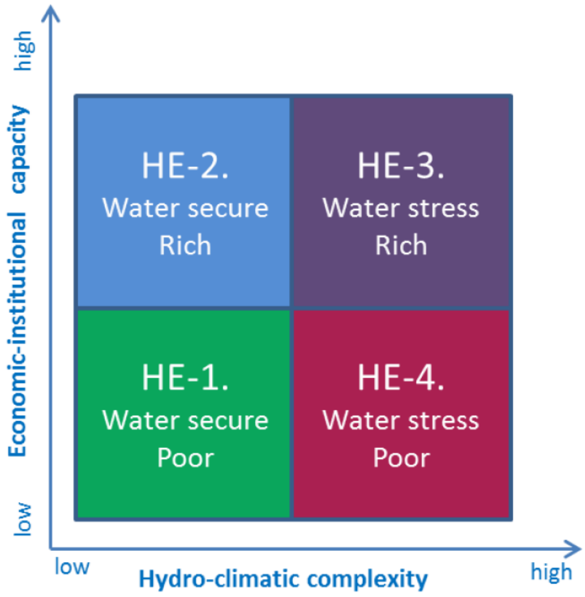

Figure 3-2: Conceptual framework for allocation of hydro-economic classification to four quadrants of water security

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 Figure 3-2)
2. magnitude and complexity of challenges related to the management of available water resources; i.e. **hydrologic challenge/complexity** (x-dimension in Figure 3-2)

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 geographic entity of watersheds. 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 and the means 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 by refined/tailored to reflect stakeholder priorities and needs.

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 a stakeholder meeting in the context of the WFaS Scenario Focus Group (Pound et al. 2013, Magnuszewski et al. 2015).

Hydrologic complexity

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

(i) *Total renewable water resources per capita* (in m3/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 (variable i, iii and iv) and a model-ensemble of six hydrological models calculated from ISI-MIP (Warszawski et al. 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've selected one indicator, namely GDP per caput (in constant PPP dollars per caput) as a measure of economic strength and financial resources available for investing in risk management. Country level GDP per capita is readily available for future periods 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 context of The Worldwide Governance Indicators (WGI) project[8] of the World Bank reports annually 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

The WGI relies exclusively on perception-based governance data sources drawing on data sources 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]) 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 of 12 indicators or drivers of state failure published since 2005 by the United States think tank ,the Fund for Peace and the magazine *Foreign Policy*.

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[8] See www.govindicators.org

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

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

[11] See index.gain.org

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

The level of education is a more general indicator that has been suggested to proxy socio-economic coping capacity, 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 to a key element of water challenges, climatic variability causing both floods and droughts. 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 for GDP per capita and education future projections 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 CPI together with GDP per capita for representation of economic-institutional coping capacity. However we were aware that as the other indicators discussed above 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 to simplify the Y-Axes to the indicator per capita GDP only. GDP was felt to be most recognizable and understandable, representative of economic strength and the financial resources available for investing in risk management. The CPI was perceived as not adding any additional value, its meaning may be ambiguous across nations, and data sources are criticized as perception-based and subjective only. The stakeholders further recommended, while selecting only GDP per capita for the Y-Axes, it was encouraged to explore the potential of adding a third dimension to the 2-dimensional space of the Hydro-Economic Classification scheme.

Against this background WFaS selected for its “fast-track” based on the following considerations. GDP per capita has been projected into the future in the SSP scenarios. Globally for all countries there is a strong positive correlation between GDP per capita and many of the other potential indicators potentially contributing to institutional capacity (e.g. education, CPI, reservoir capacity per capita, WGI). WFaS thus by using per capita GDP as proxy for a broader socio-economic perspective (i.e. economic and institutional coping capacity) remains using an existing and well-known path. We argue changing the indicator is not justified at this point in time because: First, 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. Second, there are major differences of opinion among experts on the definition of many of the above discussed indicators, e.g. corruption, fragile state, 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 WFaS consortium including the stakeholders perceived the selected variables for the X-dimension as proxy for hydrologic complexity as generally comprehensive and useful. They also recognized the importance of an appropriate indicator on the Y-dimension to proxy a country’s / watershed’s economic and institutional coping capacity to increase resilience against challenges arising from high levels of hydrological complexity. When hydrology is complex undoubtedly access to investments is 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 warning), all require initial investments. Yet, institutions, management and governance are crucial for making resilience effective

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

or prioritize often scarce financial resources. For example, even when reservoirs and monitoring are in place, optimal governance of up-stream and down-stream management is essential in case of flooding. Other inherently governance dependent resilience options include transparency and data sharing (both ground- and surface water), monitoring of human water use across sectors (agriculture, households and industry), legal aspects of access to water, and establishing supra-national watershed commissions.

3.4 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 scientific consortia of WFaS. The framework makes use of available results of climate projections[14] based on the RCPs and socio-economic developments based on the SSPs to develop a set of quantitative water projections. These climate and socio-economic 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 socio-economic variables of the SSPs can be best quantified at spatial scale of countries, climate change variables including runoff require calculations at the grid-cell level. We employ estimates of monthly runoff using a model ensemble of six hydrological models developed in the ISI-MIP project. Consistent with first estimates of Integrated Assessment Models (IAM) community the WFaS 'fast-track' water scenarios currently build on three RCP-SSP combinations (SSP1 and RCP4.5, SSP2 and RCP6.0, SSP3 and RCP6.0) (see above 2.1). These scenarios cover the diagonal in SSP scenario matrix in Figure 3-1, and are therefore a reasonably good representation of the scenario space.

Table 3-1: Assumptions applied in the WFaS 'fast-track' scenario runs, deployed at country level

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 3-1 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,

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

country’s exposure to hydrological challenges and economic-institutional coping capacity, i.e. its position in the above described HE-classification (Table 3-2).

Table 3-2: 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), we assume by 2050 a 20% reduction in domestic water use intensity due to behavioral change

Thus scenario assumptions, such as rates of technological and structural change rates, have then 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 between 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 employed water models, namely WaterGAP (Table 3.5). Structural change in the electricity sector is represented by the replacement rates of power plants with more efficient systems, since 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 behavior changes. Structural change in the domestic sector is indicated by a 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 socio-economic change are now being developed using the FAO/ IIASA Global-Agro-Ecological Zones (GAEZ) modeling system (Fischer et al. 2007, Fischer et al. 2012). They provide future crop area distribution and improvement of irrigation efficiency. More details on the entire process of scenario development is presented elsewhere (Tramberend et al. 2015).

3.5 Multi-model assessment

This initiative has developed a spatial-temporal quantitative assessment of future water resources availability based on a multi-model assessment framework. The multi-model approach is becoming widely used in future assessments because ensemble averages provide more robust projections than individual models and avoid drawing conclusions from potential individual outliers (Dankers et al. 2014, Schewe et al. 2014). The approach is used to better understand the uncertainty and limitations of the modeling, while providing a degree of confidence in the results, where many 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 (approx. 50km x 50km at the equator). The emission scenarios of the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011) are applied as climate scenarios, and the socio-economic assumptions are designed to be consistent with the Shared Socioeconomic Pathways (SSPs) (O'Neill et al. 2014). 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, 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. Table 3.3 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 3.4). The atmospheric forcing data set was compiled and made available by the Inter-Sectoral Impact Model Intercomparison Project (Warszawski et al. 2014). In total, this study made use of 15 ensemble members (five GCMs x three GHMs) of projections.

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 because of the diversity of methods applied to reflect such a diverse socio-economic development process. Table 3.5 and Table 3.6 present drivers and parameters for estimation of industrial and domestic water demand, 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 national-level representative values into grid-scale according to population distributions, PCR-GLOBWB and WaterGAP downscale with urban area data. In this analysis, for the purpose of consistency, water demands estimated by H08 were re-downscaled using the same urban area information as the other models.

Table 3-3**:** Global Hydrological Models (GHM) 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

Table 3-4: General Circulation Models (GCM) 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 3-5: Drivers and parameter for estimation of industrial water demand

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

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

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

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

Table 3-6: Drivers and parameter 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

3.6 Food and agriculture modelling framework

In the long run, the increase of demand for agricultural products is largely driven by population and economic growth, both foremost occurring in developing countries. It has become increasingly complex and challenging to achieve food security 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 the impacts of climate variability and changes. Resources needed to meet future food demand will also depend on future food preferences, in particular the future levels of meat consumption. Increasing pressures on land in the last decades have been the consequence and must be mitigated, where possible, through increased land use intensity and more efficient land management.

Economic growth and food security have been mutually reinforcing factors throughout the history of development. Rising per capita incomes and functioning markets foster improved household food security, which can enhance economic growth through better social stability and a better health status of the labor force. However, earlier experiences suggest that food insecurity cannot be fully eradicated by economic growth alone. In the recent decades, strong growth 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 for achieving food security raising food production is a necessary but not sufficient condition. In addition to enhancing the resource base and increasing land productivity, achieving food security also entails ensuring equitable distribution of food, particularly to food-deficit countries and people, reducing distortions and barriers in global food markets, and avoiding unnecessary wastage of food at all levels from field to fork.

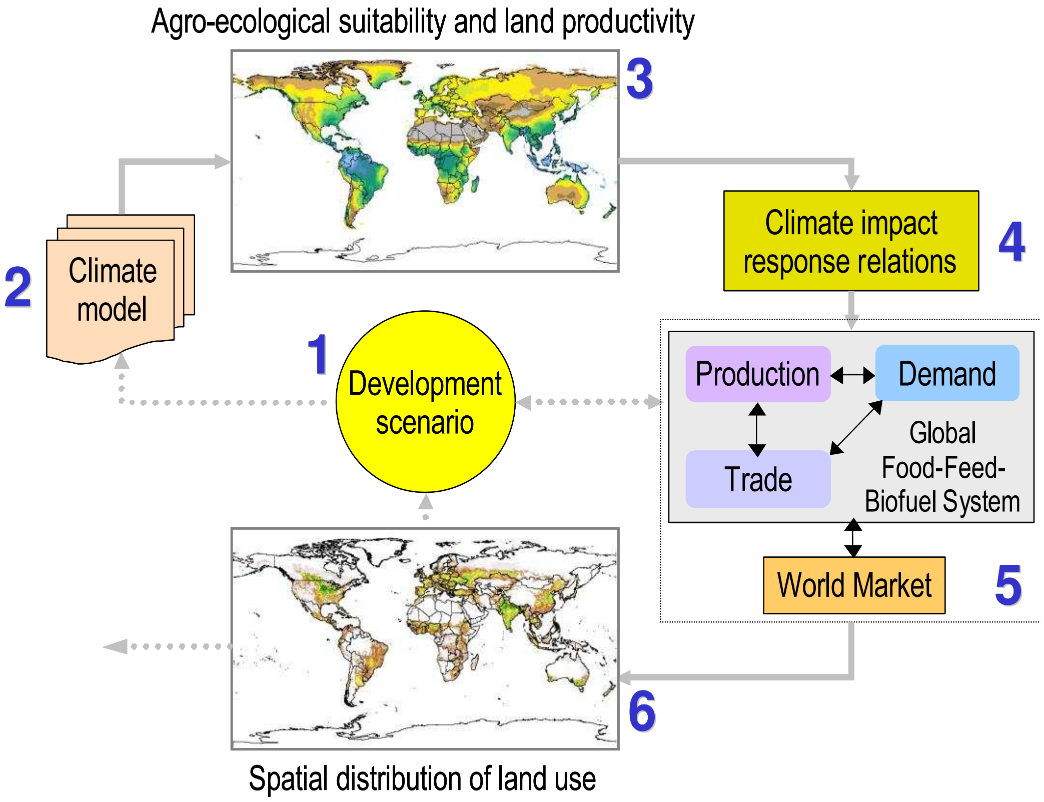

Figure 3-3: Framework for ecological-economic world food system analysis

3.6.1 The modeling framework

The analysis is based on a state-of-the-art ecological-economic modeling approach. The scenario-based quantified findings of the study rely on a modeling framework which includes as components, the FAO/IIASA Agro-ecological zone model (AEZ) and the IIASA world food system model (WFS). The modeling framework encompasses climate scenarios, agro-ecological zoning information (Fischer et al. 2012), demographic and socio-economic drivers, as well as production, consumption and world food trade dynamics (Fischer 2011, Fischer et al. 2009, Fischer et al. 2007).

This modeling framework comprises six main elements, as sketched in Figure 3-3:

1. A storyline and quantified macro-drivers of development, here chosen from among the Shared Socio-economic Pathways (see below), is selected to inform the world food system model of demographic changes in each region and of projected economic growth in the non-agricultural sectors. It also provides storyline assumptions characterizing in broad terms the international setting (e.g. trade liberalization; international migration), regarding technological progress, and the priorities of land use regulation. In addition, a set of Representative Concentration Pathways quantifies selected environmental variables, e.g. greenhouse gas emissions and atmospheric concentrations of CO_2.
2. The emissions pathway associated with the chosen development scenario is used to select among available published outputs of simulation experiments with general circulation models (GCMs) to define future climate scenarios for modeling of agriculture production systems and water resources.
3. The agro-ecological zones method takes as input a climate scenario and estimates on a spatial grid of 5′ by 5′ latitude/longitude the likely agronomic impacts of climate change in terms of soil moisture conditions, attainable rain-fed and irrigated crops yields, and irrigation water requirements of crops.
4. Estimated spatial climate change impacts on yields are incorporated into the parameterization of the national crop production modules of the world food system model.
5. The global general equilibrium world food system model is used – informed by the development storyline and estimated climate change yield impacts – to produce internally consistent world food system scenarios portraying each respective development pathway. The simulations were carried out on a yearly basis from 1990 to 2080.
6. In a final step, the results of the world food system simulations are ‘downscaled’ to the spatial grid of the resource database for spatial attribution of physical resource use, quantification of land cover changes and spatial cropping patterns.

3.6.2 SSP scenario implementation

In the analysis presented here, we make use of a new set of scenarios that was developed by the research community to harmonize and provide a common context for climate change impact, mitigation and adaptation assessments (Moss et al. 2010). A range of possible future socio-economic conditions are described in the Shared-Socio-economic Pathways (SSP) (O'Neill et al. 2015). On the most fundamental level, each SSP is described by a narrative. The SSP storylines describe socio-economic developments without the assumption of climate policies and climate change. However, in parallel possible future levels of climate change were explored through the development of different representative concentration pathways (van Vuuren et al. 2011). For implementation in this study, the development pathways SSP2 (“*Middle of the road*”) and SSP3 (“*Regional rivalry*”) were assumed to be consistent with emission trajectories and climate outcomes of the RCP 6.0, and the SSP1 scenario (“*Sustainability*”) applies the atmospheric conditions of RCP 4.5.

Here we provide a brief summary of the salient features that characterize different SSPs and we indicate some implications this may have for the food and agricultural sector, the land use and for associated irrigation water withdrawal (Figure 3-3).

SSP1 –Sustainability scenario**:** The world shifts gradually toward a more sustainable path that respects perceived environmental boundaries. This development pathway envisages: Relatively low population growth and an emphasis on education; effective institutions; rapid technological change and improved resource use efficiency; liberalization of markets; risk reduction and sharing mechanisms.

For scenario implementation, these general tendencies of development in the SSP1 storyline were interpreted to have the following specific agriculture/irrigation related implications:

- Improved agricultural productivity through more rapid reduction (compared to reference technological assumptions on yields) of prevailing yield gaps toward environmentally sustainable and advanced technology yield levels
- Progressive elimination of barriers and distortions in international trade of agricultural products
- Progress towards effective land use regulation especially for preventing deforestation caused by expansion of cropland
- Enforcement of legally protected conservation areas
- Large improvements of irrigation water use efficiency where possible
- Reliable water infrastructure and water supply
- Improving nutrition with environmentally benign diets with lower per capita consumption of livestock products (this last assumption was not included in the SSP1 reference implementation but will be assessed in a separate scenario variant).

SSP2 - Middle of the Road scenario: In the SSP2 world the development is progressing along past trends and paradigms. Main characteristics of this pathway include: Population growth continues at slowing rates and levels off in second half of century; markets are globally connected but they function imperfectly; somewhat slow progress in achieving development goals of education, safe water, and health care; environmental systems experience further degradation; barriers to enter markets are reduced only slowly; significant heterogeneities exist within and across countries. The SSP2 World is characterized by dynamics similar to historical developments. For scenario implementation this means continuation of past agricultural growth paths and policies, continued protection of national agricultural sectors, and further environmental damages caused by agriculture, and includes:

- Progress of agricultural productivity in developing countries as portrayed in FAO perspective study “World Agriculture: Towards 2030/2050” (FAO, 2012)
- Increasing per capita consumption of livestock products with growing per capita incomes
- Barriers and distortions in international trade of agricultural products are reduced only slowly
- Some improvements of water use efficiency, but only limited advances in low-income countries
- Some reduction of 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 and protection to prevent deforestation due to cropland expansion

SSP3 - Regional Rivalry scenario**:** The SSP3 storyline portrays a pathway where the world development is stagnating. Some key characteristics of SSP3 include: Growing concerns about globalization and focus on national/regional issues and interests; population growth is low in developed countries, but continues at high rates in developing countries; overall a large increase of world population and slow economic growth combine to result in poor progress in achieving development goals of education, safe water, health care; global governance and institutions are weak; weak institutions contribute to slow development; markets are protected and highly regulated; low priority is given for addressing environmental problems and serious degradation of environmental systems occurs in some regions; low investment in education and technology development; altogether this causes large disparities within and across countries.

Development in the SSP3 World leads to manifold problems in food and agriculture, characterized by:

- Poor progress with agricultural productivity improvements in low-income countries due to lack of investment and education for yield gap reduction
- 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)
- Poor land use regulation and continued deforestation of tropical rain-forests
- Only modest improvements of irrigation water use efficiency
- Persistent over-exploitation of groundwater aquifers
- 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

The characteristics of the three development pathways and the main assumptions used in the implementation of the scenario simulations are summarized in Table 3-7. The sustainability scenario SSP1 achieves land productivity improvements exceeding those in SSP2.

Table 3-7: Overview on assumptions for food and agriculture scenario simulations

	SSP1 Sustainability	**SSP2 Middle of the road**	**SSP3 Regional rivalry**
Yield growth	Faster than medium	Medium	Slower than medium
Irrigation share	Above medium	Medium	Below medium
Trade liberalization	Full	Incomplete	Constrained
Land use change	Strong regulation	Some regulation	Deforestation allowed
Protected areas	Fully enforced	Fair enforcement	Limited enforcement

Lowest technology advances and productivity gains materialize in SSP3. These assumptions were implemented regarding crop yield increases, changes in cropping intensity (i.e. multi-cropping), and concerning the share of irrigated land in total cropland.

As to institutional factors affecting the food and agriculture sector, it was assumed that agricultural protection measures would be fully eliminated by 2040 in SSP1 and would be reduced, but incomplete and at a slower pace, in SSP2. Protection measures persist in SSP3 with only small reductions. Concerning land use change regulation it was assumed that legally protected conservation areas would be fully enforced in SSP1 and some leakages of land conversion would be tolerated in SSP3. Also, there is strong regulation and concern to prevent deforestation by agricultural land conversion; yet, some deforestation still takes place due to urban development or lack of alternatives. In SSP3, land regulation is assumed to be weak and deforestation for cropland expansion notably in Africa and Latin America continues.

3.7 Uncertainty of water supply and demand

Available surface water resource

This analysis applies a multi-model approach with 5 GCMs and 3 GHMs, for a total of 15 ensemble members. Model biases are inevitable in meteorology and hydrology. Thus we use a multi-model approach for greater confidence in model results and to estimate uncertainty due to model bias. Figure 3-4 shows as example time series of precipitation for each region based on 5 GCMs (a.) and runoff simulated by 15 ensemble members (5 GCMs x 3 GHMs) (b.). Light colors illustrate uncertainty ranges, and solid lines are ensemble means. Although showing the uncertainty complicates the message, it is informative to show that sometimes significant uncertainty exists compared to the trend from the whole ensemble.

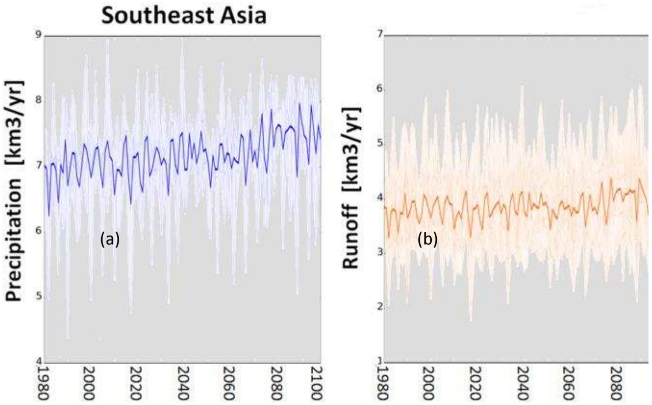

Figure 3-4: Long term trend under *Middle of the Road* scenario: a) precipitation b) runoff

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. Figure 3-5 shows three kinds of water demand (agricultural, industrial and domestic) for China. Each model presents three water scenarios, respectively. Although assumptions on socio-economic, technological and structural change were harmonized, ensemble projections of water use for the first half of the 21st century showed large variability among the models. The spread was much larger in the industrial sector compared to 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 water demand of each sector. The approaches used vary as each model

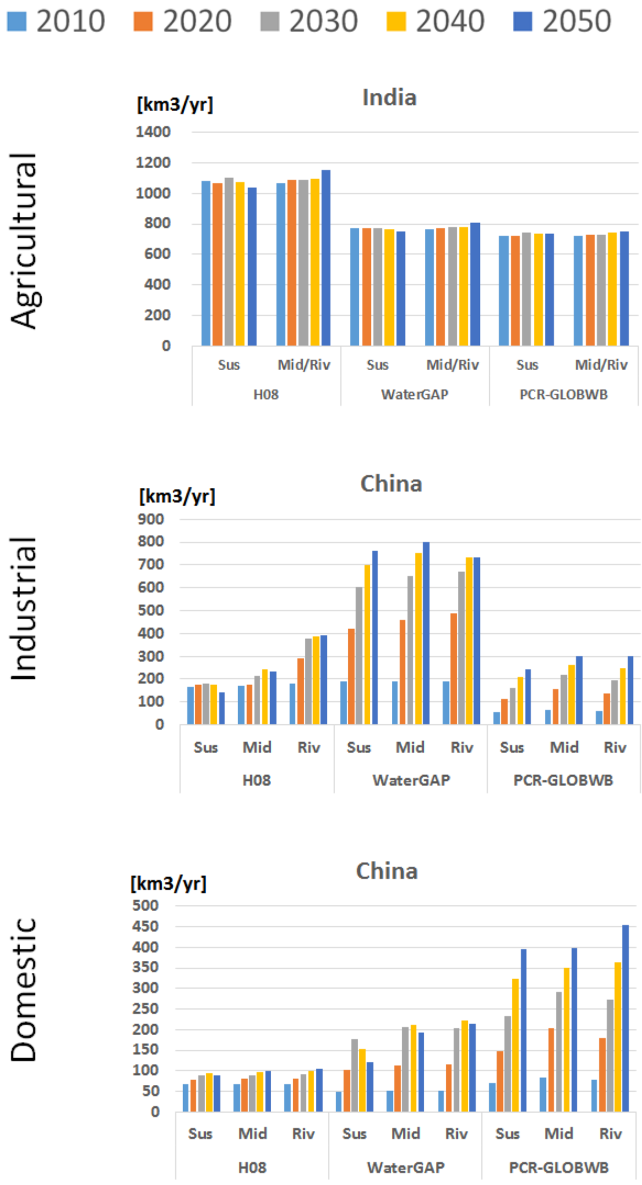

Figure 3-5: Multi-GHMs comparison of each water demand example of India and China

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. Despite potential model and data limitations, the WFaS initiative advances an important step beyond earlier work by attempting to account more realistically for the nature of human water use behavior in the 21st century and identifying associated uncertainties. Results given in this report are ensemble means; using ensemble means works well to detect long term and relatively large trends.

4 Global Results

4.1 Socio Economics

Population and economic development are key drivers for the estimation of water demand presented in this study (section 4.5). Socio-economic development also bears an important effect on water availability (section 4.4) as they determine GHG emission scenarios, a major driver for climate change projections.

4.1.1 Population

Applying the methods of multi-dimensional mathematical demography (KC and Lutz 2014) projected national populations based on alternative assumptions on future fertility, mortality, migrations and educational transitions that correspond to the five SSPs. In terms of total world population size the trajectories resulting from the five SSPs stay very close to each other until around 2030. By the middle of the century already a visible differentiation appears resulting in a global population by 2100 between 6.9 billion in the lowest scenario SSP1 ‘*Sustainability*’ and 12.6 billion in the highest scenario SSP3 ‘*Regional Rivalry*’. Note that population in the ‘Sustainability’ scenarios by 2100 is below the current level of 7.3 billion people. In the ‘*Middle of the Road*’ scenario population peaks in the 2070s and then declines to just below 9 billion by 2100. The difference between the scenarios is primarily due to developments in Africa and Asia. In contrast population development in the Americas, Europe and Oceania are comparatively similar across the scenarios (Figure 4-1).

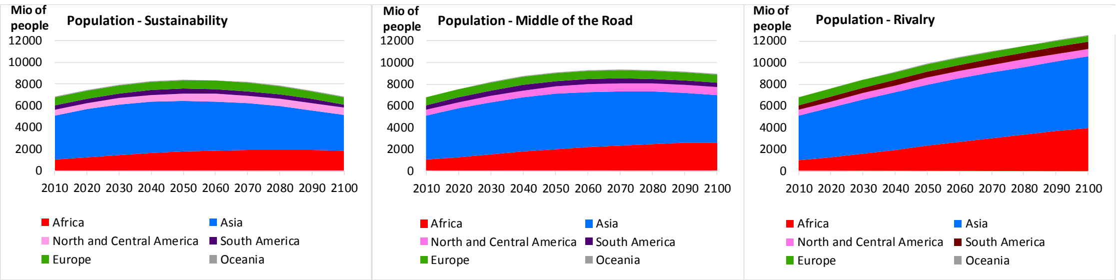

Figure 4-1: Population development until 2100, by continent and scenario

Sub-regional development for Africa, Asia and Europe are presented in Figure 4-2 for the ‘*Middle of the Road’* scenario. The maps in Figure 4-3 highlight the change in population between 2010 and 2050 on a country level.

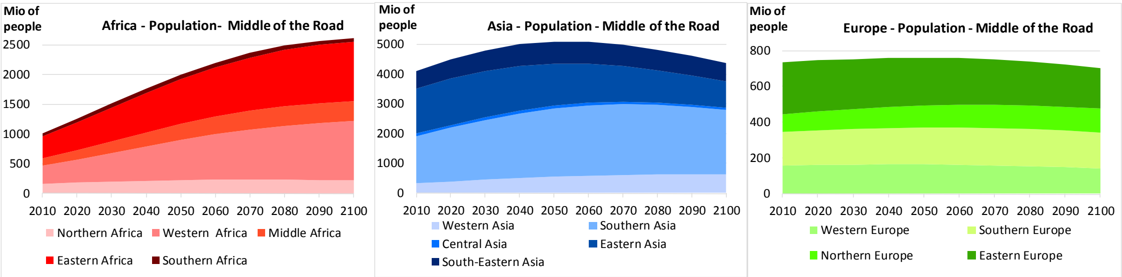

Figure 4-2: Population development in the ‘*Middle of the Road*’ scenario for the sub-regions of Africa, Asia, and Europe

Africa: In the ‘Rivalry’ scenario Africa’s population doubles during less than two generations (less than 40 years) from 1.0 billion in 2010 reaching 2.0 billion in the beginning of the 2040s. By 2100 the current population has almost quadrupled reaching 3.9 billion or 31% of global population. Africa’s high population growth in ‘Rivalry’ is closely linked to the lack of improvements in education over time, especially the low percentage of female, aged 20-39, with secondary and tertiary education[15]. Africa's population growth is also significant in the '*Middle of the Road'* scenario with population doubling by 2050 and reaching 2.6 billion in 2100 (Figure 4-2, left and Table 4-1, upper). In this scenario countries with a population over 100 million in 2050 include Nigeria (372 mio), followed by Ethiopia (159 mio), DR Congo (146 mio), Egypt (125 mio) and UR Tanzania (102 mio). Even in the 'Sustainability' scenario Africa's population increases by over 700 million people (+72%) until 2050 when growth rates become more moderate and peak at 1.9 billion in 2080.

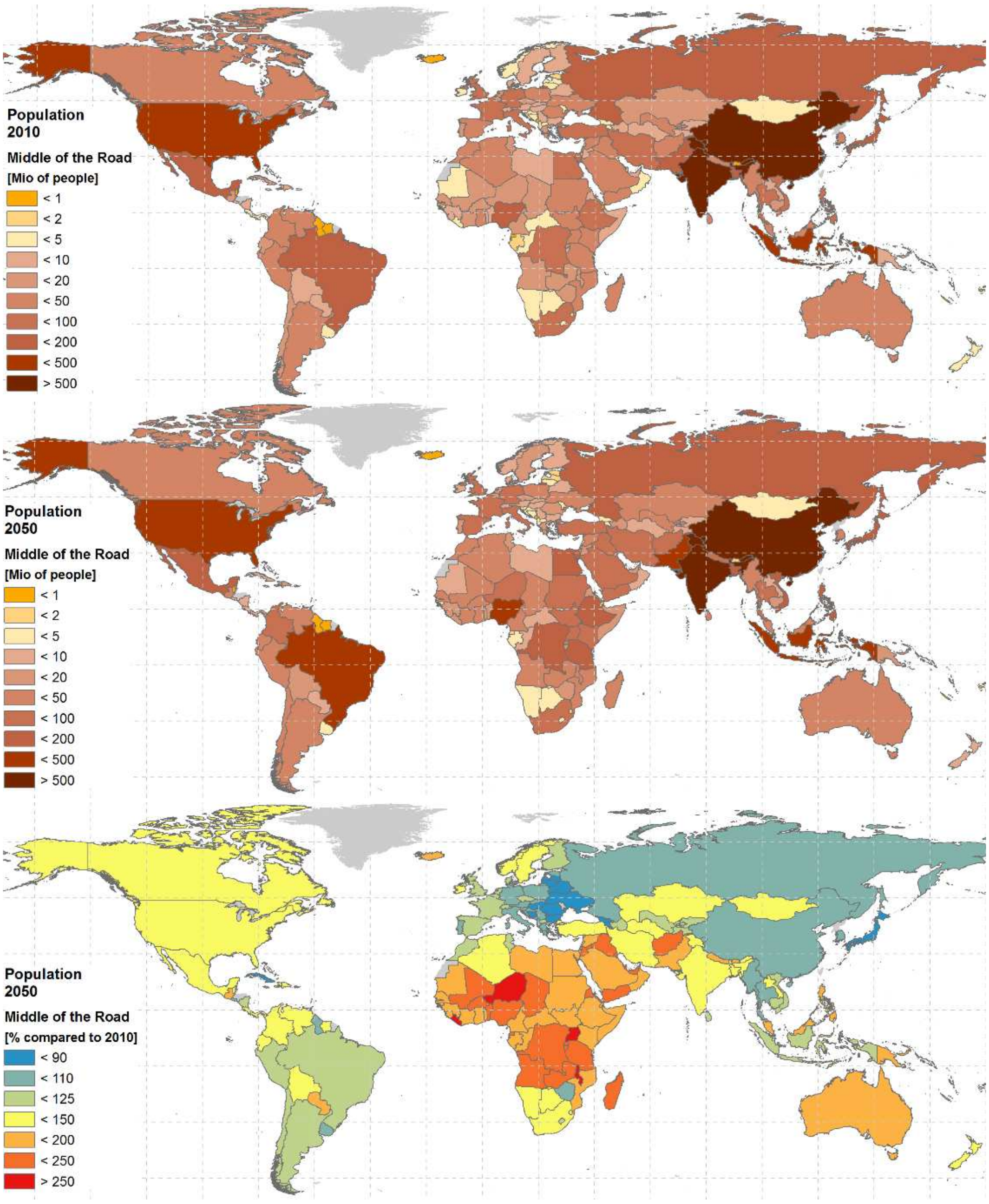

Figure 4-3: Population – *Middle of the road* scenario
Top: population 2010. Middle: population 2050. Bottom: change rate of population [%] compared to 2010

Asia: Asia today is home to 4.1 billion people, 60% of global population. A continuous population increase is only projected in the 'Rivalry' scenario reaching as much as 6.6 billion in 2100. In the 'Sustainability' and '*Middle of the Road'* scenario Asia's population peaks in the 2040s and 2050s with about 4.7 and 5.1 billion people respectively. Two thirds of population increase in Asia is due to developments in India. For example the '*Middle of the Road'* scenario projects between 2010 and 2050

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[15] For more information see KC and Lutz 2014

an additional 509 million people making India by far the largest nation of the world with a total population of 1.7 billion. Other countries with a significant amount of increasing population (> 50 mio until 2050) include Pakistan, Bangladesh, Indonesia and Philippines. Countries in the Middle East and Western Asia also generally increase by between 44 million (Afghanistan) and 10 million (United Arab Emirates). On the other hand for many countries in Asia population is expected to grow moderately in the coming decades or even decline such as China and Japan.

Europe: Europe's current population of 735 million (year 2010) declines in the '*Regional Rivalry'* scenario to 670 in 2050 and 543 in 2100. In the '*Middle of the Road'* and '*Sustainability*' scenario population increases moderately until the 2050s by about 26 and 33 million respectively. After 2050 population further declines.

4.1.2 Economic growth and income

The SSP population and human capital projections provided key input for the long-term economic growth projections. (Dellink et al. 2015) applied a methodology based on a convergence process with emphasis on the key drivers of economic growth in the long-term: population, total factor productivity (TFP), physical capital, employment and human capital, and energy and fossil fuel resources. TFP related drivers include the rate of change of the technological frontier, the speed of convergence between low and high income countries, and openness of the economy. The authors note that "*the projections are subject to large uncertainties, particularly for the later decades, and disregard a wide range of country-specific drivers of economic growth that are outside the narrow economic framework, such as external shocks, governance barriers and feedbacks from environmental damage. Hence, they should be interpreted with sufficient care and not be treated as predictions.*" GDP and income levels are presented in 2005 USD using constant purchasing power parity (PPP).

Global GDP levels at the end of this century are lowest in the 'Regional Rivalry' scenario (with lowest levels of international co-operation and trade) amounting to around 220 trillion USD. In the 'Sustainability' and '*Middle of the Road'* scenario this increases to 650 and 570 trillion USD. This pattern is similar for income (i.e. per capita GDP) levels. Owing to its large population Asia and Africa are the main drivers for differences across scenarios, especially in the second half of this century (Figure 4-4, Figure 4-5). This is also reflected in the relative increase in GDP, which is largest in these continents (Figure 4-6 bottom).

The relative contribution of North and Central America, Europe and Oceania (i.e. including the majority of industrialized countries) to global GDP declines significantly in all scenarios. Currently half (51%) of GDP is generated in this region. By 2050 this declines to 33% in '*Regional Rivalry'*, followed by 32% in '*Middle of the Road'* and a low of 29% in '*Sustainability*'. Notwithstanding per capita GDP in these regions remains higher until 2050 (and thereafter) compared to the other major regions.

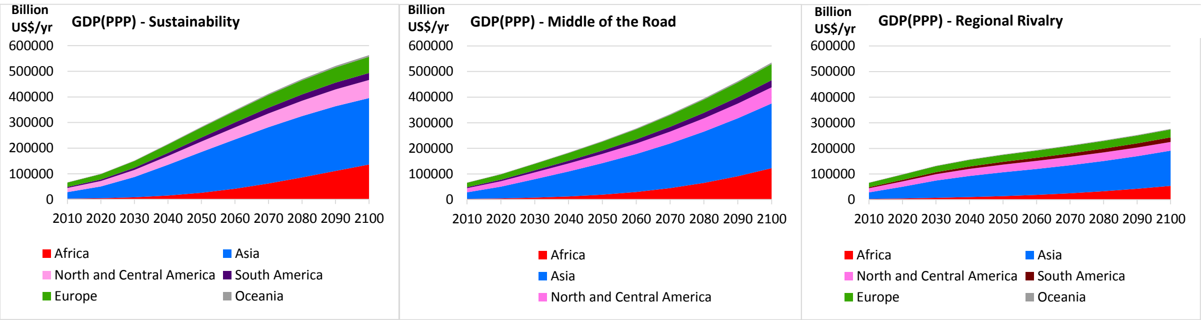

Figure 4-4: For three scenarios GDP development till 2100 for the 6 continents

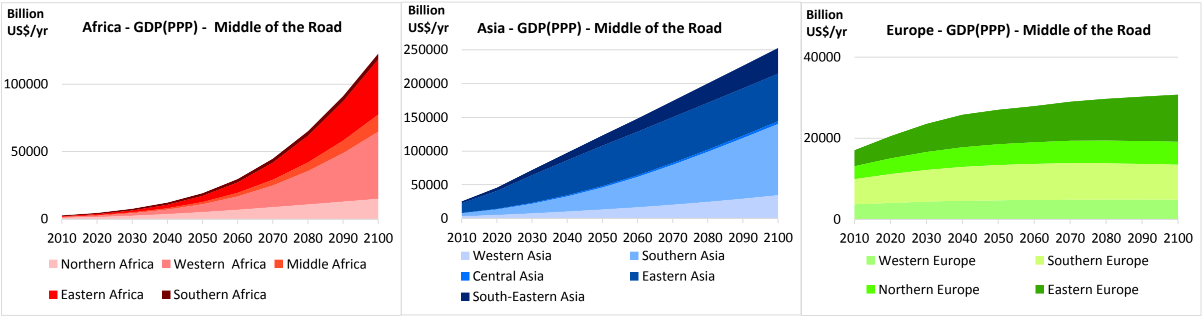

Figure 4-5: For the 3 scenarios population development till 2100 for subregions Africa, Asia and Europe

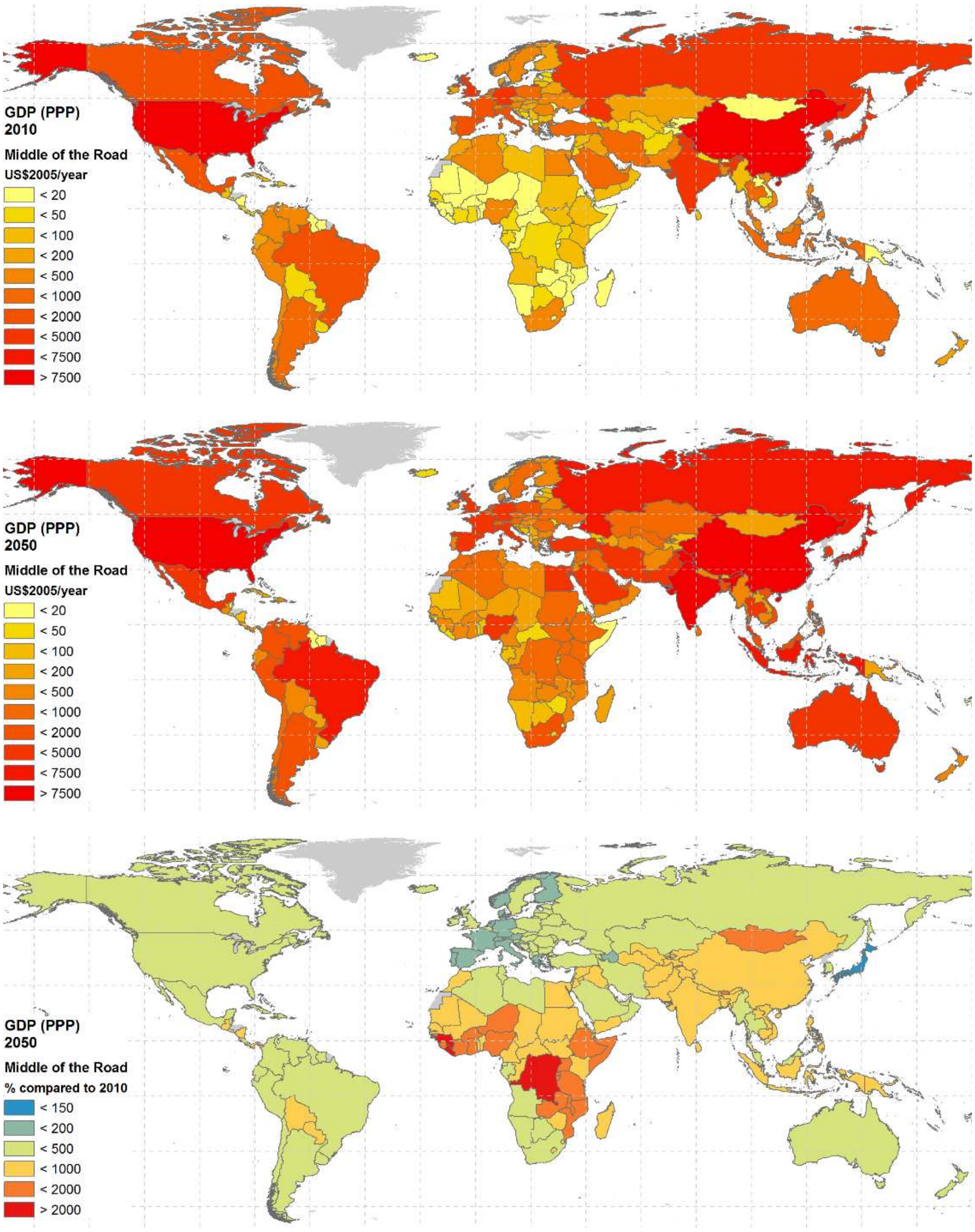

Figure 4-6: Gross domestic product – *Middle of the Road* scenario
Top: GDP 2010. Middle: GDP 2050. Bottom: change rate of GDP [%] compared to 2010

Figure 4-7 and the maps in Figure 4-8 highlight per capita GDP on a regional and country scale and the changes between today and 2050. On a global level income (per capita GDP) by 2050 is highest in the 'Sustainability' scenario, a 3.5 increase of current levels and lowest in the 'Rivalry' scenario, only just above twice current levels. The closure in income gaps is highest in 'Sustainability' and lowest in 'Rivalry'. For example Asia's per capita GDP today is only 20% of those of North and Central America compared to 46% (*Middle of the Road*) by 2050. Although showing a high increase, Africa remains well below global average per capita GDP in all scenarios. Even in 'Sustainability', by 2050, Africa's per capita GDP is only about 43% of the global average. In contrast Asia's and South America's catch-up to global average levels is more pronounced.

Table 4-1 presents a comprehensive summary of the regional distribution of population, GDP and per capita GDP in 2010 and 2050 for the *'Middle of the Road'* scenario. As discussed above results highlight the remaining high levels of income (per capita GDP) in North and Central America, Oceania, and Europe in the coming decades.

Table 4-1: Population, GDP and GDP per capita comparison
Middle of the Road scenario

Population					**Change rate**
[Mio of people]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Africa	1021	15%	2010	22%	197
Asia	4104	60%	5097	56%	124
North and Central A.	533	8%	692	8%	130
South America	392	6%	490	5%	125
Europe	739	11%	763	8%	103
Oceania	36	1%	57	1%	158
World	6825		9110		133

GDP	**Mio US$2005/year**				**Change rate**
[Mio US$$_{2005}$/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Africa	2753	4%	19176	8%	697
Asia	25550	38%	123096	54%	482
North and Central A.	16197	24%	36076	16%	223
South America	3965	6%	12989	6%	328
Europe	17048	26%	34758	15%	204
Oceania	937	1%	2576	1%	275
World	66450		228671		344

GDP per capita					**Change rate**
[US$$_{2005}$/year/cap]	**2010**	% o🌍	**2050**	% of🌍	(% of 2010)
Africa	2696	28%	9541	38%	354
Asia	6226	64%	24148	96%	388
North and Central A.	30411	312%	52126	208%	171
South America	10106	104%	26504	106%	262
Europe	23076	237%	45555	181%	197
Oceania	23076	237%	45290	180%	196
World	9736		25102		258

% of World: % of the World's average GDP/cap

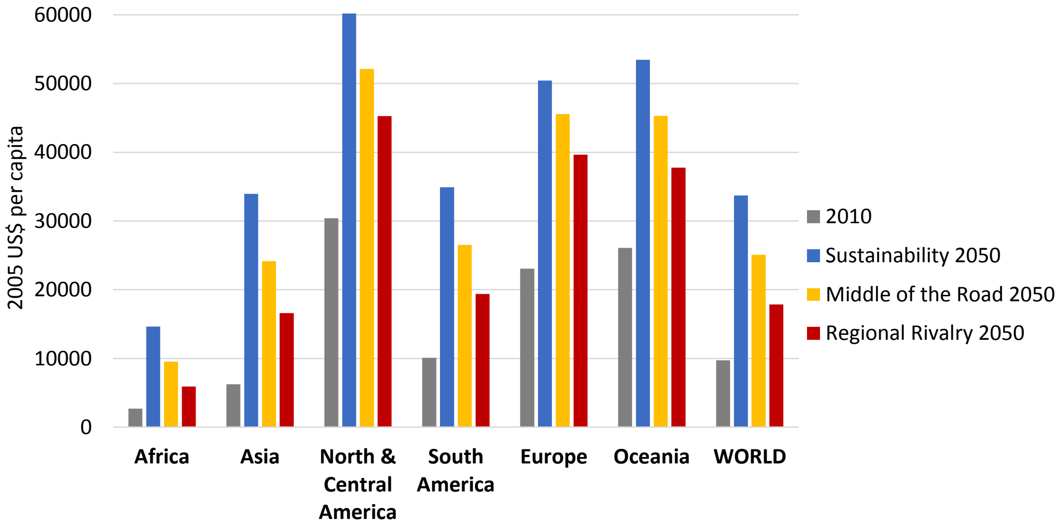

Figure 4-7: Per capita GDP in 2010 and 2050 for the three scenarios

At the same time their share in global GDP declines from a current 51% to 29-33% (depending on the scenario) while population remains fairly constant. Asia exhibits an increasing share in global economy with a contribution of 38% in 2010 and of 51% by 2050. In contrast Africa's GDP growth (from 4% in 2010 to 8-9% in 2050), although impressive in its growth rates, is apparently insufficient to compensate for a strong population growth. The continent therefore lags behind in income even in 2050 when Africa's GDP per capita will be only 33-43% of global average.

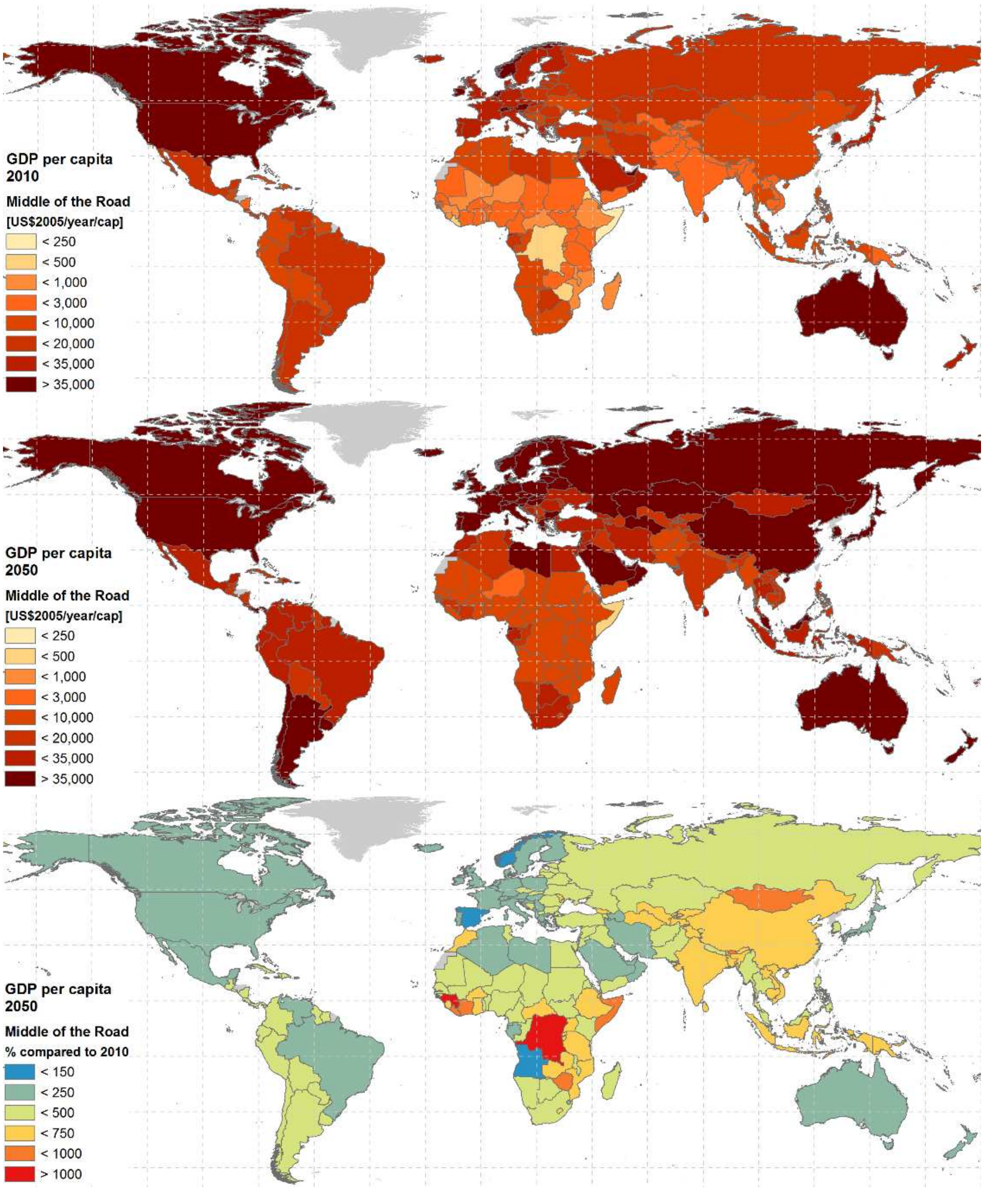

Figure 4-8: Gross domestic product per capita – *Middle of the Road* scenario
Top: GDP/cap 2010. Middle: GDP/cap 2050. Bottom: change rate of GDP/cap [%] compared to 2010

Austria and priority countries of the Austrian Development Agency

Figure 4-9 presents socio-economic development pathways along the storylines of the three scenarios for Austria and the priority countries of the Austrian Development Agency. Table 4-2 summarizes the socio-economic variables for the ‘*Middle of the Road’* scenario by country in 2010 and 2050.

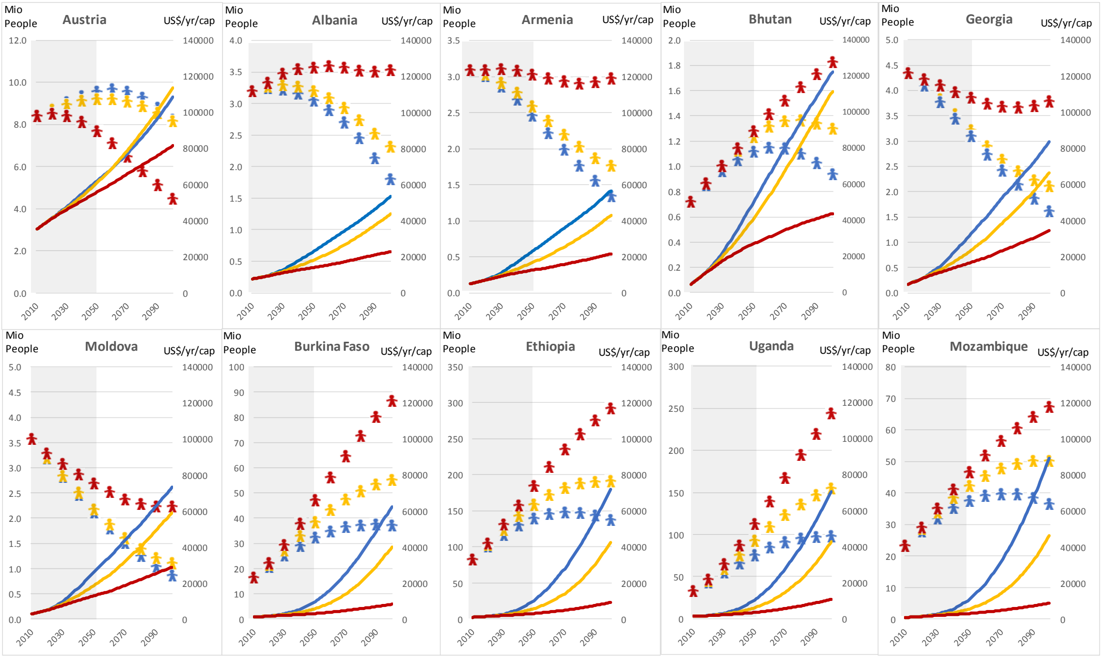

Figure 4-9: Changes in Gross domestic per capita and population for ADA priority countries (blue ‘*Sustainability*’, yellow ‘*Middle of the Road’*, red ‘*Regional Rivalry*’ scenario)

Austria: Like other high-income European countries Austria’s population declines in the ‘Rivalry’ scenario after an early peak in the 2020s. By 2050 population is 11% below and by 2100 as much as 47% lower compared to current 8.4 million people. An explanation for this decline are the assumptions for fertility (low), mortality (High) and migration (none) for OECD countries of the SSP3 scenario (Rivalry - Fragmented World – storyline see (O'Neill et al. 2015) and Appendix A). Further description of the assumptions of the SSP’s is given as a supplement to the IIASA SSP database[16]. The projection for all the other ADA priority countries show the opposite trend, assuming an increasing population for the ‘Rivalry’ scenario because of a high fertility assumption for Non-OECD countries.
Nevertheless because of the rather extreme impact of the SSP3 scenario till 2100 we only consider the period till 2050. Population development in the ‘*Middle of the Road*’ and ‘*Sustainability*’ scenario is significantly different when population increases until about the middle of the century, followed by a moderate decline until 2100. Economic development and income (GDP per capita) is fairly similar in the ‘Sustainability’ and ‘Middle of the Road’ scenarios, but significantly lower in the ‘Rivalry’ scenario.

Albania, Moldova, Armenia, Georgia: Population development trends across the three scenarios are different in Europe’s and Central Asia’s low income countries compared to high-income countries. Population remains fairly stable in ‘Rivalry’ but declines vigorously in *'Middle of the Road'* and even more in ‘*Sustainability*’. Income growth is strongest in ‘*Sustainability*’. Nevertheless GDP per capita in 2050 reaches just about the global average and is only about half the European average. Across the four countries the strongest economic growth occurs in Moldova where GDP per capita increases between 2010 and 2050 by a factor of between 5 (‘*Regional Rivalry*’) and 9 (‘*Sustainability*’).

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[16] https://tntcat.iiasa.ac.at/SspDb/static/download/ssp_suplementary%20text.pdf

Bhutan: Bhutan stands out in its strong economic development compared to the other ADA target countries. Starting at the same income level as Armenia and Georgia, GDP per capita is projected to increase by 2050 between 6-fold in 'Rivalry' and 11-fold in 'Sustainability'. Bhutan's income level is thus by the middle of the century well above global average reaching almost the European average.

Bhutan's population grows in all three scenarios continuously until 2050 and thereafter only declines in 'Sustainability'. The relatively low population of 0.7 million in 2010 has increased to between 1.1 in 'Sustainability' and 1.3 in 'Rivalry' by 2050.

Burkina Faso, Ethiopia, Mozambique, Uganda: In the African ADA target countries population increase significantly until the mid of the century when growth flattens or decreases only moderately. Growth is much stronger in '*Regional Rivalry*' compared to '*Sustainability*' because of the high fertility and no migration assumption in the '*Regional Rivalry*' scenario. '*Middle of the Road'* takes an intermediate position with the following rates of increase between 2010 and 2050 and population numbers in 2050: Mozambique (1.8-fold increase, 42 million in 2050), Ethiopia (1.9-fold, 158 million), Burkina Faso (2.3-fold, 37 million), Uganda (2.8-fold, 93 million). Across the four countries population growth is projected to be strongest in Uganda, a trend continuing until 2100 (Figure 4-10). Although economy grows strongly, for example by a factor of 10 to 20 between 2010 and 2050, income levels remain throughout the century well below most other countries of the world[17]. However there is some gap closure over time. By 2050 per capita GDP in all four countries has increased from a current 3-4% of global average to 9%. The four countries also remain on the lower end of income within Africa.

Table 4-2: Population, GDP and GDP per capita comparison
ADA priority countries – Middle of the Road scenario

Population [Mio of people]	**2010**	**2050**	**Change rate** (% of 2010)
Austria	8.4	9.2	110
Albania	3.2	3.2	100
Armenia	3.1	2.6	84
Georgia	4.4	3.2	74
Moldova	3.6	2.2	61
Bhutan	0.7	1.2	171
Burkina Faso	16.5	38.6	234
Ethiopia	82.9	158.8	191
Uganda	33.4	93.3	279
Mozambique	23.4	42.3	181

GDP [Mio $\text{US\$}_{2005}$/year]	**2010**	**2050**	**Change rate** (% of 2010)
Austria	297	561	189
Albania	25	58	237
Armenia	15	44	288
Georgia	20	76	374
Moldova	10	41	408
Bhutan	3	51	1471
Burkina Faso	19	221	1181
Ethiopia	77	896	1158
Uganda	38	555	1445
Mozambique	19	236	1226

GDP per capita [$\text{US\$}_{2005}$/year/cap]	**2010**	**% of** 🌍	**2050**	**% of** 🌍	**Change rate** (% of 2010)
Austria	35366	363%	60919	243%	172
Albania	7660	79%	18181	72%	237
Armenia	4901	50%	16821	67%	343
Georgia	4651	48%	23448	93%	504
Moldova	2785	29%	18622	74%	669
Bhutan	4780	49%	41202	164%	862
Burkina Faso	1136	12%	5725	23%	504
Ethiopia	932	10%	5639	22%	605
Uganda	1149	12%	5954	24%	518
Mozambique	823	8%	5579	22%	678

% of World: % of the World's average GDP/cap

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[17] Chateau et al. 2012 explains the methodology for the long-term economic growth modeling

By 2050, the per capita GDP in these countries is between 5580 and 5950 (constant 2005 U$ PPP). This compares to 9540 and 25100 for Africa's and global average respectively.

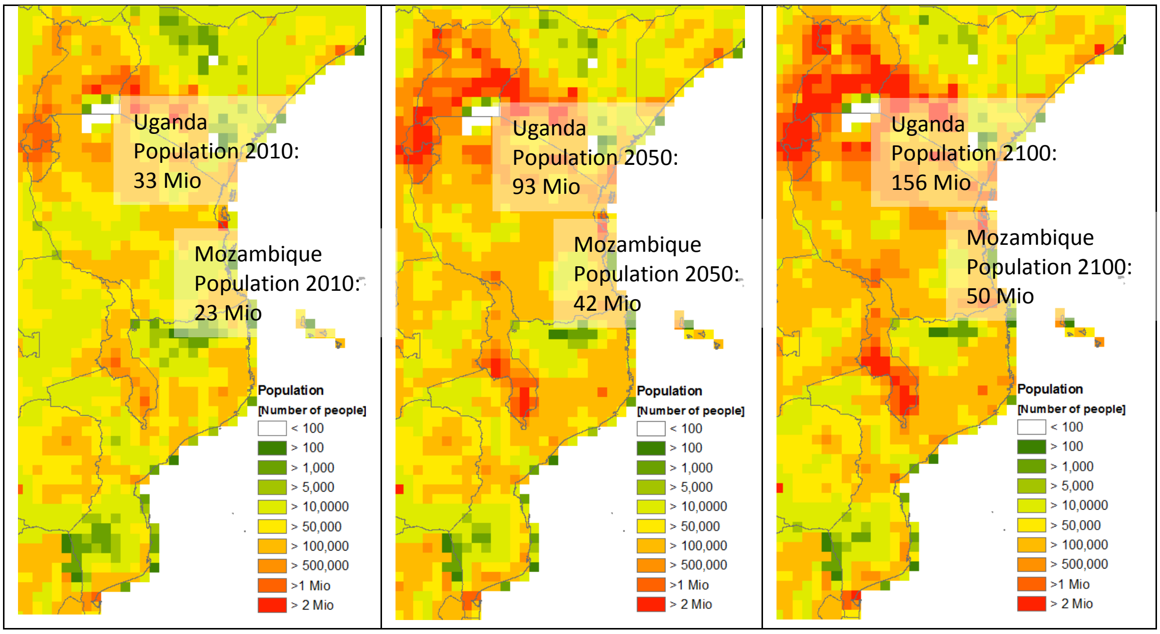


Figure 4-10: Population in detail at the example of Eastern Africa. Source: Jones 2014

4.2 Energy system development and scenarios

Water and energy resource systems are tightly linked. Secure and reliable access to both resources is critical to basic survival, as well as ongoing economic development, at all scales and in every region of the world. Water is needed for nearly all production and conversion processes throughout the energy sector. It is used for fuel extraction and processing; for electricity generation; and increasingly for growing biofuels. Similarly, energy is essential for water extraction from both surface and subsurface sources, treatment, conveyance, and delivery to users. Choices made in one sector have direct and indirect impacts on the other. Energy production technology choice determines the amount of water required to produce energy. At the same time, the availability of freshwater resources, management policies, and allocation rules determine how much water can be secured for energy production. This linkage carries significant implications for managing water and energy security challenges.

4.2.1 Energy demand change and implications on water use

In this section, we present results from the 2015 World Energy Outlook (WEO-2015) and the related reports (International Energy Agency (IEA) 2015). In these reports, three possible future scenarios for energy system development are considered: *Current Policies Scenario*, *New Policies Scenario*, and *450 Scenario*. The *Current Policies Scenario* takes into account only policies affecting energy markets that had been enacted as of mid-2015. The *New Policies Scenario*, the central scenario in WEO-2015, takes into account the policies adopted as of mid-2015, together with relevant declared policy intentions, even though specific measures needed to put them into effect may not have been adopted. The *450 Scenario* depicts a pathway to the 2°C climate goal that can be achieved by fostering technologies that are close to becoming available at commercial scale.

Between 1990 and 2010, world primary energy demand increased by 55%, from about 8800 to 13600 million tonnes of oil equivalent (Mtoe). This demand is projected to further increase in the next few decades. However, future energy and climate policies play a powerful role in determining the pace at which energy demand grows and the choice of energy technology mix. According to WEO-2015, world primary energy demand will increase by 12 to 45% between 2010 and 2040, to reach between 15200 and 19700 Mtoe, depending on the scenario considered (Figure 4-11). This increase will be driven mainly by demand growth in India, China, Africa, the Middle East, and Southeast Asia. Non-OECD countries account together for all the increase in global energy demand, as demographic and structural economic changes, together with greater efficiency, reduce collective demand in OECD countries from the peak reached in 2007.

Declines are led by the European Union, Japan, and the United States (International Energy Agency (IEA) 2015).

World primary energy demand for all fuels, except for fossil fuels under the *450 Scenario*, grows through to 2040. In all scenarios, fossil fuels remain the dominant source of energy supply to 2040, but their share of the energy mix falls, just slightly in the *Current Policies Scenario* but much more rapidly in the *450 Scenario*. Renewables increase significantly, but their growth only just outpaces that of total energy demand, meaning that their share of the energy mix changes little. Similarly, nuclear sees little change. The outlook for all forms of low-carbon energy (renewables, nuclear power, and others) is more positive in the *450 Scenario* and they collectively meet 46% of primary energy demand by 2040 (Figure 4-11).

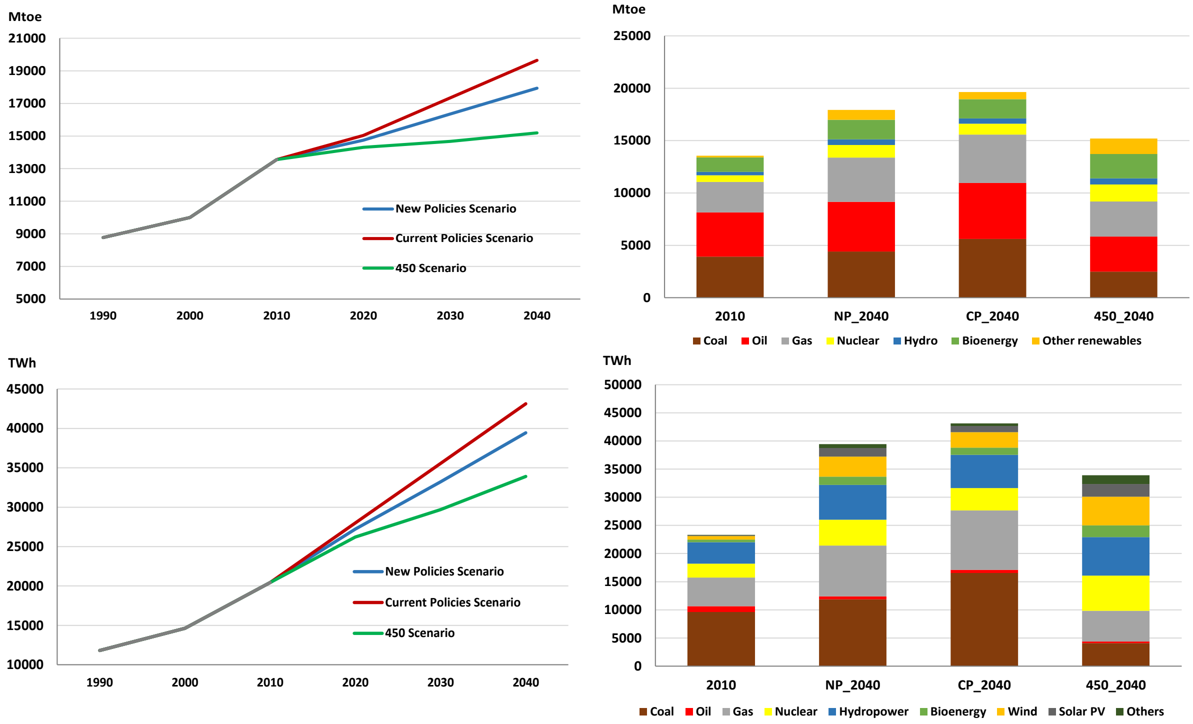


Figure 4-11: Global primary energy demand (upper-left) and electricity generation (down-left) under the different WEO-2015 scenarios and changes in technology mix of global primary energy demand (upper-right) and electricity generation (down-right) between 2010 and 2040. Source: (International Energy Agency (IEA) 2015)

The power sector is the major energy end-use sector. At present, the power sector accounts for over 60% of coal demand, 40% of gas demand, 55% of the use of renewables, and 42% of global energy-related CO_2 emissions. The power sector must therefore be at the heart of any strategy that addresses economic growth, energy and water security, and climate change. Electricity demand is strongly correlated to economic growth, although the extent of the linkage depends on the level of economic development of each country, the structure of the economy, and the extent of access to electricity. In the *New Policies Scenario*, demand increases over 70% from about 20150 Terawatt hour (TWh) in 2010 to almost 34500 TWh in 2040, with an average annual growth rate of 2%. Demand is even more robust in the *Current Policies Scenario*, to reach 37600 TWh in 2040, growing an average of 2.3% per year. However in the *450 Scenario*, demand growth moderates to 1.5% per year as efficiency measures take hold, amounting to 30015 TWh in 2040. Non-OECD countries drive the growth in global demand, as they are, in general, undergoing rapid economic and population growth, and associated rising incomes and shifts from rural to urban areas. Major increases in electricity demand will take place in India, Southeast Asia, and Africa, with an annual growth rate of about 4% between 2010 and 2040 (International Energy Agency (IEA) 2015).

The growing demand for power engenders global electricity generation to increase. Global electricity generation is expected to increase significantly from 23318 TWh in 2010 to between 33900 and 43100 TWh in 2040, depending on the policy scenario. The energy mix changes markedly over time. The contribution of fossil fuels to total electricity generation will decrease from 77% (15740 TWh) in 2010 to between 64% (27660 TWh) and 29% (9850 TWh) in 2040, depending on the policy scenario. Generation from renewables grows the fastest, as their costs fall and government support continues, and it increases two to three and a half times, to reach between 11500 and 17800 TWh by 2040. Hydropower remains the largest source of renewables generation, while wind power and solar PV expand rapidly, but from a much lower base. Output from nuclear power plants increases up to 150%, to reach up to 6200 TWh by 2040 (Figure 4-11).

The Growing demand for energy and the shifts in technology will have important implications on water demand and use. Global water withdrawals for energy production in 2010 is estimated at 583 km^3, representing about 15% of the world's total water withdrawals. Power generation is the major water demand in the energy sector, requiring more than 90% of withdrawals. The largest users of water for energy production are the world's largest electricity generators: the United States, the European Union, China and India. Global water consumption of the energy sector – the volume withdrawn but not returned to its source – amounts to 66 km^3. (International Energy Agency (IEA) 2012).

Projections of water demand to support future energy production vary by scenario. There is a general trend toward a substantial increase of water consumption by the energy sector in all scenarios over 2010-2035, while the trend of withdrawals is more variable across the scenarios. The differences across the scenarios are largely a consequence of divergent trends related to energy demand, the changes in the generation technology mix and the cooling technologies used, and the growth rates of biofuels production.

In the *Current Policies Scenario* (representing a pathway that assumes no change in existing energy-related policies), global water withdrawals for energy production continue to rise throughout the projection period, climbing to 790 km^3 in 2035, about 35% higher than in 2010. In the *New Policies Scenario*, global withdrawals reach 690 km^3 in 2035, an increase of about 20% over 2010, with growth slowing noticeably after 2020. Water consumption grows significantly by about 85% in the *New Policies Scenario* and doubles in the *Current Policies Scenario*.

Slower energy demand growth in the *New Policies Scenario* (averaging 1.2% per year, compared to 1.5% in the *Current Policies Scenario*) plays a significant role in its comparatively lower water requirements. The share of coal-fired power plants (that withdraw large quantities of water) in each scenario also contributes to the difference in water requirements. In the *New Policies Scenario*, coal-fired generation is reduced considerably, by 30% at the end of the Outlook period, and inefficient plants are retired more quickly compared to the *Current Policies Scenario*. Moreover, the power sector sees a continued change in the technologies for cooling thermal power plants. There is a trend toward wet cooling towers (that reduce withdrawals but increase consumption compared to once-through system) in both scenarios. This trend is more pronounced in the *New Policies Scenario* in which there is a shift from older coal plants based on traditional once-through systems. Additionally, the expanded role of renewables, such as wind and solar PV, also reduces water withdrawals in the *New Policies Scenario*, with their generation in 2035 is 25% and 60% higher, respectively, compared to the *Current Policies Scenario*.

In the *450 Scenario*, global water withdrawals reach about 600 km^3 in 2035, only 4% higher than in 2010, while consumption almost doubles. Compared with the other two scenarios, the *450 Scenario* sees much more modest energy demand growth (averaging 0.6% per year) and a marked shift in the power sector away from coal-fired power plants and towards renewables. Water withdrawals and consumption for biofuels expand the most in the *450 Scenario*, even though the increase after 2020 is slowed somewhat by penetration of non-irrigated advanced biofuels.

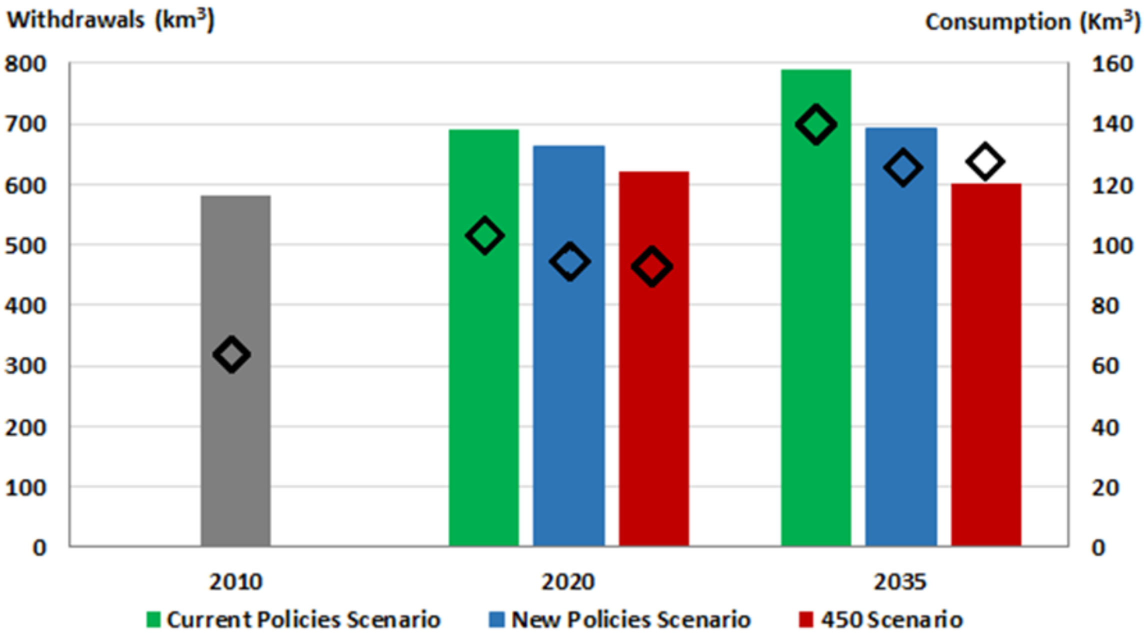


Figure 4-12: Global water withdrawals (rectangular bars) and consumption (black squares) for energy production by scenario. Source: International Energy Agency (IEA) 2012

4.2.2 Climate change impacts on the energy sector

Water is growing in importance as a criterion for assessing the technical, economic and environmental feasibility of energy projects (International Energy Agency (IEA) 2012). The vulnerability of the energy sector to water constraints is widely spread geographically and across types of energy production. Regions already experiencing water scarcity conditions face obvious risks; but, even regions with sufficient water resources can face constraints related to droughts, heat waves, seasonal variation, regulations, or combinations of these factors. Climate change is expected to decrease overall water availability in many parts of the world and to increase its temperature. These impacts will likely impact the reliability of existing energy operations and the viability of proposed projects, compromising future energy security and imposing additional costs for necessary adaptive measures.

The electricity sector is especially vulnerable to water constraints because it strongly depends on the availability and temperature of water resources for cooling thermal power plants and running hydropower turbines, which together generate the major share of global electricity. Several studies in the literature investigate the impacts of climate change on regional electricity generation. For example, (Lehner et al. 2005) assess the impacts of global change on hydropower potential in Europe. They find that this potential could be reduced by 6% for whole Europe and by 25% or more for southern and southeastern European countries by the 2070s compared to baseline setting. (Van Vliet et al. 2012) analyze the vulnerability of US and European electricity supply to climate change-induced lower summer river flows and higher river water temperatures. Their results show a summer average decrease in capacity of power plants of 6.3-19% in Europe and 4.4-16% in the United States depending on cooling system type and climate scenario for 2031–2060, with increased probability of extreme reductions in thermoelectric power production. This reduction of electricity generation potential could significantly raise electricity prices, impacting negatively both consumer and producer benefits (Van Vliet et al. 2013).

A recent study completed within the Water Futures and Solutions Initiative (WFaS) investigates the global impacts of climate change on electricity generation (van Vliet et al. 2016). Results show that over the coming decades, some regions will experience higher streamflow and only moderate water temperature increases, while others, notably the USA, southern and central Europe, Southeast Asia and southern parts of South America, northern and southern Africa, and southern Australia, will experience decreases in streamflow over time. Furthermore, strong increases in water temperature are expected in eastern North America, Europe, Asia and areas of southern Africa. These changes will lead to average reductions in global annual hydropower capacities between 1 and 4% compared to observed conditions, depending on the time horizon and climate scenario. The effects of climate change on hydropower will likely be especially strong in South America and Australia. For thermoelectric power, results show average reductions in global annual thermoelectric capacities between 5 and 12% compared to observed conditions, depending on the time horizon and climate scenario, due to the combined effects of streamflow reductions and temperature increases. Parts of North America, Europe, Africa, and Australia will likely face the most severe impacts (Figure 4-13).

Several adaptation options are available to address climate change-related water impacts on the energy sector. In the power sector, these include an increased diversification in the electricity sector, with greater reliance on renewable energy technologies that are independent from water availability and water temperature (e.g. solar PV, wind power); improving the efficiency of power plants; for instance by replacing fuel sources in thermoelectric power plants; deployment of more advanced cooling systems, including wet closed-loop system, and dry and hybrid systems; and switching to seawater cooling for thermoelectric power plants along the coast. In biofuels production, some solutions could be implemented to reduce water use of biofuel crops such as growing less-water intensive crops, growing crops in rainfed conditions where possible, and growing crops in multifunctional plantings. More generally, the energy sector can look to exploit unconventional water resources such as saline water, treated wastewater, and storm water (International Energy Agency 2012).

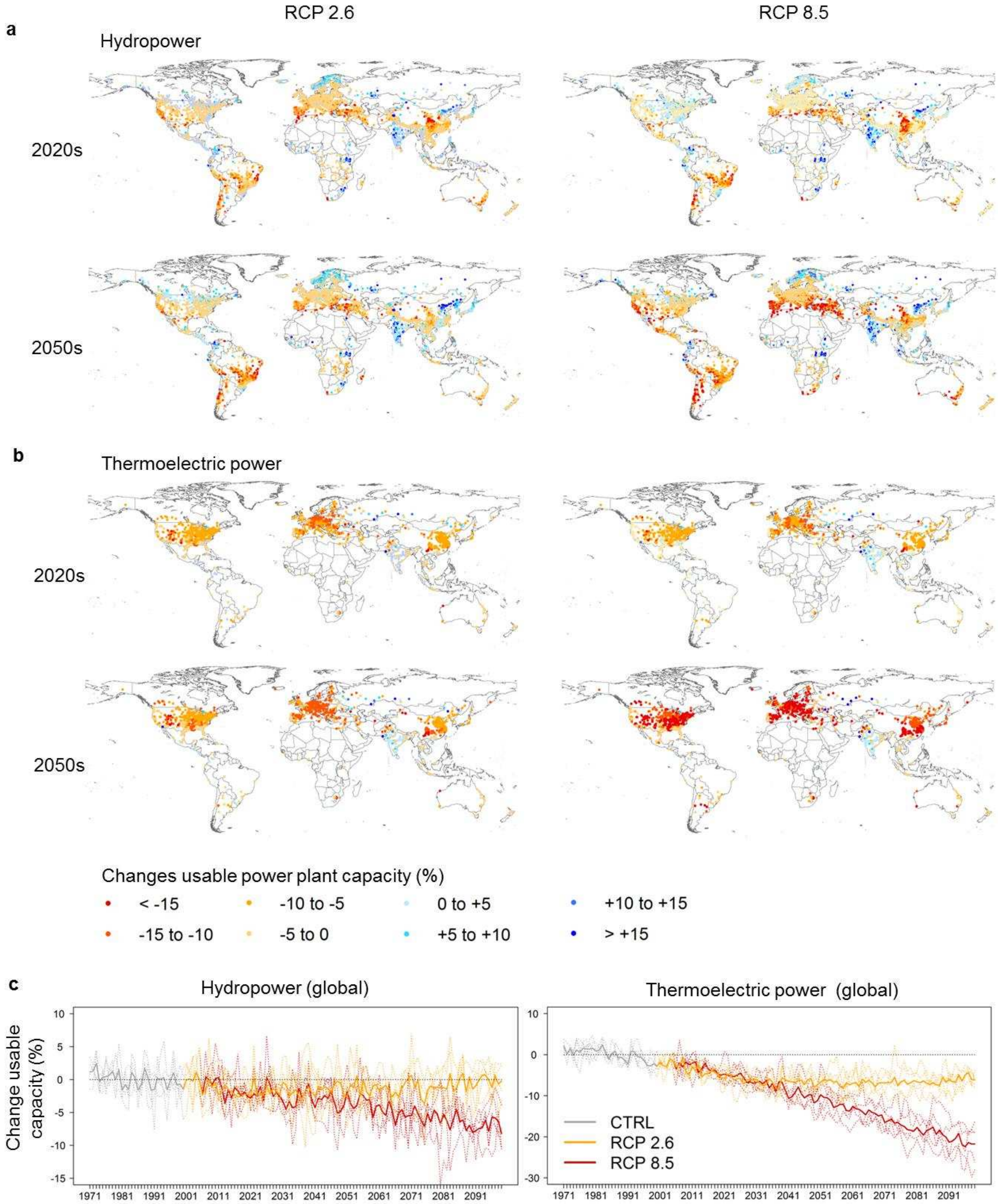


Figure 4-13: Impacts of climate and water resources change on annual mean usable capacity of current hydropower and thermoelectric power plants.

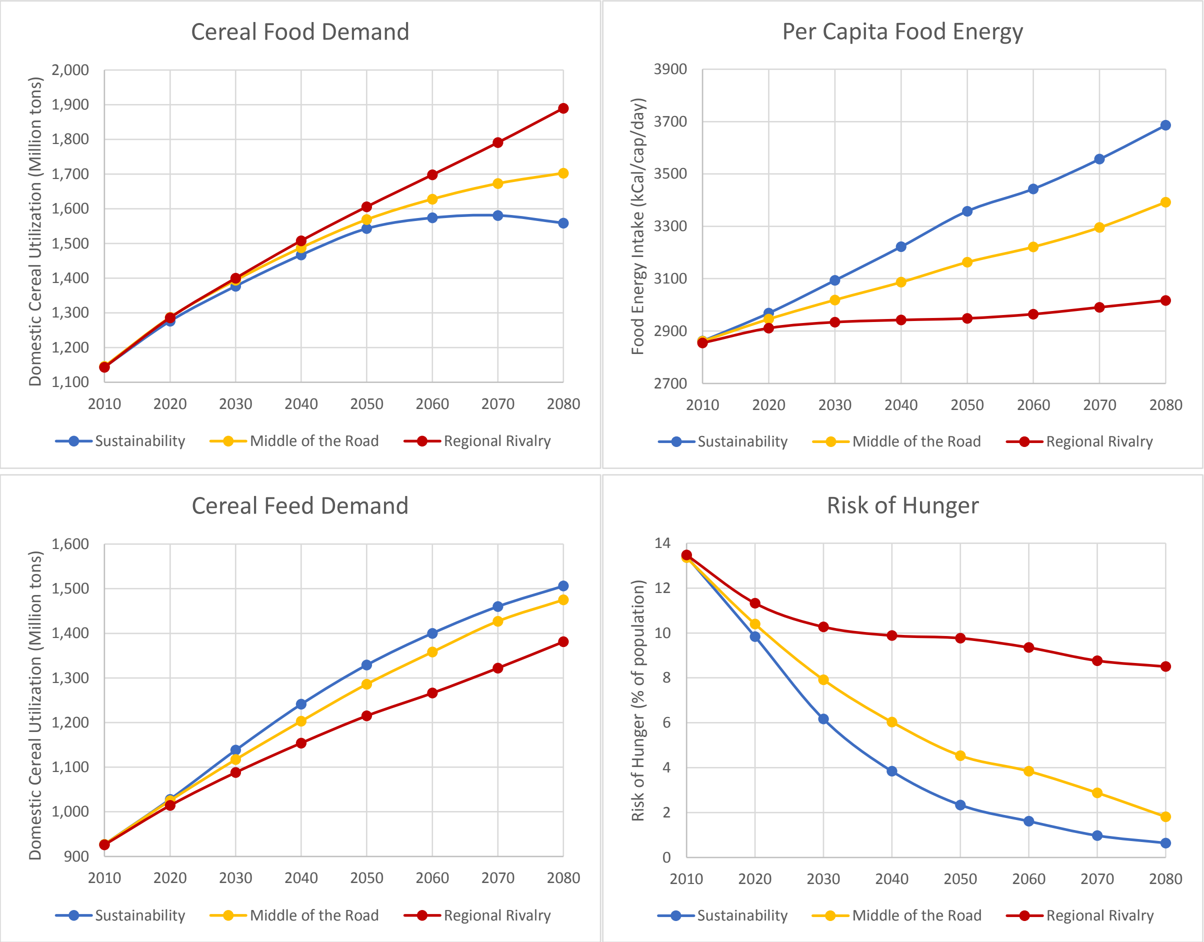
Relative changes in annual mean usable capacity of hydropower plants (a) and thermoelectric power plants (b) for RCP2.6 and RCP8.5 for 2010–2039 (2020s) and 2040–2069 (2050s) relative to the control period 1971–2000. Global trends of changes in annual mean hydropower and thermoelectric power usable capacity for 1971–2099 based on the GCM-ensemble mean results (thick lines) and for the five individual GCMs separately (thin dotted lines) for both RCP2.6 (orange) and RCP8.5 (red) (c). Source: (van Vliet et al. 2016)

4.3 Food and agriculture development

As in the past decades, the growing wealth and population numbers will be driving a rising food demand for better nutrition and more protein-rich diets. Based on the demographic and economic macro-drivers 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) were undertaken to explore possible future directions of the food and agriculture systems and to quantify for each development pathway the attainable nutrition levels and associated resource use.

4.3.1 Food demand

Globally, average food energy intake in the WFS model is estimated at 2860 kCal/cap/day in 2010, with regions ranging from less than 2300 kCal/cap/day in Africa, on average about 2780 kCal/cap/day in Asia and Latin America, to more than 3500 kCal/cap/day in Northern America, Europe and Oceania. The projected per capita food energy intake in 2050 reaches levels between 2950 kCal/cap/day (*Regional Rivalry* scenario) and 3360 kCal/cap/day (*Sustainability* scenario), and in 2080 respectively 3000 to 3700 kCal/cap/day (Figure 4-14).



Cereal Food Demand

Per Capita Food Energy

Cereal Feed Demand

Risk of Hunger

Figure 4-14: Selected indicators of global food system development under the different SSP scenarios

Global cereal food use in 2010 as simulated in the WFS model amounts to 1145 Million tons and global cereal feed use is estimated in the model at 927 Million tons. In 2050 scenario results for cereal food use fall in the range of 1540 Million tons (*Sustainability* scenario SSP1) to 1610 Million tons (*Regional*

Rivalry scenario SSP3). In 2080, the range of scenario results for cereal food use widens, from a low of 1560 Million tons of cereals (*Sustainability* scenario) to a high estimate of 1890 Million tons in the population-rich *Regional rivalry* scenario (Figure 4-14).

The total number of people, their wealth and dietary preferences are principle drivers of future global food demand. Section 4.1 shows the range of projected global population development and economic growth in the three development pathways over the period 2010 to 2080 analyzed in this study. Starting from 6.9 billion people in 2010, the world population in SSP1 reaches 8.0 billion in 2030 and its peak of about 8.5 billion around 2050. Beyond mid-century global population decreases in scenario SSP1 and by 2080 amounts to 7.9 billion people. Global population also peaks in scenario SSP2, but later (about 2070) and at a higher level of 9.4 billion. In scenario SSP3 population growth continues until the end of this century, resulting in a global population of 8.5 billion people in 2030, nearly 10.0 billion in 2050 (45% more than in 2010) and a total of 11.6 billion in 2080, about 70% higher than in 2010.

From the diagram it can be seen that population in 2050 in the *Regional Rivalry* scenario is 18% higher than in the *Sustainability* scenario, and 47% higher in 2080. Furthermore, global cereal food demand in the *Regional Rivalry* scenario is 4% higher than in the *Sustainability* scenario in 2050, and 21% higher in 2080. As a result, per caput cereal food consumption is highest in the *Sustainability* scenario and least in the *Regional Rivalry* scenario. Just as one would intuitively expect in a scenario with less but better endowed people, the per caput nutritional status and per caput cereal food demand is superior in the *Sustainability* scenario compared to the other two scenarios analyzed here.

Yet, despite this clearly higher average per caput cereal food consumption in the *Sustainability* scenario, the absolute amount of global total cereal food consumption is less than in the Regional Rivalry scenario due to much higher population numbers under *Regional Rivalry*.

This compares to a cereal feed use in 2050 of between 1500 Million tons (scenario SSP1) and 1380 Million tons (scenario SSP3). Note that cereal feed use in scenario SSP3 is lower than in the other two development scenarios. This can be explained by the fact that population numbers in developed countries is lowest in the *Regional rivalry* scenario SSP3, e.g. 1.15 billion people in 2080 compared to 1.49 billion people in the *Sustainability* scenario SSP1. As a consequence, demand for livestock products in developed countries in SSP3 is lower than in the other scenarios and with it livestock production and feed use.

4.3.2 People at risk of hunger

The number of people at risk of hunger estimated for 2010 amounts to 920 Million, some 13.5% of global population. This number is rapidly decreasing in two development pathways and the share of people at risk of hunger is below 2% of global population by 2080, i.e. 1.8% in scenario SSP2 and 0.6% in scenario SSP1. Only in the *Regional Rivalry* scenario the demographic growth is too substantial and economic development is insufficient to end hunger and the estimated number of people at risk of hunger stagnates at about 800 Million or some 8.5% of the global population in 2080 (Figure 4-14).

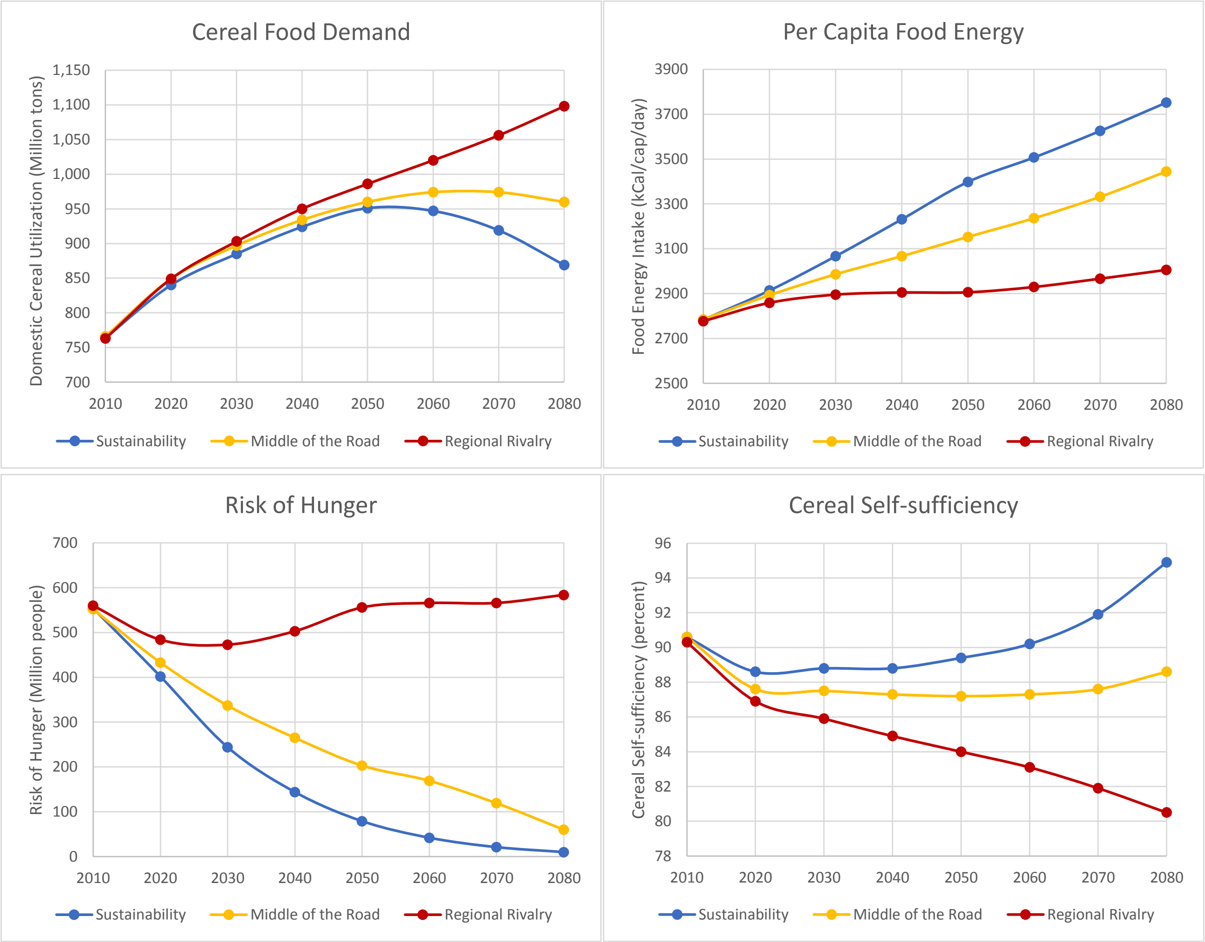


Figure 4-15: Selected indicators of food system development in Asia under the different SSP scenarios

Selected food system indicators for the Asia region are presented in Figure 4-15. Cereal food demand up to 2050 among the three scenarios falls within a relatively narrow range between 950 Million tons (scenario SSP1) to 985 Million tons (scenario SSP3) compared to 765 Million tons in 2010. Driven by the respective population development, cereal food demand in Asia beyond 2050 decreases in the *Sustainability scenario* to 870 Million tons in 2080, remains at 960 Million tons in the *Middle of the Road* scenario, and increases to 1100 Million tons by 2080 in response to population growth in the *Regional rivalry* scenario.

The cereal self-sufficiency ratios for the Asia region is also shown in Figure 4-15 indicating that the high level of regional self-reliance (about 90 percent as simulated in 2010) may initially fall slightly until 2030. In the longer term the cereal self-reliance ratio of the Asia region is projected to recover and increase in the *Sustainability* scenario SSP1 to 95%, well beyond the 2010 level, would remain close to 90% in the *Middle of the Road* scenario SSP2, and would gradually decline to about 80% in the *Regional Rivalry* scenario SSP3.

The estimated number of people at risk of hunger in the Asia region in 2010 amounts to 550 Million. This number is rapidly declining in two development pathways and hunger is practically eliminated by 2080. Only under the *Regional Rivalry* scenario the economic development is insufficient and the estimated number of people at risk of hunger stagnates at about 10.6% of the Asian population, i.e. 580 Million in 2080 (Figure 4-15).

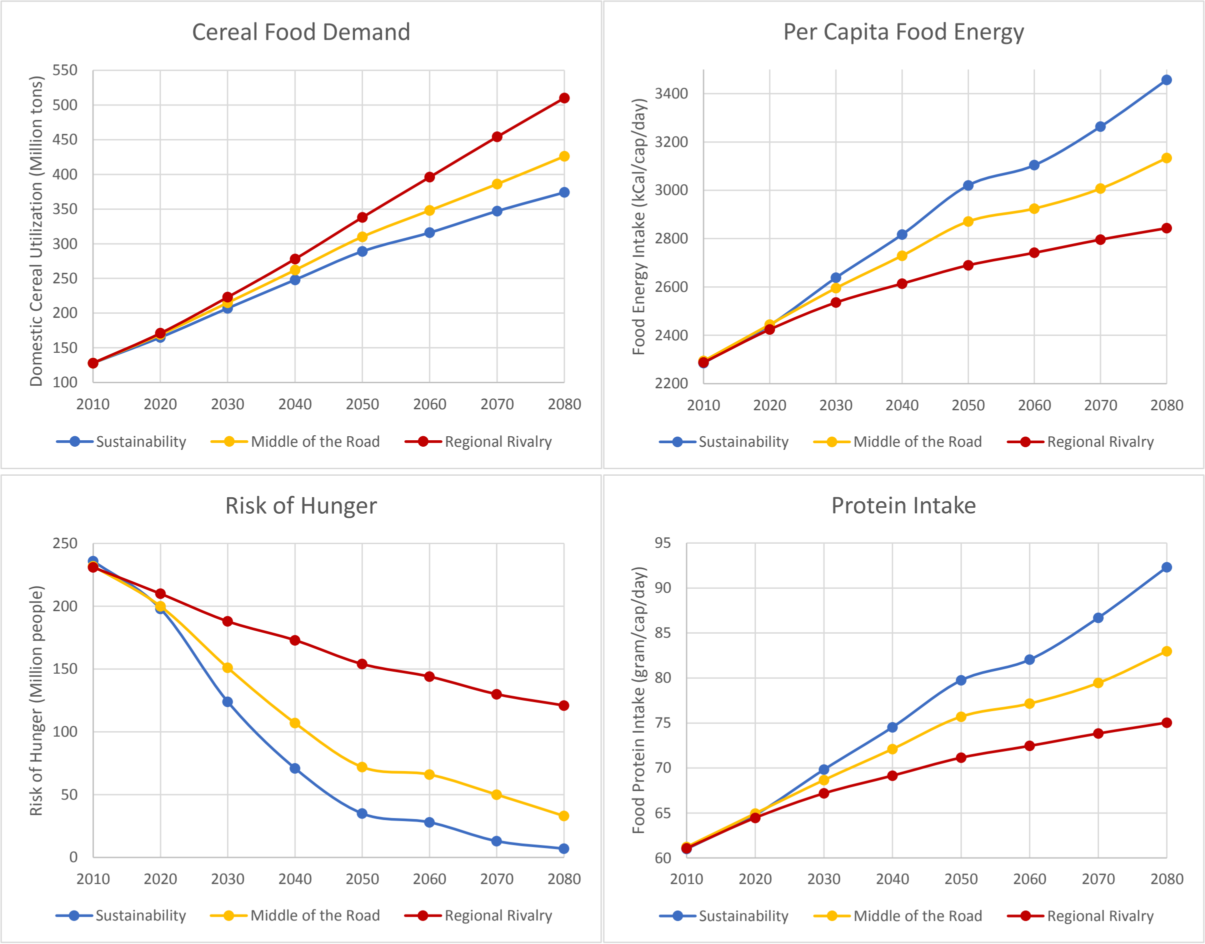


Figure 4-16: Selected indicators of food system development in Africa under the different SSP scenarios

Food system development indicators for the Africa region are summarized in Figure 4-16. Driven by population growth and substantial income gains, cereal food demand in the Africa region is rapidly increasing, from 128 Million tons in 2010 to between 290 Million tons (scenario SSP1) and 340 Million tons (scenario SSP3) in 2050, and between 375 Million tons (scenario SSP1) and 510 Million tons (scenario SSP3) in 2080. The assumed swift economic growth in Africa, especially as portrayed in the storylines of scenario SSP1 and SSP2 (see Figure 4), results in greatly improved diets and food energy intake, exceeding even in the worst case an average 2800 kCal/cap/day. By 2080, hunger is almost completely eliminated in the SSP1 and SSP2 scenarios. In the *Regional Rivalry* scenario, though gradually improving, the estimated number of people at risk of hunger amounts to 155 Million (or 9.5%) in 2050 and to 120 Million (or 5.6%) in 2080.

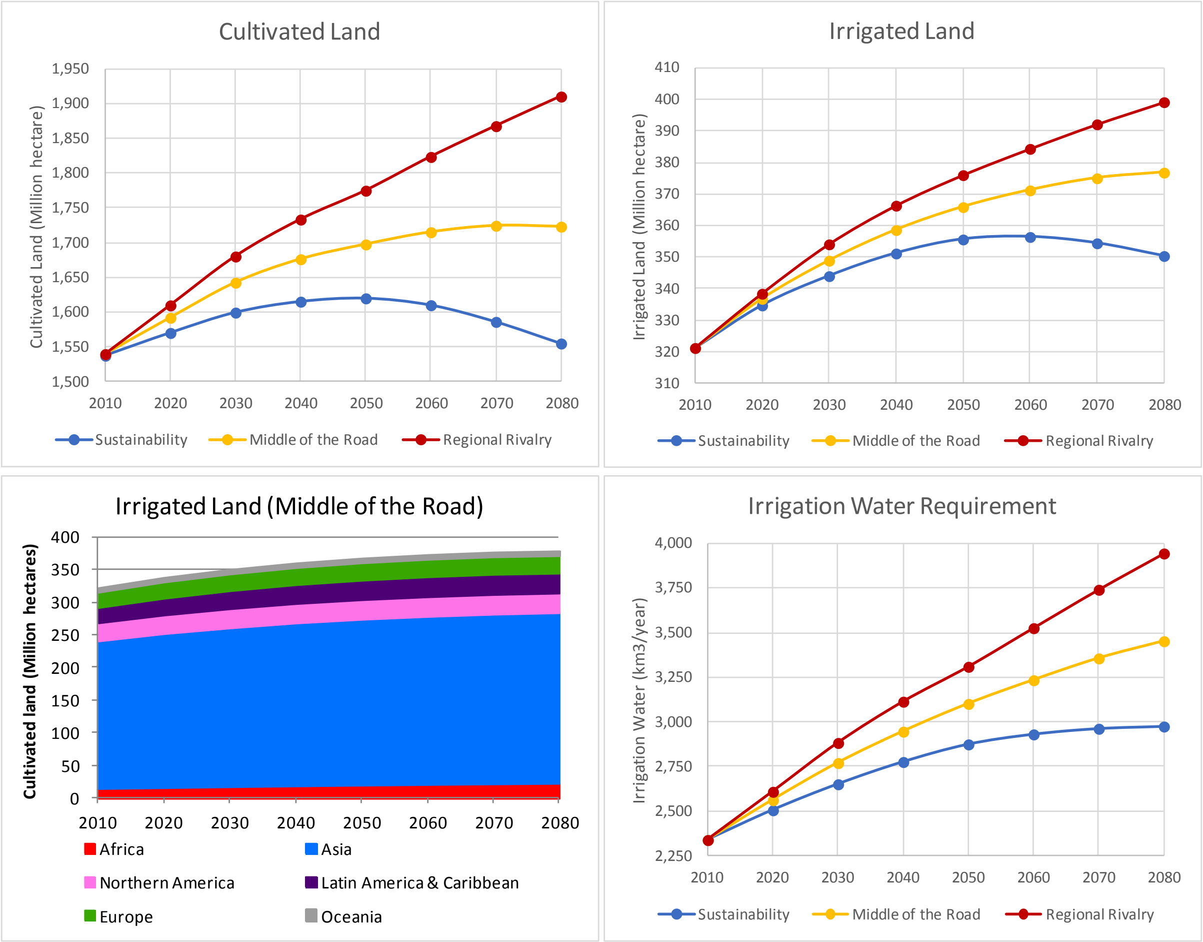


Figure 4-17: Evolution of cultivated land, area equipped with irrigation and total irrigation water requirement in Asia under the different SSPs

4.3.3 Evolution of cultivated land

The strong rise in global food and feed demand is putting additional pressures on land, water, energy resources and the environment. Results of the WFS and GAEZ model simulations indicate a further increase in the global use of cultivated land (i.e. arable land and land under permanent crops) from a total of 1540 Million hectares in 2010 to reach under the different development scenarios between 1620 and 1775 Million hectares by 2050, and between 1555 and 1910 Million hectares in 2080 (Figure 4-17). In the *Sustainability* scenario the peak of global cultivated land use, about 1620 Million hectares, is reached around 2050 and use of cultivated land subsequently decreases. Global cultivated land use steadily increases in the *Middle of the Road* scenario, reaching about 1700 Million hectares in 2050 and some 1725 Million hectares in 2080, i.e. around 12% higher than in 2010. 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 1910 Million hectares (Figure 4-17), i.e. some 370 Million hectares (or nearly 25%) higher than in 2010.

For the land equipped with irrigation the projected extents increase from 321 Million hectares in 2010 to between 356 Million hectares (scenario SSP1) and 376 Million hectares (scenario SSP3) in 2050, and between 350 Million hectares (scenario SSP1) and 400 Million hectares (scenario SSP3)in 2080 (Figure 4-17). This means that the aggregate global irrigation share, i.e. the share of cultivated land equipped with irrigation in total cultivated land, remains almost constant at about 21% in the *Regional Rivalry* scenario (SSP3) and increases somewhat in the *Sustainability* scenario (SSP1) (from 21% in 2010 to

22% in 2050 and 22.5% in 2080) and the *Middle of the Road* scenario (SSP2) (21.5% in 2050 and 22% in 2080). Note that about 70% of the land equipped with irrigation is located in the Asia region, with an irrigation share of 42% in 2010 increasing to about 46% in 2050 and 48% in 2080.

Furthermore, we have estimated future global irrigation water requirements based on changes in irrigated areas projected in the WFS scenario simulations and the multi-model ensemble mean of irrigation requirements per unit area derived from the outputs of six major hydrological models participating in the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP; (Warszawski et al. 2014). For the year 2010 we obtained an estimate of global irrigation water use amounting to 2340 km^3/year. Keeping the irrigation system efficiency parameters at base year level, the irrigation water requirements calculated for 2050 were in the range of 2875 km^3/year (*Sustainability* scenario) to 3310 km^3/year (*Regional Rivalry* scenario), and in 2080 ranging from 2975 km^3/year to 3945 km^3/year. Hence, the estimated increases of global crop irrigation water requirements come in 2050 to 23% to 42% above the level in 2010 and reach 27% to 69% in 2080 (Figure 4-17).

Climate change and the increase of irrigated land combine in the scenario projections to increase crop irrigation water requirements as detailed in Table 4-3. The results indicate an aggregate impact of climate change on irrigation water requirements due to warming and changes in precipitation in 2030 of 2.2% (in the *Sustainability* scenario based on RCP4p5) to 2.8% (in RCP6p0). In 2050, using as weights for aggregation the areas equipped with irrigation in the base year, the climate change induced impacts on crop irrigation requirements fall into a range of 4.5% to 5.6%, and in 2080 the range becomes 7.8% to 9.8%. Cultivated land equipped with irrigation in 2050 is 10.7% (scenario SSP1) to 16.9% (scenario SSP3) above the level in 2010, and by 9.0% to 24.1% in 2080. Also, the specific geographic distribution of the expanding new irrigated areas results in some regions in an increase of the average irrigation requirement per unit area in addition to climate induced changes, i.e. the newly developed irrigated areas tend to require more water input than previously existing irrigated land.

Table 4-3: Climate and land use components of increased irrigation requirements

	Climate change induced (% change relative to 2010)			Irrigated area increase (% change relative to 2010)			Irrigation requirements (% change relative to 2010)		
	Sustain-ability	Middle of the Road	Regional Rivalry	Sustain-ability	Middle of the Road	Regional Rivalry	Sustain-ability	Middle of the Road	Regional Rivalry
2030	2.2	2.8	2.8	7.0	8.5	10.1	13.4	18.5	23.3
2050	4.5	5.6	5.6	10.7	13.8	16.9	22.9	32.6	41.6
2080	7.8	9.8	9.8	9.0	17.2	24.1	27.2	47.7	68.7

Note: To account for climate change, RCP4p5 climate model results were used in the Sustainability scenario and RCP 6p0 results were used in the Middle of the Road and Regional Rivalry simulations.

When combining climate change and land use change impacts, the estimated increase of global irrigation water demand becomes 22.9% to 41.6% in 2050, and 27.2% to 68.7% in 2080. As noted before, these estimates are calculated assuming an overall irrigation system efficiency as in the base year 2010. For instance, meeting a 33% increase of crop irrigation demand (as shown for 2050 in the *Middle of the Road* scenario) with current water withdrawals would require the irrigation system efficiency to improve on average by 0.7% per annum between 2010 and 2050.

Model estimates and data on crop water requirements and irrigation water withdrawal provided in FAO (2012) indicate an overall global system efficiency expressed as a water requirement ratio (i.e.

the ratio of estimated crop irrigation water requirements over irrigation water withdrawal) of 56 percent, with large gains possible in many developing countries.

Due to the spatial pattern of global warming, climate change impacts on irrigation requirements are more pronounced in higher latitude regions such as in East Asia, Europe and Northern America. In the Africa and Latin America regions the projected changes of irrigated land dominate the increase of irrigation water requirements. A summary of regional factors contributing to the increase of irrigation water demand in the analyzed scenarios is presented in Table 4-4.

Table 4-4: Regional climate and land use components of increased irrigation demand in 2050

	Climate change induced (% change relative to 2010)			Irrigated area increase (% change relative to 2010)			Irrigation requirements (% change relative to 2010)		
	Sustain-ability	Middle of the Road	Regional Rivalry	Sustain-ability	Middle of the Road	Regional Rivalry	Sustain-ability	Middle of the Road	Regional Rivalry
Africa	4.6	4.5	4.5	24.9	36.7	46.8	157.4	241.1	320.6
Asia	4.1	5.4	5.4	9.6	12.2	14.7	13.8	18.3	20.2
Northern America	5.8	6.5	6.5	7.0	7.5	7.7	12.5	13.9	14.0
Latin America	4.6	5.1	5.1	17.6	24.9	34.7	61.5	102.5	171.0
Europe	9.2	10.1	10.1	9.9	11.6	14.4	23.3	26.5	31.6
Oceania	4.5	4.7	4.7	7.8	9.7	10.9	11.4	16.3	18.6

Note: To account for climate change, RCP4p5 climate model results were used in the Sustainability scenario and RCP 6p0 results were used in the Middle of the Road and Regional Rivalry simulations.

The relatively large expansion of food production required in the different development pathways is achieved foremost by means of intensification, i.e. higher output per unit of cultivated land, through yield improvements, increased input use, and somewhat increased multi-cropping intensity and irrigation shares (Figure 4-18). In the *Sustainability* scenario about 90% of the crop output increases in 2050 (relative to 2010 crop production) can be attributed to intensification and only 10% are due to conversion of additional cropland. In 2080 an additional 60% of crop production is achieved from a cultivated land extent almost the same as in 2010, i.e. by then all simulated production increases come from higher yields. In the *Middle of the Road* scenario, the additional crop production in 2080 (compared to crop production in 2010) is achieved with about 12% more cropland, i.e. on average 85% of the production increases are derived from intensification. Only in the *Regional Rivalry* scenario, where technological improvements are somewhat slower and a larger share of the production increases occurs in developing regions, the arable land expansion, foremost in Africa and Latin America, is responsible for about a third of crop production increases.

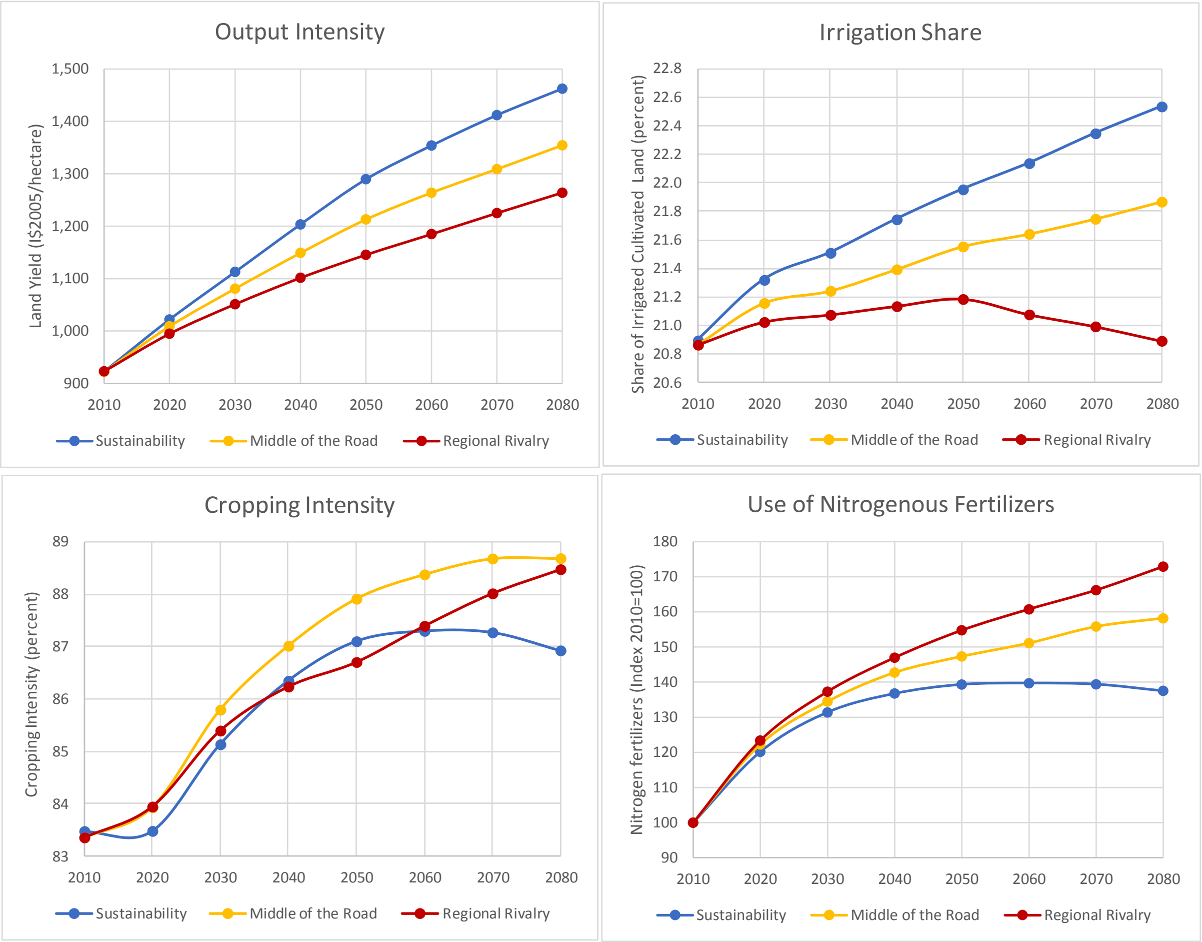


Figure 4-18: Indicators of global food system intensification under the different SSPs.

Even though the increases of global cultivated land are quite modest compared to simulated global production changes, some forest conversion due to cropland and urban land expansion takes place, albeit to a varying extent in the different scenarios. Cumulative deforestation caused by cropland expansion and built-up conversion up to 2080 is shown in Figure 4-19.

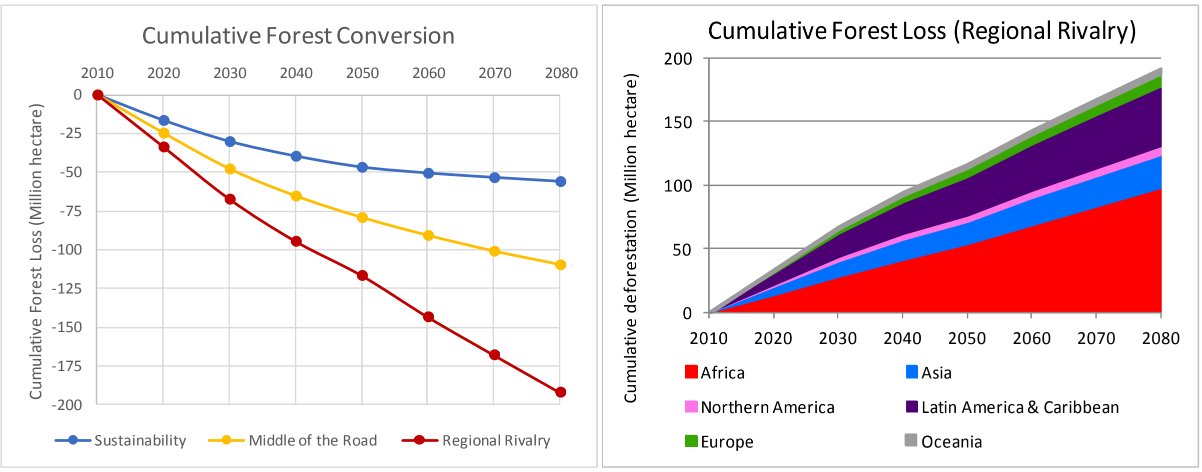


Figure 4-19: Cumulative global forest loss under the different SSPs.

The smallest amount of global deforestation occurs in the *Sustainability* scenario, around 47 Million hectares by 2050, and 56 Million hectares by 2080. In the *Middle of the Road* scenario, accumulated forest conversion due to cropland expansion and urbanization is 80 Million hectares by 2050 and reaches 110 Million hectares by 2080. The largest forest conversion takes place in the *Regional Rivalry* scenario, accumulating to 117 Million hectares in 2050 and as much as 192 Million hectares by 2080.

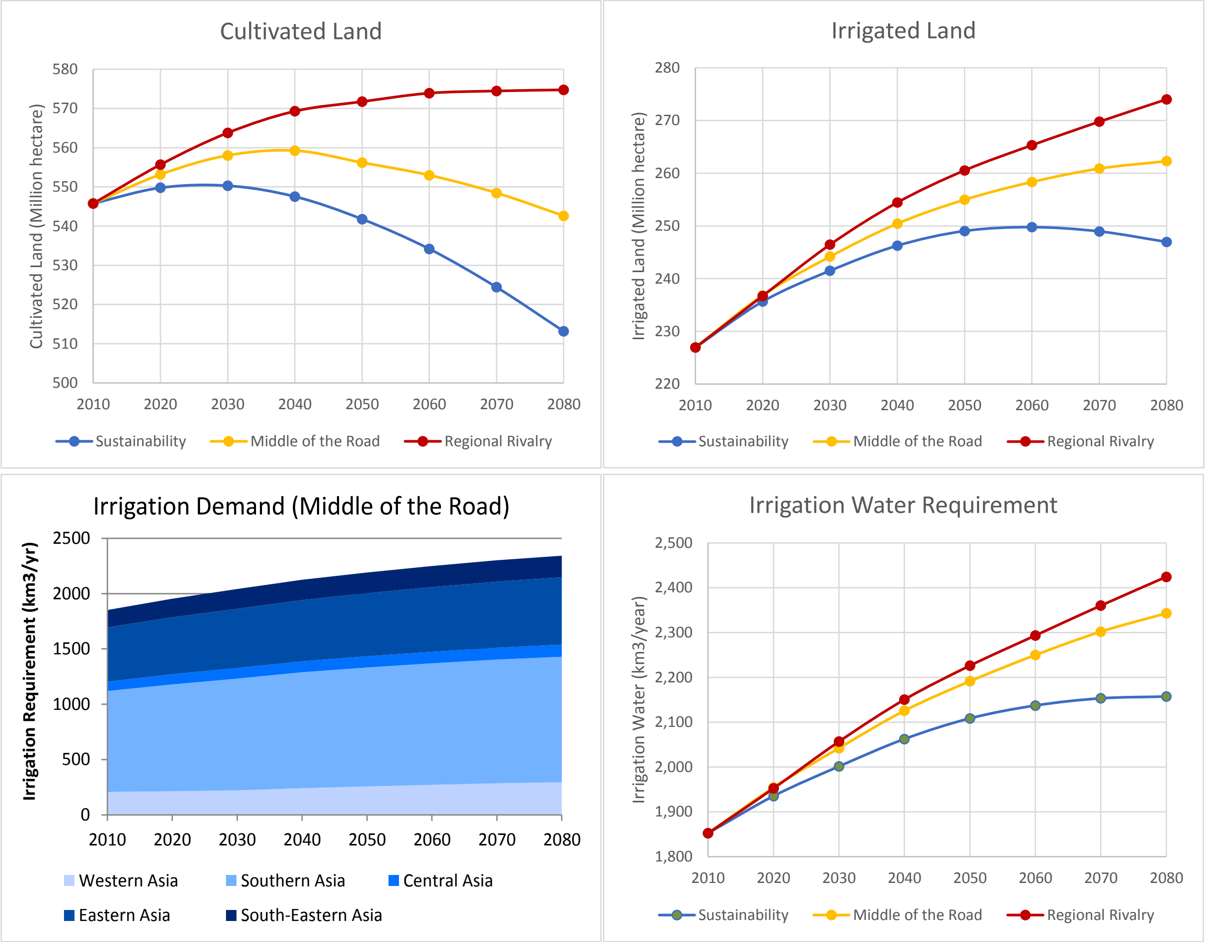


Figure 4-20: Evolution of cultivated land, area equipped with irrigation demand in Asia under the different SSPs.

Since availability of additional land suitable for crop production is rather limited, especially in South and East Asia, the growth in food demand and production has strong implications for the intensity of production, both regarding required yield increases and enhanced multi-cropping.

The increase of cultivated land in Asia is very small compared to simulated production changes. Projected cereal production in the three analyzed scenarios is up by 26 to 30 percent in 2050 compared to 2010, and by 36 to 40 percent in 2080. Total crop production in the Asia region (at FAO I$2005 constant international prices of 2004-2006) increases by 31 to 37 percent in 2050 (relative to 2010) and by about 50 percent in 2080 compared to 2010. For livestock production the projected increases in the Asia region are even higher, namely 58 to 67 percent in 2050, and 85 to 115 percent in 2080.

As most of the production expansion is achieved through yield increases, this implies a further intensification of input use in terms of agro-chemicals, energy and water. Especially in the intensively farmed areas of South and East Asia this may increase the risks of environmental over-exploitation and degradation. For instance in the *Middle of the Road* scenario, projected use of nitrogenous fertilizers in 2050 in the Asia region is 43 percent higher than in 2010 and 48 percent higher in 2080.

For the land equipped with irrigation the projected extents increase from 227 Million hectares in 2010 to between 249 to 261 Million hectares in 2050, and between 246 and 278 Million hectare in 2080 (Figure 4-20). The aggregate regional irrigation share, i.e. the share of cultivated land equipped with irrigation in total cultivated land, increases from 42 percent in 2010 to about 46 percent in 2050, and 48 percent in 2080.

For the year 2010 we obtained an estimate of irrigation water demand in the Asia region amounting to 1852 km^3/year. Keeping the irrigation system efficiency parameters at base year level, the irrigation water requirements calculated for 2050 were in the range of 2109 km^3/year (*Sustainability* scenario) to 2226 km^3/year (*Regional Rivalry* scenario), and in 2080 ranging from 2157 km^3/year to 2425 km^3/year or 16% to 31% above the level in 2010 (Figure 4-20).

Table 4-5: Climate and land use components of increased irrigation requirements in Asia

	Climate change induced (% change relative to 2010)			Irrigated area increase (% change relative to 2010)			Irrigation requirements (% change relative to 2010)		
	Sustain-ability	Middle of the Road	Regional Rivalry	Sustain-ability	Middle of the Road	Regional Rivalry	Sustain-ability	Middle of the Road	Regional Rivalry
2030	1.6	2.8	2.8	7.8	8.0	7.6	8.9	10.5	9.9
2050	3.2	5.5	5.5	11.6	12.1	12.5	14.5	17.6	17.7
2080	5.6	9.7	9.7	11.2	14.4	17.1	17.1	24.7	27.1

Note: To account for climate change, RCP4p5 climate model results were used in the Sustainability scenario and RCP 6p0 results were used in the Middle of the Road and Regional Rivalry simulations.

The results in Table 4-5 indicate an aggregate impact of climate change on irrigation water requirements due to warming in 2030 of 2.1% (in *Sustainability* scenario based on RCP 4p5) to 2.7% (in RCP6p0). In 2050, the climate change impacts on irrigation water demand range from 4.1% to 5.4%, and in 2080 the range becomes 7.2% to 9.4%. In comparison, cultivated land equipped with irrigation in 2050 is 9.6% to 14.7% above the level in 2010, and by 8.7% to 20.6% in 2080.

Among all the major world regions distinguished in this analysis, Africa is envisaged to have the most dynamic development, with population numbers increasing up to 3.3 times and GDP growing up to 30-fold in the period from 2010 to 2080. It does not come as a surprise that this macro-driver development is resulting in rather dynamic trajectories of agricultural production and resource use, as shown in Figure 4-21.

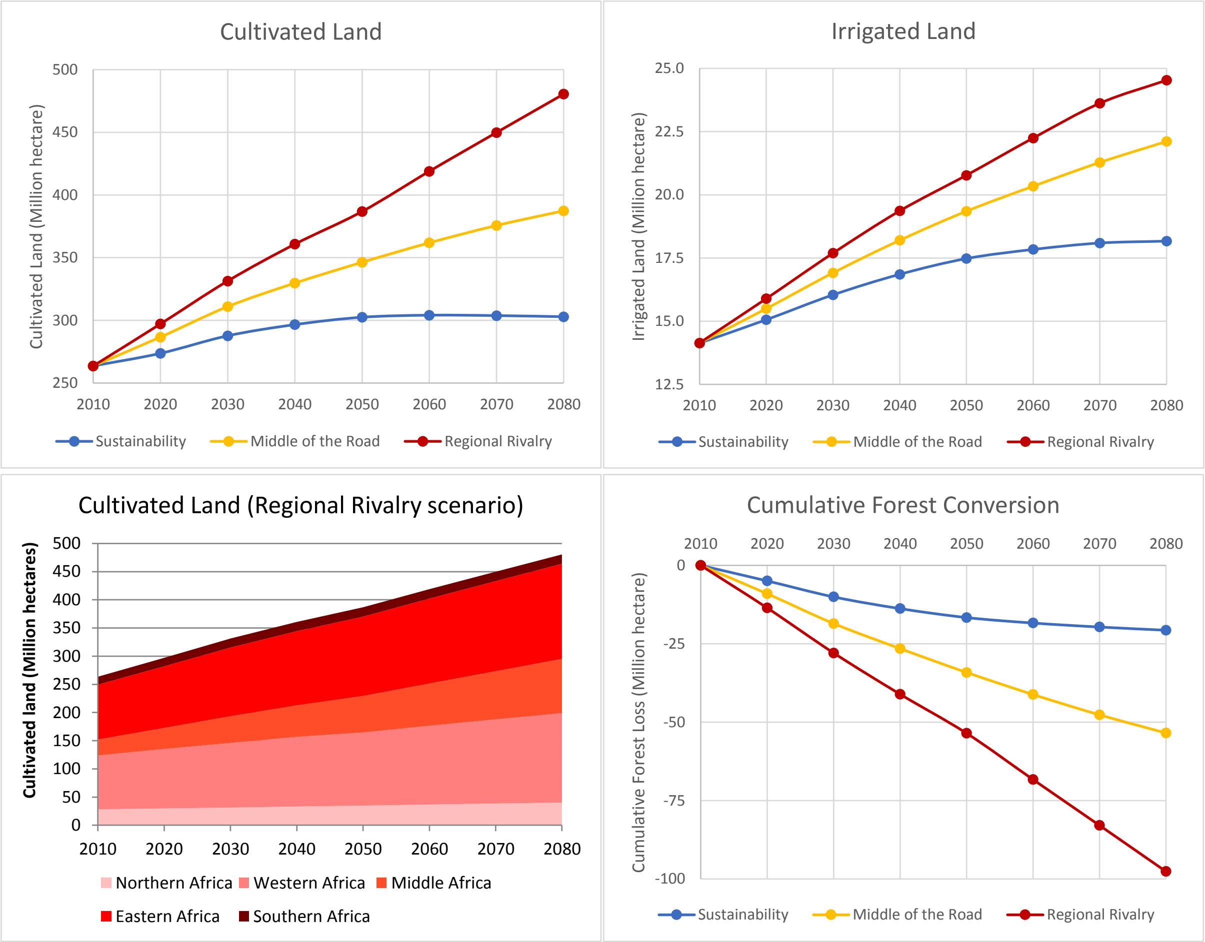


Figure 4-21: Evolution of cultivated land, area equipped with irrigation and cumulative deforestation in Africa under the different SSPs.

African cultivated land use in 2010 is estimated at 264 Million hectares, increasing to extents between 288 Million hectares (scenario SSP1) to 331 Million hectares in 2030, to a range of 302 to 387 Million hectares in 2050, and between 303 and 481 Million hectares in 2080. Only under the conditions of the Sustainability scenario (SSP1) cultivated land us is projected to stabilize at about 300 Million hectares, whereas land conversion for agricultural expansion continues throughout the simulation period in the other two development pathways.

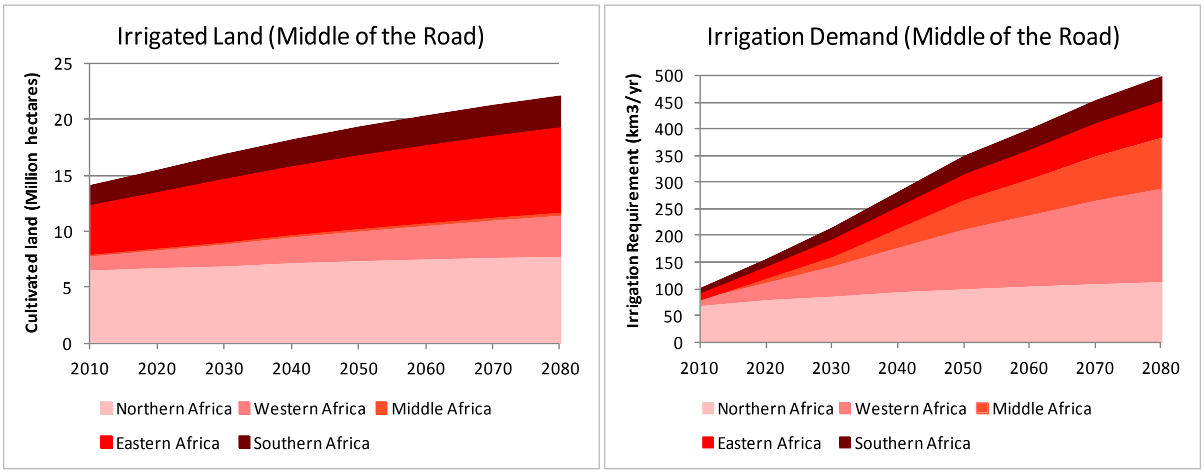


Figure 4-22: Evolution of irrigated land and irrigation water requirements in Africa under the Middle of the Road scenario.

Irrigation, although expanding swiftly as well, plays an important role only in two sub-regions, Northern Africa and Southern Africa. Cultivation in the other sub-regions remains foremost rain-fed with irrigation shares below 5%, albeit of a rapidly growing cultivated land base. Regional trajectories of irrigated land and associated irrigation water requirements are shown in Figure 4-22.

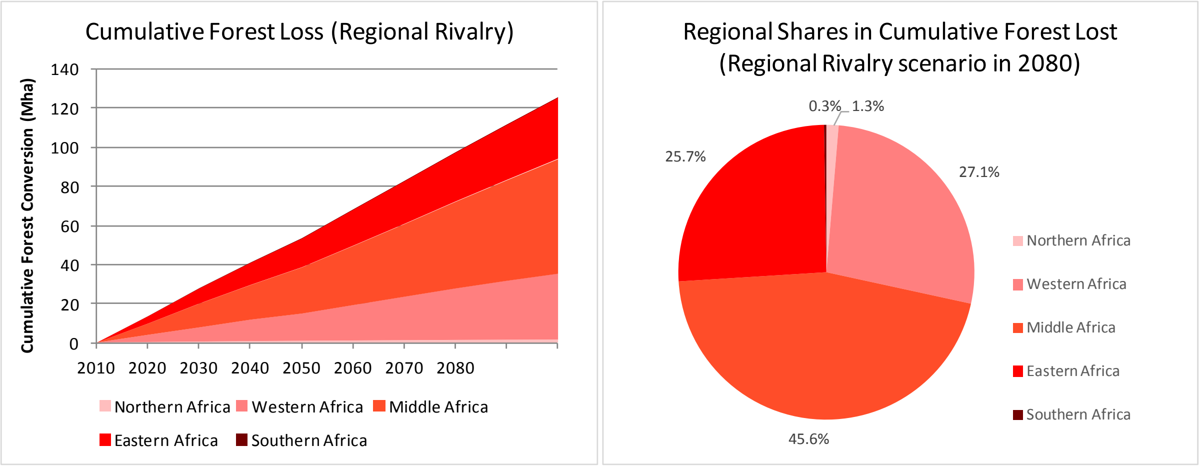


Figure 4-23: Cumulative forest conversion due to cropland and urban land expansion in Africa under the Regional Rivalry scenario.

As indicated earlier in Figure 4-19, African cropland expansion comes with significant deforestation, notably in the *Regional Rivalry* scenario, where the pressure to produce food results in cumulative forest conversion amounting to 54 Million hectares in 2050 and to nearly 100 Million hectares by 2080. Note that nearly half of total forest conversion occurs in Middle Africa and about one quarter each in the Western Africa and Eastern Africa regions.

4.3.4 Concluding remarks on Food and agriculture development

The quantified scenarios presented in this report illustrate the magnitude of challenges facing the regional and global food and agricultural systems in the next decades. The analysis suggests that due to the dynamics of demographic and economic development the required production increases in the next two to three decades will fall within a relatively narrow range of outcomes if hunger is to be successfully eliminated by mid-century. Beyond 2050, the differences in population numbers and economic growth among scenarios become large and the scenarios portray vastly different demands for agricultural products and associated resource use and environmental risks.

Production increases in all scenarios mainly rely on intensification, i.e. substantial increases of output per unit of cultivated land. While this is possible and achievable due to large prevailing yield gaps in Africa and developing Asia, it cannot be taken as given and will require major efforts by the countries and the international community. Even then, only in two of the three scenarios adequate nutrition levels are achieved in all regions and the risk of hunger is much reduced by 2050 and practically eliminated by 2080. In the *Regional Rivalry* scenario food production in Africa and parts of Asia cannot meet the demand of rapidly growing populations and the reduction of hunger stagnates at a relatively high absolute level, still decreasing somewhat in terms of the percentage of population at risk.

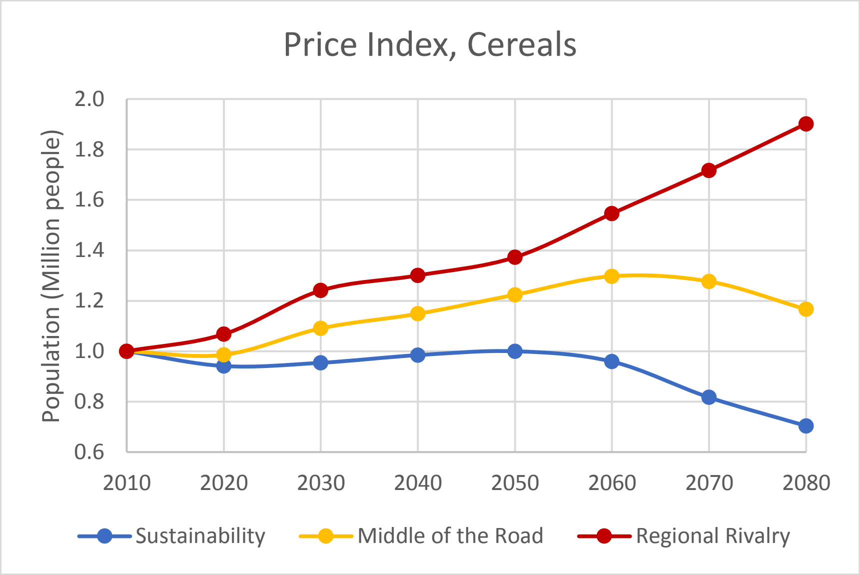


Figure 4-24: Cereal price index (2010=100) under the different SSP scenarios.

In the world food system model the various national/regional components are linked together by means of a world market, where international clearing prices are computed to equalize global demand with supply. The index of cereal prices generated in each scenario are shown in Figure 4-24. 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. Price development in the Regional Rivalry scenario signals that meeting food demand is becoming increasingly difficult in this scenario and adds to the risk of hunger in this SSP3 world.

Cropland expansion and intensification, if not regulated and managed well, increase the risk of environmental damages. Intensification inevitably means intensified application of nutrients and other agro-chemicals, may results pollution and over-exploitation of water resources to meet irrigation requirements, and may cause excessive deforestation when yield improvements do not materialize as needed. Such specific assumptions can be tested in the modelling framework but have not been explored in the current analysis. Also, the scenario implementations of the analysis presented here have used empirical relationships of enriching diets with livestock products as per capita incomes rise, leading as well to increasing feed requirements. In follow-up work we will explore the differential impacts of widely adopting more healthy and less environmentally burdening diets involving less livestock products than currently.

4.4 Water Supply

Future projections of water availability over long time period at regional and country level, are presented in this section. Climate change results in alterations in hydrological cycle and affects spatial-temporal distribution of water resources (Field et al. 2012).

The severity of climate change is characterized here by using two different RCPs. The *Sustainability* scenario is combined with RCP 4.5 which assumes that the difference of energy from sunlight absorbed by the Earth and energy radiated back to space (radiative forcing) is stabilized before 2100 (see Box 1 in section 3.1). Causes of change in radiative forcing include changes in the concentrations of greenhouse gases and aerosols.

The *Middle of the Road* and *Regional Rivalry* scenarios are combined with RCP 6.0 which assumes that the radiative forcing is stabilized after 2100. Furthermore, population change is an important factor for water resources assessment that needs to be considered since the finite water resources need to be shared. Here, we analyze separately the three scenarios as their population projections are different. The population dataset used in this assessment is based on (Jones and O'Neill 2013) which downscaled and gridded the projected population based on the SSPs.

The WFaS project provides estimations of both surface water and groundwater resources availability. The present analysis defines that surface water is composed of runoff within a region or country and inflow through river networks.

4.4.1 Available surface water

An impact assessment of climate change at sub-regional and country levels is presented here. This macroscopic perspective provides highly valuable insights that are worth taking under consideration, although it may overlook some aspects related to the heterogeneity of water resources and local scale water issues.

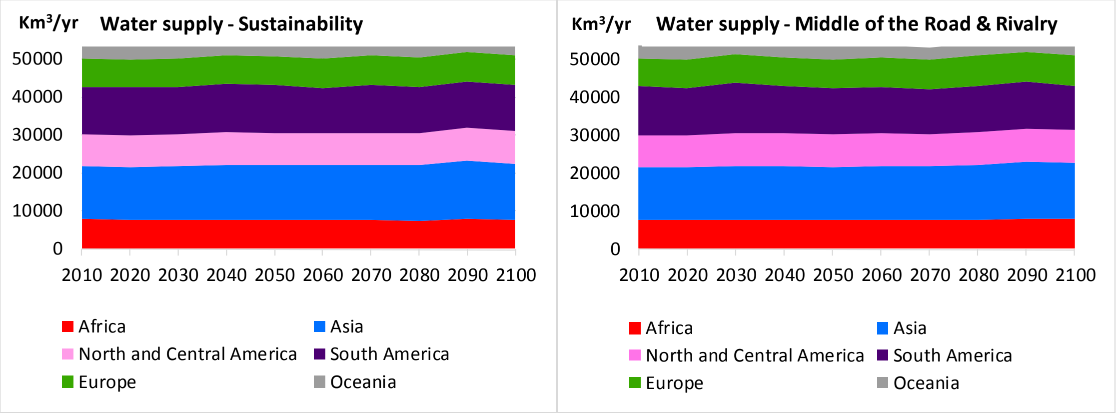


Figure 4-25: Projections of surface water availability for the different continents under two scenarios until 2100

Available surface water resources at continent-level presented in Figure 4-25 shows a relatively constant development as opposed to the development of population, GDP, or water demand (presented in section 4.5). At sub-regional level the change will be small ranging from -5 to +5 per cent (Figure 4-26 bottom).The change of surface water availability will be more pronounced at country level as shown in Figure 4-26 which displays the spatial distribution of surface water resources averaged for a ten year time period of 2005-2014 (henceforth the 2010s) compared to the time period 2045-2054 (henceforth the 2050s) for *Middle of the Road* and *Rivalry* scenarios. For instance, several countries undergoing already water scarcity conditions in the 2010s will have to cope with lower surface water resources availability in the 2050s. Figure 4-26 middle shows a band of decreasing water resources availability from Spain and Morocco to Pakistan. Below this band there is a strip with increasing water resources availability from Mauritania to Sudan. These countries have to face a South (more water) - North (less water) difference. On the other hand, almost all African countries have to cope with a large decadal variability which can be seen for the case of Niger. Niger's water resources availability will increase but for the time period 2045-2054 all forcing climate models show in addition a peak in precipitation compared to the period 2035-2045 or 2055-2064.

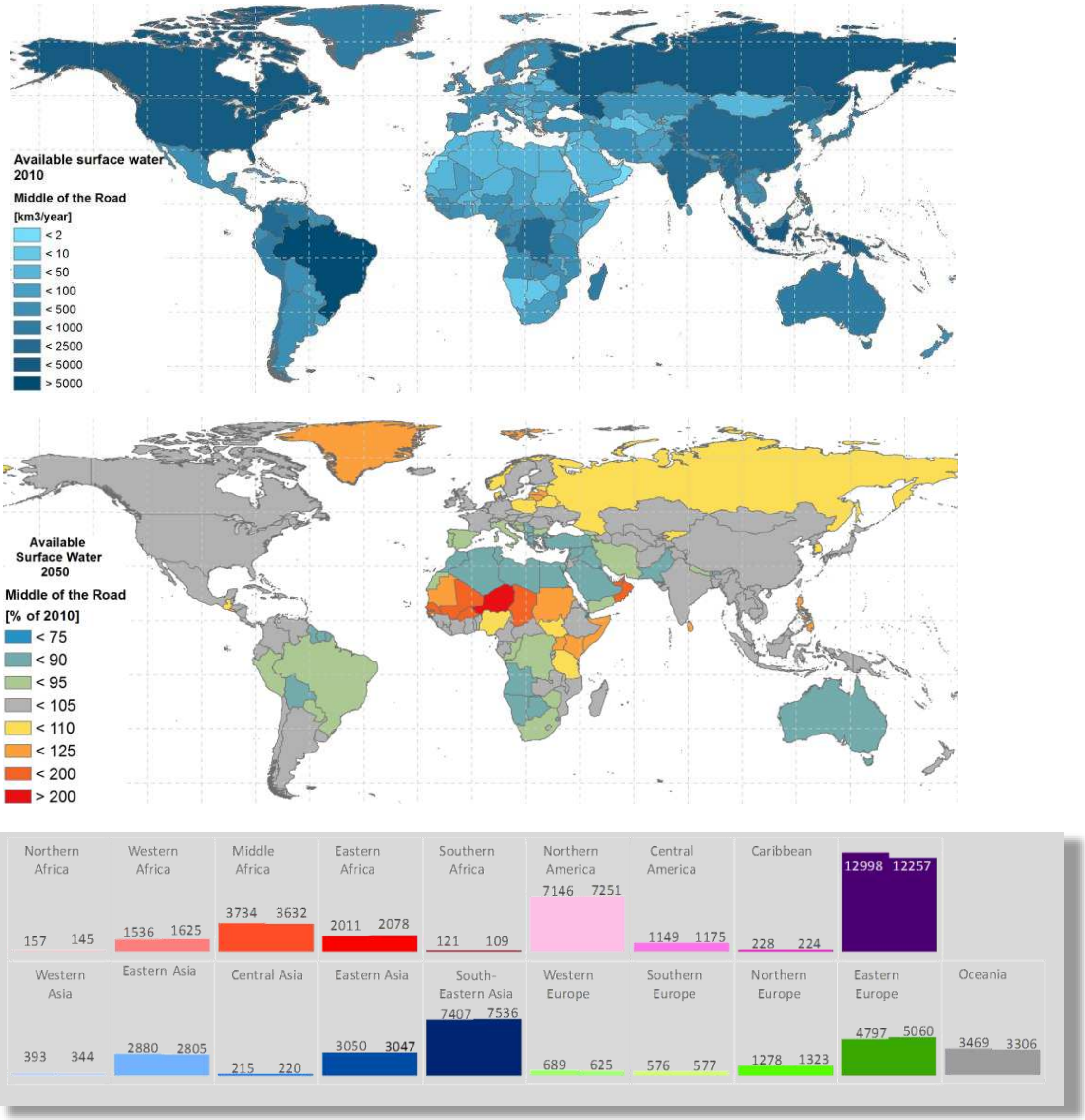


Figure 4-26: Available surface water – *Middle of the Road* scenario

Top: Available surface water 2010.

Middle: Available surface water 2050.

Bottom: change rate of available surface water [%] compared to 2010

4.4.2 Available surface water per capita

Available surface water resources per capita (the so-called the Falkenmark Indicator) is one of the most widely used measures of water stress, (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
- absolute scarcity < 500 m^3/year/cap

In some reports the range between 1700 and 2500 m^3/year/cap is described as vulnerability range (WWAP 2015). In this study, the total renewable water resources are not restricted to the local (i.e. per country) available freshwater, but it includes also the water resources originating from upstream countries (more details can be found in section 4.4.4 on transboundary dependency). Therefore, some countries such as Egypt and Sudan (fed by the upper Nile) or India (fed by Indus, and Ganges-Brahmaputra) does not appear in the water scarcity categories in contrast to other publications such as the 2015 World Water Development Report (WWAP 2015).

According to Falkenmark indicator, Morocco, Algeria, Tunisia, the Arabic peninsula, Pakistan and China are already categorized into “stress” in the early half of 21st century under all three scenarios. Table 4-6 ranks the countries with the lowest water resources availability per capita across the world.

Table 4-6: Available surface water per capita – ranking of the countries with lowest water per capita worldwide

Water per capita	**2010**	**2050**	**2050 (% of 2010)**
[m^3/year/cap]		**between 3 scenarios**	**between 3 scenarios**
Qatar	130	60 - 110	46% - 85%
Yemen	430	140 - 290	33% - 67%
Bahrain	450	120 - 250	27% - 56%
Jordan	550	220 - 230	40% - 42%
Oman	720	570 - 720	79% - 100%
Israel	890	390 - 500	44% - 56%
Cape Verde	920	1230 - 2150	134% - 234%
Saudi Arabia	1020	400 - 690	39% - 68%
Djibouti	1070	280 - 470	26% - 44%
Algeria	1070	600 - 650	56% - 61%
Lebanon	1150	750 - 820	65% - 71%
Morocco	1220	640 - 840	52% - 69%
Pakistan	1250	600 - 860	48% - 69%
United Arab Emirates	1420	600 - 1220	42% - 86%
Tunisia	1570	980 - 1110	62% - 71%
Eritrea	1620	700 - 720	43% - 44%
Singapore	1680	1340 - 1400	80% - 83%
China	1690	1720 - 1920	102% - 114%
Belgium	1700	1420 - 1720	84% - 101%

For countries from Morocco to Bangladesh water resources per capita will generally decrease triggered mainly by population growth, but also by declining water resources (see Figure 4-3 and Figure 4-27 For some African countries such as Burkina Faso, Uganda, Burundi, Rwanda, Kenya, and Nigeria, the situation will worsen mainly because of the impact of population change. The opposite trend is projected for the cases of Poland which goes from vulnerable in the 2010s to no stress in the 2050s, and China which is under water stress in the 2010s but will be in the category above 1700 m^3/year/cap in two out of three scenarios in the 2050s.

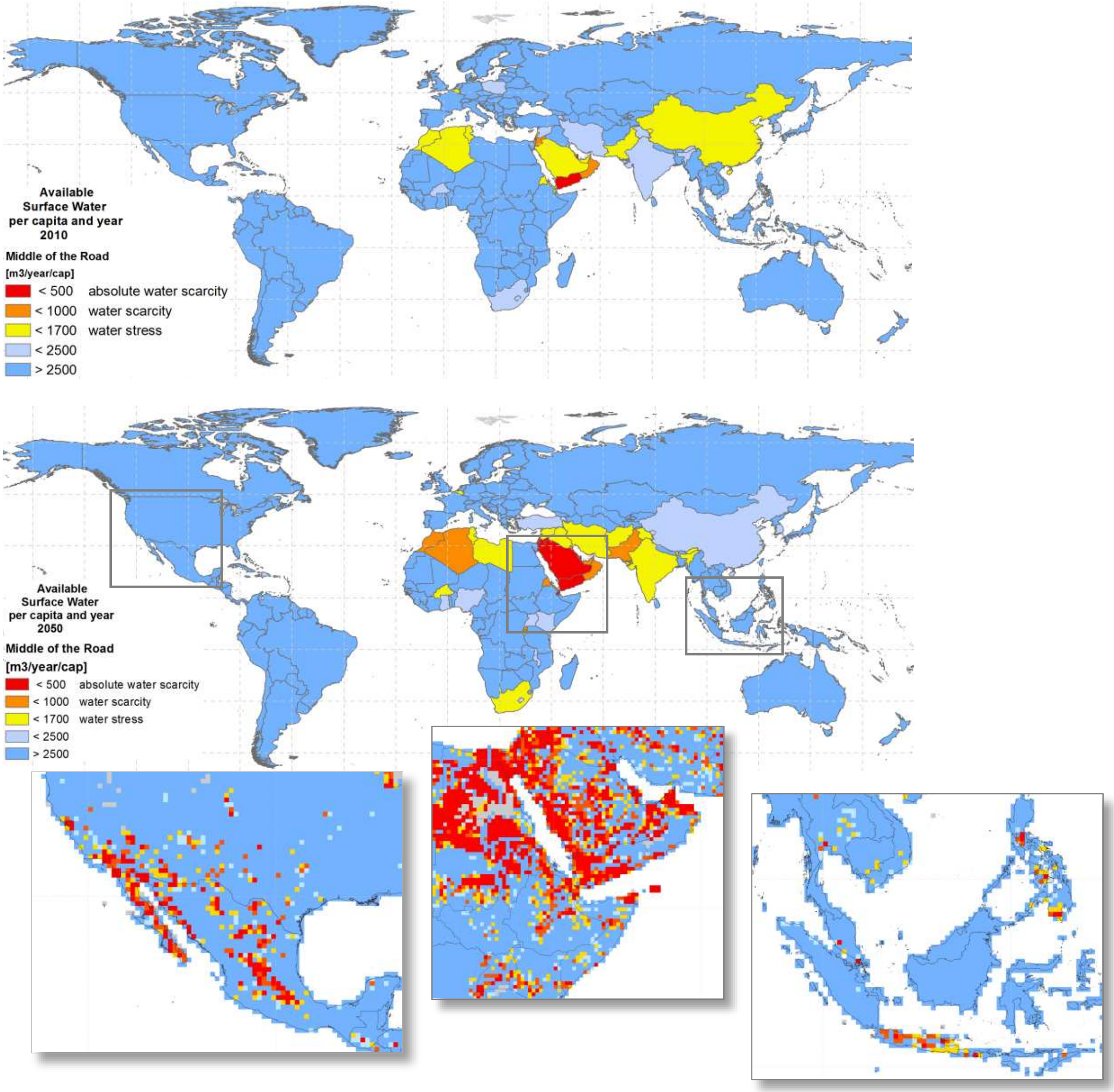


Figure 4-27: Available surface water – *Middle of the Road* scenario
Top: Available surface water per capita 2010. Available surface water per capita 2050.
Bottom: Sub-country scale of Available surface water per capita 2050 for three regions

Despite the fact that Figure 4-27 shows countries with or without water stress, a detailed analysis at the sub-country scale is needed. USA and Mexico are categorized not water stressed countries but there are hotspots of absolute scarcity such as California, Baja California, and Central Mexico. Egypt is also not categorized as water stressed because the major part of population lives on the shore of the Nile, although large parts of the country suffer from absolute water scarcity. Furthermore, countries located in the tropics such as Indonesia with average water resources availability of around 17,000 m^3/year/cap has water scarce areas in Java where almost half of the population of Indonesia is living (140 million).

Austria and priority countries of the Austrian Development Agency

Table 4-7 and Figure 4-28 present total and per capita available surface water resources in the 2010s and the 2050s for Austria and ADA priority countries. By the 2050s, the range of water availability per capita between the three scenarios is shown. Some countries such as Armenia, Ethiopia and Uganda are or will move into the category “vulnerable”. Although water availability will increase in Burkina Faso by around 1.5 times, this will be overtopped by population increase of around 2.3 times, pushing Burkina Faso into the water stress and water scarcity categories, depending on the scenario.

Table 4-7: Available surface water per capita – ADA priority countries

	Available surface water [km^3/year]		**Avail. sur. water per cap [km^3/year/cap]**	
	2010	**2050**	**2010**	**2050**
Austria	98	93 - 100	11600	9700 - 13000
Albania	50	41 - 43	15400	11900 - 13500
Moldova	22	20 - 22	6200	8200 - 10200
Armenia	7	5 - 6	2200	2000 - 2300
Georgia	69	60 - 64	15800	16500 - 19700
Bhutan	51	45 - 50	69500	35000 - 44000
Burkina Faso	28	39 - 43	1700	820 – 1300
Ethiopia	413	413 - 453	5000	2200 - 3200
Uganda	161	190 - 195	4800	1700 – 2500
Mozambique	601	559 - 595	25600	12600 - 14800

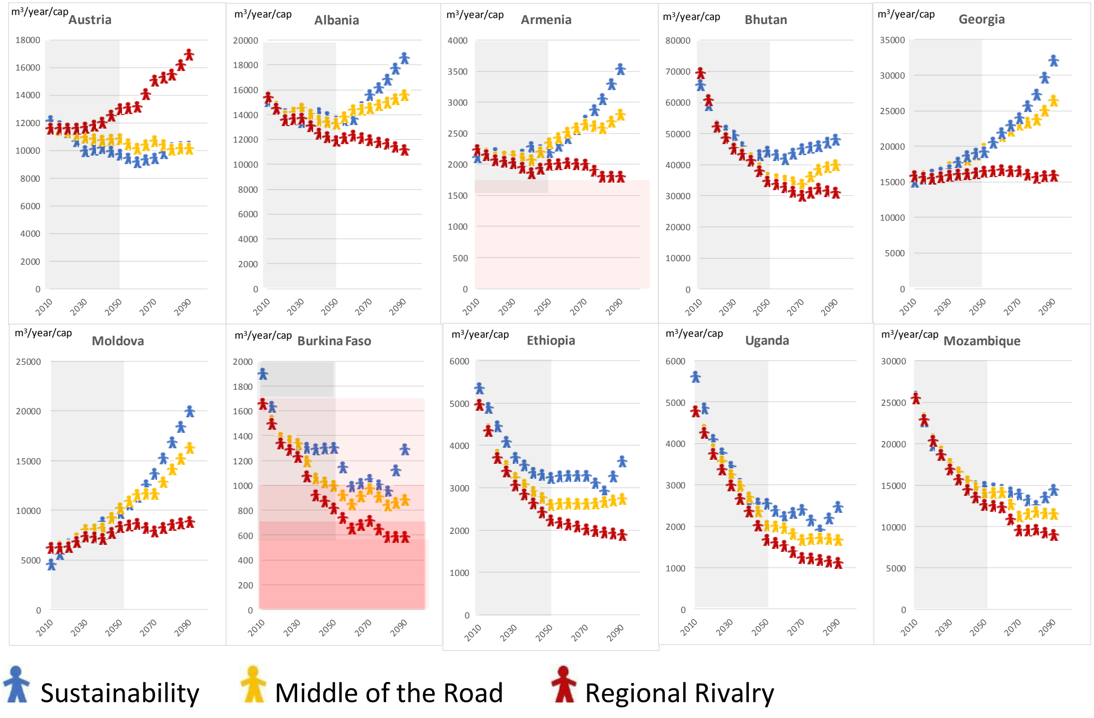


Figure 4-28: Available surface water per capita for ADA priority countries – three scenario comparison

4.4.3 Groundwater

If surface water is insufficient to satisfy demand during the dry season or dry years, groundwater can serve as an alternative source of water for irrigation. Additionally, groundwater may be the main source for irrigation and drinking wherever access to surface water is limited. 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 abstracted in Asia (Siebert et al. 2010).

For this study PCR-GLOBWB is used to project groundwater abstraction. Projections for the *Middle of the Road* scenario are presented here using the ensemble of five GCM as meteorological forcing. Our results estimate 66% of groundwater is abstracted in Asia in 2010.

Table 4-8: Groundwater abstraction – ranking of the countries with the highest abstraction in the world

Groundwater Abstraction		[km^3/year]				**Change rate**
Ranking	**Countries**	**2010**	**Share**	**2050**	**Share**	(% of 2010)
1	India	201	25%	278	25%	139
2	USA	103	13%	118	11%	114
3	China	102	13%	152	14%	150
4	Iran	60	8%	73	7%	122
5	Pakistan	60	8%	70	6%	116
6	Mexico	25	3%	32	3%	127
7	Russian Federation	22	3%	37	3%	168
8	Saudi Arabia	22	3%	29	3%	135
9	Bangladesh	11	1%	13	1%	117
10	Japan	11	1%	12	1%	109
11	Turkey	11	1%	17	2%	162
12	Italy	9	1%	11	1%	115
13	Taiwan	9	1%	19	2%	202
14	Uzbekistan	9	1%	12	1%	132
15	Bulgaria	8	1%	23	2%	292
16	Brazil	8	1%	12	1%	154
17	Germany	7	1%	9	1%	137
18	France	6	1%	7	1%	125
19	Spain	5	1%	6	1%	116
20	Argentina	5	1%	8	1%	164
	World	**800**	**100%**	**1113**	**100%**	**139**

Figure 4-29 shows spatial distribution of groundwater abstraction in the 2010s and its increase until the 2050s. In total, 800 km^3/year of groundwater is used globally in the 2010s and more than 1100 km^3/year will be used in the 2050s. This is an increase of 39% compared to the 2010s[18]. India, USA, China, Iran and Pakistan will remain the top five consumers of groundwater. Groundwater abstraction in China will even increase by 50% in the 2050s (see Table 4-8). Some countries such as Bulgaria and Georgia with an already high rate of groundwater abstraction will more than double their abstractions by the 2050s.

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[18] Note that this projection assumes constant irrigation area at year 2000. It is expected that groundwater abstraction will be larger due to expansion of irrigated area.

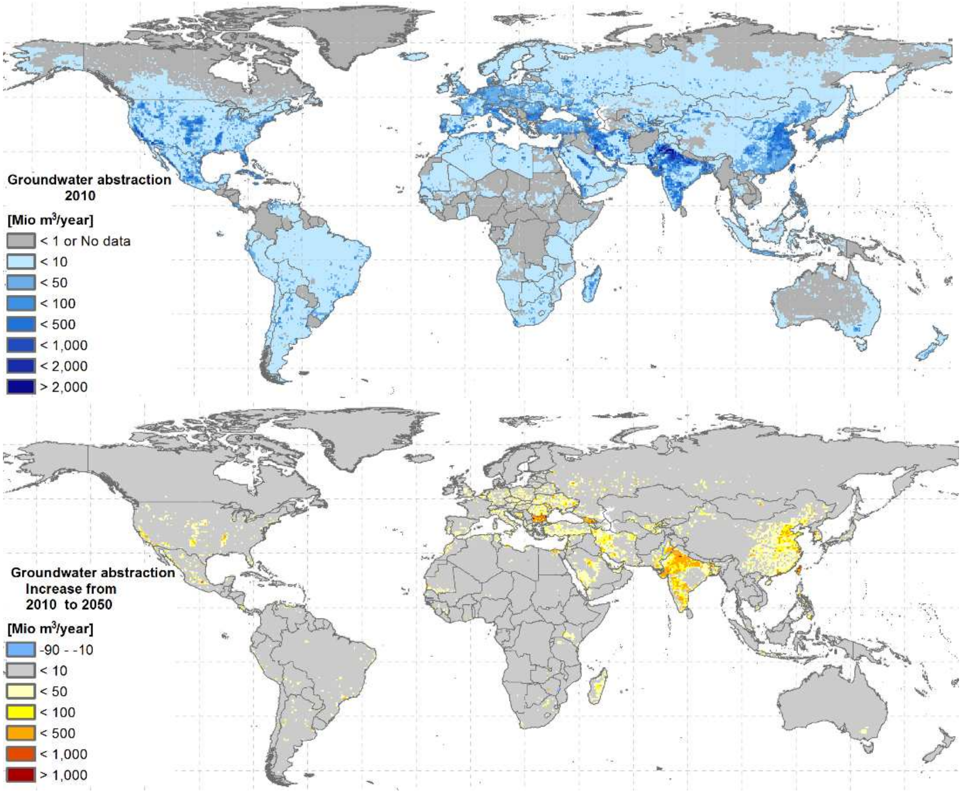

Figure 4-29: Groundwater abstraction in the 2010s - *Middle of the Road* scenario
Top: Groundwater abstraction in the 2010s. Bottom: Change (in Mio m^3/year) till 2050

Rapid aquifer depletion due to overexploitation (abstraction exceeds recharge) is a growing issue globally. It gives rise to many economic and environmental problems such as rising of pumping costs, desiccation of wetlands, decline of river flows, and increase of pollution risk.

Figure 4-30 shows groundwater abstraction in India, China and Pakistan originating from both renewable and non-renewable resources. Abstraction from non-renewable resources in India, China, and Pakistan represents approximately 24%, 12%, and 55% of their groundwater abstraction, respectively. Although the absolute amount of groundwater abstraction in Pakistan is the smallest, the share of abstraction originating from nonrenewable groundwater resources is the largest.

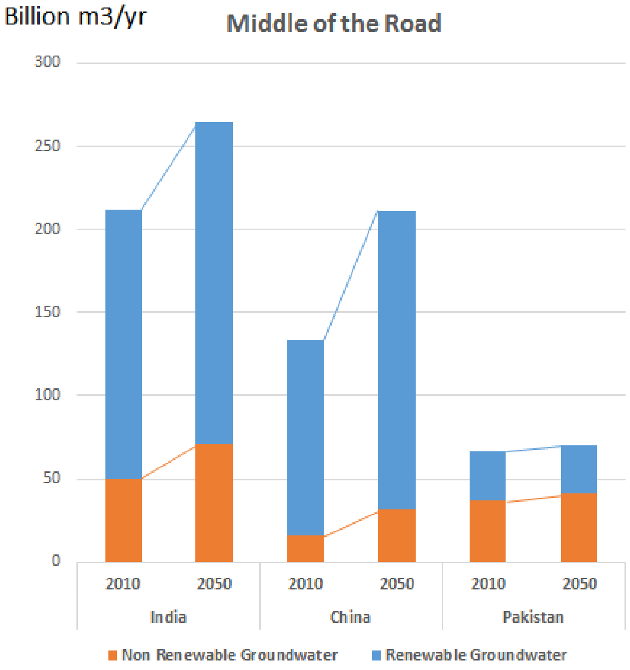

Figure 4-30: Groundwater abstraction in India, China and Pakistan

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Table 4-9 shows groundwater abstraction in the 2010s and its increase until the 2050s for Austria and ADA priority countries. Results indicate that countries with a lower abstraction rate in the 2010s such as Uganda and Mozambique show a high increase rate. Georgia will be within the top twenty biggest groundwater users around the world in the 2050s, with an increase rate of more than 100%. In the next phase of its work WFaS will determine whether this level of groundwater use is sustainable or not, and what solutions can be implemented to prevent the overexploitation of groundwater.

Table 4-9: Groundwater abstraction – ADA priority countries

Groundwater Abstraction			**Change rate**
[Mio m^3/year]	**2010**	**2050**	(% of 2010)
Austria	1249	1571	126
Albania	460	569	124
Moldova	609	1724	283
Armenia	773	1337	173
Georgia	4260	10320	242
Bhutan	18	48	269
Burkina Faso	0.5	6	1190
Ethiopia	10	21	201
Uganda	3	17	559
Mozambique	33	71	212

4.4.4 Transboundary dependency of water resources

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. The existing 263 transboundary lake 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).

The water dependency ratio is defined by (Food and Agriculture Organization (FAO) 2010) as the proportion of renewable water resources within a country that originates outside its borders therefore it is an indicator of the level of dependence of a country on its neighbors in terms of water resources. A country with a ratio of 1 receives all its renewable water from upstream countries. Figure 4-31 shows three examples of water dependency. Ethiopia has a low water dependency of 4%, Syria has a high dependency of 73%, and Egypt imports almost all its water (94% dependency rate). Results indicate also that water availability and the linked dependency ratio change during the year.

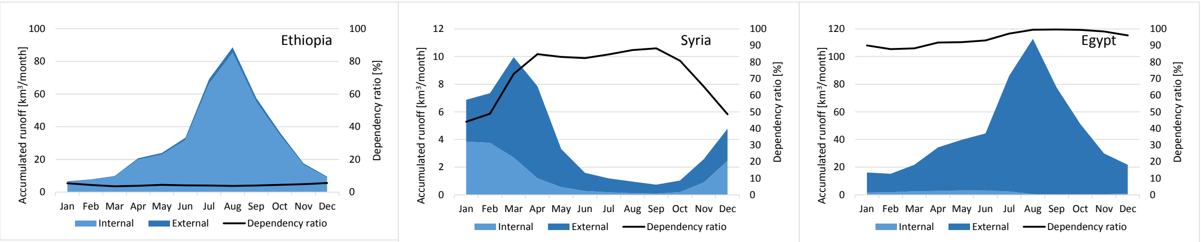

Figure 4-31: Flow regime and water dependency in the 2010s (2005-2014) at the example of Ethiopia, Syria and Egypt

In contrast to the historical ratio given by FAO AQUASTAT, the indicator is calculated using five different GCMs and 3 different GHMs. The water dependency ratio does not include groundwater use or possible allocation of water to downstream countries through water transfer.

Figure 4-32 shows the percentage of total renewable water resources originating from outside a country and it depicts main areas of water dependency in Europe (Danube, Volga), in Asia (Syr Darya, Amu Darya, Indus, Ganges–Brahmaputra), Africa (Nile, Niger, Okavango, Zambezi, Congo) and in South America (Rio Paraguay, Rio Uruguay). The dependency ratio does not change significantly by 2050. The water dependency ratio does not take into account the total water demand. It is only based on the water supply and does not indicate if the local (by country) freshwater is sufficient to meet total water demand.

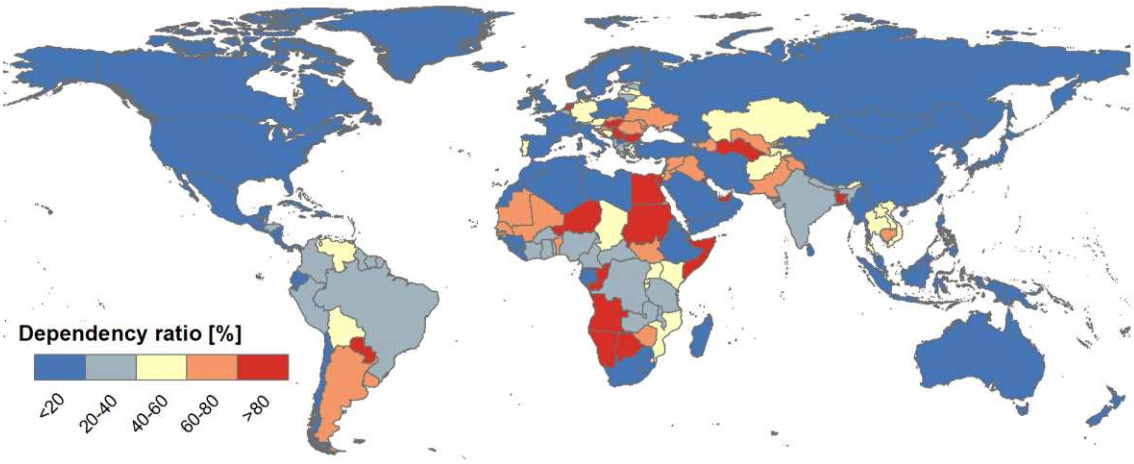

Figure 4-32: Dependency ratio 2010 (definition based on FAO AQUASTAT)

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Figure 4-33 shows the water dependency ratio over the year (average for each month from 2005 to 2014) for Austria and the ADA priority countries. The water dependency rate for Austria is quite high, mainly because of the inflow from the Upper Danube but the flow regime does not show pronounced dry and wet seasons. This is different for almost all the other countries where seasonal variations might lead to water shortage in some months and the need for inter-countries policy guidance to share the scarce water resources in these months.

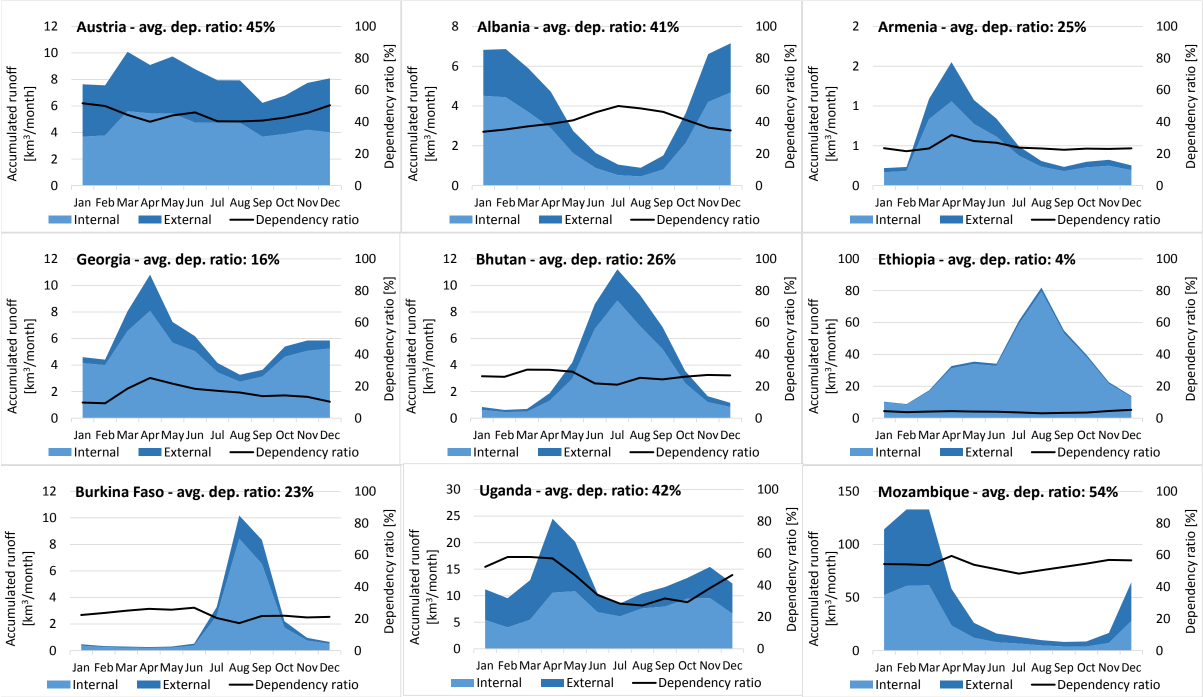

Figure 4-33: Dependency ratio of the ADA priority countries

4.5 Water demand

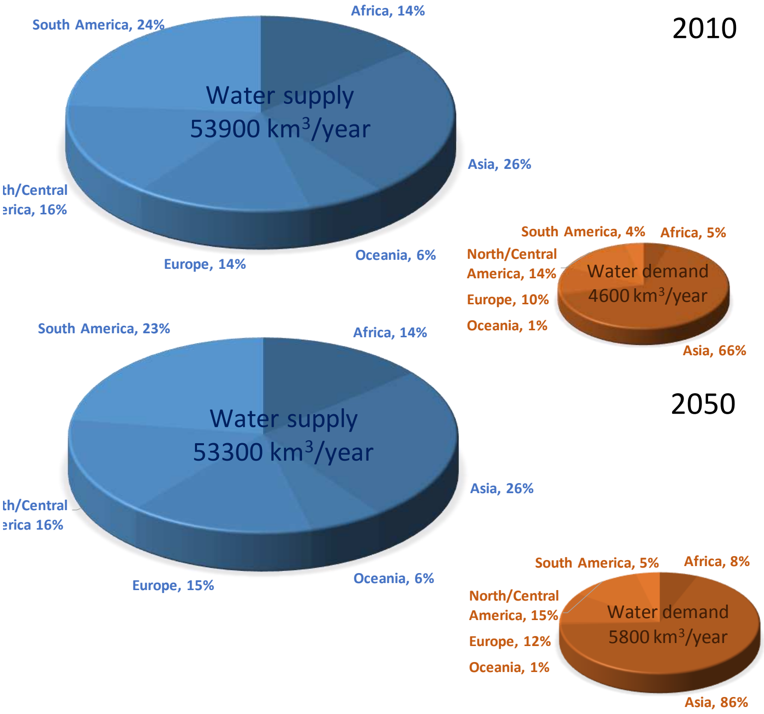

Figure 4-34: Surface water supply and demand for 2010 and 2050 – *Middle of the Road* scenario

Figure 4-34 displays surface water availability and demand per year under *Middle of the Road* scenario for 2010 and 2050. Results show that at global level water demand represents a small part of the available surface water resources both in 2010 (9%) and 2050 (11%). Nevertheless, these results hide the fact that water is not always available for human uses in the quantities or at the quality, time and place required because of several biophysical and economic constraints. Detailed results presented subsequently show the different constraints faced by various continents, sub-regions, and countries.

Water demand is calculated for the three scenarios considered, using ensembles of three global GHMs and five GCMs which have been described earlier36. Results shown in this section are the mean of the outcomes of these 15 ensembles mostly for *Middle of the Road* scenario which represents an intermediate future socio-economic pathway. It is important to mention that the projection of agricultural water demand presented in this report does not include future socio-economic change assumptions such as changes in technological and farming practices and changes of irrigated areas which will be part of the next phase of WFaS. As for now, irrigated area is fixed to that of year 2000. Yet, this estimate provides reasonable insights of future change under climate change. Future scenarios for the agricultural sector are still being developed, and WFaS project will release updated agricultural projections in the next phase.

4.5.1 Total water demand

Figure 4-35 and Figure 4-36 present water demand by scenario for the different continents and selected sub-regions through to 2050. Figure 4-37 presents water demand in 2010 and 2050 at country-level for the *Middle of the Road* scenario. Results indicate a consistent increase of global demand across scenarios through to 2050. Specifically, global demand increases between 2010 and 2050 by 20% under *Sustainability* scenario from 4530 to 5440 km^3, by 27% under *Middle of the Road* scenario from 4570 to 5800 km^3, and by 33% under *Rivalry* scenario from 4590 to 6100 km^3. These considerable differences among water demand projections (ranging from 360 to 660 km^3 per year) under the various scenarios underline the importance of human society's choice of nowadays policies that will shape its future socio-economic and climatic conditions.

During the next decades, the most intensive growth in water demand across the world is expected to occur in Africa, South America, and Asia, under all scenarios, and in Europe under *Middle of the Road* and *Rivalry* scenarios. Water demand in Africa will expand rapidly (up to 60% by 2050 compared to 2010) compared to all other continents driven by the intensive growth of population and income, although its share from global demand remains small (about 6%). Water demand in South America will also rise significantly (up to 50% by 2050 compared to 2010) owing to both population and income growth, but its share from global demand is at present 4% and in 2050 it will be 5%. At present, 65% of global water demand takes place in Asia, where the major irrigated land of the world is located. By 2050, water demand in Asia will grow by 30%, to represent about 70% of global demand, brought about primarily by income growth. The increase of water demand in Europe depends on the scenario considered. It increases slightly (by 9%) under the *sustainability* scenario due to the assumed technological improvement, but it escalates substantially under *Middle of the Road* and *Rivalry* scenarios (between 25 and 35%), driven mainly by the limited technological progress. Its share from global demand will amount to 10% by 2050.

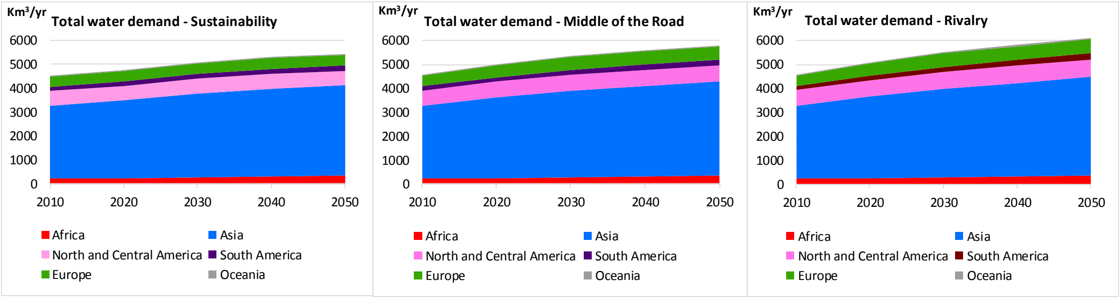

Figure 4-35: Total water demand by continent until 2050.

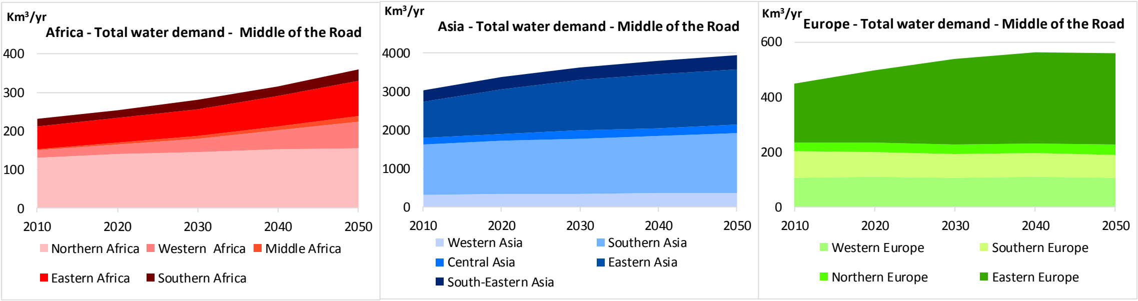

Figure 4-36: Total water demand by sub-region in Africa, Asia and Europe until 2050

The smallest changes of water demand across the world by 2050 compared to 2010 will be seen in Oceania, and North and Central America. Water demand in Oceania will moderately increase under all scenarios up to 18% owing to the slow growth of GDP compared to other continents. Oceania holds the lowest share of global demand (about 1%).

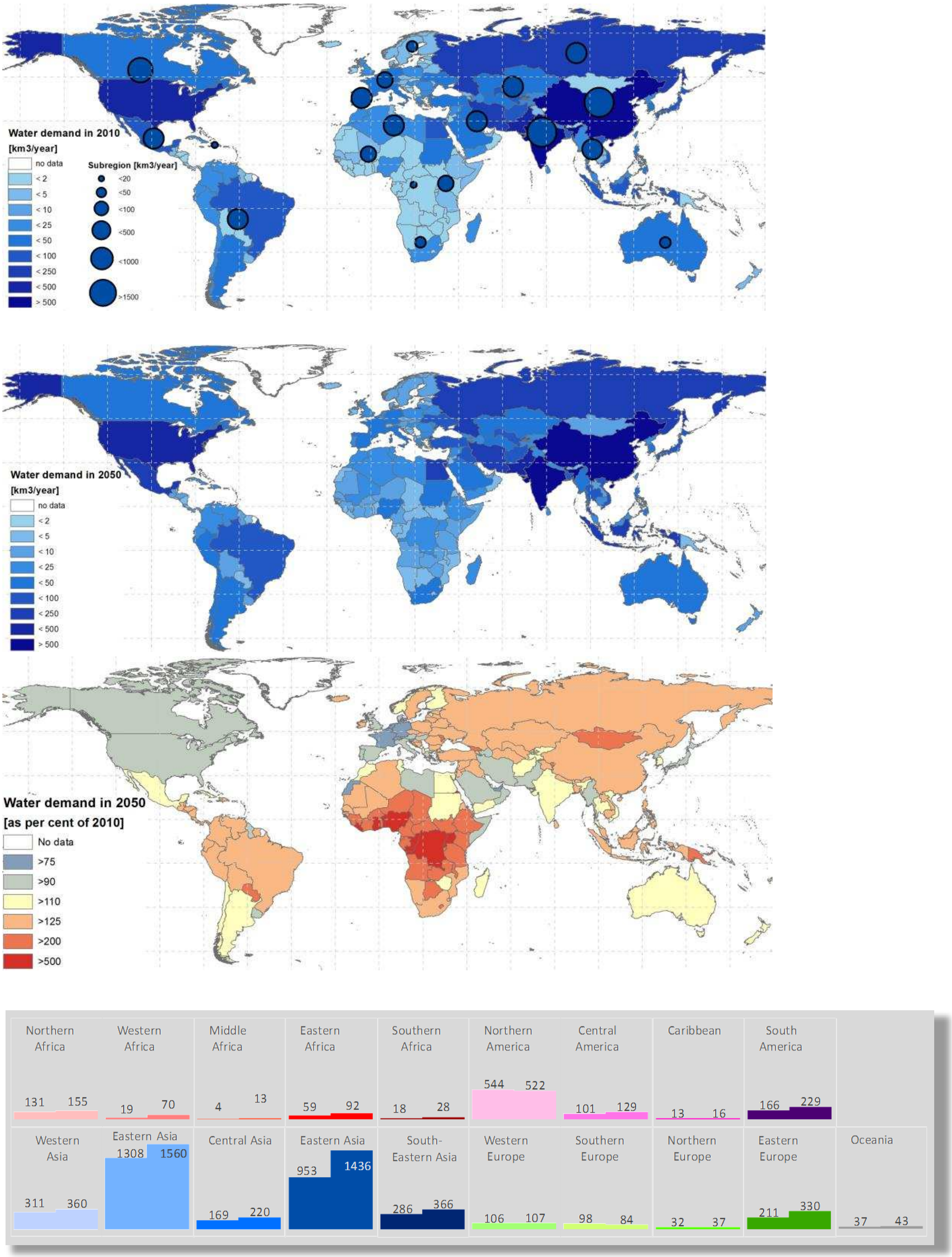

Figure 4-37: Water demand in 2010 and 2050 at country-level – *Middle of the Road* scenario

Water demand in North and Central America will increase very little under *Middle of the Road* and *Rivalry* scenarios and it will even decrease under *sustainability* scenario due to the limited growth of population and income. Its share from global demand will decrease from 15% in 2010 to 12% in 2050. Results of water demand projections for the selected sub-regions under *Middle of the Road* scenario show significant differences among these sub-regions. In fact, water demands are very unevenly distributed by the sub-regions of the continents and do not generally coincide with the availability of water resources. For Africa, water demand in northern Africa remains the largest in the continent.

It increases by 18% between 2010 and 2050, although its share in total African demand is falling from 60 to 40% in the same period. By contrast, the share of western Africa sub-region of total African demand is rising markedly from 8 to 20% between 2010 and 2050, sustained by a rapid demand increase of more than three and a half times (about 51 km^3). Water demand in Middle Africa will increase threefold, with its share from Africa total demand increasing from 2 to 4% between 2010 and 2050. Water demand in eastern and southern Africa sub-regions will increase steadily, maintaining their shares in Africa total demand.

For Asia, water demand in Southern Asia remains the largest by 2050 (40% of Asia total demand), although it increases slightly between 2010 and 2050. Water demand in eastern Asia will increase considerably between 2010 and 2050 (by 50% or 483 km^3), to represent about 36% of Asia total demand by 2050. Water demand in the other sub-regions will increase steadily, maintaining their shares in Asia total demand.

For Europe, water demand in Eastern Europe in 2010 is the largest across the continent, and it will remain so by 2050, with an increase of demand by 56% (or 119 km^3) between 2010 and 2050. On the other hand, the shares of water demand in Western and Southern Europe of total European demand will fall as the demand will be almost the same in Western Europe and will decrease in Southern Europe by 2050 compared to 2010 because of the technological change assumptions to use water more efficiently (see sector 3.4 and table 3.2) and low population growth. Water demand in Northern Europe will increase steadily, due to a higher population growth compared to Western and Southern Europe. Northern Europe will maintaining its share in Europe total demand.

Results at country-level indicate that water demands in China, India, United States, Russia, and Pakistan are at present the largest across the world and they will remain so in the 2050s. Major absolute increases of demand worldwide will take place in China (478 km^3), India (203 km^3), and Russia (66 km^3). However, the major relative increases in water demand worldwide will be seen in many

African countries such as Uganda, Rwanda, Liberia, DR Congo, Congo, Gambia, and Nigeria, with demands are expected to increase more than six fold by 2050 for the *Middle of the Road* scenario. In Asia, water demand will double by 2050 compared to 2010 in many countries including Armenia, Georgia, Papua New Guinea, and Mongolia. In Europe, water demand will rise in the Eastern part between 2010 and 2050, especially in Moldova, Ukraine, Bulgaria, and Czech Republic. In South America, water demand will rise in all countries between 2010 and 2050, especially in Paraguay, Columbia, and Bolivia. In North and Central America, water demand will increase significantly between 2010 and 2050 in some countries such as Panama, Guatemala, and Nicaragua.

The present assessment does not analyze the impacts of demand change on water quality. However, it is expected that the growth of water demand, the increasing importance of domestic and industrial waste water discharges, and the potential increase of fertilizers utilization, due to the need to improve agricultural productivity, will impair water quality if no adequate abatement measures are implemented.

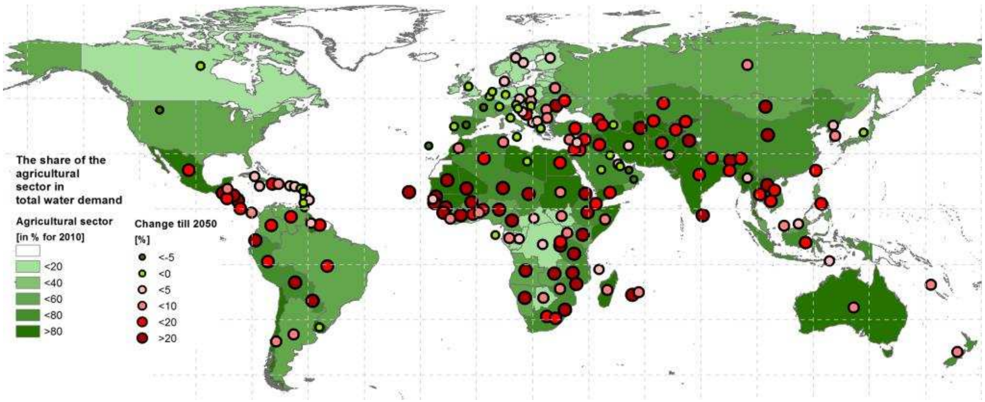

Figure 4-38: Share of agricultural water demand in 2010 and changes by 2050

4.5.2 Water demand change by sector

Table 4-10 shows water demand in 2010 and 2050 by continent and sector and Figure 4-38 shows changes of the share of agricultural water demand by 2050 at country level under *Middle of the Road* scenario. It is important to analyze the contribution of each sector to total water demand in each continent, sub-region, and country because it indicates in which sector water policy interventions should mostly be implemented to address water scarcity.

Results indicate that agriculture currently represents the major water demand sector at global level and in all continents, except in Europe. The share of agricultural water demand represents about 70% of total global demand, about 80% of total demand in Africa, Asia, and Oceania, and about 50% in North, Central and South America. In Europe, industry represents the major water demand sector, with its share exceeding 50% of total demand. By 2050, the share of agricultural demand will decrease in all continents, except in North and Central America, due to the intensive expansion of other water uses, driven by population and income growth. Agriculture will remain the major demand sector at global level, representing 60% of total demand. The loss of the relative

Table 4-10: Water demand by continent and sector under the *Middle of the road* scenario.

Total water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Africa	231	100%	359	100%	155
Asia	3026	100%	3941	100%	130
North and Central Am	659	100%	667	100%	101
South America	166	100%	229	100%	137
Europe	447	100%	558	100%	125
Oceania	37	100%	43	100%	115
World	4566	100%	5796	100%	127

Agr. water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Africa	187	81%	194	54%	103
Asia	2508	83%	2617	66%	104
North and Central Am	348	53%	367	55%	106
South America	97	58%	99	44%	103
Europe	133	30%	139	25%	105
Oceania	30	80%	31	73%	105
World	3302	72%	3447	100%	104

Ind. water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	
Africa	18	8%	64	18%	353
Asia	316	10%	760	19%	240
North and Central Am	229	35%	182	27%	80
South America	31	19%	47	21%	153
Europe	241	54%	325	58%	135
Oceania	2	5%	3	7%	144
World	838	18%	1381	24%	165

Dom. water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	
Africa	26	11%	101	28%	390
Asia	202	7%	565	14%	280
North and Central Am	82	13%	118	18%	143
South America	39	23%	82	36%	211
Europe	72	16%	93	17%	128
Oceania	6	15%	9	21%	160
World	427	9%	967	17%	227

importance of agricultural demand will be especially pronounced in Africa and Asia where most of global population and economic growth will take place.

Agricultural water demand will change between 2010 and 2050 for all sub-regions. Major absolute increases will be seen in Southern Asia (61 km^3), Eastern Asia (25 km^3), Western Asia (14 km^3), and Northern America (14 km^3). Agricultural demand will decrease slightly only in Northern Europe. In relative term, demand changes will range between -2% in northern Europe and +8% in Southern Africa. On the other hand, domestic water demand will increase significantly in all sub-regions, except in Western Europe where it stagnates. Major absolute increases will be seen in Eastern Asia (159 km^3), Southern Asia (114 km^3), South-eastern Asia (45 km^3), and South America (43 km^3). In relative term, domestic demand will rise by more than threefold in All African and Asian sub-regions, and it will more than double in Central and South America. Industrial water demand will increase in all sub-regions, except Northern America, and western and Southern Europe. Major absolute increases will be seen in Eastern Asia (300 km^3), Eastern Europe (100 km^3), and Southern Asia (77 km^3). In relative term, industrial demand will grow up to eight times in Western, Middle, Eastern and Southern Africa, but from a much lower base compared to other sub-regions across the world. Industrial demand will also increase significantly in Southern, Central, and Eastern Asia up to two and a half times.

Table 4-11: Water demand by sector in ADA priority countries under
Middle of the road scenario

Total water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Austria	3.4	100%	3.3	100%	94
Albania	1.9	100%	2.4	100%	124
Moldova	3.1	100%	7.6	100%	244
Armenia	3.4	100%	5.4	100%	157
Georgia	3.0	100%	8.3	100%	273
Bhutan	0.7	100%	0.9	100%	142
Burkina Faso	0.5	100%	2.1	100%	384
Ethiopia	3.0	100%	12.8	100%	420
Uganda	0.4	100%	5.8	100%	1350
Mozambique	1.0	100%	2.0	100%	192

Agr. water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Austria	0.17	5%	0.18	5%	103
Albania	1.20	62%	1.40	59%	117
Moldova	1.08	35%	1.10	15%	102
Armenia	1.54	45%	1.70	31%	110
Georgia	0.79	26%	0.91	11%	115
Bhutan	0.65	97%	0.66	69%	102
Burkina Faso	0.23	42%	0.23	11%	101
Ethiopia	1.93	63%	1.98	15%	102
Uganda	0.03	8%	0.03	1%	94
Mozambique	0.76	73%	0.8	42%	111

Ind. water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Austria	2.57	75%	2.33	72%	91
Albania	0.25	13%	0.36	15%	144
Moldova	1.81	58%	5.96	79%	329
Armenia	0.71	21%	1.24	23%	174
Georgia	1.40	46%	4.97	60%	356
Bhutan	0.01	0%	0.18	19%	2224
Burkina Faso	0.05	1%	0.35	17%	703
Ethiopia	0.22	7%	3.01	23%	1358
Uganda	0.10	23%	0.78	14%	792
Mozambique	0.03	3%	0.13	7%	469

Dom. water demand	**Amount**				**Change rate**
[km^3/year]	**2010**	**Share**	**2050**	**Share**	(% of 2010)
Austria	0.70	20%	0.75	23%	106
Albania	0.48	25%	0.62	26%	129
Moldova	0.20	7%	0.50	7%	248
Armenia	1.19	35%	2.48	46%	208
Georgia	0.84	28%	2.40	29%	285
Bhutan	0.01	2%	0.11	11%	795
Burkina Faso	0.27	49%	1.51	72%	567
Ethiopia	0.89	29%	7.83	61%	875
Uganda	0.29	69%	4.94	86%	1677
Mozambique	0.25	24%	1.01	51%	402

Austria and priority countries of the Austrian Development Agency

Table 4-11 provides information on total and sectoral water demand for Austria and ADA priority countries in 2010 and 2050. Total water demand will decrease slightly in Austria, but is expected to increase in the other countries. The largest increases will be seen in Ethiopia, Uganda, Burkina Faso, Georgia, and Moldova. Agriculture is at present the largest water demand sector in the lower and middle income economies such as Bhutan, Mozambique, and Ethiopia, representing more than 60% of total demand. However, industry is the major water demand sector in high income economies such as Austria. By 2050, the share of agricultural water demand will decrease in all countries, except in Austria where it will not change. Industrial and domestic water demands and their shares will rise significantly in several countries including Bhutan, Ethiopia, Uganda, and Moldova, driven by strong demographic and economic growth.

Results indicate that the changes of total and sectoral water demand in ADA priority countries depend strongly on the current level of development of each country. For instance, total water demand in Austria is expected to decrease. The reason is the decline of the already large industrial water demand driven by investments in water efficiency and less-water intensive technologies. In contrast owing to the huge increase of domestic water demand, total water demand in Uganda will increase rapidly, but from a much lower base.

4.6 Water security

As shown in the sections on population and GDP (section 4.1) and on water supply and demand (section 4.4 and 4.5), the increasing world population, rising demand for food production and economic development, and changing spatial and temporal pattern of water supply are the main causes for water becoming a more scarce resource. The World Economic Forum ranked water crises as the largest global risk for the next decade, as climate change and increasing demand for water are expected to worsen the World's water future (World Economic Forum 2015).

4.6.1 Water scarcity - Imbalance between supply and demand

The integrated WFaS modelling approach is to assess current and future imbalances between water supply and demand. We employ the water resources vulnerability index (Raskin et al. 1997) also known as Water Exploitation Index (WEI) (EEA 2005), defined as the ratio of total annual withdrawals for human use to total available renewable surface water resources. Regions are considered water scarce if annual withdrawals are between 20-40% of annual supply, and severely water scarce if withdrawals exceed 40%.

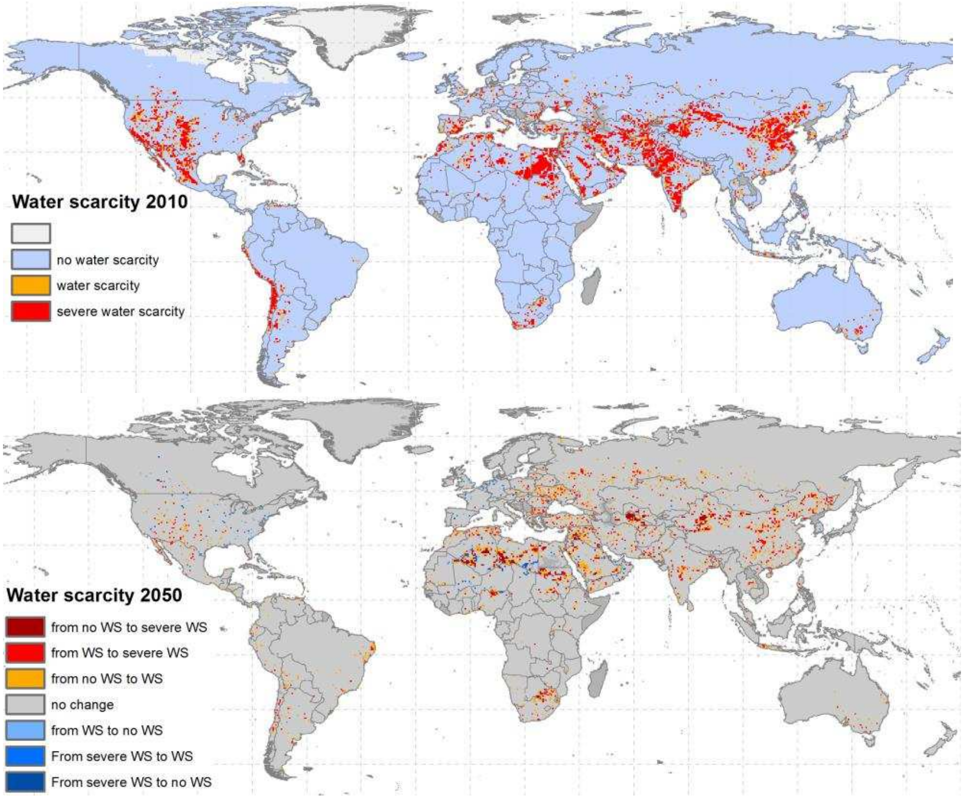

Figure 4-39: Water scarcity - *Middle of the Road* Scenario for each grid cell (0.5^o grid or ~ 50km by 50km)

In the WFaS framework, we consider annual as well as seasonal variations of water demand and supply, as water scarcity often occurs in a certain time of the year. We also look into the most water scarce month to characterize the regional water scarcity.

Figure 4-39 top shows hotspots of water scarcity for the 2010s in Western South America and Mexico, North East Brazil, Chile, North Africa, Afghanistan - Pakistan – India and North-Eastern China, South-Western Australia, and South Africa. By 2050 (Figure 4-39 bottom), additionally regions including Northern and Southern Africa, Middle East, Central and Eastern Asia are projected to experience severe water scarcity condition. Figure 4-39 highlights changes in water scarcity class between 2010 and 2050 for the *Middle of the Road* scenario (SSP2) on annual basis.

4.6.2 Potential population exposed to future severe water scarcity

Combining the future projections of global population with the WFaS scenario analysis on water scarcity reveals an increasing number of people exposed to conditions of severe water scarcity by 2050. In the 2010s on average 1.9 billion people (27% of the total global population) live in potential severe water scarce areas and in 2050 it will increase to 2.7 to 3.2 billion depending on the socio-economic scenarios (see Figure 4-40) (32% for all scenarios).

When considering monthly variability of supply and demand into account, currently 3.6 billion people worldwide (51%) are living in potential severe water scarcity areas and this figure will increase to 4.8 to 5.7 billion by 2050 (57% to 58%). 73% of the affected people live in Asia in 2010 (69% in 2050). These numbers agree well with a recent study by (Mekonnen et al. 2015), who estimated about four billion people living currently under conditions of severe water scarcity at least for one month of the year.

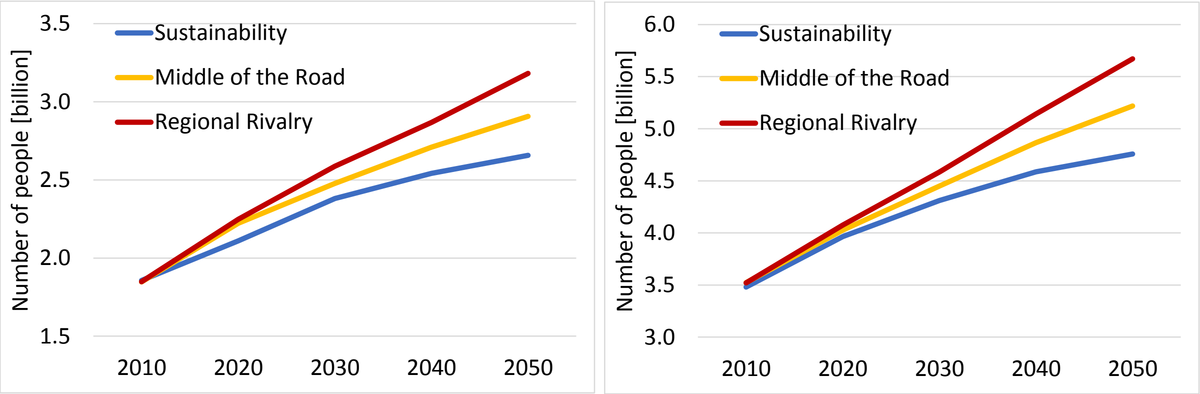

Figure 4-40: Potential Population under severe water scarcity for all three scenarios from 2010 to 2050.
Left: On annual basis. Right: On basis of the most water scarce month

Figure 4-41 shows the potential population under severe water scarcity. Especially dense populated countries like India and China show the large fraction under severe water scarcity. The symbols in Fig 4-41 show the percentage of people in the sub-regions (i.e. Eastern Africa) under severe water scarcity.

The bottom part of Figure 4-41 shows the difference between 2050 and 2010. In sub-Saharan Africa the absolute number but also the percentage of people living under severe water scare condition will increase up to two times (Western and Eastern Africa). In all the other sub regions the number of people under water scarcity will increase but the percentage of people will only slightly increase. In China in many areas the number of people and also the percentage will decline, but this will be superimposed by an increasing number of people in big cities under water scarcity conditions. Mainly in the belt from 10° to 40° northern latitude (South USA, Mexico and Morocco to India) the number and the percentage of people under severe water scarcity will increase.

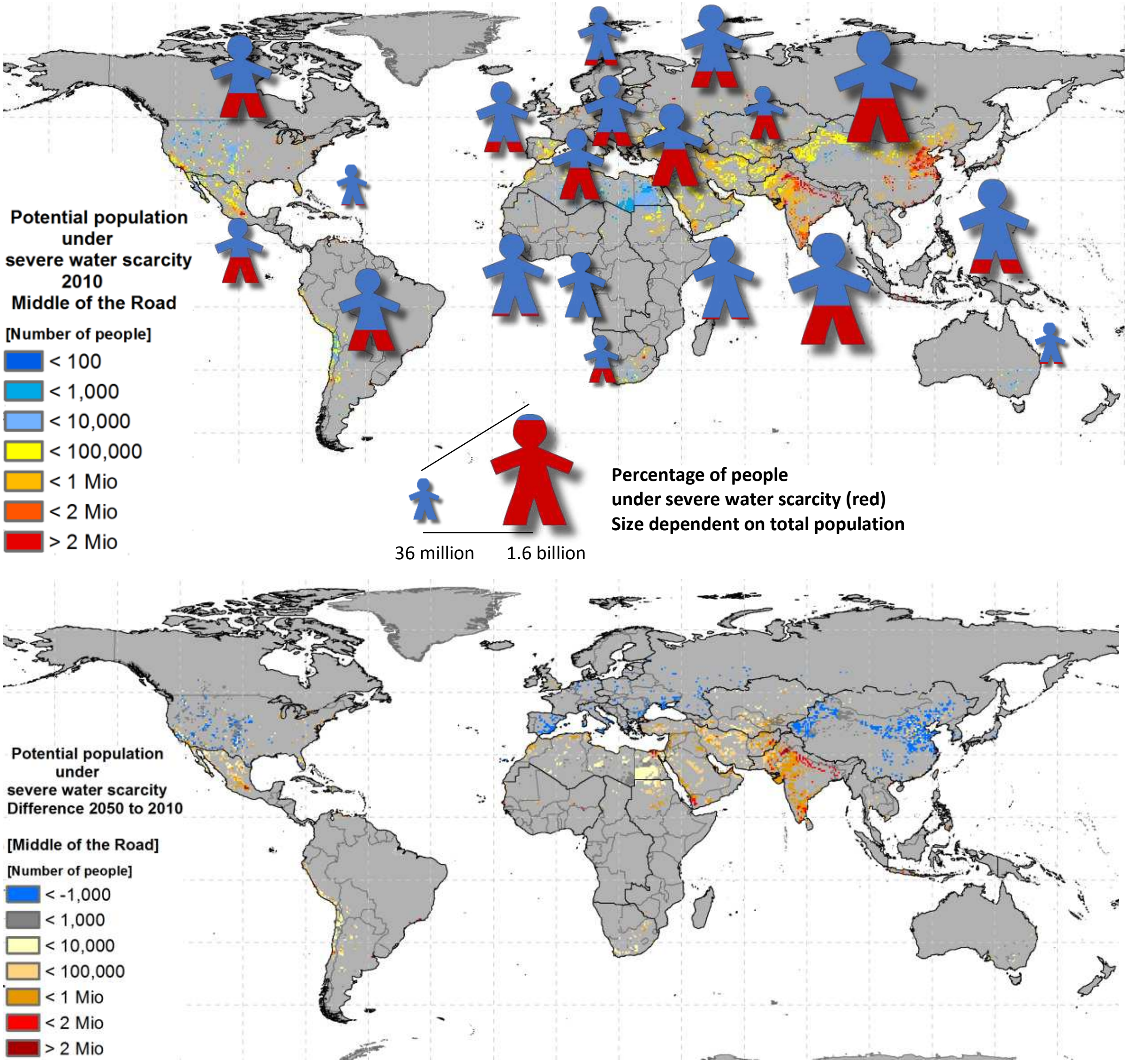

Figure 4-41: Potential Population under severe water scarcity in 2050 – *Middle of the Road* Scenario

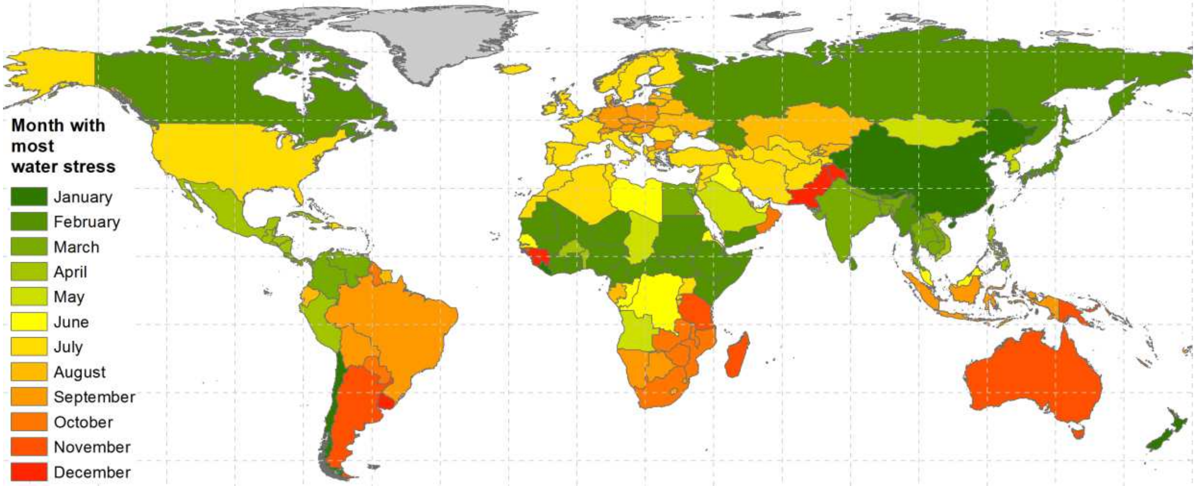

Figure 4-42: Most water scare month in the period 2005-2014 – *Middle of the Road* Scenario

While there are variations in precipitation during the year, it is important to look into the intra annual variability of water scarcity. Figure 4-42 shows the month at which the rate between total water demand and water supply is highest (most water scarce month). Figure 4-43 shows the percentage of people under severe water scarcity for the most water scarce month in the 2010s and the 2050s for the *Middle of the Road* Scenario (SSP2) aggregated to country scale. It indicates an increase for a number of countries mainly in the belt from 10° to 40° northern latitude. The estimation of water scarcity in this study takes upstream discharge (exogenous runoff) from into account. For example, Egypt freshwater supply comes mainly from the Nile which flow across ten different countries before arriving in Egypt. Since half of the population in Egypt lives along the Nile, they are potentially not affected by water scarcity. This study does not include the aspect of water quality, inter-basin water transfer or water management.

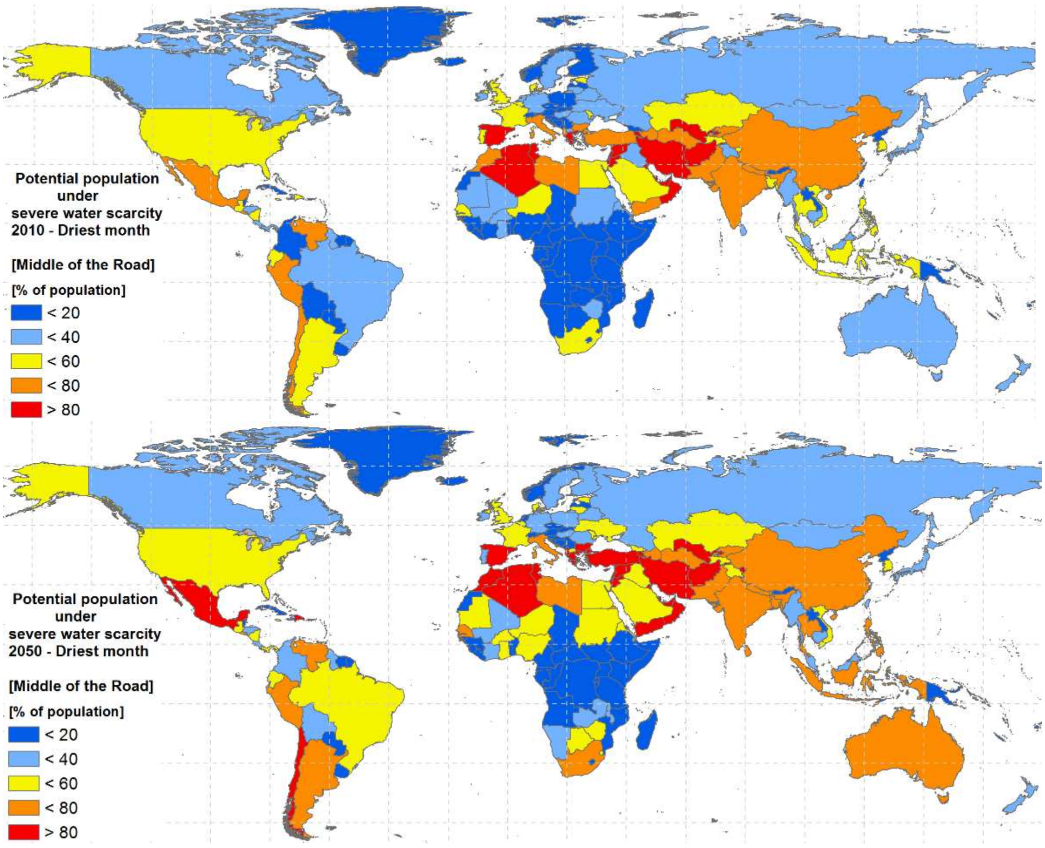

Figure 4-43: Potential Population under severe water scarcity in 2050 – *Middle of the Road* Scenario

Austria and priority countries of the Austrian Development Agency

Table 4-12 shows the possible affected percentage of people from severe water scarcity for Austria and the ADA priority countries. From This assessment Austria, Bhutan, Mozambique have no or a low percentage of people under water scarcity. But water scarcity will be an increasing problem for Albania, Moldova, Armenia, Georgia and Burkina Faso but also for Ethiopia and Uganda.

Table 4-12: Potential Population under severe water scarcity in 2010 and 2050 - ADA countries– *Middle of the Road* Scenario

Population under severe water scarcity	**2010**		**2050**	
[% of population]	**Year**	**Month**	**Year**	**Month**
Austria	0	0	0	0
Albania	0	69	0	83
Moldova	34	49	47	47
Armenia	35	94	76	100
Georgia	5	6	42	49
Bhutan	0	4	0	4
Burkina Faso	0	37	6	44
Ethiopia	0	3	3	19
Uganda	0	0	5	13
Mozambique	0	0	0	2

4.7 Hydro-economic classification

To facilitate presentation of results, we applied an integrated assessment, the Hydro-Economic (HE) classification, and have grouped 178 country results into four classes depending on their hydro-climate complexity and economic-institutional coping capacity (Appendix C). 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 (Figure 4-44). The water challenges are composed of four indicators; renewable water resources per capita, water use intensity, variability in runoff and dependency of external water resources. The economic-institutional coping capacity (Y-axis) is represented by GDP per capita. (See details in section 3.3 and section 4.1-4.6). For simplicity these are termed *HE-1* Water secure and poor; *HE-2* Water secure and rich; *HE-3* Water stress and rich, *HE-4* Water stress and poor (see Figure 4-33). For example, countries/watersheds classified into HE-4 face significant hydro-economic challenges as their hydrological-climatic conditions are complex while their economic-institutional coping capacity is low.

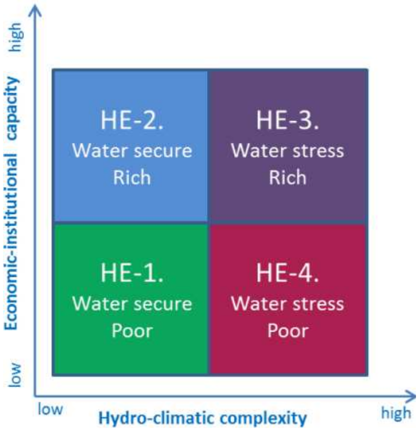

Figure 4-44: Hydro-Economic dimension

Location of countries/watersheds move over time in the two-dimensional space of HE classes according to hydro-climatic and socioeconomic conditions. Each of the three scenarios '*Sustainability*', *'Middle of the Road'* and *'Regional rivalry'* presents different plausible future pathways. All scenarios foresee significant levels of economic growth (i.e. increasing GDP) in all countries, and every country shows increase in their GDP per capita at least in the 2050s as well (except Angola under the *Regional Rivalry* scenario).

Table 4-13: The number of countries in each Hydro-Economic classes. Country results are accumulated at subregional level

Number of countries		**2010**				**2050**											
						Sustainability				**Middle of the Road**				**Regional Rivalry**			
	Total	**HE1**	**HE2**	**HE3**	**HE4**	**HE1**	**HE2**	**HE3**	**HE4**	**HE1**	**HE2**	**HE3**	**HE4**	**HE1**	**HE2**	**HE3**	**HE4**
Global	178	112	44	7	15	36	114	22	6	51	96	19	12	66	79	13	20
Northern Africa	5	3	1	0	1	0	1	4	0	0	1	4	0	0	0	3	2
Western Africa	16	15	0	0	1	10	3	1	2	11	1	0	4	12	0	0	4
Middle Africa	9	8	1	0	0	5	4	0	0	5	4	0	0	7	2	0	0
Eastern Africa	17	16	0	0	1	15	1	1	0	14	1	0	2	13	1	0	3
Southern Africa	5	5	0	0	0	1	4	0	0	1	3	0	1	2	2	0	1
Western Asia	15	1	0	7	7	0	1	11	3	0	1	11	3	0	1	9	5
Southern Asia	7	5	0	0	2	2	3	1	1	2	3	1	1	2	3	0	2
Central Asia	8	5	0	0	3	1	4	3	0	2	3	2	1	2	3	0	3
Eastern Asia	4	2	2	0	0	0	3	1	0	0	3	1	0	0	3	1	0
South-Eastern Asia	11	9	2	0	0	1	10	0	0	5	6	0	0	7	4	0	0
Northern America	2	0	2	0	0	0	2	0	0	0	2	0	0	0	2	0	0
Central America	7	7	0	0	0	0	7	0	0	2	5	0	0	4	3	0	0
Caribbean	10	6	4	0	0	1	9	0	0	2	8	0	0	4	6	0	0
South America	12	12	0	0	0	0	12	0	0	1	11	0	0	4	8	0	0
Western Europe	12	5	7	0	0	0	12	0	0	0	12	0	0	2	10	0	0
Southern Europe	8	0	8	0	0	0	8	0	0	0	8	0	0	0	8	0	0
Northern Europe	10	1	9	0	0	0	10	0	0	0	10	0	0	0	10	0	0
Eastern Europe	10	6	4	0	0	0	10	0	0	0	10	0	0	1	9	0	0
Oceania	10	6	4	0	0	0	10	0	0	6	4	0	0	6	4	0	0

This results in an upward shift along the y-axes moving more countries into the classes HE-2 or HE-3. By the 2050s, the number of countries in HE-1 is therefore lower compared to 2010 while the number of countries in other classes increases (Table 4-13). Depending on the actual implementation of the potential of increased economic strength, this may increase the countries' coping capacity for adaptation and risk management related to water challenges. The class HE-1 has 112 countries and is dominant in the 2010s. However many of them will shift over time into the class HE-2, and by 2050, HE-2 will be dominant in the *Sustainability* (114 countries), *Middle of the Road* (96 countries) and the *Regional Rivalry* (79 countries) scenario (Figure 4-45).

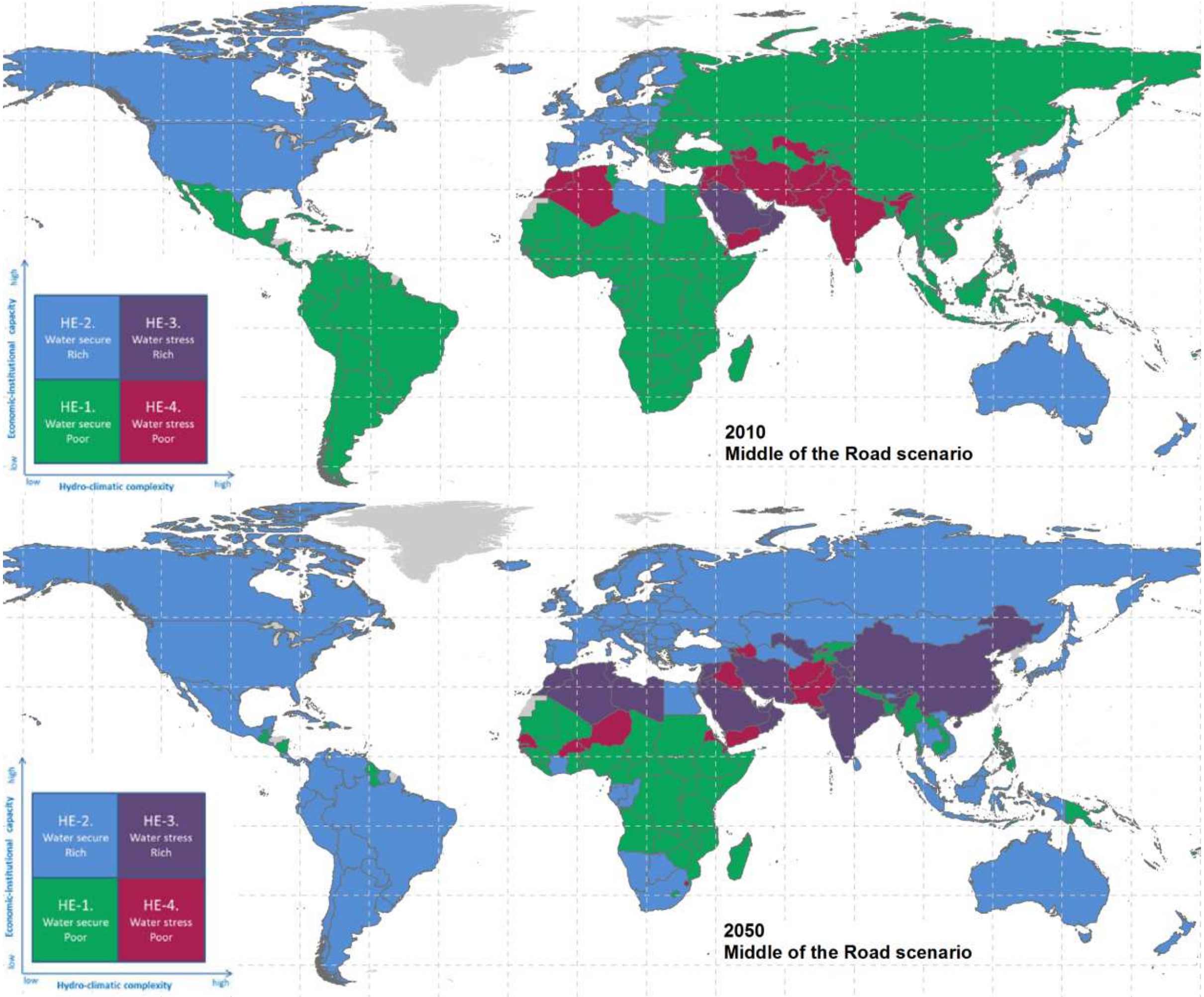

Figure 4-45: Country-level Hydro-economic class in 2010 and 2050 - *Middle of the Road* scenario

The share of global population living in HE-3 and HE-4 countries will increase until 2050, slightly less than half (43-47%) of global population will live in these higher water challenge classes throughout all scenarios (Table 4-14). Concerning population living in class HE-4 countries, there is a significant difference between the *Sustainability* scenario and the other two scenarios. The *Middle of the Road* and *Regional Rivalry* scenario suggests a significant increase of population living in these countries with lower coping capacity and high hydrologic complexity. In 2010 one fourth of global population lives in countries classified into HE4 including Southern Asia (1.4 billion), followed by Western Asia (200 million). By 2050 population in the class HE-4 under the *Sustainability* scenario will decrease to 470 million because some countries will shift to the class HE-3. But under the *Middle of the Road* and *Regional Rivalry* scenario, population in HE4 will be about 630 million and 3.0 billion, respectively.

Consistently, Southern Asia has the largest population in this class in the 2050s, too. Western Asia has the second largest population, followed by Western Africa and Northern Africa.

GDP will have increased in every country by 2050 (Table 4-15). As a result, total GDP will be 4.3, 3.4 and 2.7 times higher compared to current GDP (in 2010) under the *Sustainability*, the *Middle of the Road* and the *Regional Rivalry* scenario respectively. Nevertheless, the total share of GDP in the classes HE-1 and HE-4 (i.e. non-rich classes) is in reverse order among the three scenarios. It is about 35% in the 2010s and it will be 7% by 2050 under the *Sustainability* scenario, while it will be 9% and 25% in the *Middle of the Road* and *Regional Rivalry* scenario.

Table 4-14: Population for each Hydro-Economic classes

Population	**2010**					**2050**														
						Sustainability					**Middle of the Road**					**Regional Rivalry**				
	Total	**HE1**	**HE2**	**HE3**	**HE4**	**Total**	**HE1**	**HE2**	**HE3**	**HE4**	**Total**	**HE1**	**HE2**	**HE3**	**HE4**	**Total**	**HE1**	**HE2**	**HE3**	**HE4**
	10^6 cap	%				10^6 cap	%				10^6 cap	%				10^6 cap	%			
Global	6814	60	15	1	24	8398	16	41	37	6	9097	23	33	37	7	9875	30	23	17	30
Northern Africa	159	80	0	0	20	204	0	55	45	0	224	0	56	44	0	256	0	0	60	40
Western Africa	304	100	0	0	0	588	28	63	0	9	678	79	5	0	17	801	82	0	0	18
Middle Africa	127	99	1	0	0	238	95	5	0	0	267	96	4	0	0	299	99	1	0	0
Eastern Africa	366	100	0	0	0	651	100	0	0	0	757	98	0	0	2	892	96	0	0	4
Southern Africa	58	100	0	0	0	72	4	96	0	0	73	4	94	0	2	72	9	89	0	2
Western Asia	316	23	0	16	61	483	0	18	48	34	544	0	18	46	37	617	0	18	34	49
Southern Asia	1599	13	0	0	87	2048	11	1	76	12	2298	11	1	75	13	2629	11	1	0	88
Central Asia	77	49	0	0	51	84	7	41	52	0	91	16	33	40	12	105	18	31	0	51
Eastern Asia	1519	88	12	0	0	1390	0	12	88	0	1422	0	11	89	0	1448	0	10	90	0
South-Eastern Asia	593	99	1	0	0	689	6	94	0	0	742	30	70	0	0	812	84	16	0	0
Northern America	344	0	100	0	0	460	0	100	0	0	450	0	100	0	0	372	0	100	0	0
Central America	148	100	0	0	0	177	0	100	0	0	199	16	84	0	0	239	21	79	0	0
Caribbean	40	86	14	0	0	40	30	70	0	0	43	36	64	0	0	51	58	42	0	0
South America	392	100	0	0	0	449	0	100	0	0	490	0	100	0	0	552	10	90	0	0
Western Europe	156	13	87	0	0	167	0	100	0	0	164	0	100	0	0	143	9	91	0	0
Southern Europe	189	0	100	0	0	213	0	100	0	0	206	0	100	0	0	175	0	100	0	0
Northern Europe	99	2	98	0	0	124	0	100	0	0	122	0	100	0	0	102	0	100	0	0
Eastern Europe	291	78	22	0	0	263	0	100	0	0	269	0	100	0	0	260	0	100	0	0
Oceania	36	24	76	0	0	56	0	100	0	0	57	25	75	0	0	50	32	68	0	0

Table 4-15: GDP for each Hydro-Economic classes. Country results are accumulated at subregional level.

GDP	**2010**					**2050**														
						Sustainability					**Middle of the Road**					**Regional Rivalry**				
	Total	**HE1**	**HE2**	**HE3**	**HE4**	**Total**	**HE1**	**HE2**	**HE3**	**HE4**	**Total**	**HE1**	**HE2**	**HE3**	**HE4**	**Total**	**HE1**	**HE2**	**HE3**	**HE4**
	Billion US$2005/yr	%				Billion US$2005/yr	%				Billion US$2005/yr	%				Billion US$2005/yr	%			
Global	66340	37	53	2	8	283008	5	51	42	2	228253	7	52	39	2	176105	11	48	27	14
Northern Africa	945	85	0	0	15	5814	0	57	43	0	4887	0	57	43	0	3787	0	0	66	34
Western Africa	521	100	0	0	0	8145	20	73	0	7	5842	83	8	0	9	4006	91	0	0	9
Middle Africa	236	91	9	0	0	2454	86	14	0	0	1620	83	17	0	0	1112	91	9	0	0
Eastern Africa	429	100	0	0	0	6689	99	1	0	0	4523	98	1	0	1	3091	98	1	0	1
Southern Africa	522	100	0	0	0	2307	1	99	0	0	1925	1	98	0	1	1423	4	95	0	1
Western Asia	3524	26	0	40	34	14623	0	24	64	12	13525	0	24	65	11	12013	0	22	59	19
Southern Asia	4426	8	0	0	92	43805	7	2	84	7	32634	6	2	84	8	22499	6	2	0	92
Central Asia	435	60	0	0	40	2315	4	59	38	0	2006	8	56	28	8	1843	8	60	0	32
Eastern Asia	14352	64	36	0	0	78722	0	13	87	0	59828	0	15	85	0	45505	0	15	85	0
South-Eastern Asia	2813	90	10	0	0	19887	3	97	0	0	15104	16	84	0	0	11268	68	32	0	0
Northern America	14289	0	100	0	0	33687	0	100	0	0	29929	0	100	0	0	24750	0	100	0	0
Central America	1618	100	0	0	0	6122	0	100	0	0	5350	8	92	0	0	4543	9	91	0	0
Caribbean	290	62	38	0	0	964	15	85	0	0	797	17	83	0	0	663	32	68	0	0
South America	3965	100	0	0	0	15688	0	100	0	0	12989	0	100	0	0	10688	6	94	0	0
Western Europe	3679	4	96	0	0	6933	0	100	0	0	6189	0	100	0	0	4666	4	96	0	0
Southern Europe	6257	0	100	0	0	12263	0	100	0	0	11301	0	100	0	0	8751	0	100	0	0
Northern Europe	3183	1	99	0	0	7351	0	100	0	0	6692	0	100	0	0	5129	0	100	0	0
Eastern Europe	3919	70	30	0	0	12257	0	100	0	0	10535	0	100	0	0	8469	0	100	0	0
Oceania	937	2	98	0	0	2983	0	100	0	0	2576	6	94	0	0	1898	6	94	0	0

The number of countries in the classes HE-3 and HE-4, which are subject to high hydro-climatic complexity and often thus suffer from larger water challenges, will increase in every scenario (Table 4-13). All countries classified into HE-3 or HE-4 in the 2010s will remain in one of these classes. By 2050s additional countries will have moved into these categories (Table 4-16), all of them countries in Asia or Africa. Especially the class HE-4 countries face significant water challenges because they have low levels of socio-economic coping capacity combined with large hydro-climatic complexity. Although the number of countries in class HE-4 will decrease under the *Sustainability* scenario from 15 to six and to 12 under the *Middle of the Road* scenario, HE-4 countries will increase under *Regional Rivalry*. The following seven countries remain consistently HE4 counties in all scenarios; Burkina Faso, Cape Verde, Djibouti, Iraq, Pakistan, Senegal and Yemen.

Table 4-16: Countries which is categorized into larger water challenge classes in the 2010s and in the 2050s under three future scenarios

2010				2050					
				Sustainability		Middle of the Road		Regional Rivalry	
Subregion	Country	HE	[US$2005/cap/yr]	HE	[US$2005/cap/yr]	HE	[US$2005/cap/yr]	HE	[US$2005/cap/yr]
Northern Africa	Algeria	4[1]	7564	3	22094	3	16835	4	11883
	Egypt	1	5544	2	29449	2	22413	3	15092
	Morocco	4	4297	3	29769	3	22291	4	13832
	Tunisia	1	8564	3	39315	3	33630	3	26606
Western Africa	Cape Verde	4	3474	4	19441	4	13039	4	9172
	Burkina Faso	1	1136	4	9620	4	5725	4	3060
	Niger	1	650	1	5976	4	2867	4	1531
	Senegal	1	1738	4	12404	4	7266	4	3861
Eastern Africa	Djibouti	4	2120	4	15194	4	11932	4	8302
	Eritrea	4	490	4	3049	4	1348	4	697
	Somalia	1	34	1	872	1	266	4	92
Southern Africa	Swaziland	1	4754	2	16478	4	11456	4	7020
Western Asia	Afghanistan	4	1185	3	7526	3	4183	4	2891
	Bahrain	3	21345	3	46425	3	42670	3	31657
	Iran (Islamic Republic of)	4	10954	3	26863	3	24054	3	20180
	Iraq	4	3231	4	14696	4	11113	4	10656
	Israel	3	26710	3	58059	3	53230	3	48597
	Jordan	4	5131	3	25776	3	20353	4	14449
	Kuwait	3	45623	3	93874	3	84044	3	91852
	Lebanon	4	12619	3	41914	3	36289	3	27156
	Oman	3	24559	3	64385	3	47995	3	35392
	Qatar	3	69798	3	115901	3	118003	3	119605
	Saudi Arabia	3	20534	3	44828	3	39642	3	38910
	Syrian Arab Republic	4	4749	3	27961	4	20580	4	14119
	United Arab Emirates	3	42353	3	79488	3	71008	3	66455
	Yemen	4	2373	4	8585	4	6566	4	4280
Southern Asia	India	4	2983	3	23798	3	15883	4	9587
	Pakistan	4	2411	4	12427	4	8475	4	5070
Central Asia	Armenia	4	4901	3	23175	3	16821	4	12612
	Azerbaijan	4	8783	3	17690	4	14131	4	11214
	Uzbekistan	4	2866	3	20839	3	15717	4	10764
Eastern Asia	China	1	6800	3	55893	3	40350	3	29410

[1] in 2010 Algeria is in HE1 in one scenario and in HE4 in two scenarios

Note that these average values in the 2050s are categorized by the World Bank as a low level of income (< 10000 US$2005/cap/year). Furthermore, zero, two and four countries among HE-4 countries are classified as countries with very low level of income (<3000 US$2005/cap/year). For instance in the 2050s in the *Regional Rivalry* scenario Afghanistan, Eritrea, Niger and Somalia still exhibit very low levels of per capita GDP.

For HE4 countries, average per capita GDP will also increase over time but they are still low compared to the global average (Table 4-17). Between 2010 and 2050 per capita GDP in HE4 countries will increase from 3350 US$2005/cap/year (34% of the average global GDP per capita) to 7400-11500 US$2005/cap/year (29-48% of the average GDP per capita) depending on the scenario.

Table 4-17: Information about GDP per capita in HE4

GDP per capita in HE4		2010	2050		
			Sustainability	Middle of the Road	Regional Rivalry
Average GDP per cap.	[US$2005/cap/yr]	4714	11927	9542	7755
Number of countries	low level (<10,000$)	15	3	6	12
	very low level (<3000$)	7	0	2	4

Austria and priority countries of the Austrian Development Agency

With regard to the priority countries of the Austrian Development Agency (ADA), Mozambique, Ethiopia and Uganda will remain in the class HE-1, Albania, Moldova, Georgia and Bhutan will shift into the class HE-2, Armenia will move into HE-3 and Burkina Faso will move into HE-4 in the 2050s under the *Middle of the Road* scenario. Growth in per capita GDP in African countries tends to be smaller than in Asian and European countries (Table 4-15). Countries with lower coping capacity in the classes HE-1 and HE-4 show relatively larger deterioration in terms of hydro-climatic complexity, although every country improves its coping capacity. Burkina Faso moves into HE-4 in all scenarios and Armenia moves into the HE-4 class by 2050 in the *Regional Rivalry* scenario only.

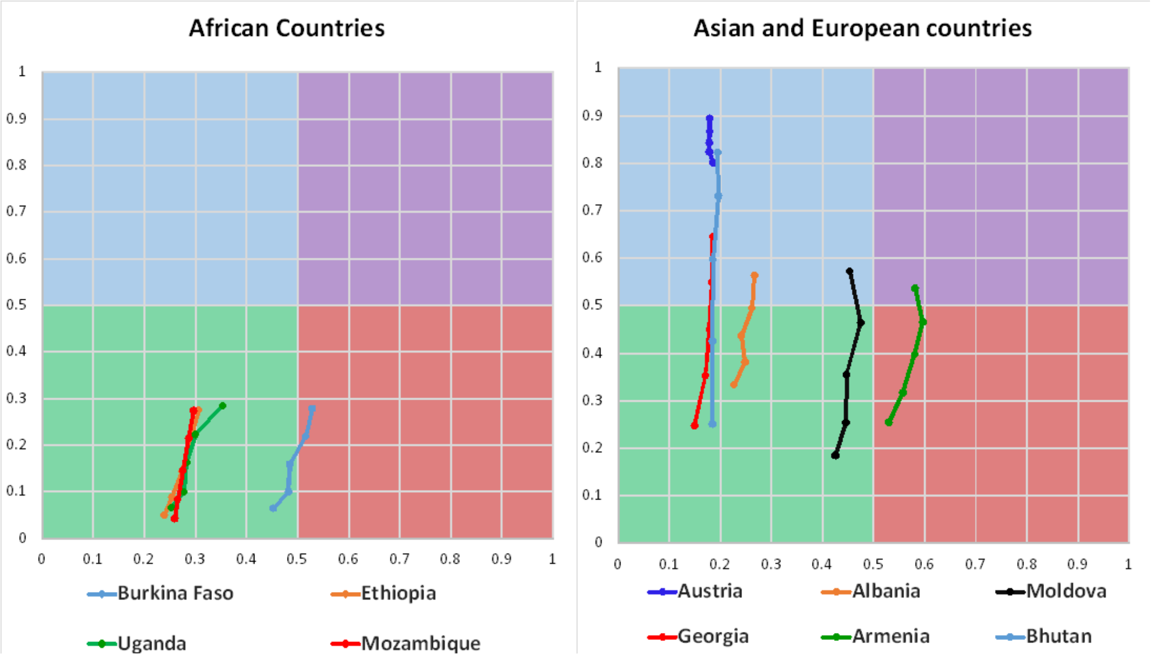

Figure 4-46: Change in Hydro-Economic classes for the priority countries of the Austrian Development Cooperation – *Middle of the Road* scenario

Using the HE classification, we have identified countries who have higher hydro-climate complexity from multiple perspectives in combination with coping capacity. Practical and specific coping methods to overcome hydro-climatic complexity are described in the next section. In the assessment framework presented per capita GDP is used as proxy for coping capacity. Increased levels of internal (own GDP growth) or external funding (donations) could thus help improve the situation. However it must be noted that external financial aid may not always be used efficiently. For example, some countries in the class HE-4 show high values in the Fragile State Index (FSI)[19] (Messner et al. 2015). The FSI annually assesses countries based on 12 variables representing social, economic and political conditions. The higher the value, the more 'fragile' a state. Countries with high FSIs may indicate that central governments could be weak or ineffective in transforming external financial support into improving domestic conditions. In Table 4-16, Somalia, Yemen, Afghanistan, Syria, Iraq, Pakistan and Niger were in the top twenty countries of the FSI in 2015. Thus not only financial support but also improvements in governance and management will be required for tackling urgent water issues in many HE-4 countries.

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[19] http://fsi.fundforpeace.org/

5 Outlook - uncovering water solutions

5.1 Policy responses for coping with growing water scarcity

This section presents an assessment of the outcomes and tradeoffs of the different water policies available to policymakers and some of the policies already used in several countries, based on literature review. However, we do not provide here definitive recommendations on specific policies to address the growing water scarcity. This is the focus of continuing work within the WFaS initiative.

Many countries worldwide face important water scarcity challenges, which will be aggravated in the coming decades, driven by economic and population growth (shown in section 4.1) and climate change impacts (shown in section 4.4). Therefore water allocation of the future will continue to become increasingly more and more 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 demands in a way that ensures water availability in both adequate quantity and quality.

Policymakers possess a wide range of policy instruments to address the multiple future water challenges, but all of these instruments entail financial and social costs. Current evidence suggests that the benefits of many policy options validate their costs. For instance, practitioners of management of disasters, such as droughts and floods indicate that it is typically more cost-effective to invest in disaster risk reduction measures to reduce the impact of a disaster 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 played a key role in sustaining economic growth. (Sadoff et al. 2015). However, as these 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 greenhouse gases emission (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).

Most of the solutions reported in the literature so far include planned measures, which require a deliberate policy decision and investment, on 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 overexploitation). 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 resources management approaches around the world are changing significantly. These changes include a shift away from mainly dependence on finding new sources of supply to address perceived new demands, 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 resources 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 and supply and demand management form the core of the water sector strategy to confront climate change. However, less attention has been devoted to the institutional aspects of water management when designing water policy interventions, although these aspects 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). Water technologies and management capabilities 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 can 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 5-1 and Table 5-2 provide a summary of water policy intervention alternatives to address water scarcity problems including institutional measures based on 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. The next step (Phase 2 of WFaS) is to incorporate the water supply and demand-side measures into comprehensive portfolios of policy recommendations and to quantify their benefits and their trade-offs.

Table 5-1: 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, reduce the risks of extreme events such as droughts and floods, and produce hydropower	Government Development and funding agencies Experts Basin authority Industries Irrigation districts Environmental NGO's	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 mitigate 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 NGO's	X	X	X	X	X	X
Treatment and use of wastewater	Removing pollutants from wastewater and reuse it for different purposes depending on the treatment level	Water utilities Industries Government Environmental NGO's Development and funding agencies Experts	X		X		X	X
Desalination	Removing salts from saline water in order to produce freshwater	Government Development and funding agencies Environmental NGO's 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 NGO's Farmers and irrigation districts Industries Households	X		X		X	X

Table 5-2: Water demand-side 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 rainfed 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 NGO's Government Experts	X	X	X		X	X
Awareness rising	Information, education and communication	Government Environmental NGO's Experts Media Development and funding agencies Civil society	X	X	X	X	X	X

5.2 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 subsequently the outcomes and tradeoffs of some of these 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 (European Commission 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 (European Commission 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 debate since the 1990s. There is a strong consensus among experts that water pricing could achieve sizable gains in efficiency and welfare in urban and industrial water networks (Hanemann 1998). However, a 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). In contrast, (Tsur et al. 2004) indicate that water pricing could achieve an efficient allocation of irrigation water without damaging farmers' benefits, if 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.

Improving water use efficiency has become also 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, improving 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 consumptive 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 has been gaining ground in some parts of the world to allocate water such as in 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 is 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. 2013).

Most developed countries invested heavily in infrastructure such as construction of reservoirs, desalinization 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 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 lack enough water storage capacity such as Ethiopia, Senegal, Rwanda, Haiti, Bangladesh, Nepal, Vietnam, and Albania (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. Drawing on lessons from previous failures to estimate the real costs of these projects could be useful in that regard. Considering more ecosystem-friendly forms of water storage, such as natural wetlands and soil moisture, could be more cost-effective and sustainable than traditional infrastructure such as dams in certain areas (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 settings such as Australia, Israel, United States, the Gulf countries, and some Mediterranean countries. The environmental concerns with 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. Desalination costs have dropped significantly over the past decades due to technological advances (Ghaffour et al. 2013). This has increased the attractiveness of desalination to policymakers as a mean to address water supply shortages in all sectors including agriculture.

Treated municipal wastewater has 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 through reuse of water, there is a challenge of moving water from the source to the end use as the energy cost of pumping water can be excessive.

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 with extraction rates 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.

As a final remark, we suggest that 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. Countries should prioritize between the different policies when outlining possible policy responses. 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. Selected policies should be tailored to the political, institutional, and financial contexts of countries. A successful policy in one setting do 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 aims at identifying a portfolio of workable water solutions that should be considered in policy and investment decisions. This identification will be based on assessing the technical and environmental feasibility of these solutions, quantifying their costs and benefits, testing their robustness, and assessing the trade-offs and synergies among them, under alternative future scenarios based on the Shared Socio-Economic Pathways and the Representative Concentration Pathways. Their appropriateness will always depend on the context within which they are to be applied. Stakeholder consultations can inform decision-makers.

6 Conclusion

The Water Futures and Solutions (WFaS) initiative has produced a consistent and comprehensive projection for global possible water futures. To carry out this assessment, new narratives of water use were established as an extension of the *Shared Socio-economic Pathways*[20], giving three future scenarios; the *Sustainability* Scenario, the *Middle of the Road* Scenario and the *Regional Rivalry* Scenario. Focusing on the near future until the 2050s, WFaS assessed how water future changes over time, employing a multi-model projection with 15 ensemble members (five General Circulation Models x three Global Hydrological Models). The impacts of socioeconomic and climatic changes on water security have been assessed through the development of a hydro-economic classification system that aggregates indicators of hydrological challenges and adaptation capacities.

The assessment indicates that the impact of socioeconomic change on water resources is significant. It is expected that food and energy production will consistently increase in coming decades, driven by population growth and economic development. WFaS projects that water demand in agriculture, industrial and domestic sectors will increase between 20 and 33% in the next decades throughout three future scenarios considered. Industrial and domestic water demand will grow much more rapid than agricultural demand, though agriculture will remain the dominant water demand sector. At continental scale, Asia remains the largest water user in the world in all sectors especially for agricultural water use. Significant rises in total water demand are expected to occur in Western, Eastern and Southern Africa, as well as in Southern and Eastern Asia. At country level, India and China have the largest demand, followed by USA, Pakistan and Russia. Water availability per capita is expected to decrease in a belt around 10° to 40° northern latitude from Morocco to India during the early half of the 21st century under all scenarios considered

Groundwater abstraction covers an important share of water demand. The largest abstractions are in India, USA, China, Iran and Pakistan. They account for 67% of total groundwater abstraction worldwide. In many countries, there are areas where groundwater abstraction has already exceeded recharge, leading to the overexploitation and degradation of important aquifer systems. In the 2050s, groundwater abstraction will increase by 39% compared to current situation. For instance, in 2010 25% of total ground water abstraction in India, China and Pakistan is unsustainable groundwater i.e. the groundwater abstraction is bigger than rate of replenishment.

Finally, this report assesses the imbalance between surface water supply and demand under the different scenarios. Results show that area of the planet which is already under severe water scarcity will further expand in the future. The three scenarios indicate an increase by 40% to 60% of the number of people living in severe water-scarce areas by 2050.

A hydro-economic classification, which categorizes countries based on their hydro-climatic complexity and economic-institutional capacity, was performed. Results of this analysis show that 22 countries are in the water stress categories (rich and poor economies remaining water stressed) in 2010 and 28 to 33 countries will be in the water stress categories in the 2050s, depending on the scenario considered. The consequence is that about 3.6 to 4.6 billion people (43-47% of total population who will produce 41-44% of total GDP) will be under the water stress category. 91 to 96% of the affected population will live in Asia

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[20] Scenarios used by the Intergovernmental Panel on Climate Change (IPCC)

(mainly Southern and Eastern Asia). Our analysis reveals that Somalia, Eritrea, Niger, Burkina Faso, Senegal, Yemen, Afghanistan and Pakistan will be the most vulnerable countries globally, as they will be highly stressed with low adaptive capacity under most of the scenarios.

Results in this report indicate that the next few decades will see an increase in demand for water, food, and energy. At the same time, these resources will be put under growing pressure by complex 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 which applies an integrated approach based on a broader systems perspective highlight that the sustainable management of water, food and energy systems should be conducted 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 socio-economic behavior, as well as climate changes, is crucial for water security; if not water constraints could affect all socio-economic development.

Policymakers 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 water supply by finding new sources of water in space and time, and demand-side measures, which promote water efficiency and conservation. The adoption of best governance practices and well-functioning institutions can contribute to both improved supply and reduced demand. All of these instruments entail financial and social costs that need to be considered when designing future water adaptation strategies to socio-economic and climatic changes. This report presents a review of some of the pathways chosen by different countries around the world to address water scarcity and achieve sustainable water use. These pathways include a careful investment in water infrastructures, an improvement of water use efficiency, the design of effective institutions, and the use of economic instruments for a better allocation of scarce water resources among competing uses.

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

Reference

Arnell, N. W. and B. Lloyd-Hughes (2014). "The global-scale impacts of climate change on water resources and flooding under new climate and socio-economic scenarios." Climatic Change 122(1-2): 127-140.

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

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

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

Brown, C. and U. Lall (2006). "Water and economic development: The role of variability and a framework for resilience." Natural Resources Forum 30(4): 306-317.

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

Chateau, J., R. Dellink, E. Lanzi and B. Magne (2012). "Long-term economic growth and environmental pressure: reference scenarios for future global projections". Conference Paper presented at the 15th Annual Conference on Global Economic Analysis, Geneva, Switzerland.

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

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

Cosgrove, W. J. and D. P. Loucks (2015). "Water management: Current and future challenges and research directions." Water Resources Research 51(6): 4823-4839.

Dankers, R., N. W. Arnell, D. B. Clark, P. D. Falloon, B. M. Fekete, S. N. Gosling, J. Heinke, H. Kim, Y. Masaki, Y. Satoh, T. Stacke, Y. Wada and D. Wisser (2014). "First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble." Proc Natl Acad Sci U S A 111(9): 3257-3261.

Dellink, R., J. Chateau, E. Lanzi and B. Magné (2015). "Long-term economic growth projections in the Shared Socioeconomic Pathways." Global Environmental Change.

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

EEA (2005). The European Environment - State and Outlook 2005. Copenhagen, European Environment Agency.

European Commission (2007). Addressing the challenge of water scarcity and droughts in the European Union. COM(2007) 414 Brussels, Belgium, European Commission.

European Commission (2012). A Blueprint to Safeguard Europe’s Water Resources. Brussels, The European Commission. COM(2012) 673.

Falkenmark, M. (1989). "The massive water scarcity now threatening Africa - why isn't it being addressed?" Ambio 18(2): 112-118.

Field, C. B., V. Barros, T. F. Stocker, Q. Dahe, D. Jon 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: Special report of the intergovernmental panel on climate change, Cambridge University Press.

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

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

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

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

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

Flörke, M., E. Kynast, I. Bärlund, S. Eisner, F. Wimmer and J. Alcamo (2013). "Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study." Global Environmental Change 23(1): 144-156.

Food and Agriculture Organization (FAO) (2010). AQUASTAT online database, Total renewable water resources. T. F. a. A. O. o. t. U. Nations. Rome, Italy.

Food and Agriculture Organization (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.

Frieler, K., M. Meinshausen, M. Mengel, N. Braun and W. Hare (2012). "A scaling approach to probabilistic assessment of regional climate change." Journal of Climate 25(9): 3117-3144.

Ghaffour, N., T. M. Missimer and G. L. Amy (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(5650): 1524-1528.

Grey, D., D. Garrick, D. Blackmore, J. Kelman, M. Muller and C. Sadoff (2013). "Water security in one blue planet: Twenty-first century policy challenges for science." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 371(2002).

Hall, J. W., D. Grey, D. Garrick, F. Fung, C. Brown, S. J. Dadson and C. W. Sadoff (2014). "Coping with the curse of freshwater variability: Institutions, infrastructure, and information for adaptation." Science 346(6208): 429-430.

Hanasaki, N., S. Fujimori, T. Yamamoto, S. Yoshikawa, Y. Masaki, Y. Hijioka, M. Kainuma, Y. Kanamori, T. Masui, K. Takahashi and S. Kanae (2013). "A global water scarcity assessment under Shared Socio-economic Pathways - Part 1: Water use." Hydrology and Earth System Sciences 17(7): 2375-2391.

Hanemann, W. (1998). Determinants of Urban Water Use. In Urban Water Demand Management and Planning. New York, USA, McGraw-Hill.

Howe, C. W., D. R. Schurmeier and W. D. Shaw, Jr. (1986). "Innovative Approaches to Water Allocation: The Potential for Water Markets." Water Resources Research 22(4): 439-445.

Huffaker, R. (2008). "Conservation potential of agricultural water conservation subsidies." Water Resources Research 44(7).

International Energy Agency (IEA) (2012). Water for Energy - Is energy becoming a thirstier resource (Excerpt from the World Energy Outlook 2012). World Energy Outlook 2012. Paris, OECD/IEA: 33.

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

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

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Jones, B. and B. C. O'Neill (2013). "Historically grounded spatial population projections for the continental United States." Environmental Research Letters 8(4).

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

KC, S. and W. Lutz (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., A. S. Holman and M. E. Webber (2008). "Thirst for energy." Nature Geosci 1(5): 283-286.

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

Lehner, B., G. Czisch and S. Vassolo (2005). "The impact of global change on the hydropower potential of Europe: A model-based analysis." Energy Policy 33(7): 839-855.

Lehner, B., C. R. Liermann, C. Revenga, C. Vörömsmarty, B. Fekete, P. Crouzet, P. Döll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J. C. Robertson, R. Rödel, N. Sindorf and D. Wisser (2011). "High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management." Frontiers in Ecology and the Environment 9(9): 494-502.

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

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

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

Mekonnen, M. M., P. W. Gerbens-Leenes and A. Y. Hoekstra (2015). "The consumptive water footprint of electricity and heat: a global assessment." Environmental Science: Water Research & Technology 1(3): 285-297.

Messner, J. J., N. Haken, P. Taft, H. Blyth, K. Lawrence, S. Pavlou and F. Umaña (2015). Fragile States Index 2015. T. F. f. Peace. Washington, D.C., USA.

Moss, R. H., J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. Van Vuuren, T. R. Carter, S. Emori, M. Kainuma, T. Kram, G. A. Meehl, J. F. B. Mitchell, N. Nakicenovic, K. Riahi, S. J. Smith, R. J. Stouffer, A. M. Thomson, J. P. Weyant and T. J. Wilbanks (2010). "The next generation of scenarios for climate change research and assessment." Nature 463(7282): 747-756.

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

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

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

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

Pound, D., K. Hardcastle, P. Magnuszewski, P. T. Yillia and E. Hizsnyik (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. Laxenburg, Austria, International Institute for Applied Systems Analysis.

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

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

Richey, A. S., B. F. Thomas, M. H. Lo, J. T. Reager, J. S. Famiglietti, K. Voss, S. Swenson and M. Rodell (2015). "Quantifying renewable groundwater stress with GRACE." Water Resources Research 51(7): 5217-5237.

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

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

Schewe, J., J. Heinke, D. Gerten, I. Haddeland, N. W. Arnell, D. B. Clark, R. Dankers, S. Eisner, B. M. Fekete, F. J. Colón-González, S. N. Gosling, H. Kim, X. Liu, Y. Masaki, F. T. Portmann, Y. Satoh, T. Stacke, Q. Tang, Y. Wada, D. Wisser, T. Albrecht, K. Frieler, F. Piontek, L. Warszawski and P. Kabat (2014). "Multimodel assessment of water scarcity under climate change." Proceedings of the National Academy of Sciences of the United States of America 111(9): 3245-3250.

Schmied, H. M., S. Eisner, D. Franz, M. Wattenbach, F. T. Portmann, M. Flörke and P. Döll (2014). "Sensitivity of simulated global-scale freshwater fluxes and storages to input data, hydrological model structure, human water use and calibration." Hydrology and Earth System Sciences 18(9): 3511-3538.

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

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

Siebert, S., J. Burke, J. M. Faures, K. Frenken, J. Hoogeveen, P. Döll and F. T. Portmann (2010). "Groundwater use for irrigation - A global inventory." Hydrology and Earth System Sciences 14(10): 1863-1880.

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

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

Tsur, Y., A. Dinar, R. M. Doukkali and T. Roe (2004). "Irrigation water pricing: Policy implications based on international comparison." Environment and Development Economics 9(6): 735-755.

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

Van Beek, L. P. H., Y. Wada and M. F. P. Bierkens (2011). "Global monthly water stress: 1. Water balance and water availability." Water Resources Research 47(7).

van Vliet, M., D. Wiberg, S. Leduc and K. Riahi (2016). "Power-generation system vulnerability and adaptation to changes in climate and water resources." Nature Climate Change.

Van Vliet, M. T. H., S. Vögele and D. Rübbelke (2013). "Water constraints on European power supply under climate change: Impacts on electricity prices." Environmental Research Letters 8(3).

Van Vliet, M. T. H., J. R. Yearsley, F. Ludwig, S. Vögele, D. P. Lettenmaier and P. Kabat (2012). "Vulnerability of US and European electricity supply to climate change." Nature Climate Change 2(9): 676-681.

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

van Vuuren, D. P., E. Kriegler, B. C. O'Neill, K. L. Ebi, K. Riahi, T. R. Carter, J. Edmonds, S. Hallegatte, T. Kram, R. Mathur and H. Winkler (2014). "A new scenario framework for Climate Change Research: Scenario matrix architecture." Climatic Change 122(3): 373-386.

Veldkamp, T. I. E., Y. Wada, J. C. J. H. Aerts and P. J. Ward (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., P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. R. Liermann and P. M. Davies (2010). "Global threats to human water security and river biodiversity." Nature 467(7315): 555-561.

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

Wada, Y., D. Wisser and M. F. P. Bierkens (2014). "Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources." Earth System Dynamics 5(1): 15-40.

Ward, F. A. (2012). "Cost-benefit and water resources policy: A survey." Water Policy 14(2): 250-280.

Ward, F. A. and M. Pulido-Velazquez (2008). "Water conservation in irrigation can increase water use." Proceedings of the National Academy of Sciences of the United States of America 105(47): 18215-18220.

Warszawski, L., K. Frieler, V. Huber, F. Piontek, O. Serdeczny and J. Schewe (2014). "The inter-sectoral impact model intercomparison project (ISI-MIP): Project framework." Proceedings of the National Academy of Sciences of the United States of America 111(9): 3228-3232.

WFaS, W. F. a. S. (2013). Project Group Meeting - 30th Sep – 2nd Oct 2013. Laxenburg, Austria, International Institute for Applied Systems Analysis (IIASA).

Wheeler, S., A. Loch, A. Zuo and H. Bjornlund (2013). "Reviewing the adoption and impact of water markets in the Murray-Darling Basin, Australia." Journal of Hydrology 518(PA): 28-41.

Winsemius, H. C., J. C. J. H. Aerts, L. P. H. van Beek, M. F. P. Bierkens, A. Bouwman, B. Jongman, J. C. J. Kwadijk, W. Ligtvoet, P. L. Lucas, D. P. van Vuuren and P. J. Ward (2015). "Global drivers of future river flood risk." Nature Clim. Change advance online publication.

World Economic Forum, G. R., 10th Edition (2015). Global Risks 2015, 10th Edition. Geneva, Switzerland, World Economic Forum.

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

WWAP (2015). The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO.

Appendix

Appendix A: SSP Storylines

The SSP storylines served as the starting point for the development of the quantitative SSP elements. Each storyline provides a brief narrative of the main characteristics of the future development path of an SSP. The storylines were identified at the joint IAV and IAM workshop in Boulder, November 2011. A brief summary of the storylines are provided here for comprehensiveness. For further details and extended descriptions of the storylines, see O'Neill et al. (2012).

SSP1 - Sustainability:

This is a world making relatively good progress towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency. Elements that contribute to this are a rapid development of low-income countries, a reduction of inequality (globally and within economies), rapid technology development, and a high level of awareness regarding environmental degradation. Rapid economic growth in low-income countries reduces the number of people below the poverty line. The world is characterized by an open, globalized economy, with relatively rapid technological change directed toward environmentally friendly processes, including clean energy technologies and yield-enhancing technologies for land. Consumption is oriented towards low material growth and energy intensity, with a relatively low level of consumption of animal products. Investments in high levels of education coincide with low population growth. Concurrently, governance and institutions facilitate achieving development goals and problem solving. The Millennium Development Goals are achieved within the next decade or two, resulting in educated populations with access to safe water, improved sanitation and medical care. Other factors that reduce vulnerability to climate and other global changes include, for example, the successful implementation of stringent policies to control air pollutants and rapid shifts toward universal access to clean and modern energy in the developing world.

SSP 2 - Middle of the Road (or Dynamics as Usual, or Current Trends Continue, or Continuation):

In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals is delayed by several decades, leaving populations without access to safe water, improved sanitation, medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

SSP 3 - Fragmentation (or Fragmented World):

The world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity, fossil fuel dependency, or addressing local environmental concerns such as air pollution. Countries focus on achieving energy and food security goals within their own region. The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Little international cooperation and low investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high as a result of the education and economic trends. Growth in urban areas in low-income countries is often in unplanned settlements. Unmitigated emissions are relatively high, driven by high population growth, use of local energy resources and slow technological change in the energy sector. Governance and institutions show weakness and a lack of cooperation and consensus; effective leadership and capacities for problem solving are lacking. Investments in human capital are low and inequality is high. A regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity. Policies are oriented towards security, including barriers to trade

Appendix B-1: WFaS water storylines and implications for industrial water use

SSP1: Sustainability – Taking the green road

Elements of the SSP storyline relevant for the ELECTRICITY 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 alternative energy technologies.

Implications for electricity water use intensity

- Reduction in energy demand will decrease the demand for water from the energy sector substantially even if world population, primary energy production, and electricity generation were to increase.
- A shift away from traditional biomass toward less consumptive energy carriers, as well as the 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 towards 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 & 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 as well.

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 & Technology development reduce the challenges of access to safe water.
- Risk reduction & 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 ELECTRICITY 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, though 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 economics.

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 towards material-growth.
- Technological progress but no major breakthrough.
- Persistent income inequality (globally & within economies)
- Implications for manufacturing water use.
- Manufacturing GVA further declines in relative terms.
- Moderate & regionally different decreases of 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 economics.
- 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 ELECTRICITY sector

- Growing resource intensity and fossil fuel dependency.
- Focus on achieving energy and food security goals within their own region.
- Barriers to trade, particularly in the energy resource and agricultural markets.
- Use of domestic energy results in some regions increase 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 where as 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 & within economies).
- Weak institutions & global governance.

Implications for manufacturing water use

- Manufacturing GVA in relative terms (% of GDP) declines slower 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 B-2: 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 drives 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 for addressing 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 towards material growth, with growing consumption of animal products.
- Conflicts over environmental resources flare where and when 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 trigger slow water security and progress in water use efficiencies.
- Global and national institutions lack of cooperation and collaboration make slow progress in achieving sustainable development goals.
- Growing population and intensity of resource leads to environmental systems degradation.
- Lower education investments do not promote slow population growth.
- Access to health care, safe water, and sanitation services are affected by population growth and heterogeneities within countries.
- Conflicts over natural resources access and corruption trigger the effectiveness of development policies.

SSP3: Regional Rivalry – A rocky road

Elements of the SSP storyline relevant for the DOMESTIC sector

- Societies are becoming more skeptical about globalization.
- Countries show a weak progress in achieving sustainable development goals.
- Environmental policies have a very little importance. Serious degradation of the environment becomes more important.
- Cooperation among organizations and institutions is weak. Their leadership is highly questionable.
- Low investments in education and in technology increases 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 water resources access and sanitation services.
- Consumption is primarily material-intensive and water use important.

- A move towards sustainable development goals will lead to authoritarian forms of government and, consequently to a rise in social water awareness.
- Water security and environmental systems health is trigger by high levels of water consumption and limited development on human capital.
- National rivalries between the countries in a certain region weak progress toward development goals and increases competition for natural resources.

Appendix B-3: 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 to have 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 with lower per capita consumption of livestock products.
- Enforced limits to groundwater over-exploitation.
- Large improvements of 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 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 towards 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 enter 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 of 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 of water use efficiency, but only limited advances in low-income countries.
- Some reduction of 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 the 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 rain-forests.
- 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 C: Hydro Economic classification by subregions and countries

Hydro-economic class		Sustainability					Middle of the Road					Regional Rivalry				
		2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Northern Africa	Algeria	1	4	4	3	3	4	4	4	4	3	4	4	4	4	4
	Egypt	1	1	1	2	2	1	1	1	2	2	1	1	1	4	3
	Morocco	4	4	4	3	3	4	4	4	3	3	4	4	4	4	4
	Tunisia	1	1	3	3	3	1	4	3	3	3	1	4	3	3	3
Western Africa	Benin	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Burkina Faso	1	1	1	4	4	1	1	1	4	4	1	1	1	4	4
	Cape Verde	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4
	Cote d'Ivoire	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
	Gambia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Ghana	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Guinea	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Guinea-Bissau	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Liberia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mali	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mauritania	1	1	1	1	1	1	1	1	1	1	1	1	1	4	1
	Niger	1	1	1	1	1	1	1	1	4	4	1	1	1	4	4
	Nigeria	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Senegal	1	1	1	1	4	1	1	1	4	4	1	1	4	4	4
	Sierra Leone	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Togo	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Middle Africa	Angola	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Cameroon	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Central African Republic	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Chad	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Congo	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Democratic Republic of the Congo	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Equatorial Guinea	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Gabon	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Sao Tome and Principe	1	1	1	2	2	1	1	1	2	2	1	1	1	1	1
Eastern Africa	Burundi	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Comoros	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Djibouti	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4
	Eritrea	1	1	1	1	1	1	1	1	1	4	1	1	1	1	4
	Ethiopia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Kenya	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Madagascar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Malawi	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mauritius	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Mozambique	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Rwanda	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Somalia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4
	Sudan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Uganda	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	United Republic of Tanzania	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Zambia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Zimbabwe	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Southern Africa	Botswana	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Lesotho	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Namibia	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	South Africa	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	Swaziland	1	1	1	1	2	1	1	1	1	4	1	1	1	1	4

Hydro-economic class		Sustainability					Middle of the Road					Regional Rivalry				
		2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Western Asia	Afghanistan	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Bahrain	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Iran (Islamic Republic of)	4	4	3	3	3	4	4	3	3	3	4	4	4	3	3
	Iraq	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Israel	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Jordan	4	4	4	3	3	4	4	4	4	3	4	4	4	4	4
	Kuwait	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Lebanon	4	3	3	3	3	4	3	3	3	3	4	3	3	3	3
	Oman	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Qatar	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Saudi Arabia	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Syrian Arab Republic	4	4	4	3	3	4	4	4	4	3	4	4	4	4	4
	Turkey	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	United Arab Emirates	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Yemen	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Southern Asia	Bangladesh	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Bhutan	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	India	4	4	4	3	3	4	4	4	4	3	4	4	4	4	4
	Maldives	1	1	1	2	2	1	1	1	2	2	1	1	1	1	2
	Nepal	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Pakistan	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Sri Lanka	1	1	1	2	2	1	1	1	2	2	1	1	1	1	2
	Armenia	4	4	4	3	3	4	4	4	4	3	4	4	4	4	4
	Azerbaijan	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4
	Georgia	1	1	1	2	2	1	1	1	2	2	1	1	1	1	2
	Kazakhstan	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Kyrgyzstan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Tajikistan	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Turkmenistan	1	2	2	2	2	1	2	2	2	2	1	1	2	2	2
	Uzbekistan	4	4	4	4	3	4	4	4	4	3	4	4	4	4	4
Eastern Asia	China	1	1	3	2	3	1	1	3	3	3	1	1	3	3	3
	Japan	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mongolia	1	1	2	2	2	1	1	2	2	2	1	1	1	2	2
	Republic of Korea	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
South-Eastern Asia	Brunei Darussalam	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Cambodia	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Indonesia	1	1	1	2	2	1	1	1	2	2	1	1	1	1	1
	Lao People's Democratic Republic	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Malaysia	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Myanmar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Philippines	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Singapore	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Thailand	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	Timor-Leste	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Viet Nam	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1

Hydro-economic class		Sustainability					Middle of the Road					Regional Rivalry				
		2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Northern America	Canada	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	United States of America	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Central America	Belize	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Costa Rica	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	El Salvador	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Guatemala	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Mexico	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Nicaragua	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Panama	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
Caribbean	Bahamas	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Barbados	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Cuba	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Dominican Republic	1	1	2	2	2	1	1	2	2	2	1	1	1	2	2
	Haiti	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Jamaica	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Puerto Rico	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Saint Lucia	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Saint Vincent and the Grenadines	1	1	2	2	2	1	1	1	2	2	1	1	1	1	2
	Trinidad and Tobago	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
South America	Argentina	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Bolivia	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Brazil	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	Chile	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Colombia	1	1	2	2	2	1	1	1	2	2	1	1	1	1	2
	Ecuador	1	1	1	2	2	1	1	1	2	2	1	1	1	1	1
	Guyana	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Paraguay	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Peru	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	Suriname	1	1	2	2	2	1	1	1	2	2	1	1	1	2	2
	Uruguay	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Venezuela	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2

Hydro-economic class		Sustainability					Middle of the Road					Regional Rivalry				
		2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Western Europe	Albania	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Bosnia and Herzegovina	1	1	2	2	2	1	1	1	2	2	1	1	1	2	2
	Croatia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Cyprus	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Greece	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Italy	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Montenegro	1	1	2	2	2	1	1	2	2	2	1	1	1	2	2
	Portugal	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Serbia	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
	Slovenia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Spain	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	The former Yugoslav Republic of Macedonia	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
Southern Europe	Austria	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Belgium	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	France	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Germany	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Luxembourg	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Malta	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Netherlands	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Switzerland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Northern Europe	Denmark	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Estonia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Finland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Iceland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Ireland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Latvia	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Lithuania	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Norway	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Sweden	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	U.K. of Great Britain and Northern Ireland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Eastern Europe	Belarus	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Bulgaria	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Czech Republic	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Hungary	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Poland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Romania	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
	Russian Federation	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
	Slovakia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Ukraine	1	1	2	2	2	1	1	1	2	2	1	1	1	2	2
	Moldova Republic of	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
Oceania	Australia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Fiji	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	French Polynesia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	New Caledonia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	New Zealand	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Papua New Guinea	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Samoa	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Solomon Islands	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Tonga	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	Vanuatu	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1

Appendix D: Additional results for all scenarios

Continent, subregional, country level

Content of the supplement Excel file

Level	Name of the Excel-sheet	Description	Unit	Scenario
	CountryList	List of countries		
Hydro-Economic classification	HE-Summary	Classification HE1-HE4 for each country for each scenario	HE-class	All
	SummaryADA.NC	Number of countries in each HE-Class	-	All
	SummaryADA.POP	Population in each HE-Class	Million of people	Middle of the Road
	SummaryADA.GDPpc	GDP (PPP) and GDP(PPP) per capita in each HE-class	Billion US$2005/yr & US$2005/yr/cap	Regional Rivalry
Population & GDP	POP.ssp1	Population	Number of capita	Sustainability
	POP.ssp2	Population	Number of capita	Middle of the Road
	POP.ssp3	Population	Number of capita	Regional Rivalry
	GDP ssp1	GDP (PPP)	Billion US$2005/year	Sustainability
	GDP ssp2	GDP (PPP)	Billion US$2005/year	Middle of the Road
	GDP ssp3	GDP (PPP)	Billion US$2005/year	Regional Rivalry
	GDPpc.ssp1	GDP (PPP) per capita	US$2005/year/cap	Sustainability
	GDPpc.ssp2	GDP (PPP) per capita	US$2005/year/cap	Middle of the Road
	GDPpc.ssp3	GDP (PPP) per capita	US$2005/year/cap	Regional Rivalry
Area	Area	Area	km2	
Water Supply	TotASWR.rcp4p5	Total Available Surface Water Resouces	m3/year	Sustainability
	TotASWR.rcp6p0	Total Available Surface Water Resouces	m3/year	Middle of the Road & Regional Rivalry
	TotASWRpc.ssp1	Total Available Surface Water Resouces per cap	m3/year/cap	Sustainability
	TotASWRpc.ssp2	Total Available Surface Water Resouces per cap	m3/year/cap	Middle of the Road
	TotASWRpc.ssp3	Total Available Surface Water Resouces per cap	m3/year/cap	Regional Rivalry
Water demand	TotDem.ssp1.rcp4p5	Total Water Demand	km3/year	Sustainability
	TotDem.ssp2.rcp6p0	Total Water Demand	km3/year	Middle of the Road
	TotDem.ssp3.rcp6p0	Total Water Demand	km3/year	Regional Rivalry
	AgrDem.rcp4p5	Agricultural water demand	km3/year	Sustainability
	AgrDem.rcp6p0	Agricultural water demand	km3/year	Middle of the Road & Regional Rivalry
	IndDem.ssp1	Industrial Water Demand	km3/year	Sustainability
	IndDem.ssp2	Industrial Water Demand	km3/year	Middle of the Road
	IndDem.ssp3	Industrial Water Demand	km3/year	Regional Rivalry
	DomDem.ssp1	Domestic Water Demand	km3/year	Sustainability
	DomDem.ssp2	Domestic Water Demand	km3/year	Middle of the Road
	DomDem.ssp3	Domestic Water Demand	km3/year	Regional Rivalry

WATER FUTURES AND SOLUTIONS

The Water Futures and Solutions Initiative (WFaS) is a cross-sector, collaborative global project. Its objective is to developing scientific evidence and applying systems analysis to help identify water-related policies and management practices that work together consistently across scales and sectors to improve human well-being through 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, examines possible futures and tests the feasibility, sustainability and robustness of options that can be implemented today and can be sustainable and robust across a range of possible futures and associated uncertainties we face.

The Water Futures and Solutions (WFaS) initiative has produced a consistent and comprehensive projection for global possible water futures. Focusing on the near future until the 2050s, WFaS assessed how water future changes over time, employing a multi-model projection.

The impacts of socioeconomic and climatic changes on water security have been assessed through the development of a hydro-economic classification system that aggregates indicators of hydrological challenges and adaptation capacities.

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