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Integrated Solutions for Water, Energy and Land

Progress report 2

Period (1 November 2016- 31 October 2017)

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1. Background

This report summarizes the progress achieved by year one in the Integrated Solutions for Water, Energy and Land project (ISWEL), following the contractual obligations the International Institute for Applied Systems Analysis (IIASA) has agreed with the Global Environment Facility through the implementing agency United Nations Industrial Development Organization (UNIDO).

The report is structured as follow. The Executive Summary in Section 2 briefly describes the purpose of the project, the process developed to achieve the main outcomes and highlights the main milestones and outputs accomplished by Month 12 of the project lifetime. A description of how outputs relate to the different project components and any possible deviation with respect to the original plan are outlined here. Section 3 "Progress by Component" describes the technical details of the activities that have been developed and the next steps planned to achieve the different outcomes and deliver all agreed project outputs. Next steps are also being described in Section 3 under each of the different ongoing activities.

2. Executive Summary

What will ISWEL deliver?

The main goal of ISWEL is to provide portfolios of cost-effective solutions and investment strategies to jointly meet future water, energy and land demands under different and contrasting climate and socio-economic pathways, whilst acknowledging regional constraints and opportunities. The project takes a global approach, with focus on two transboundary basins facing multiple development and environmental challenges: The Indus river basin in South Asia and the Zambezi river basin in Southern Africa.

At the global level, this assessment is developing an integrated view of risks and opportunities in the medium to long run to meet key social, economic and environmental targets linked to water, energy and land, by identifying which hotspots of the globe will require most attention. For the first time, exposure of the most vulnerable populations to multi-sector risks and challenges are being taken into account using novel datasets developed within the project.

Within the basins, the project seeks to co-develop with regional stakeholders a common understanding of how different development pathways may unfold and what solutions exist to jointly meet regional water-, energy- and land-related development goals. Building capacities around nexus research and management is a key feature of this project. Together this dual track approach will help formulate a framework for wider use in considering the synergies and trade-offs in reaching food, water and energy security.

How is ISWEL being framed?

Building on the scientific and technical capacities of IIASA, the next-generation of tools is now in development and are being linked together into a systems analysis framework (SAF), in order to answer major questions on the water-energy-land nexus. This fully integrated assessment framework is representing and connecting the biophysics and economics of water, energy and land systems. The four models that integrate the SAF are: The Hydrological Community Water Water Model (CWatM), the Hydro- economic model (ECHO), the energy-economic model MESSAGE and the agro-economic model GLOBIOM. The models describing the water system (CWatM and ECHO) are being developed from new within this project. MESSAGE and GLOBIOM are being upgraded to improve the representation of sectorial interlinkages and to enhance their spatial resolution. At the global scale, this novel and innovative framework will be scalable (i.e. applicable at multiple scales), flexible (i.e. capable of answering multiple questions), and transferable (i.e. applicable to different locations) (outcome 1.2, Table 1).

For the global assessment, high-resolution hydroclimate (temperature, precipitation and runoff) and socio-economic (population, GDP, income and inequality) datasets have been post-processed and/or developed to capture and represent how changes in these mega-trends will develop through the 21st Century. These future projections use the Shared Socioeconomic Pathways (SSPs) and the Representative Concentrations Pathways (RCPs) developed by the International Panel on Climate Change (IPCC). These pathways describe very contrasting narratives of alternative development options and are widely used by the scientific community, which will ensure that the project outcomes are comparable.

The spatially-explicit mega-trend projections are being used as inputs into the SAF for exploring the biophysical (e.g. land productivity), hydro-climate (e.g. water availability, and variability) and resource demand impacts across the globe. The mega-trends are examined in a multi-dimensional approach that maps where multi-sectorial hotspots may emerge in the future according to different levels of global mean temperature change (e.g. 1.5°, 2° or 3°) and different socioeconomic scenarios (outcome 2.2, Table 1). Hotspots in the context of

ISWEL are broadly understood as those parts of the world where multiple, moderate climate-related impacts on water, energy and land sectors overlap. The assessment is particularly novel in two aspects: firstly, the quality and number of impact indicators used in a framework incorporating multiple climate and socioeconomic scenarios; secondly, the hotspots use the new socio-economic projections of income distribution and inequality, to estimate for the first time, global population exposure and vulnerability to multi-sectoral risks. This first diagnostic assessment in a second stage is going to be used as the basis for exploring specific interventions, which can deliver a portfolio of synergistic solutions and policy/investment recommendations tailored to the regional context where they need to be implemented (outcome 2.2, Table 1).

In the basins, early engagement with local stakeholders has been crucial to frame regional challenges, priorities and possible solutions with regards to the water, energy and land. Engagement is and will continue to enrich the value of the research as it provides an opportunity for exchanging knowledge, building partnerships and joint capacities around nexus management and research (outcome 3.1 and 3.2, Table 1). Also, and very importantly it will support the uptake of project outcomes. The strategy developed within the ISWEL project has been to liaise with regional organizations that are well connected on the ground and with ongoing processes related to nexus-related activities. In the Zambezi, partnerships have been established with Zambezi Water Course Commission (ZAMCOM), Global Water Partnership (GWP), Southern African Development Community (SADC) and the New Partnerships for African Development (NEPAD). In the Indus, alliances are now being established with the Center for Water Informatics and Technology from Lahore University for Management Sciences (WIT-LUMS), the International Water Management Institute (IWMI), International Center for Integrated Mountain Development (ICIMOD), and the World Bank, these latter three coming together under the Indus Basin Partnership.

Having established these entry points, the ISWEL team has mapped a number of stakeholders in each basin that will join the three further planned workshops in each basin. The goal of these meetings is: 1) building of partnerships and identifying basin needs (meeting 1); 2) co-development of regional development scenarios using as a starting point the narratives provided by the SSPs and RCPs from the IPCC (meeting 2)(outcome 1.1, Table 1); 3) validation of results and discussion on their uptake by stakeholders (meeting 3); and 4) building of capacities for nexus management and research to support the development of knowledge networks around the nexus (back-to-back with meetings 2 and 3) (outcome 3.2, Table 1).

Meeting one in Zambezi took place in September 2017, and for Indus is being discussed and planned with partners for the first trimester of 2018. The exploration of solutions and tangible strategies within the basins will start with the second meeting (outcome 2.1, Table 1), once the development and/or upgrades of the sectorial models and integration with the SAF is complete (outcome 1.2, Table 1). The second meeting in Zambezi is planned for April 2018 (Month 17) and in the Indus for June 2018 (Month 20). The third meeting with the presentation and validation of the results will occur in the first semester of 2019. It should be noted that these interactions and timelines are fluid and dictated, in part, by the capacities and priorities of partners in the regions to respond and interact with the ISWEL team.

One important outcome of the ISWEL project is the dissemination of knowledge in different Forums (academia, high level panels, etc.) and formats (scientific publications, policy briefs, online). Since the project inception, the ISWEL team has participated in multiple meetings and conferences. These together with a number of publications in high impact peer review research papers have initiated dissemination of the work to a range of audiences (outcome 3.3, Table1).

To ensure the scientific rigor a Project Steering Committee (PSC) was appointed at the start of the project. The PSC meets once a year to discuss the progress and provide recommendations and support to progress towards the outcomes and outputs (outcome 4.1). The first meeting with the PSC took place in June 2017 at IIASA and substantial and very useful recommendations were provided to improve the coherence and impact of the project, which have been accounted for and addressed in the following stages of the project.

Overall progress and deviations with respect to the work plan

The project is developing well and making good progress. Overall the work is in line with the work plan of the proposal and updates discussed in February 2017 (see Table 1 and Annex I). Successful completion of the stakeholder engagement component will require effort beyond what was outlined in the initial project plans. This is due to a combination of factors but most importantly the requirement for a meaningful engagement to try and ensure ownership and uptake by regional organisations through the evolution of the work and utility beyond the project which forms part of an existing process. The detail of the outputs against the components are detailed in Table 1.

What have been the most important outputs/milestones for the period?

1. Two new sectorial models have been developed over the course of year 1: The Hydrological Community Water Model (CWatM) and the Hydro- economic model (ECHO) (milestones linked to output 1.2.1).

2. Upgrades to the agro-economic model GLOBIOM include better representation the sectorial linkages with water and the environment and two new modules that translate land use change projections into impacts on terrestrial biodiversity and nitrogen flows from cropland. New datasets have been collected and processed to improve the representation of land cover within the case study basins. (milestones linked to output 1.2.1).

3. Upgrades to the MESSAGE energy-economic model include, new representation at the basin level and coupling to the ECHO hydro-economic model; improved representation of infrastructure, water demands and return flows from the energy sector and inclusion of energy demands from the water sector with linkage to SDG6. (milestone linked to output 1.2.1).

4. In terms of datasets, the ISWEL team has generated spatially explicit projections of indicators of water, energy, and land impacts that are combined with new, high-resolution projections of income and inequality to provide a multi-dimensional assessment of hotspots and nexus solutions at global and regional scales (milestones linked to output 1.1.1 and 2.1.1).

    - Water: a) spatially explicit maps of current and future water scarcity, variability, drought, and flooding under different socio-economic and climate change scenarios, and b) observation based groundwater pumping and associated non sustainable groundwater abstraction under current and future climate (milestones linked to output 1.1.1).

    - Energy: a) the first global spatial projections of clean cooking fuel access for the SSPs, b) projected changes in cooling degree day demands and frequency of heat events, c) global assessment of hydroclimate risk to a dataset of 50,000+ thermal and hydro power plants using 4 hydrological indicators (milestones linked to output 1.1.1).

    - Land: a) spatially explicit maps of current yield, fertilizer and irrigation water needs, and nitrogen flows for 19 crops[1] and 15 management intensities under current climate, and b) downscaled projections of future land cover and land use at 5 arcmin spatial resolution and c)

[1] Barley, bean, cassava, chickpea, cotton, field pea, ground nuts, maize, millet, potatoes, rape, rice, rye, sugar beet, sugarcane, sunflower, sorghum soya and wheat

projections of future exploitation of water for the environment due to irrigated crop production under current and future climate (milestones linked to output 1.1.1).

5. A protocol developed for coupling the four sectorial models and building the multiscale Integrated Assessment Framework for nexus assessment (milestone linked to output 1.2.1)

6. The development of explorative SSP-based scenarios for the two basins, as a starting point for the discussion with stakeholders in the scenario workshops (milestones linked to output 1.1.1)

7. A multidimensional assessment of desalination technologies as the first of a range of relevant technological solutions with tradeoffs and opportunities for the WEL nexus. The assessment includes the spatial and temporal industrial and unit scaling dynamics, cost dynamics and future projections and technology specific water-energy-land nexus indicators. This will enable a deeper understanding of the solutions to be considered and the use of processed and first quality data in the modelling exercises (milestone linked to output 2.1.1)

8. Assessment of exposure and vulnerability to multi-sectoral hotpots under different climate and socioeconomic scenarios (milestone linked to output 2.2.1)

9. Undertaken a first consultation in the Zambezi held between 23-29 September in Lusaka. This meeting has been extremely important to continue building partnerships with our main partner ZAMCOM but also build new alliances with regional organizations involved in nexus processes and dialogues (milestone related to output 3.1.1). This first meeting identified the stakeholders main priorities in the basin and riparian countries in regards to cross-sectorial and trans-boundary cooperation and thus, to help shape the regional assessment.

10. A partnership established with Water Informatics and Technology from Lahore University for Management Sciences (WIT-LUMS) to co-organize the first meeting with Pakistan organizations. Alliance with the International Water Management Institute (IWMI), International Center for Integrated Mountain Development (ICIMOD), and the World Bank in order to co-organize the Indus scenario workshop as a co-operation under the Indus Basin Partnership (milestone related to output 3.1.1).

11. A first analysis of stakeholders representing all four sector (water, energy, land, and the environment) and riparian countries from Indus. This stakeholder mapping exercise has been developed in collaboration with local partners to ensure a good representation.

12. Extensive dissemination of the grant opportunities currently available at IIASA through the Young Summer Student Program (YSSP) to support at least 1 PhD student from each basin to visit IIASA between June-September 2018 to conduct a three-month research project in the context of ISWEL. Active search of candidates and two good candidates approached (one per basin).

13. Participation in 20 scientific conferences and 5 high level panels. 12 peer-review papers prepared (4 submitted to high-impact peer review journals and 8 in progress)

Table 1. Targets, outputs in year one, and deviations with respect to original plan. Note: Details on the specific progress and outputs are provided in Section 3.

Component 1. Development of a systems analysis framework for assessing solutions to nexus challenges					
Outcome 1.1. Development of scenarios describing uncertainties in future trends and drivers					
	Indicators	**Timeline**	**Targets (as described in the proposal**	**Key outputs/milestones for the period:**	**Deviations with respect to initial planning**
Output 1.1.1 Stakeholder-informed scenario co-design for capturing uncertainties in future trends and drivers	Number of stakeholder-informed regional change pathways Number of stakeholder informed 'solution' and 'policy' scenarios Number of stakeholder consultations	Month 1-14	At least two stakeholder-informed regional change pathways per case study At least eight stakeholder informed 'solution' and 'policy' scenarios One stakeholder consultation in each case study	System boundaries defined (i.e. spatial and temporal units of analysis) Downscaled spatially explicit (urban and rural) global population and GDP datasets (0.5 degrees) for all five SSPs scenarios. Downscaled spatially explicit land use projections (0.5 degrees) for all five SSPs scenarios	Yes. Output 1.1.1 was initially planned to be delivered in Month 14. Scenario Workshops in the two basins have been postponed to Month 18 (Zambezi) and Month 20 (Indus). Output 1.1.1 for the two basins are expected to be ready by Month 25
Outcome 1.2 Method and tool development					
	Indicators	**Timeline**	**Targets (as described in the proposal):**	**Key outputs/milestones for the period:**	**Deviations with respect to initial planning**
Output 1.2.1 Nexus modeling tool developed and presented with preliminary results: Tool will illuminate trade-offs among sectors and explore solutions for	Nexus modeling tool developed (yes/no) Number of presentations of nexus modelling tool and preliminary results	Month 1-33	A completed nexus modelling tool Two presentations of the nexus modelling tool and preliminary assumptions and results (one in each region)	Hydrological CWATM model calibrated at the global level and for Zambezi Protocol established for connecting hydro-economic model ECHO and CWATM Energy MESSAGE model upgraded to represent	NO

achieving multiple development and environmental objectives				energy infrastructure and demands at basin level ECHO and Energy MESSAGE models coupled at basin scale Improved representation of sectorial water demands and environmental flow requirements, as well as different sources of water supply in GLOBIOM Development of ecosystems security related indicators in GLOBIOM: Nitrogen leaching & Biodiversity Representation of regions in GLOBIOM expanded to include new regions for countries within case study basins and datasets collected for the case study regions	

Component 2. Exploring nexus solutions at global and regional scales

Outcome 2.1 Regional assessment of nexus challenges and solutions: Understanding of sectorial trade-offs, synergies, and solutions for meeting nexus challenges improved among regional stakeholders

Output 2.1.1 Tangible strategies for improving regional decision-making across sectors and borders identified for two selected regions	Indicators	Timeline	Targets (as described in the proposal)	Key outputs/milestones for the period:	Deviations with respect to initial planning
	Identification and documentation of key regional insights (yes/no)	Month 5-33	Joint GEF-IIASA-UNIDO Summary for Policymakers (SPM)	Multidimensional assessment of first set of technological solutions to	NO

				manage the nexus: desalination	
Outcome 2.2 Global nexus hotspots and transformation pathways: multi-sectorial vulnerability hotspots under different socioeconomic and hydro-climatic scenarios identified					
Output 2.2.1 Global assessment of multi-sectorial hotspots and transformation pathways	Indicator	Timeline	Targets (as described in the proposal)	Key outputs/milestones for the period:	Deviations with respect to initial planning
	Global assessment of multi-sectorial hotspots and transformation pathways (yes/no) Identification and documentation of knowledge and data gaps (yes/no)	Month 5-33	Documentation and communication of key insights from global assessment in publications and SPM Inclusion of knowledge and data gaps in SPM	Fast-track assessment of multi-sectoral vulnerability hotpots assessment under different climate and socioeconomic scenarios	NO
Component 3. Capacity Building and Knowledge Management: Building the foundation for a knowledge and capacity network on nexus decision support					
Outcome 3.1 A foundation of a regional and global knowledge and capacity network established					
Output 3.1.1 Establishment of connections and interactions among stakeholders from a wide array of institutions, sectors and countries;	Indicator	Timeline	Targets (as described in the proposal)	Key outputs/milestones for the period:	Deviations with respect to initial planning
	Number of stakeholder meetings per case study region Expert advisory meetings (yes/no)	Month 1-36	Three total stakeholder meetings in each case study region (includes consultation on study design) (~one per year)	Zambezi: Partnerships established with ZAMCOM. Alliances established with GWP, SADC and NEPAD First consultation completed Indus:	Yes Establishing partnerships with local stakeholders has taken more time than initially planned. Political sensitivities in the Indus added extra

including expert advisory meetings			Number of informal expert advisory meetings conducted	Partnerships established with LUMS. Alliances established with IWMI, ICIMOD and World Bank List of stakeholders representing all sectors and countries for Indus developed and consulted with LUMS. Working plan for holding First Consultation	complexity to the organization of the first consultation. First meeting in the Indus, originally planned for Month 14, has been re-scheduled to Month 16
Outcome 3.2 Capacity building: Regional capacity for nexus assessment and solution identification improved					
	Indicator	**Timeline**	**Targets (as described in the proposal)**	**Key outputs/milestones for the period:**	**Deviations with respect to initial planning**
Output 3.2.1.a Two capacity building workshops per case study region, held concurrently with stakeholder meetings	Number of capacity building workshops	Month 4-36	Two capacity building workshops per case study region		NO
Output 3.2.1.b Exchange of scientists/experts with partner academic institutions, ministries and/or multilateral organizations	Number of scientists/experts exchanged	Month 1-35	At least one scientist/expert per case study region	Active dissemination among basin partners of the 2018 call for applications for PhD students working in the basins to join Young Summer Student Program (YSSP)	NO

Outcome 3.3 Knowledge dissemination: Infrastructure established to disseminate findings of the project					
	Indicator	Timeline	Targets (as described in the proposal)	Key outputs/milestones for the period:	Deviations with respect to initial planning
Output 3.3.1.a Participation in high-level panels, conferences, and events	Number of presentations at high level events	Month 1-36	Presentations at a minimum of three high level events per year	Participation in 20 Scientific conferences and 5 High Level Panels	NO
Output 3.3.1.b Online database for sharing of scenario results	Development of online database (yes/no)	Mont 18-36	Online database accessible and populated with scenario results		NO
Output 3.3.1.c Two experience notes shared via IW:Learn	Number of experience notes shared	Month 34-36	One experience note per case study completed		NO
Output 3.3.1.d Joint GEF-IIASA-UNIDO Summary for policymakers describing project insights and outcomes	Development of a Joint GEF-IIASA-UNIDO Summary for Policymakers (SPM) (yes/no)	Month 33	Joint GEF-IIASA-UNIDO Summary for Policymakers (SPM)		NO
Output 3.3.1.e Scientific publications and white papers		Month 1-36	At least eight scientific publications and/or white papers submitted	12 Peer-review papers prepared (4 submitted and 8 in progress)	NO

	Number of publications		over the life of the project		
Component 4 Project Management					
Reporting	Annual progress report delivered (yes/no)	Month 1-36	At least one progress report per year	First Progress Report (Month1- 3) Second Progress Report (Month 1-12)	NO
(External) project oversight	Annual meeting with the Project Steering Committee	Month 1-36	At least one meeting per year	Two videoconferences 1 Face-to-face meeting 8-9 June 2017	NO

3. Progress by component

Component 1. Development of a system analysis framework

Outcome 1.1 Development of scenarios describing uncertainties in future trends and drivers

Summary: Achievement of outcome 1.1. requires the development and post-processing of quantitative and spatially explicit projections of climate (e.g. temperature, precipitation) and socio-economic (e.g. population, GDP, income) drivers under different development pathways. These scenarios describe the climate and socioeconomic mega-trends into the future, and are used to assess the biophysical (land productivity), hydro-climate (water availability, and variability) and resource demand at the global and basin level. For the global assessment, we use the Shared Socioeconomic Pathways (SSPs) and the Representative Concentrations Pathways (RCPs) developed for the Intergovernmental Panel on Climate Change (IPCC). For the two basins, the SSPs and RCPs provide the context to define the regional specific change pathways, and it is expected that these scenarios can be refined (e.g. by including important regional factors) and improved (e.g. incorporating better information datasets) in collaboration with the stakeholders.

Progress by Month 12: Activities have focused in defining system boundary conditions, including: 1) the definition of the physical and administrative boundaries and times series; 2) high-resolution downscaling of global socioeconomic projections for all five SSPs;[2] 2) the development and post-processing of hydro-climate datasets as inputs for the models and hotspots assessment; and 2) estimation of future land use and land cover changes for the different SSPs and RCPs. A detailed description of the activities and milestones accomplished, and next steps is provided below. Also, efforts have been placed into the development of explorative SSP-based scenarios in the basins, as a starting point for the discussion with stakeholders during the workshops.

System analysis boundaries

Table 2 summarizes the system boundaries agreed as a basis for having a unified spatial and temporal scale of analysis as well the shared datasets that different models will use.

Table 2. System Boundaries

Geopolitical borders	Global Administrative Unit Layers (GAUL2015)
Watershed boundaries and sub-basin delineations	Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (https://www.isimip.org/) global drainage direction map (DDM30) and HydroBasins (http://www.hydrosheds.org).
Downscaled Climate Datasets	Bias-corrected climate forcing from the ISI-MIP project data from five leading global climate models (GCMs) and four emissions pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) at 0.5°x0.5° grid resolution (I.e., 50 km by 50 km); daily values used and aggregated to monthly, seasonal, annual, decadal and 30-year statistics as appropriate for the model inputs
Socioeconomic data	Shared Socioeconomic Pathways (SSPs) (1-5) at 10 year time steps (2000-2050) • GDP; country-scale • Urban and rural populations; 0.125° grid resolution and country-scale Sectoral water demands (domestic and industrial) from Water Futures and Solutions fast-track modeling effort for SSPs 1-3 for two leading global water demand models at 0.5°x0.5° grid resolution; monthly values at 10 year time steps (2000-2050)

Downscaling of population and GDP datasets

Socioeconomic indicators key to assessing future climatic impacts (i.e., income and poverty) have previously only been available at the national level. To enhance the resolution of these socio-economic drivers and trends,

[2] Sustainability (SSP1), Middle or the Road (SSP2), Fragmentation (SSP3), Inequality (SSP4), and Conventional Development (SSP5)

the ISWEL team has developed spatially explicit projections of rural and urban income distributions at both subnational (province and state) levels and 0.125-degree resolution (approx. 10km at the equator). These datasets are key inputs for the global and regional assessment of nexus solutions (outcomes 2.1 and 2.2), and for the first time include high-resolution projections of income and inequality. Combining these novel datasets with available projections of gridded urban and rural populations, the ISWEL team is making novel spatial assessments of the vulnerability of populations under various climatic and socioeconomic futures.

Three primary principles guided the development of projections of downscaled subnational socioeconomic indicators of population and GDP trends: aggregations of indicators must be consistent with national values in each time period, indicator progression in each state or province should be limited to values observed in the historical period, and estimations of very poor populations should be aligned as closely to national projections as possible. In order to generate projections consistent with these goals, a new dynamic-recursive non-linear optimization model was developed, which seeks to estimate future state-level socioeconomic indicators while maintaining certain socioeconomic equations of state in future periods. The model determines state-level income and inequality for a future time period given state-level data from the past time period as well as national-level data from both the current and past time periods.

The projection model was applied to all 184 countries for which SSP projection data exists, utilizing World Bank data to determine initial national shares of household income. State-level income and inequality values were separately projected for each country's urban and rural populations and all five SSPs. The recursive-dynamic model was executed for each decade from 2020 until 2050, solving each time period sequentially. In total, 3700 model instances were executed and their results were compiled into a global dataset for all SSPs and years in the projection horizon.

It was found that both the magnitude and spatial distribution of affluence and poverty vary greatly across the SSPs (**Figure 1**). Our central scenario is an income threshold of $10 per day, to capture the fraction of population that are "vulnerable to poverty" and who lack "economic stability and resilience to shocks that characterizes middle-class households" (López-Calva & Ortiz-Juarez, 2013; World Bank, 2013). It was observed that for scenarios of high economic growth (SSP1, 5) the number of people vulnerable to poverty drops by an order of magnitude relative to today (**Figure 1**a, c, e). This corresponds to huge gains in incomes that are not offset by migration and urbanization patterns, such that incomes increase by well over 500 percent in areas with the highest concentrations of poor populations, notably sub-Saharan Africa and southeast Asia (**Figure 1**b, d).

Future distributions of income between urban and rural populations vary greatly both across SSPs and regions (**Figure 2**). The regional breakdown of populations of urban and rural income relative to the present daywas analyzed for three income thresholds: $2/day (extreme poverty), $10/day (vulnerable to poverty), and $20/day (low income). In scenarios of high development (SSP1 and 5), extreme poverty is effectively eradicated in both urban and rural contexts even as those regions in which they exist in highest numbers today (Asia and Africa) have growing shares of total population in both urban and rural contexts. In these scenarios, populations vulnerable to poverty in 2050 fall to magnitudes at or below extreme poverty today. Furthermore, the number of rural populations with low income are reduced to levels similar to rural populations in extreme poverty today with most of the socioeconomic development is focused in Asia and Africa. In short, SSPs 1 and 5 describe a future of limited poverty across the globe by 2050 fueled either by great technological innovation (SSP1) or by large increases of fossil fuel use (SSP5).

The work required to generate these datasets and their relevant results has been summarized and a research article has been submitted to Nature Sustainability and is pending review. These spatial datasets of urban and rural income and inequality and their derivatives (populations under various income thresholds) have been combined with analyzed climate data at the same spatial scale to determine hotspots of vulnerable populations under various climate futures, described further in Section 3, outcome 2.2.

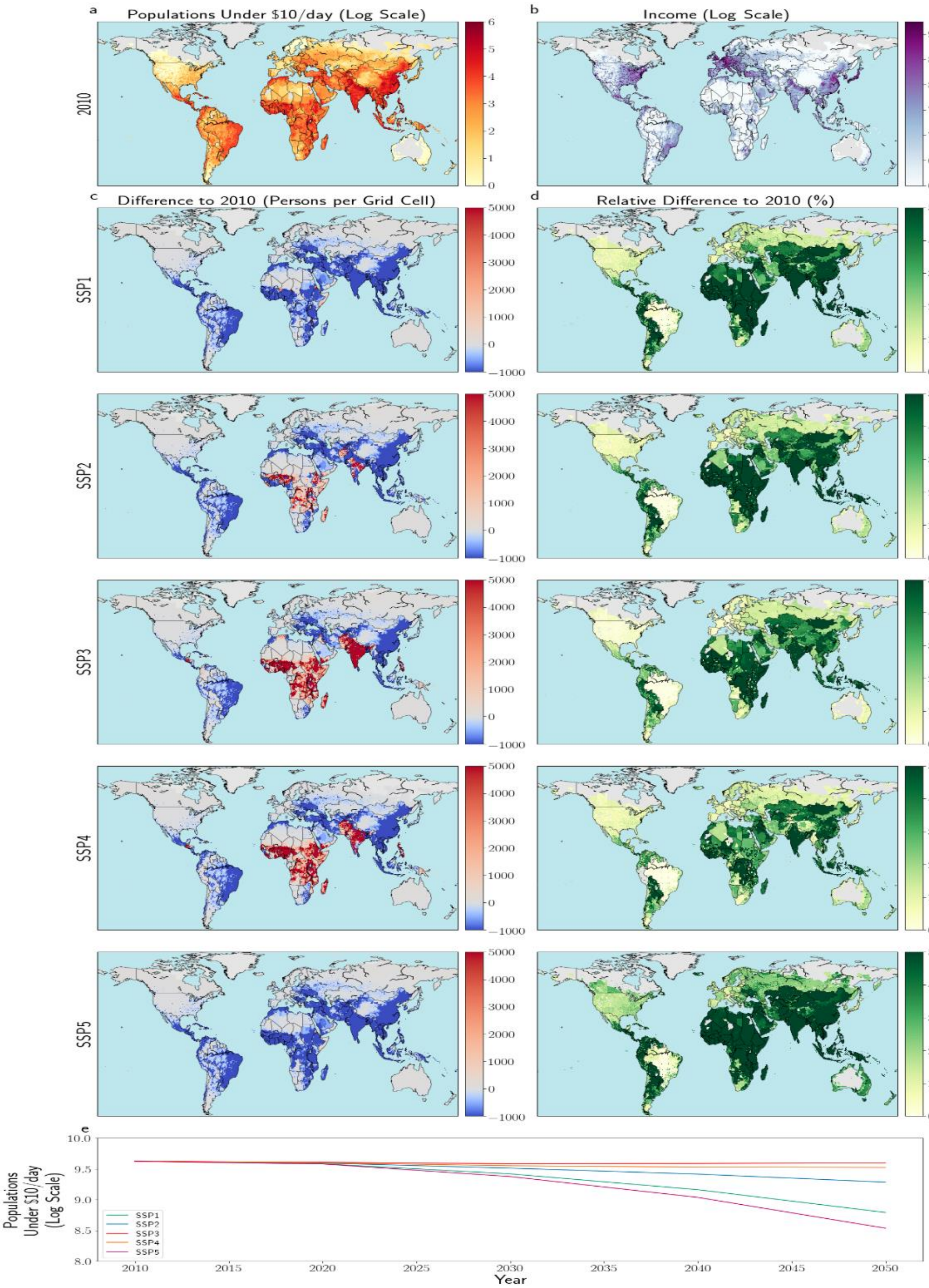


Figure 1 Spatial patterns of populations in moderate poverty (incomes less than $10 per day, Panel **a**) and of total income (household income per capita multiplied by population, Panel **b**) in the present day. Panel **c** presents the change in moderate poverty (persons per grid cell) for each SSP in 2050 relative to 2010. Panel **d** shows the change in income (in percent) for 2050 relative to 2010 for each SSP. Panel **e** displays the time series of global population living below $10 per day for each SSP from 2010-2050. Scenarios of highest development (SSP1 and 5) show the largest reductions in moderate poverty whereas scenarios of low development (SSP3 and 4) show almost no change.

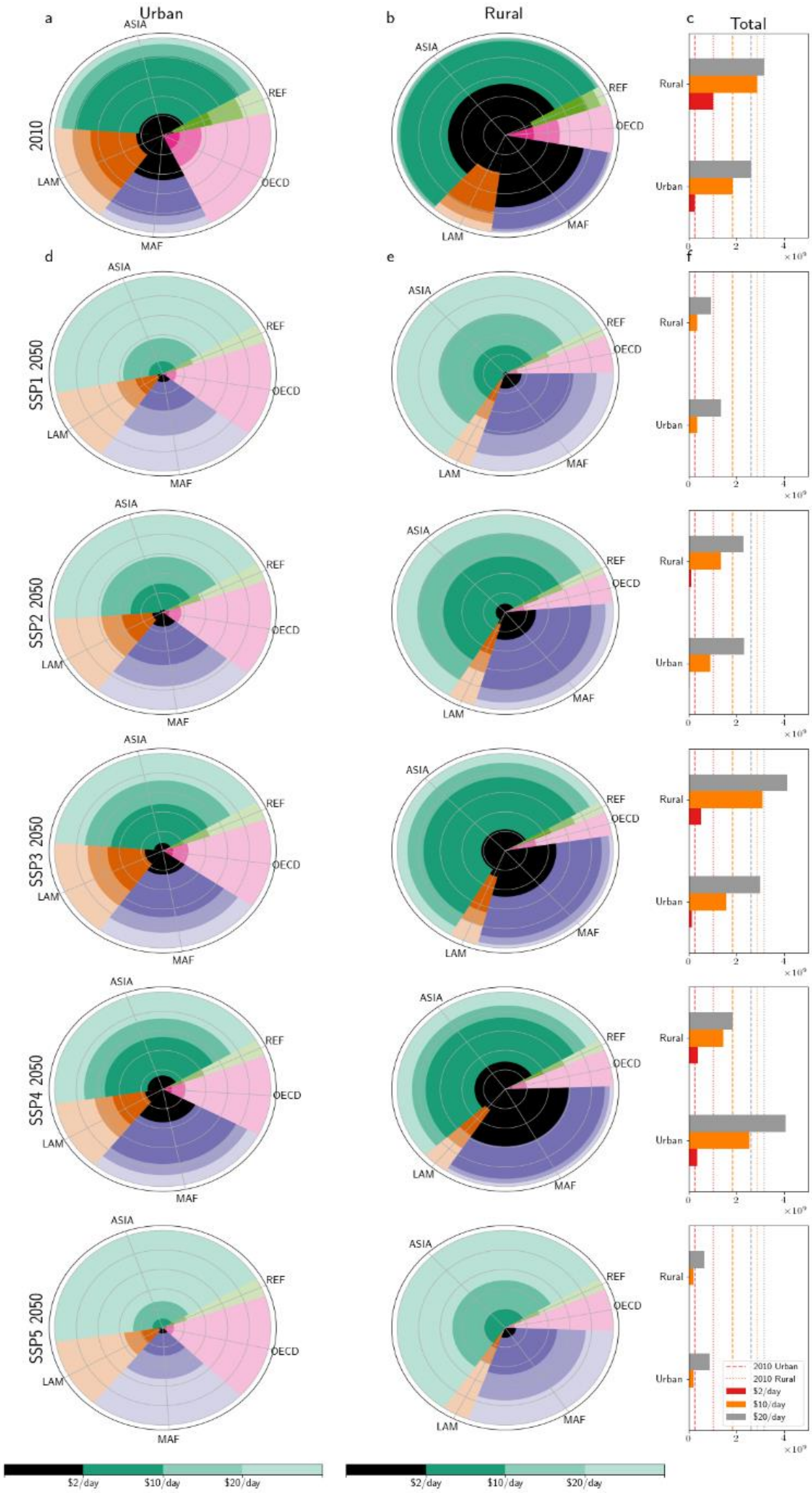


Figure 2 Regional differences of urban and rural poverty across scenarios. Left panels show radar graphs of the proportion of urban (Panels **a, c**) and rural (Panels **b, d**) populations under thresholds of income of $2 (black), $10 (dark), and $20 (medium) per day. The outermost radius of the graphs represents the total population (light color). The panels show this breakdown both in the base year (Panels **a, b**) and for each projected future scenario (Panels **c, d**). The rightmost panels (Panels **e, f**) show the total magnitude of urban and rural populations below each income threshold ($2 - red, $10 - orange, $20 - grey) for present day (Panel **e**) and each future scenario (Panel **f**). We show in the background of each panel the values for present day as dashed (urban) and dotted (rural) lines for each income threshold for comparison.

Downscaling of future land use and cover change

A downscaling procedure using an econometric algorithm was developed to provide spatially explicit (5x5 arcminutes) land cover and land cover change maps for GLOBIOM results. The developed downscaling algorithm covers cropland (see Figure 3 for example of cropland change from 2010 to 2050 in the scenario SSP2 x RCP4.5), grassland, forest, and other land cover changes, as well as all GLOBIOM crops and cropping systems. First land cover change projections were generated for SSPxRCP scenario combinations.

Next steps are i) to refine the thematic granularity of the land cover change projections (by including afforestation and forest management from the global forestry management model G4M, short rotation plantation, and urban areas), ii) to incorporate updated remote sensing info behind the econometric model (ESA-CCI 2017), and iii) to improve the downscaling algorithm by providing stronger consistency with other aggregated GLOBIOM data (production totals etc.).

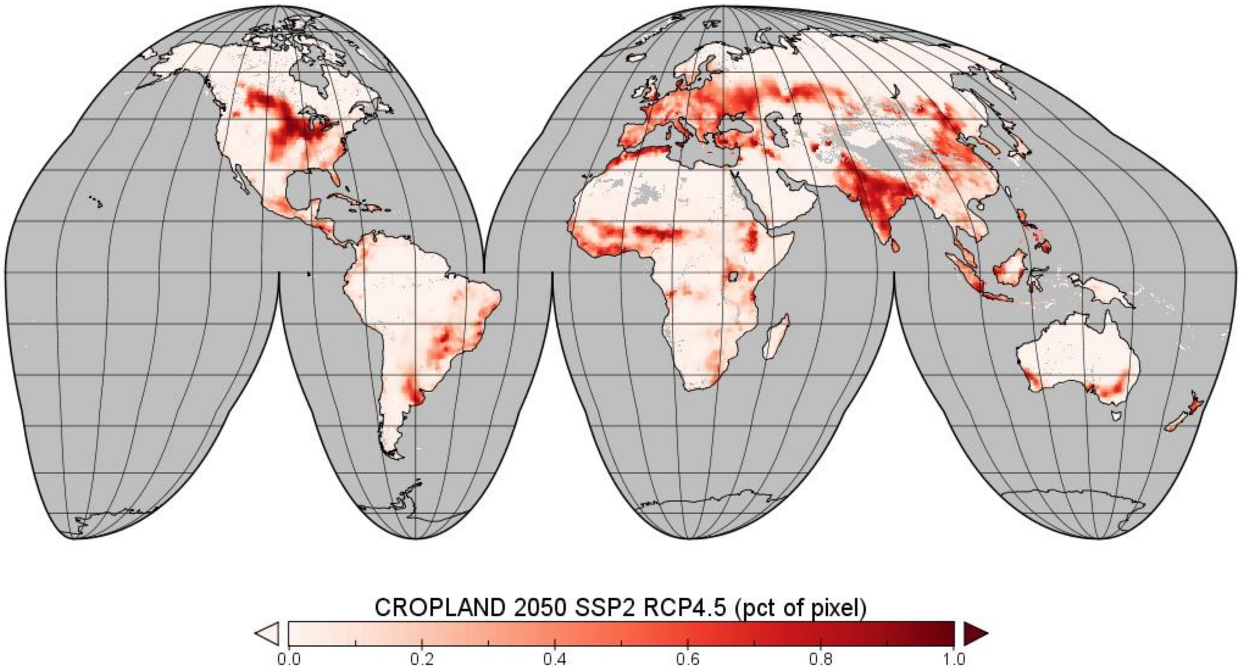


Figure 3 Downscaled GLOBIOM cropland in 2050, SSP2 RCP4.5 (percent of pixel, 1=100%)

Yield gaps and potential consequences of future closing of yield gaps

The intensification potential for a total of 19 major crops (barley, bean, cassava, chickpea, cotton, field pea, ground nuts, maize, millet, potatoes, rape, rice, rye, sugar beet, sugarcane, sunflower, sorghum soya and wheat), was estimated using the Environmental Policy Integrated Climate (EPIC) model at 5 arc-min resolution (EPIC hypercube dataset). Crop yield and biomass were simulated annually under 15 management scenarios (increasing N-fertilizer and irrigation water supply) to investigate the productivity response of individual crops in different global environments under historical weather. The results (hereafter referred to as 'hypercube') allow estimation of fertilization and irrigation requirements to achieve certain levels of productivity. Besides annual outputs of crop yields, the hypercube was extended to inform on monthly dynamics of crop growth, nutrient cycles, soil hydrology, and soil organic carbon, allowing – inter alia – quantification of environmental externalities associated with crop intensification (see for example irrigation requirements to increase maize yield in Figure 4. More than 50 crop growth and environmental variables were simulated with a monthly resolution.

In terms of next steps, the hypercube will be updated with new simulations, implementing improved spatial parameterization of some crops. The new simulations will provide better accounting for crop dormancy where applicable, rice multi-cropping, and fix some inconsistences in crop calendars. In addition, new simulations with improved spatial distribution of spring and winter wheat will be added. In the next phase we will extend the hypercube intensification experiment (hypercube v.2) to account for climate change impacts. We will use climate change scenarios to investigate possible changes in crop productivity as well as fertilization and irrigation water requirements in the mid-term horizon.

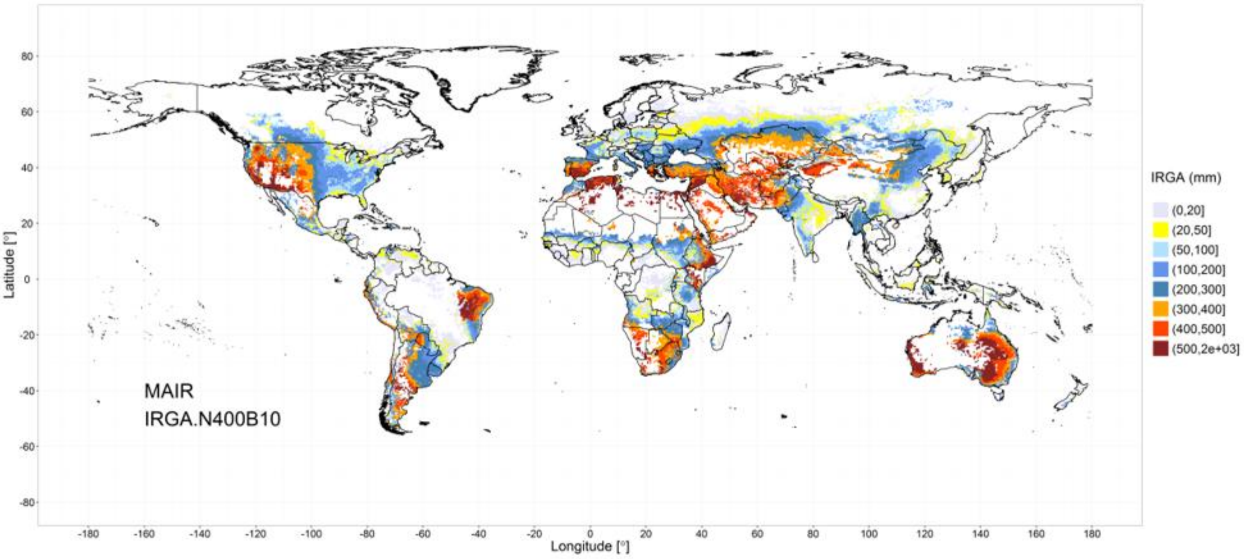


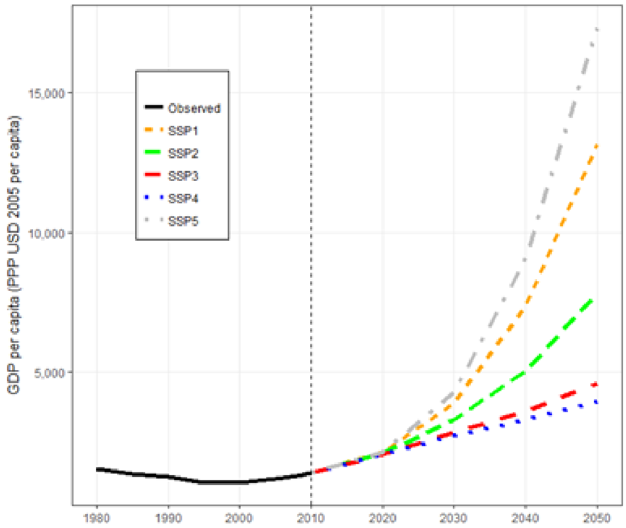
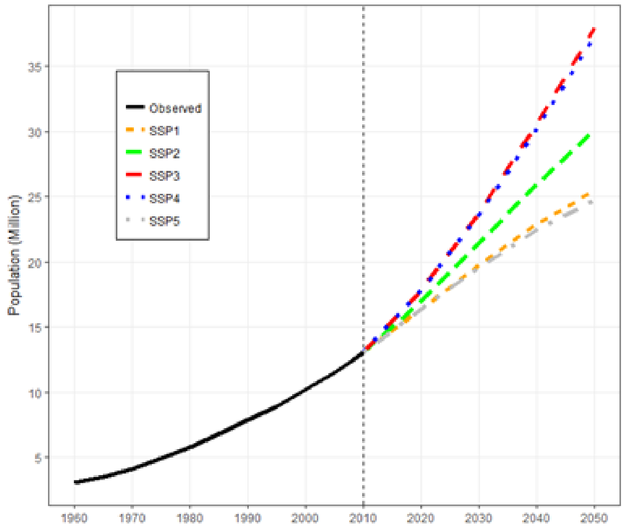
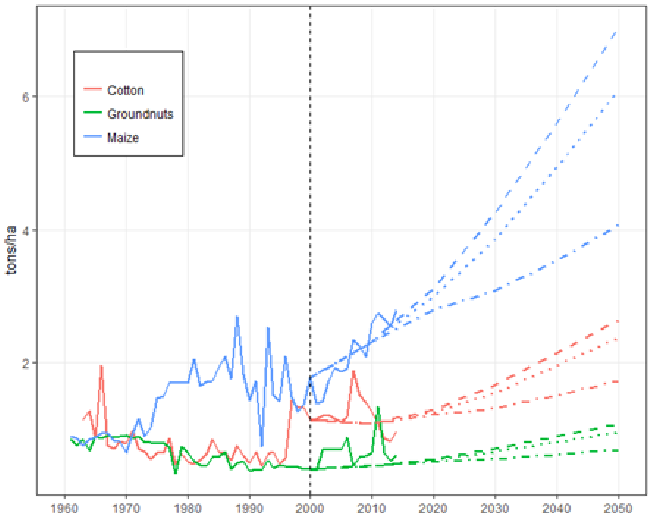
Figure 4 Net irrigation water requirement (in mm a^{-1}) to achieve high-input maize yields under ample nutrient supply

Developing regional explorative scenarios for the basins

Zambezi

To begin the scoping of the nexus issues in the Zambezi region and to prepare for the scenario workshop a number of exploratory scenarios for the Zambezi region were developed using the socioeconomic drivers for the SSPs, and quantified these using GLOBIOM. The drivers we included in our exploratory scenarios included population, GDP, tech change, demand for water from other sectors such as domestic and industry and irrigation water application efficiency and increased water storage for three SSPs. We also combined these with impacts from climate change on crop yields, nutrient requirements and irrigation water requirements as well climate impacts on surface water availability. These scenarios will be completed in the course of the next Month to include the representation of the water and energy future trends, and used as a starting point for the discussions in the scenario focus group. A brief overview of the selected drivers is for the region is presented in Table 3.

Table 3. Drivers and future projections for the Zambezi region under all five SSPs

Driver	Projections for different SSPs
GDP per capita (IIASA SSP database: Kc & Lutz 2014; Dellink et al. 2015)	
Population (IIASA SSP database: Kc & Lutz 2014)	
Major Crop yields (FAOSTAT for historical and IIASA SSP projections: Herrero et al. 2014; Fricko et al. 2017)	

Driver	Projections for different SSPs
Irrigation efficiency	*Irrigation water application efficiency (Hanasaki et al. 2013)* SSP1: 0.3% decrease per year SSP2: 0.15% decrease per year SSP3: no decrease *Improvements in water storage (for irrigation in water stressed months)* SSP1: up to 15% of potential monthly irrigation water demand can be taken from water abundant months SSP2: up to 10% of potential monthly irrigation water demand can be taken from water abundant months SSP3: no additional irrigation water demand can be taken from water abundant months

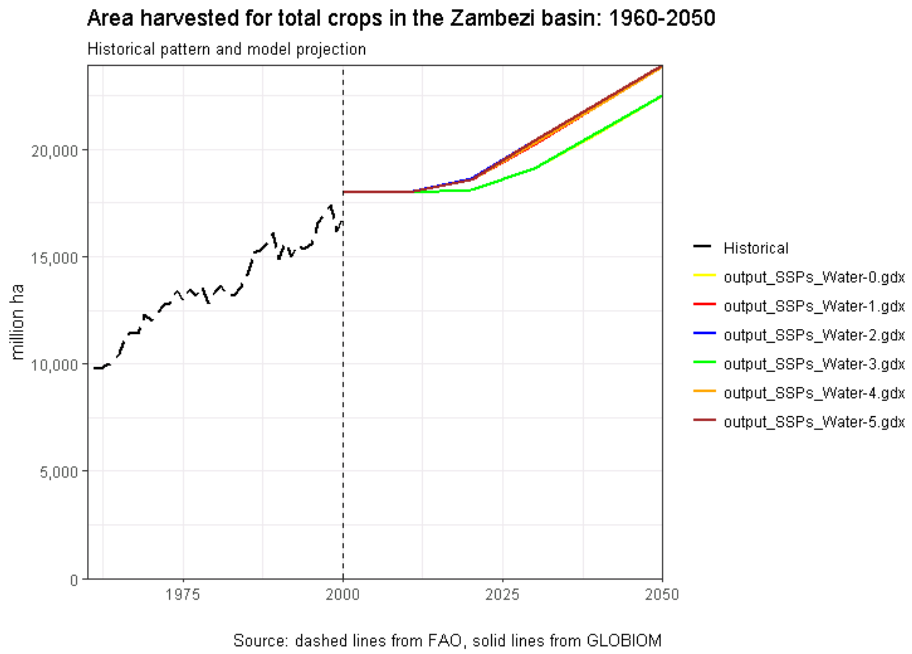


Figure 5 Harvested area for crops in Zambezi river basin: 1960-2050

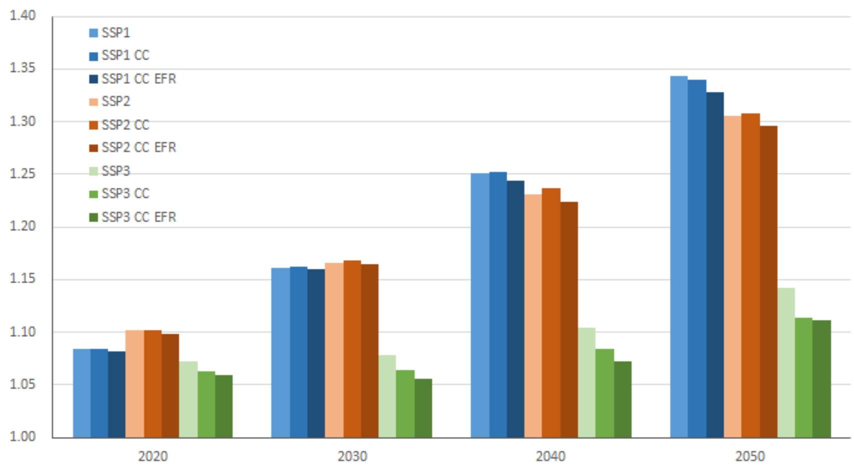


Figure 6 Relative change in per capita calorie availability for Zambezi region from year 2000 calorie availability

We examined the overall development of the agriculture sector for the region under the different socioeconomic and climate futures as well as the relative impacts on food security. The historical trend for cropland area expansion continues into the future to meet the growing demand for crop products (Figure 5). Figure 6 presents kilocalorie availability per capita per day, a commonly used indicator to measure food security, which considers the total food products demanded by a region and translates the quantity of product to calories. As the income per capita increases over the time period for the SSPs, food demand, and kilocalories available, increase in the region. However, climate change reduces calorie availability as well as the when agriculture water demand additional pressure to protect stream flows.

Indus

To begin the scoping of the nexus issues in the Indus region, existing stakeholder developed regional scenarios for South Asia were used as a starting point. The process to develop the scenarios was led by the CGIAR Program on Climate Change, Agriculture and Food Security (CCAFS) and began in 2012. With regional stakeholders, scenarios were created that focus principally on regional challenges such as the impacts of future climate and socioeconomic drivers on food security, environment and rural livelihoods for South Asia (Palazzo et al. 2014). Over two workshops, five plausible socio-economic scenarios were developed by stakeholders using narratives, conceptual maps, and semi-quantified indicators (Table 4). The scenarios were defined by the end state, or world in 2050. The process included 35 participants from the region, which includes Bangladesh, India, Pakistan, Sri Lanka, Nepal, representing National Bodies (Nepal Development Research Institute), private sector (Yes Bank Limited, India and Policy Development Consultants, Sri Lanka), NGOs, researchers, global bodies (World Bank and Climate and Development Knowledge Network).

Table 4 Short descriptions of the CCAFS scenarios by each scenario's factors of change (human capital, governance and institutions, science, technology and innovation, political stability and conflict, economic structure, and demographics)

Union of South Asia	Jugaad	Unstable flourishing	People Power	Precipice
• Populations are educated, informed and aware population • Institutional capacity and coordination, both within and between countries, are high • There is a high availability and transfer of science and technology in the region • South Asia is politically stable • The service and industry sectors are the most prominent • Population growth has been low, and urbanization has been moderate	• Populations are relatively uneducated and uninformed • Institutional capacity and coordination is weak, both within countries and at the regional level • There is a low transfer and availability of science and technology • Political instability and conflict are common in South Asia • The agricultural sector is dominant as other sectors have stagnated • Population growth is high	• Populations are aware, informed and educated population • There is high institutional capacity and high coordination across agencies • There is a high availability and transfer of science and technology in the region • Political instability and conflict is always a threat • The agricultural sector is dominant • Population growth is relatively low and urbanization is moderate	• Populations are aware, informed, educated population • There is low institutional capacity and low coordination across agencies • There is a high transfer and availability of science and technology • Political instability and conflict are common in the region • The agricultural sector is not dominant • There is relatively low population growth and urbanization is moderate	• Populations are relatively well educated and aware thanks to successful efforts of the earlier decades; • Institutional capacity and coordination is weak; • There is a low transfer and availability of science and technology; • Political instability and conflict are common in South Asia; • The agricultural sector is dominant as other sectors have risen and diminished, and there are informal urban economies; • Owing to the prosperity in the earlier decades, population growth is medium, and so is urbanization.

The scenarios were then quantified using GLOBIOM using scenario semi-quantitative that were translated into numerical values using the regional SSP values as starting point after critically comparing and mapping the regional scenarios to the SSPs (Figure 7). The drivers we included in the initial quantification include GDP, population, crop yields, livestock yields, producer input costs. The process and quantitative scenarios for South Asia can be found in Palazzo et al. (2014).

Figure 7 CCAFS scenarios mapped to the SSP scenarios (adapted from O'Neill et al. 2015)

The original stakeholder scenarios focused on food security issues in the region from socioeconomic development and productivity of the agriculture sector. The quantification follows with others in that the future impact of climate change on crop yields in comparison with current yields in South Asia are likely to be negative (Knox et al. 2012; Palazzo et al. 2014). However, in the original quantification, it was only included the biopsychical impacts of climate change on the irrigation water requirement for crops rather than also include the climate impact on the availability for water for irrigation. The study of Gerten et al. (2011) revealed that there is a large chance that climate change alone will decrease per capita water availability by more than 10% in the majority of South Asian countries. These model improvements will allow to connect, at a high spatial resolution, the impacts from climate change on the irrigation water requirements from crops and the climate impacts on water availability. Other aspects of the scenarios were also included, which had not been included in the first process, both as drivers and also to critically compare the model results (Table 5). Modeling the regional scenarios again under the impacts of climate change on both the irrigation demand and water supply side can provide a better picture of the impacts of water scarcity within the region both from climate change and also due to conflicts over water use from other sectors. The agricultural sector is responsible for between 87% and 98% of total water withdrawal in the region, however water use by domestic and industrial use will increase over the coming decades depending on the socioeconomic development of the region (Figure 8) (Wada et al. 2014). Hence, decreasing water availability in South Asia, which according to some studies, is already a water stressed region, will have strong negative impact on future crop yield and food security (Figure 9).

The results from the new water-energy-land quantification of the regional scenarios are preliminary and will be a starting point for the stakeholder engagement and scenario building.

Table 5 Additional qualitative information from the CCAFS regional scenarios considered in the new quantification

	New USA	Jugaad	Unstable Flourishing	People Power	Precipice
Water availability for agriculture	Investment in tech increases **application efficiency**	**Conflicts over water**, no intl. agreement in water sharing, water misuse and corruption; attempt to use local knowledge to manage and conserve	**Dams restrict water flow**, some advanced ag **water management practices**	Declining but **technology mitigates** to some extent competition from other sectors	Decline, which gets worse over time
Yield change for irrigated agriculture	Pushes biological boundaries, bridges yield gap	Limited due to scare water and costly inputs	High tech and functioning institutions increase availability of inputs and water, yields increase	Increasing	Increasing and then decreasing
Area for irrigated agriculture	**Intensification**, rather than expansion (but still increase)	Decreasing area because of water stress, poor management, conflict zones	Increased due to **investment and technology**	Decrease in area but **higher efficiency** (from technology), competition over land with industry	Area reduced

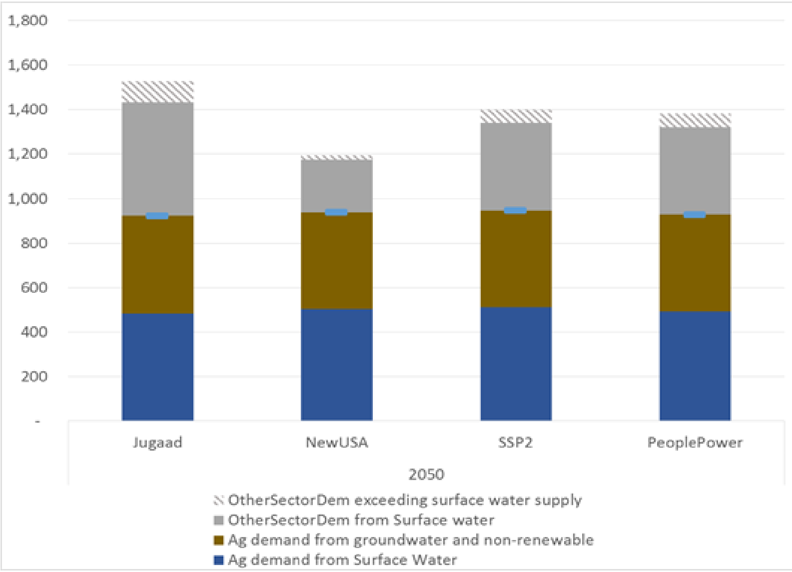


Figure 8 Water demand by agriculture and other sectors from groundwater and surface water under for South Asia in 2050 (blue dashed line is that total water demand for agriculture)

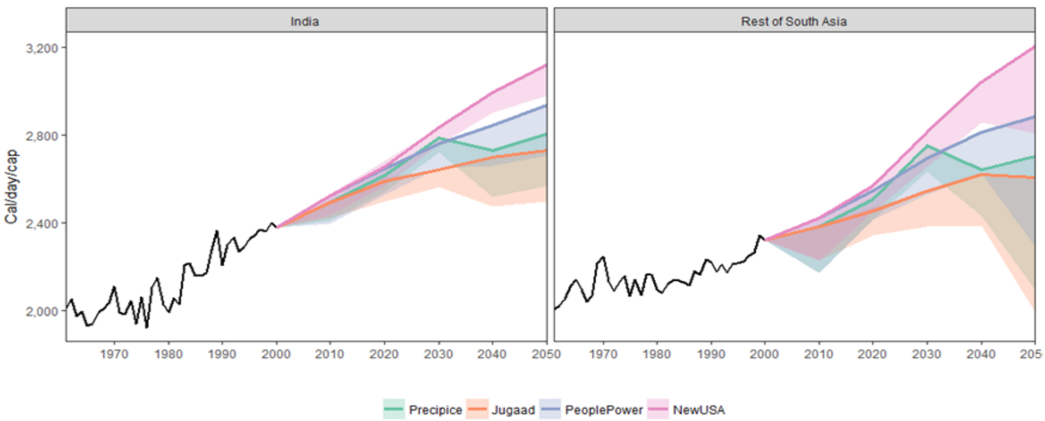


Figure 9 Kilocalorie Availability for India and other countries in South Asia under new W-E-L quantification of CCAFS regional scenarios

Outcome 1.2 Method and tool development

Summary: Achievement of outcome 1.2 requires the development of the System Analysis Framework (SAF). This process requires a two-step process: 1) the development or upgrade of sectorial tools to better incorporate the nexus connections: and 2) the coupling of the different models. The models that will be used to build the SAF include: the hydrological Community WATer Model (CWatM), the hydro-economic model (ECHO), the Energy-economic model (MESSAGE) and the Agro-economic model (GLOBIOM). The CWATM and ECHO are two new models that are being developed in the context of ISWEL, while MESSAGE and GLOBIOM have been widely applied by IIASA researchers in the past, but they are now being upgraded to better represent the sectorial linkages. The target of this outcome is to develop an SAF that is scalable (i.e. applicable at multiple scales), flexible (i.e. capable of answering multiples questions), and transferable (i.e. applicable to different locations).

Progress by Month 12: Activities in year one have largely been devoted into the development and upgrade of new and existing tools. A detailed description of the milestones/ouputs achieved so far is provided below under the Section on "Development and Improvement of tools appropriate for sectorial nexus assessment". The procedure agreed to link all four models and build the system's analysis framework is discussed under the Model Integration Section.

Development and improvement of tools appropriate for sectorial nexus assessment

Hydrological system

This section provides an overview on the progress achieved to improve the representation of the hydrology within the water system. Towards this end, a new hydrological model (CWatM) has been developed by IIASA researchers, to simulate how future water availability and demands can evolve in response to socioeconomic change and how water availability will change in response to climate, at both global and regional scale (e.g. basin). The configuration of the model is open source and community-driven to promote the work amongst a wider water community and it is flexible enough to introduce further planned developments such as water quality (e.g., nutrients, salinity) and hydro-economy. The basic components of CWatM, which include all necessary hydrological processes for addressing water supply and demand modeling are described in Figure 10.

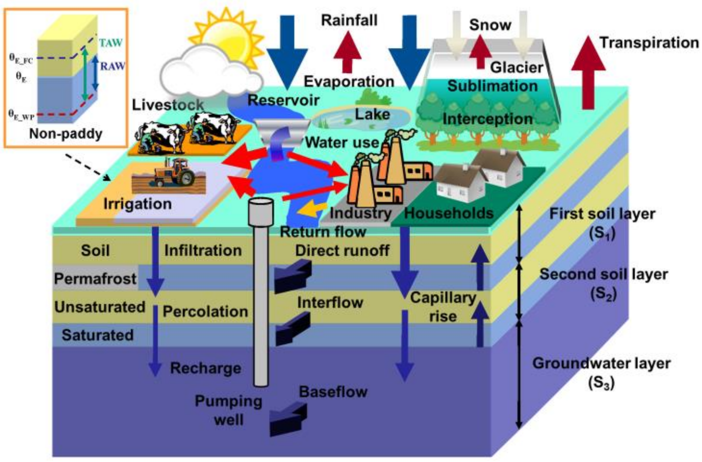


Figure 10 Main components and processes of the Community Water Model (CWatM)

Climate boundary forcing, socio-economic trends, and water management options used by CWatM are fed by external scenario inputs and policy options (outputs from sub-components 1.1 and 2.1 and related to stakeholder engagement). Based on these inputs, CWatM is capable of simulating the necessary variables for the hydro-economic model assessment e.g. water demand from different sectors, irrigation efficiency, water supply and return flows from water use.

Global

Year one of ISWEL has been mostly dedicated to the development of the tool and its calibration for several ground river discharge stations around the World. Calibration assures that the main hydrological processes for runoff and discharge are simulated as best as possible over different hydrological regimes around the globe and the importance of different hydrological processes (e.g. snow and glacier modelling, evaporation from wetlands, etc.) are reflected. This will lastly contribute to make the model regionally and locally more relevant, given that un-calibrated global hydrological models very often over- or underestimate real water supply (Burek et al., 2016). Figure 11 shows the comparison of measured vs. modelled river discharge for four stations under different climate and physiographic conditions across the globe using CWatM. With this calibrated model setting all necessary parameter sets, e.g. surface water supply, groundwater recharge, water demand from different sectors especially agriculture for past and future projections can be simulated and provided to the SAF.

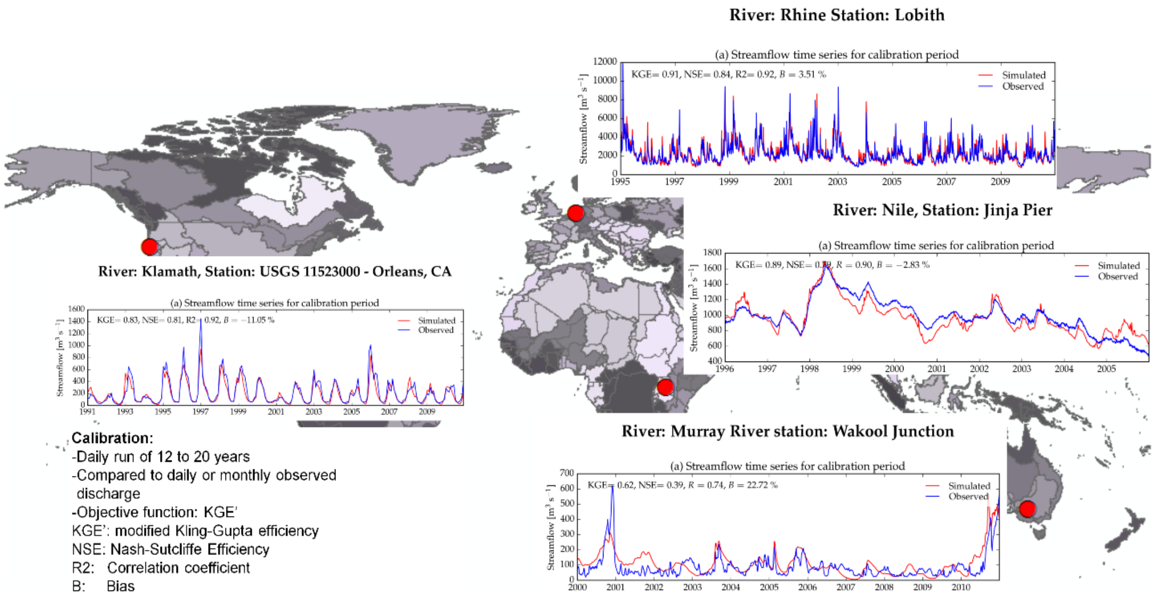


Figure 11 Global discharge simulation with CWatM for four selected stations with results

Zambezi

In the course of year one, CWatM has been calibrated for the Zambezi Basin. Calibration was done using 6 sub-catchments, and measured discharge provided by the Global Runoff Data Centre (2007). Figure 12Figure 12 shows two-time series of measured vs. simulated monthly river discharge, and the comparison shows good agreement of modeled discharge with measured data.

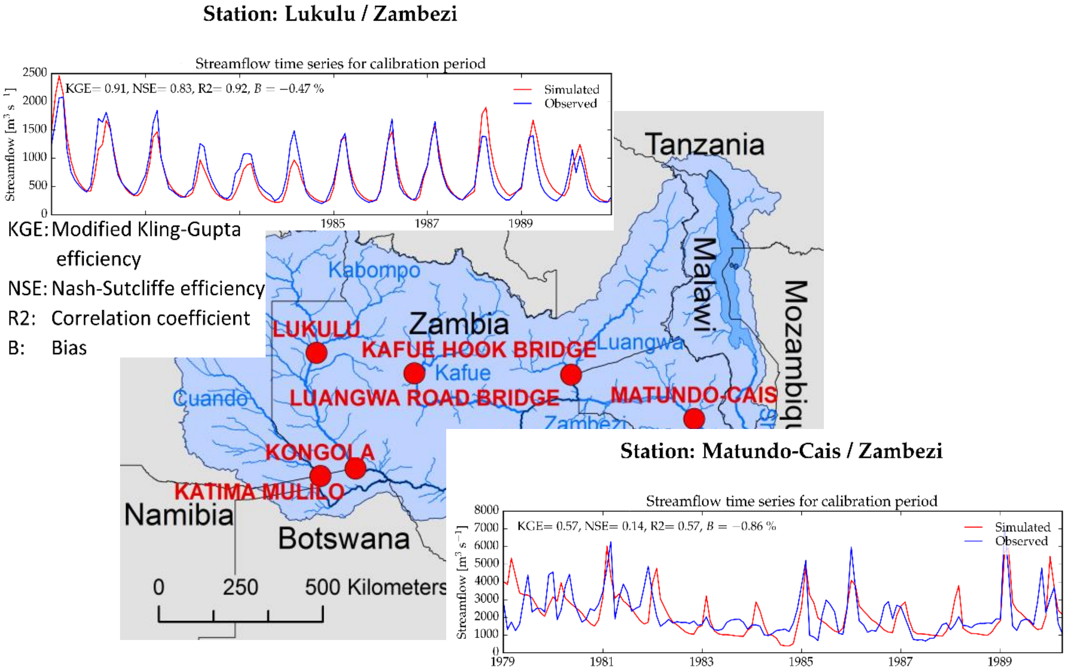


Figure 12 Calibration result for two station in the Zambezi basin

In the ISWEL project socio-economic trends and climate change are important drivers for hydrological processes, therefore it is necessary to use climate change projections from global circulation models (GCMs) based on the latest IPCC emission scenarios (IPCC AR5). In previous studies (Burek et al., 2016; Hoogeveen et al., 2015; Schewe et al., 2014) a large climate and hydrological model ensemble from the inter-sectoral impact model inter-comparison project (ISI-MIP) fast track data (Warszawski et al., 2014) was used. ISI-MIP stores bias corrected climate projections for different global warmings (as input for global and regional hydrological models).

By comparing the outputs of the hydrological model ensemble we see especially for Sub-Sahara Africa a strong overestimation of river discharge, which indicates an erroneous picture if compared to water demands. **Figure 13** shows a comparison of discharge for the Lukulu/Zambezi of different hydrological models. The GHMs in **Figure 13**a used one of the GCM (here historical run from HadGEM2-ES climate model from 1971-2004) as climate forcing data. Apart from WaterGAP and CWATM (both calibrated) one can see a strong overestimation of discharge for all other models compared to the measured discharge. **Figure 13**b shows results of CWATM with different climate forcings. The measured discharge and the results using observed precipitation (Watch - WFDEI data) (Weedon et al., 2014) as forcing, show good accordance. The comparison with climate forcing using ISI-MIP2b GCM model ensemble data shows still good agreement. However, results using ISI-MIP fast track forcing data show an overestimation (green box in Figure **13**b same as in **13**a but different scale). ISI-MIP2b climate forcing has used a better bias-correction method compared to the ISI-MIP fast track. Figure 13 shows the necessity to put efforts into calibration of the hydrological model (CWATM) for regional applications in order to be in line with measure water resources and to minimize the uncertainty from hydrological modeling.

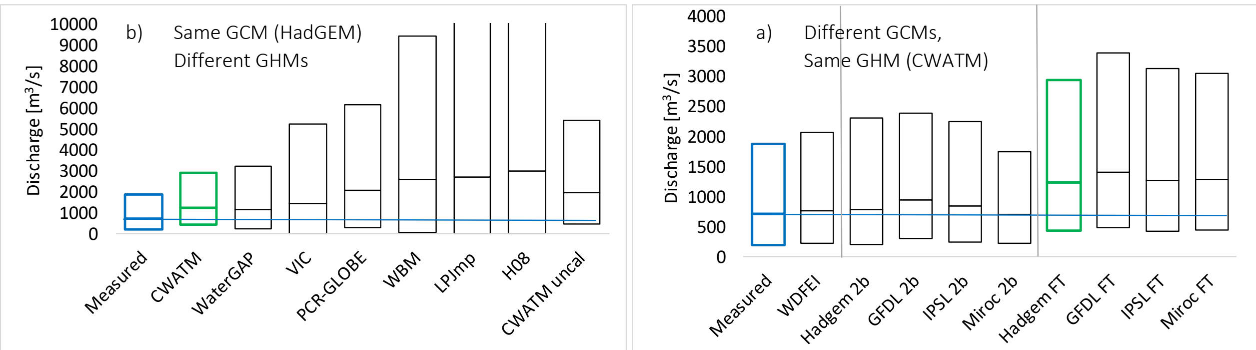


Figure 13 Box plot (5% percentile, average, 95% percentile of discharge for the Lukulu/Zambezi from 1971-2004) for different global hydrological models (GHM). a) GHM ensemble from ISI-MIP Fast track with HadGEM2-ES climate forcing b.) CWATM results with different GCM climate forcing.

Figure 14 summarizes the hydrological processes CWATM simulates at grid cell level (0.5 degrees) for the entire Zambezi basin. For each grid cell, the model is capable of simulating available water resources (i.e. river discharge, groundwater and reservoir storage), and the water demand from different sectors. To estimate water resources availability at a specific point, CWATM takes into account existing climate, water managements (e.g. reservoirs) and water use upstream. CWATM is now ready to communicate with other modules to adjust water demand and water resources according to changes in e.g. land use, irrigation, reservoir storages.

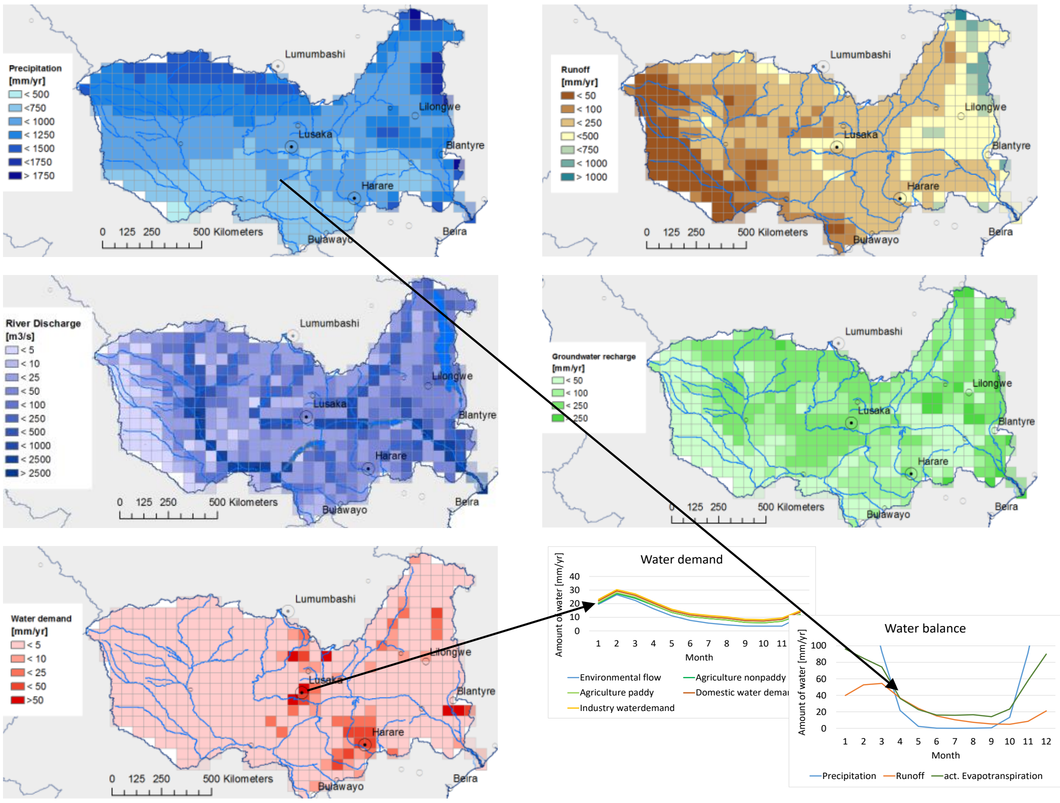
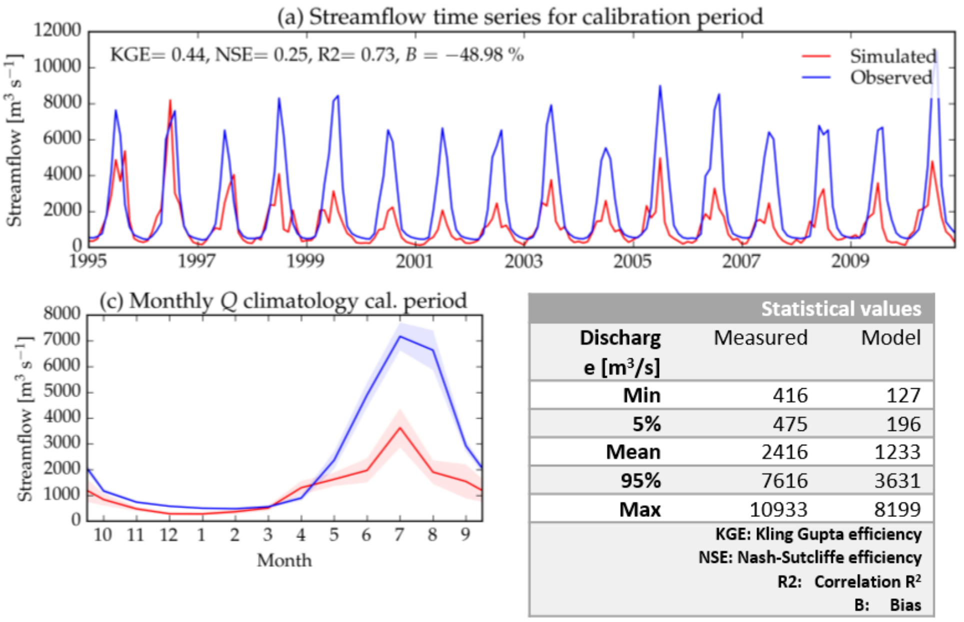


Figure 14 Parameter sets of different hydrological variables as input for hydro-economic modelling

Indus

The set up and calibration of CWATM in the Indus is still not completed. Preliminary calibration results (Figure 15) show that the model response is yet insufficient, as CWatM is currently underestimating river discharge at the basin scale. This has required to the ISWEL team to carefully re-assess some of the input-parameters. In particular efforts in the past months have been concentrated on: 1) revising and defining appropriate basin boundaries, 2) compile and analyze available climate datasets for the basin and 3) review the existing literature to find possible explanations for this underestimation. The following sections provide details on these tasks.



Discharge [m³/s]	Measured	Model
Min	416	127
5%	475	196
Mean	2416	1233
95%	7616	3631
Max	10933	8199

Statistical values
KGE: Kling Gupta efficiency
NSE: Nash-Sutcliffe efficiency
R2: Correlation R^2
B: Bias

Figure 15 First calibration with CWATM for Indus, station: Upper Indus Basin - Besham

Estimation of the catchment area of the Indus and Upper Indus catchment

Under or overestimated basin area may lead to a wrong estimation of physical parameters like precipitation but also to a wrong estimation of population and therefore to a misleading assessment of groundwater recharge, water scarcity, etc. In different studies the area of the Indus basin is estimated between 833,000 – 1,230,000 km^2. For ISWEL, it was agreed to calculate stream and drainage area delineations based on the data and methods described by Khan et al. (2014), which provided similar results to those of the SIHP (WAPDA) project (Figure 16).

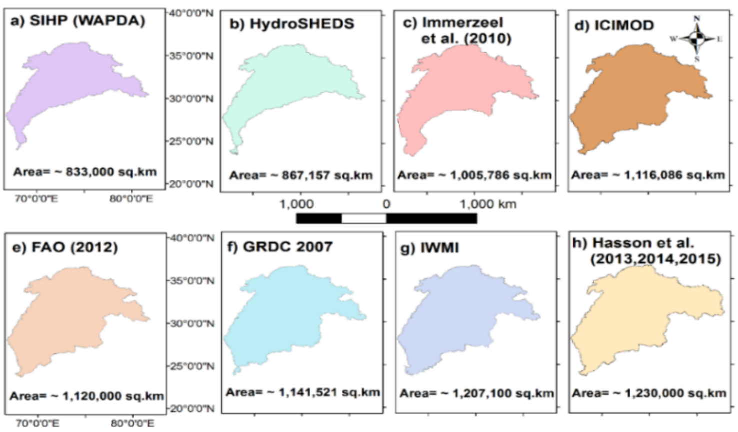


Figure 16 Variability in the Indus Basin boundaries based on various studies

Uncertainty in precipitation

Twelve different global datasets are analyzed for the Upper Indus basin (Figure 17). These datasets are either based on a.) climatic stations or b.) satellite information or c.) climatic models or d.) combination of the first three methods. These datasets show a huge difference for the average precipitation (260mm – 1135 mm) but also for the extremes (max: 762mm – 1896mm).The ISWEL team is now investigating options to address this uncertainty

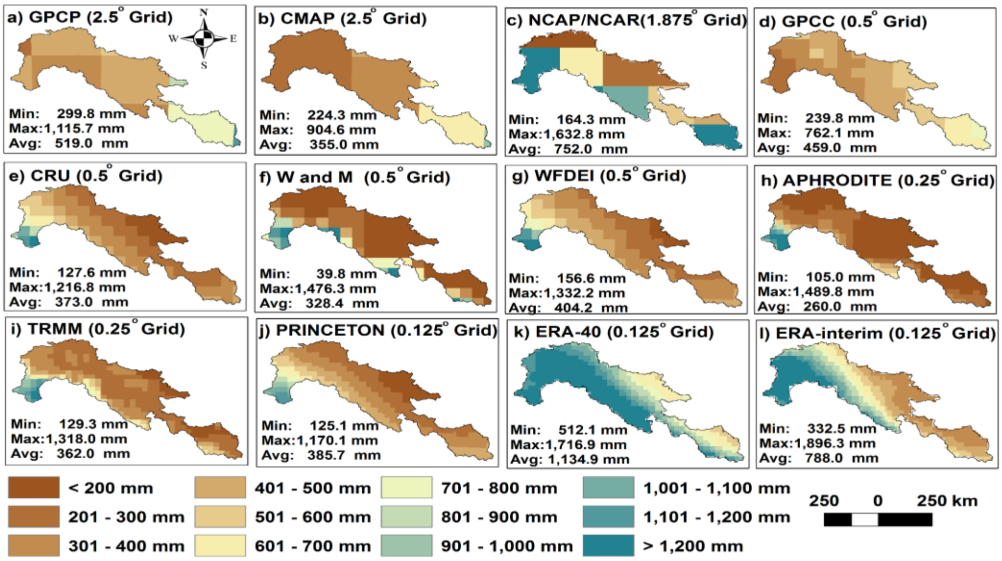


Figure 17 Spatial distribution of the selected gridded precipitation datasets in the Upper Indus Basin. Statistical values for the period 1999-2010.

Underestimation in discharge

Generally precipitation in the basin seems to be underestimated by global precipitation datasets, and this is leading to an underestimation of modelled water flows or overestimation of glacier-melt contributions in almost all hydrological models e.g. H08, PCR-GLOBWB, WaterGAP (Satoh et al., 2017). For example FAO uses GLOBWAT (Hoogeveen et al., 2015) simulations for estimating surface water resources. While the model reflects measured discharges for most regions of the World, it shows large underestimation of Indus discharge (2396 m^3/s measured, 137 m^3/s modelled) (Hoogeveen et al., 2015, Table 5, p. 3838). As shown in Figure 15, CWatM is also underestimating discharge. From a water-scarcity perspective, the implications of this underestimation are very relevant, as it provides an over-estimated picture of water stress in the Indus (Burek et al., 2016; Schewe et al., 2014).

These results show the importance of a regional assessment. Bias corrected precipitation datasets and the resulting river flows stored in the ISI-MIP project significantly underestimates precipitation and therefore river flow. Therefore, the projected water scarcity, drought and flooding results have to be validated carefully, to be used for water resource planning and management. For the purpose of the project in the Lower Indus basin it might be necessary to use measured river flows from the Upper Indus basin as initial starting point, and calibrate the CWatM to produce more realistic river flows from the Upper Indus, which will subsequently reduce the bias in the Lower Indus.

To improve the representation of the hydrological system the next steps include:

1. Overcome Indus underestimation of precipitation (by statistical bias correction of discharge) and validate CWatM for Indus
2. Define parameter sets for exploring nexus solutions (parametrize solutions, options, measures)
3. Establishing the linkage with ECHO, MESSAGE and GLOMBIOM under same sets of future nexus scenarios

Hydro-economic and energy-economic systems

Currently under development in the ISWEL project is a new engineering-economic modeling tool for application in long-term transboundary river basin planning. The Extended Continental-scale Hydro-economic Optimization model (ECHO) maps cost-effective solutions that address the tight couplings between water and energy infrastructure systems. Solutions in this context represent transformative policies as well as basin-wide infrastructure configurations and investment strategies that may enable sustainable development. ECHO outputs scenarios to mid-century that provide information on the utilization of water and energy resources within the basin, trade with other regions, and locations of production or conversion technologies, air/wastewater emissions, and infrastructure investment requirements.

Figure 18 depicts the geographic and technological scope of ECHO applied to the case study basins. The basins are divided into different catchments and then further subdivided into different countries using digital elevation and administrative boundary datasets [GADM 2013, Lehnr and Grill 2013]. The process of delineation is automated, and can be updated based on improved boundary definitions. The delineation is used to assess resource availability and the spatial transfers of water and energy across the basin, including transboundary flows. A reduced-form river network is estimated for this purpose. It is reduced-form because it represents the dominant direction of flow between spatial units, but does not include all tributaries. This simplification supports additional computing power needed for the rich representation of technology options included in ECHO.

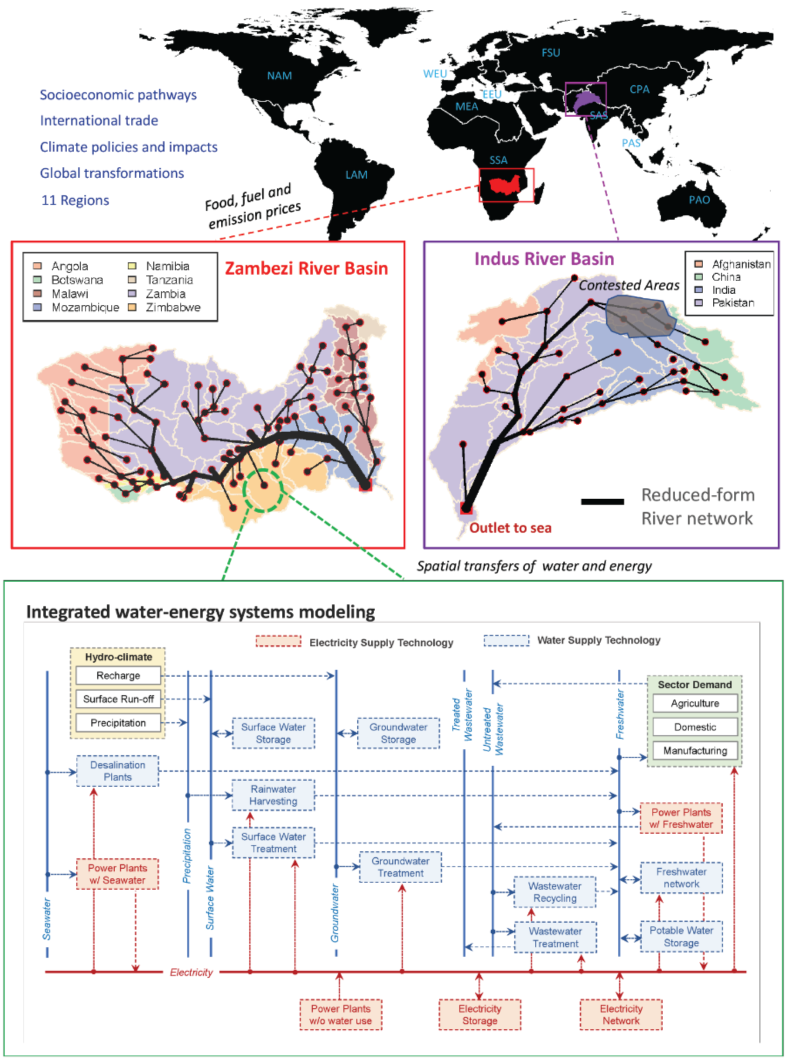


Figure 18 Geographic and technological scope of ECHO applied to each case study region. The tool is nested within the global integrated assessment model MESSAGEix-GLOBIOM (top) to account for land-use, and shifts in international trade and commodity prices. Integrated water-energy systems representation (bottom) facilitates consistent accounting of important interactions across water and energy systems

ECHO incorporates a systems engineering representation of the water and energy supply chains (Figure 19). Water supply technologies represented in the framework include groundwater and surface water pumps, water distribution, reservoirs, irrigation, wastewater treatment, and desalination. A diverse array of existing and emerging power generation options are also considered for electricity supply, including low-carbon and fossil fueled options. The analysis also covers electricity transmission between catchments and countries in a simplified way. Fuel supply chains and technologies are tracked explicitly for fuels produced within the basin.

A defining feature of ECHO is the linkage to the existing global integrated assessment model (IAM) MESSAGEix-GLOBIOM. The IAM simulates global energy and agricultural markets, land-use and commodity prices, and corresponding greenhouse gas emissions over the 21st century [Fricko et al., 2017]. Price trajectories for fuels, crops and emissions simulated with the IAM are passed to ECHO to incorporate future shifts in basin technology and trade strategies driven by shifts in global markets. Critical land-use dependencies, including the types and locations of crops and forestry activities, are represented in the basin tool using the IAM linkage. ECHO also connects with the CWatM to estimate water availability and to harmonize water demand (described below). In this way, ECHO provides a bridge between the global and regional modeling activities in the ISWEL project.

Critical to finding suitable infrastructure pathways with ECHO is an understanding of future resource consumption. In particular, consumption patterns aligned with the goals of poverty eradication and a transition towards sustainable livelihoods. With this objective, the representation of ECHO in each case study region is framed to identify infrastructure solutions that harmonize with decent living indicators from the scientific literature [Rao and Min, 2017]. Figure 19 presents results from analysis of household energy requirements for building designs (or archetypes) that incorporate best construction and material practices from a sustainable livelihoods perspective [Matrucci and Rao, 2017]. The requirements are computed using building-level simulations with the EnergyPlus software, for selected cities from the Indus and Zambezi regions. Future work will assess the current building stock in each basin to derive corresponding future trajectories for building energy use that reflect a transition towards decent living standards.

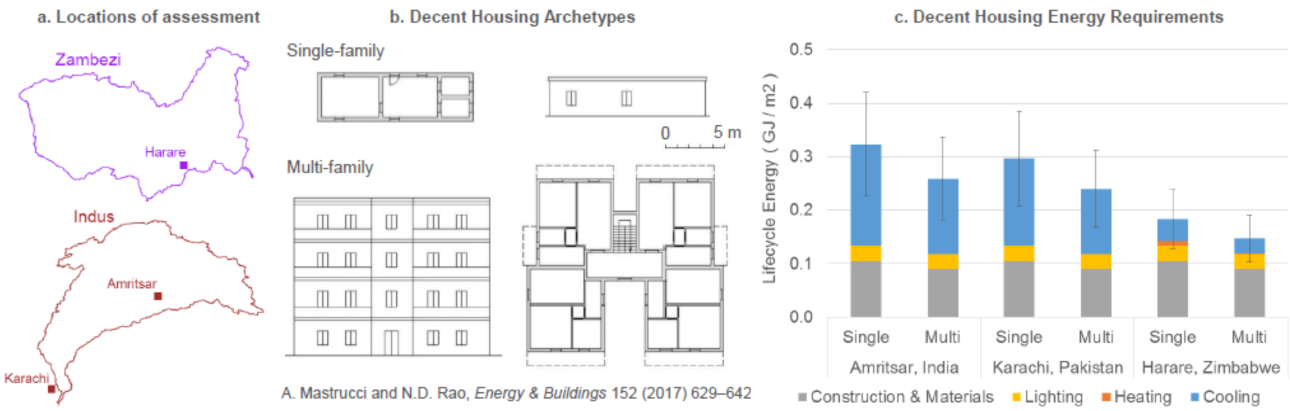


Figure 19 Projected building energy requirements for housing archetypes aligned with decent living standards in different prominent urban areas from the case study basins.

Further ongoing analysis is focused on household fuel choice in the case study basins. The transition from wood/charcoal fuels to modern forms of energy, such as electricity and liquefied natural gas, will provide a number of benefits in terms of reduced air pollution and upstream forestry/land-use impacts [Dlamini et al., 2016]. The assessment of cooking fuels incorporates results from the MESSAGE-Access framework, which is a fuel choice model calibrated to household expenditure surveys compiled for countries throughout the developing world [Cameron et al., 2016]. The framework determines the cost of subsidies needed to protect low-income populations from price changes induced by increasing infrastructure costs. Future work will focus on downscaling regional results (Figure 20) to match the spatial scale in the basin tool, and projecting fuel choices under changing policies.

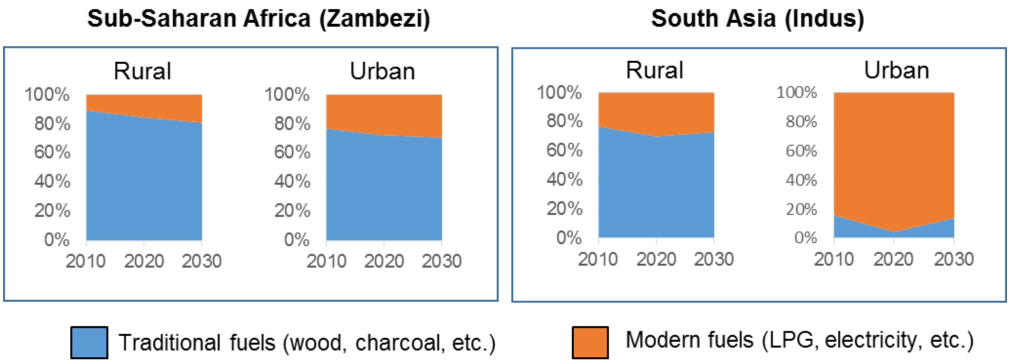


Figure 20 Household fuel choice projections for Sub-Saharan Africa and South Asia based on a mid-range socioeconomic development scenario.

Domestic water demands have also been assessed in the context of clean water and sanitation targets aligned with the UN's Sustainable Development Goals (SDG). Using maps of population, urbanization and income projections (i.e. output from 1.1), the analysis identifies the anticipated capacity of water distribution and wastewater treatment facilities required to ensure the SDG targets for universal access by 2030 are achieved. The framework has been applied globally, and Figure 21a depicts the modeled number of people connected to piped water access and wastewater collection relative to a baseline scenario in which the additional SDG water access policies are removed. The results are aggregated into basin ecological regions in Figure 21b to highlight overlaps with water scarcity. It can be seen, for example, that regions of the Indus and Zambezi basins face multiple challenges in meeting the clean water and sanitation objectives because of existing water scarcity combined with a wide universal access gap projected for 2030. Future work will integrate the projections for clean water and sanitation access into ECHO to ensure the required investment and energy inputs are accounted for in a consistent way.

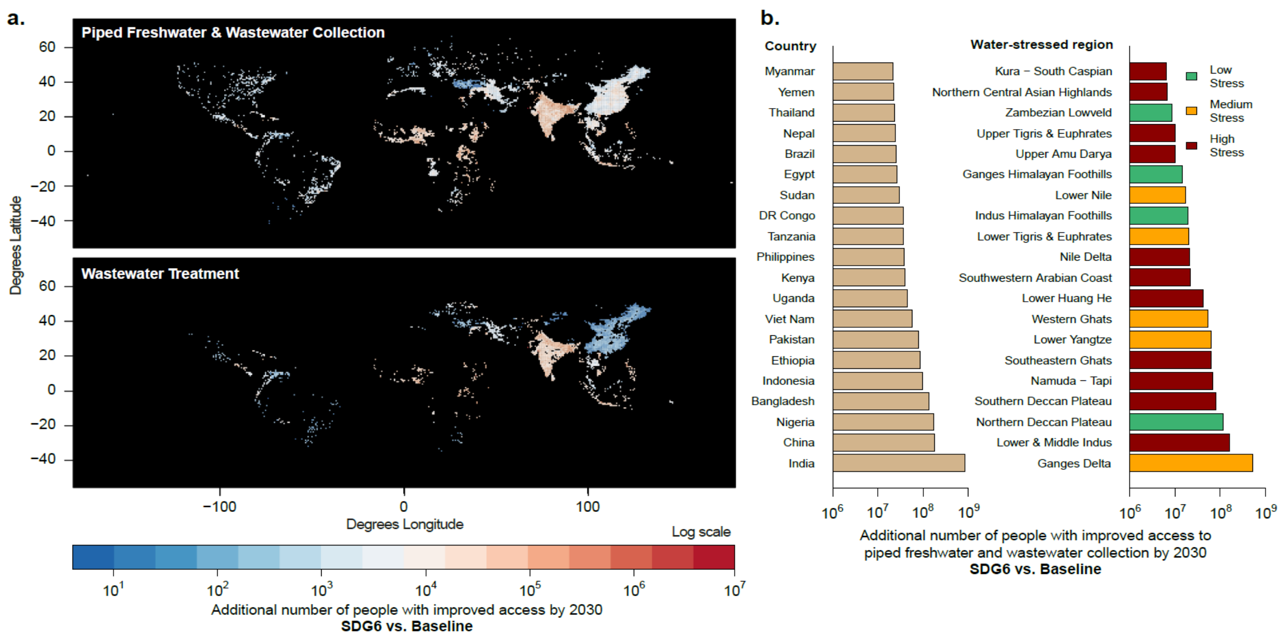


Figure 21 Comparison between projected piped water access and wastewater treatment rates under the water SDG (SDG6) and baseline water policy scenarios. a. Differences in population with piped water access and wastewater collection aggregated by country and water stressed river basin in the SDG6 scenario relative to the baseline scenario; and b. Spatially-

explicit differences between projected piped water access and water treatment levels in the SDG6 scenario relative to the baseline scenario.

Concurrent to the development of the water and energy consumption projections has been the assessment of available resources within each basin. The expected performance of wind and solar technologies as distributed electricity generation sources were determined using an interactive database (Figure 22) [renewables. Ninja, 2017]. Future work will identify cost-effective locations for project siting by incorporating other criteria including topography and existing infrastructure (transmission). Future work will also include the development and application of a similar approach to the costing of new hydropower and reservoir systems in the case study basins.

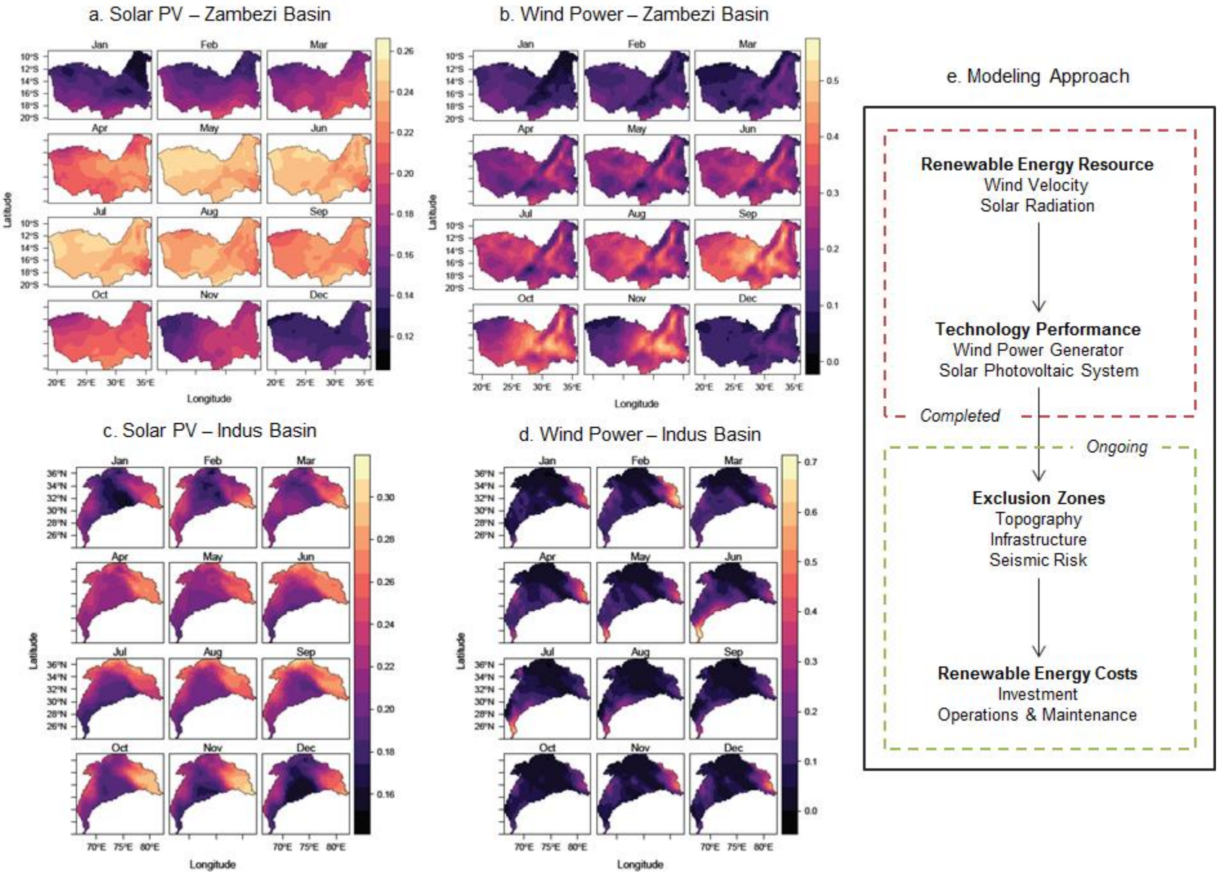


Figure 22 Monthly wind and solar power generation capacity factor estimated in each basin and the approach used to quantify implementation costs.

ECHO also requires estimates of water resource availability, and these are provided through a direct linkage to the CWatM. Specifically, the run-off and baseflow trajectories simulated with CWatM at a high spatial resolution (0.5 degrees) have been processed to define average inflow scenarios for the catchments represented in the basin tool. Moreover, the estimates of water withdrawal and return flow volumes are harmonized to the projections used in CWatM. This provides a consistent framework for estimating adaptation responses with ECHO to water scarcity metrics modeled with CWatM. Future work will downscale adapted water demands from ECHO into CWatM to explore the implications for hydrological systems at a high resolution. Presumptive environmental flow standards for both surface and groundwater extractions will also be subsequently derived based on the unmanaged inflows estimated for each catchment [Richter et al., 2012; Gleeson and Ricther, 2017]. In future work, the presumptive standards will be used in ECHO to identify pathways and investment strategies that maintain water supplies and environmental flows.

Water quality metrics are also being derived based on hydrologic simulations with CWatM to provide a more complete view of the constraints on infrastructure. Figure 23 depicts average daily water temperature results obtained for countries located in the Indus basin [Wanders et al., 2018]. Future work in ISWEL will apply this information to derive maximum bounds on the operation and expansion of power plants that require water for cooling. The bounds push ECHO to consider pathways that involve alternative cooling technologies (e.g., air cooling), relocation of thermal power plants to other catchments with more water, or switching to an entirely new generation technology to avoid water use.

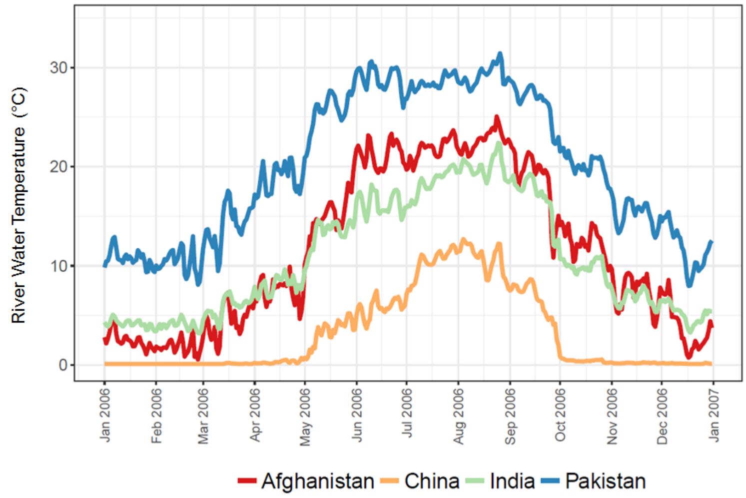


Figure 23 Average daily river water temperature trajectories in the Indus Basin distinguished by country

An understanding of the current and historical situation is also crucial to developing long-term infrastructure strategies with the basin tool. For water and energy systems, this means collecting relevant data on the type, location and age of existing technologies in each case study basin. Major strides have been made in the collection and harmonization of regional water and energy data in the ISWEL project. This work has included a review of national, regional and local planning documents to identify existing and planned projects. Figure 24 depicts data collected for the power sector in Pakistan, and compares it to results from a global database. Ongoing interactions with stakeholders in the engagement and capacity development activities will continue to be used to assure the most up-to-date data are included.

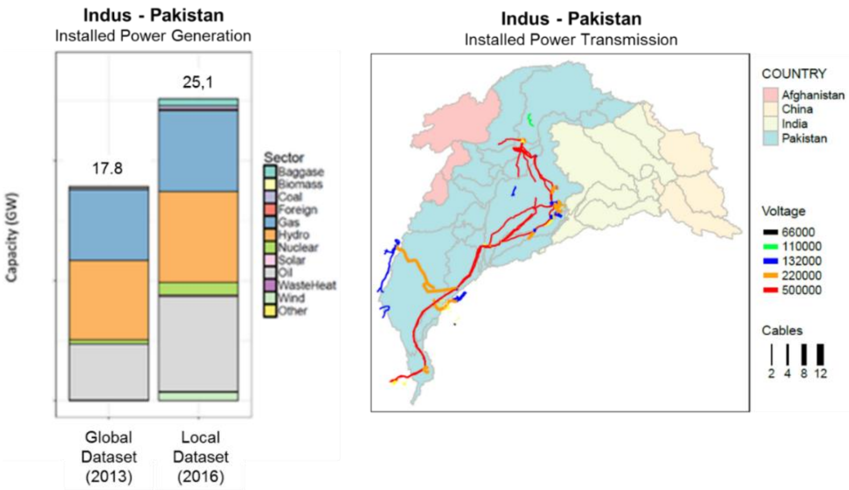


Figure 24. Power generation capacity in the Indus Basin from different sources

In summary, work completed on ECHO has thus far focused mainly on the collection, modeling and harmonization of data related to resource availability, consumption and existing infrastructure. Upcoming work will focus on finalizing the input datasets and producing initial scenarios with the integrated framework. Ultimately, ECHO will be used with the co-developed scenario narratives from the stakeholder engagement activities. This will support outcome 2.1.1 of the ISWEL project: the identification of tangible strategies for improving regional decision-making across sectors and borders identified for the two selected.

In terms of next steps, effort will be placed in year 2 of the project into the development of:

1. Fuel choice and electricity demand scenarios aligned with decent living standards.
2. Hydropower potential, reservoir siting and costing of renewable energy technologies.
3. Implementation of transformation scenarios for the case study basins.

Agro-economic system

Improvements in GLOBIOM during year one have been focused on: 1) the development of the irrigation module, 2) enhancing the representation of localized water constrains, 3) exploring options to include the energy requirements of the agricultural sector for cultivation, irrigation, water pumping and fertilizer production, and 4) the representation of biodiversity impacts linked land use changes. A detailed description of the individual improvements is provided below.

Irrigation water demand and enhanced representation of water constrains

The model development and improvements to the representation of the spatial and temporal nature of water demand and supply within GLOBIOM builds on the work from Sauer et al. (2010). Water balance for irrigation was made spatially explicit for both the irrigation water demand and water supply availability, and considers now the source of water used for irrigation and seasonality of water and can reflect the impacts of socioeconomic change and climate change.

Figure 25 presents the conceptual framework for representing water scarcity within GLOBIOM which connects simulations of various process-based biophysical crop/hydrological models to estimate the irrigation water demand (IWD) and net water availability (NWA) by land unit.

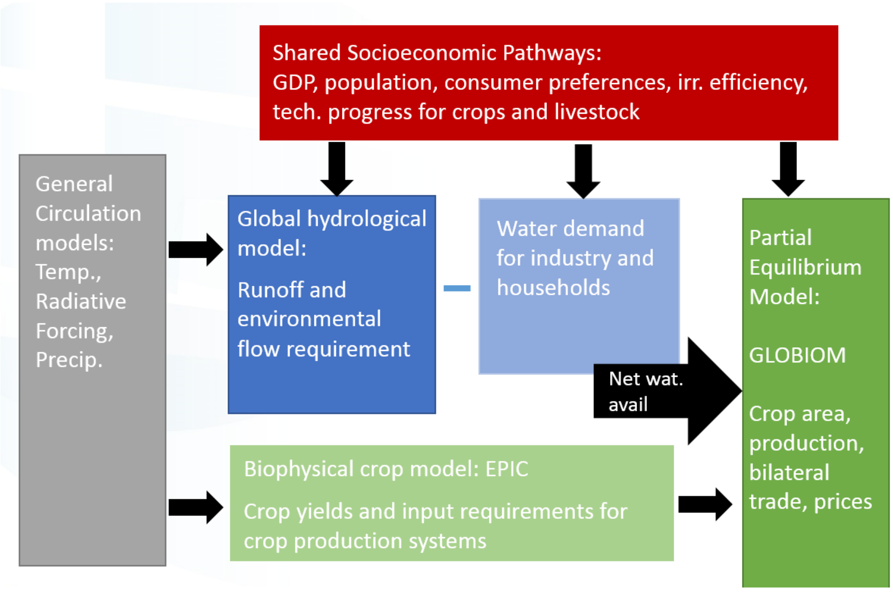


Figure 25 Conceptual framework for representing biophysical water availability and irrigation demand within a global land use model (adapted from Pastor et al. in review).

Monthly surface water availability is simulated from 2000 to 2050 at a 0.5° x 0.5° spatial resolution using the LPJmL global hydrological model (Bondeau et al., 2007; Gerten et al., 2004) at the moment, with plans to use the Community Water Model (CWatM) once the model is ready. To use within the GLOBIOM spatial resolution the mean monthly runoff is estimated by aggregating according to the average discharge rates in each river basin. Additionally, runoff is estimated under the conditions of temperature, radiative forcing, and precipitation from different GCMs to consider the impact of climate change with respect to changes in water availability.

Using the spatially explicit map of irrigated areas source from groundwater from Siebert et al. (2010), the share of irrigated area at the 0.5-degree level sourced by surface water and groundwater was determined. Using the shares and the irrigation water demand, the total volume of water demanded by each source on a yearly basis was calculated and estimated. The use of groundwater over the growing period based on the share of irrigation water requirements that cannot be met by surface water due to limited monthly stream flows. If the available groundwater is in excess of the surface water deficit, the model distributes the excess groundwater supply according to the monthly demand for water. Non-renewable withdrawals were calculated as the water deficit that cannot be fulfilled by surface water or groundwater in year 2000. The amount of water withdrawal coming from groundwater and nonrenewable sources is assumed to remain constant over time.

Irrigation water requirements at the monthly level were calculated using the model EPIC (Outcome 1.1), which were harmonized for base year to match the water demands from Aquastat (FAO 2016), using the irrigated cropland area dataset available from SPAM (You and Wood, 2006) to inform the irrigated area by crop. In the current modeling framework agriculture is the residual user of water, demand for water for domestic and industry/energy take priority over agriculture. The Water Futures and Solutions fast-track modeling effort was used to model water demand from domestic and industrial users for SSPs 1-3 for two global water demand models (WaterGap and PCR-GLOBWB) (Wada et al. 2016). It was found that these other sectoral demands are important to consider as they can in some cases exceed the current and future water availability in some locations (Figure 26). The quantity of water needed to maintain and protect the environment (environmental flow requirement) were also included, and looked at the impacts of excluding this water from the water available for use by agriculture for irrigation. Pastor et al (in review) outlines our work that examined the food security impacts of protecting environmental flows and how trade can be a mitigating factor to reduce the negative impacts reduced water availability either from climate change or from protections of streamflows (Figure 27 and Figure 29).

Alternatively, an index was developed to identify locations (or hotspots) where demand for water for irrigation would exceed the quantity of water for environmental flows, which we call the Agricultural Water Exploitation Index (AEWI) (Figure 28). While this index addresses only the exploitation of surface water, it was found that

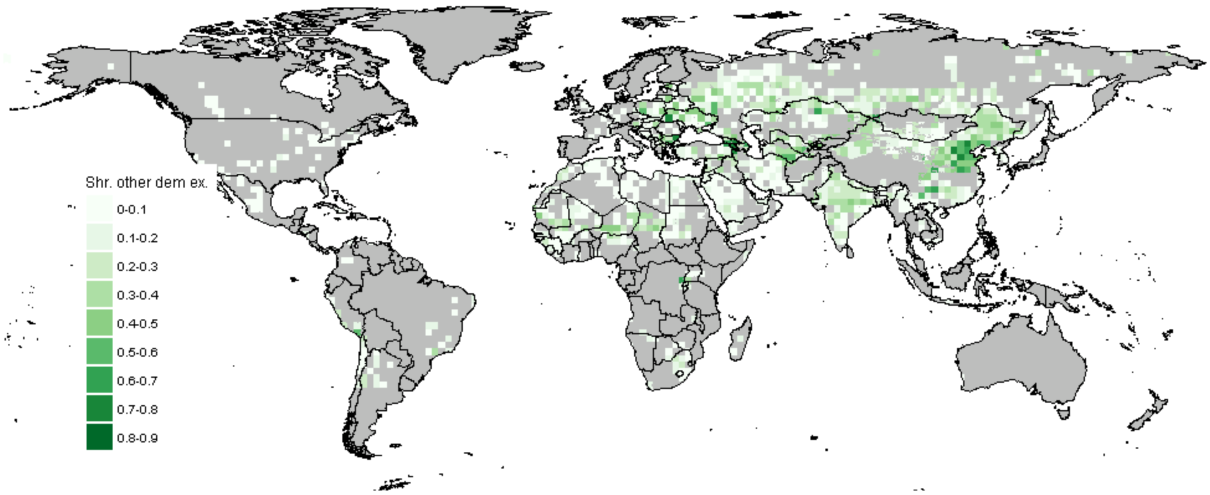


Figure 26 Other share of domestic and industrial water use that exceeds the water available in 2050 for SSP3

exploitation increases in some areas of significant irrigated crop production in the US, India, and China, while in others exploitation shifts to new areas or decreases over time due to the shifting of irrigated agricultural production to areas where water is less scarce. Likewise, it was also found that future impacts from climate change may increase annual precipitation levels but not always when it can be utilized by agriculture, highlighting the importance in considering the temporal nature of water supply and demand. This work was presented at the Impacts World Conference in 2017 and a paper discussing more detailed conclusions is in preparation to be submitted by the end of 2017.

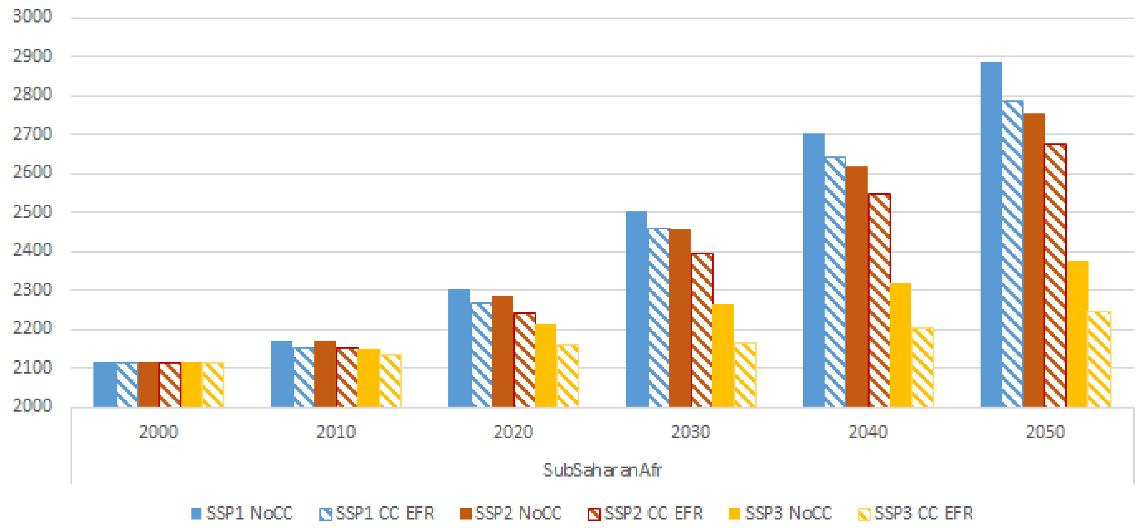


Figure 27 Kilocalorie availability per capita per day in sub-Saharan Africa under various SSPs and climate impacts and scenarios of protections of environmental flow requirements of surface water.

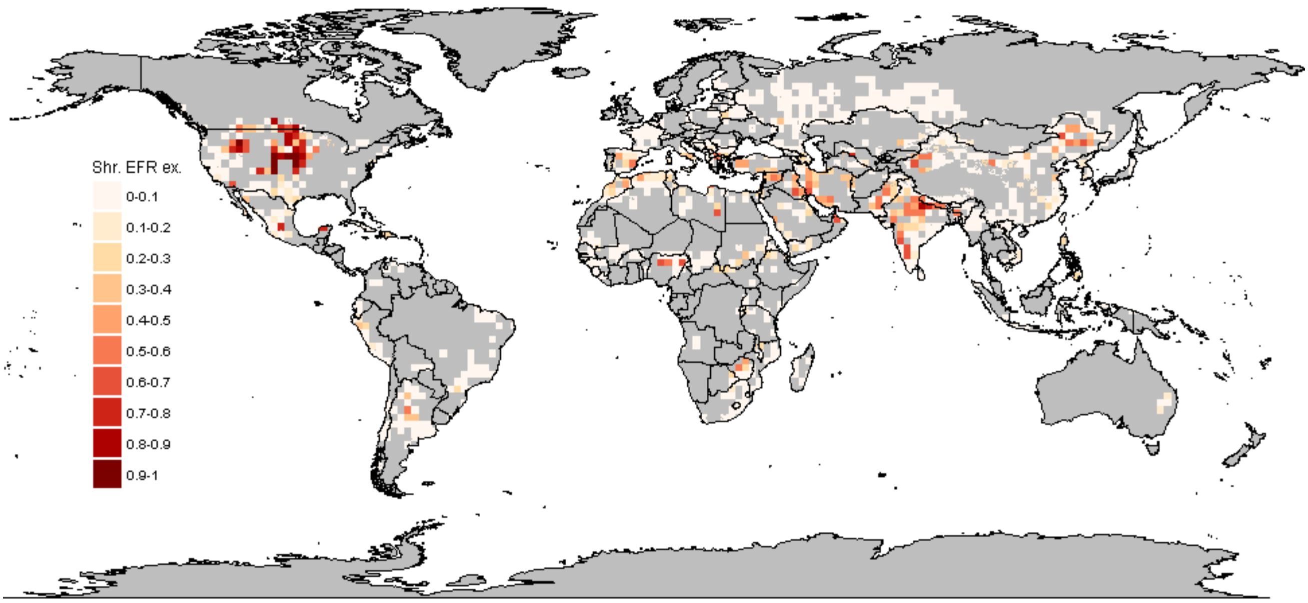


Figure 28 Agricultural Water Exploitation Index (AWEI) for SSP3 (RCP 8.5)

The Agricultural water exploitation index (AWEI) is defined as the share of the environmental flow requirement of surface water exceeded by irrigation demand (aggregated from the monthly levels).

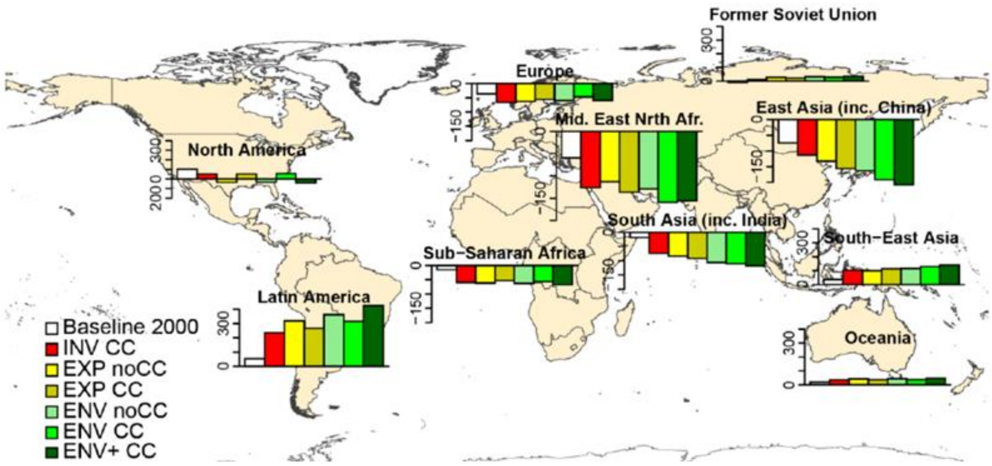


Figure 29 Net exports of crop products under various climate and water availability scenarios

Energy demand for agriculture

Another important input for agricultural production is energy. Energy is used directly for agricultural management activities and indirectly via the application of other inputs in agriculture. Fertilizer production, for example, is very energy intensive and irrigation consumes large amount of energy.

The high dependence of modern agriculture on energy inputs creates significant risks for future agricultural production and thus global food security due to the increasing volatility of energy prices (Woods et al., 2010; Pelletier et al., 2011).

The relation between agricultural production and energy use is complex and often non-linear (Pelletier et al., 2011). Thus, impacts resulting from energy price changes in the agricultural sector are an important feedback loop to be accounted for in the nexus modelling framework.

To improve the representation of energy demands within GLOBIOM, we started explicitly integrating energy costs of agricultural production processes in the land use model GLOBIOM. As first steps, suitable and accessible data sources have been reviewed and a conceptual framework is under development. A “prototype” version is planned to be ready second trimester for 2018.

Impacts of land use on biodiversity

Earth’s biodiversity is degrading rapidly, to the point that it has been suggested that humans are directly observing the Earth’s sixth mass extinction. In contrast to the previous mass extinctions, the current decline in biodiversity is owed mostly to anthropogenic factors, the recent rapid land use and land cover changes (LULCC) being the largest single driver of habitat loss and degradation. The projected future LULCC are expected to potentially significantly worsen such trends, and it is therefore important to be able to estimate such impacts.

A new indicator was developed to account for biodiversity impacts associated with future land use and cover change estimated with the GLOBIOM. As illustrated in the Figure 30, the method uses the spatially explicit LULCC projected for particular scenarios by the GLOBIOM model and further downscaled to 5 arcmin spatial resolution. A quantification of the biodiversity impacts for five taxa (amphibians, birds, mammals, reptiles and plants) was made using a state of the art version of one of the most robust models in ecology, linking the habitat area available to the number of species it can host (species-area relationships).

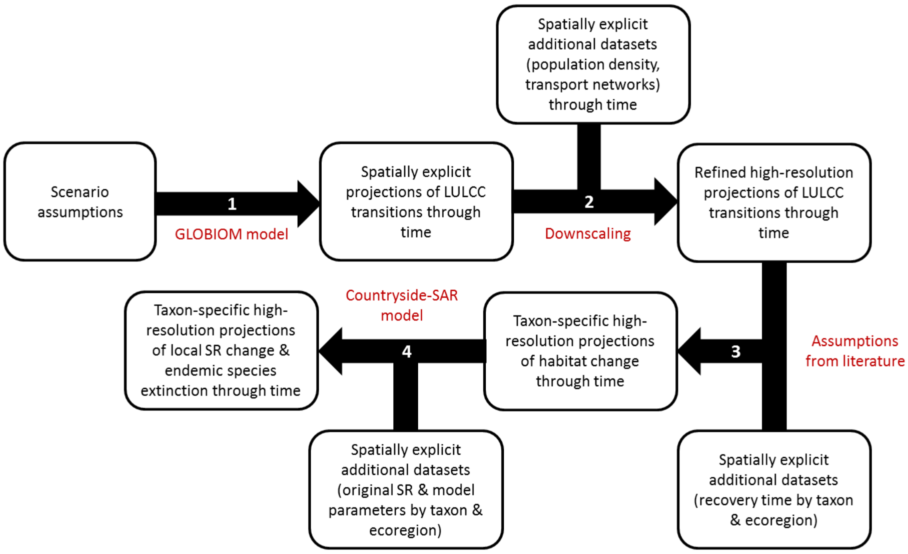


Figure 30 Illustration of the modelling framework used for diagnosing biodiversity impacts form future land use change projections

Preliminary results for 11 scenarios were analyzed spanning various combinations of RCP and SSP scenarios, so to provide an estimate of losses in biodiversity for these 5 taxa. These results were presented at the Impacts World 2017 conference (Potsdam, Germany, 11th-13th October 2017). As illustrated in Figure 31, future trends indicate a modest but robust decrease in the globally averaged number of species. The spatially explicit nature of results also allows to diagnose the hotspots of robust losses to biodiversity across all scenarios and taxa (see Figure 32). A simplified indicator (increase in total agricultural land as a proxy for habitat degradation) was used in the global hotspot analysis paper.

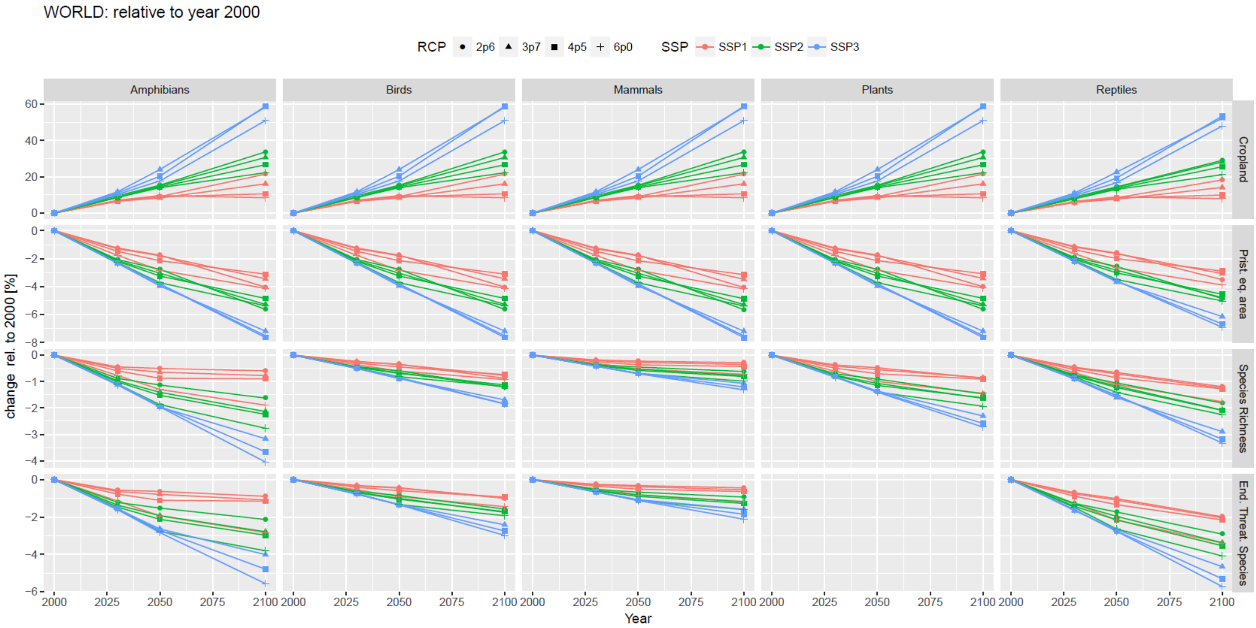


Figure 31 Illustration of land-use change induced global trends in the average number of species across various scenarios (SSPs and RCPs) and taxa (amphibians, birds, mammals, reptiles and plants) [preliminary results].

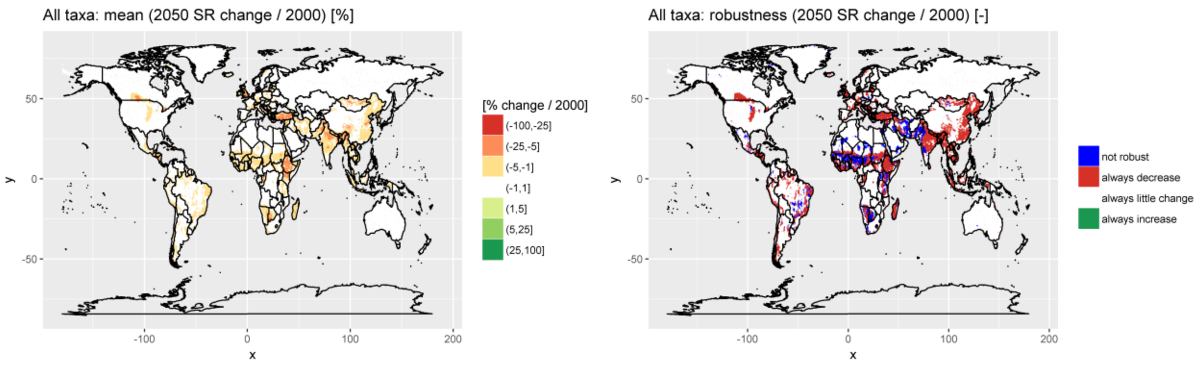


Figure 32 Illustration of hotspots of land-use change induced changes in species richness (left panel – average impact across scenarios and taxa; right panel – robustness of changes across taxa and scenarios).

Nutrient balance of croplands

Intensification through increased fertilizer application since the end of World War II has led to a doubling of the amount of reactive nitrogen in the Earth's surface. Strong concentration of reactive nitrogen in the freshwater and marine water streams of intensified production areas like China, Europe and Northern America have significant impact on their ecosystems through eutrophication. Yet, increased fertilizer application is suggested as one of the ways to further increase productivity and close yield gaps in many developing countries. It is therefore important to estimate the associated risks with reactive nitrogen

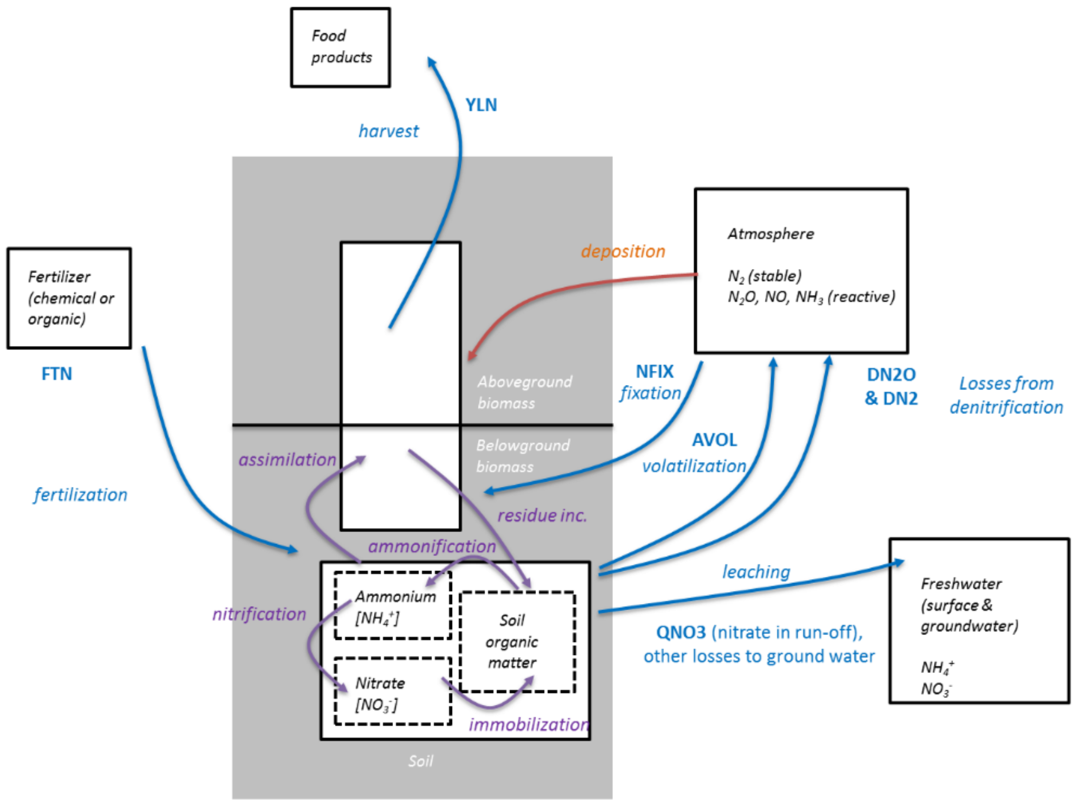


Figure 33 Illustration of the various nitrogen flows of cropland estimated with the EPIC crop model. Brown color indicates flows not accounted for in the hypercube simulations, while purple (resp. blue) colors depict fluxes exchanged within cropland (resp. between cropland and the environment).

To estimate those risks, reactive nitrogen flows associated were estimated based on the future changes to cropland extent and intensity as projected by GLOBIOM. The EPIC was used to quantify the various fluxes of reactive nitrogen associated with cropland fertilization (see Figure 34) from 19 crops and 15 management scenarios (hypercube simulations). These estimates were associated with the future location and extent of the various crops and cropping systems as estimated by GLOBIOM (and further downscaled, see previous sections) to provide spatially explicit assessment of changes in reactive nitrogen flows from cropland (see Figure 34) for an example of changes in nitrate leaching to freshwater systems, averaged over 3 SSPs for RCP4.5).

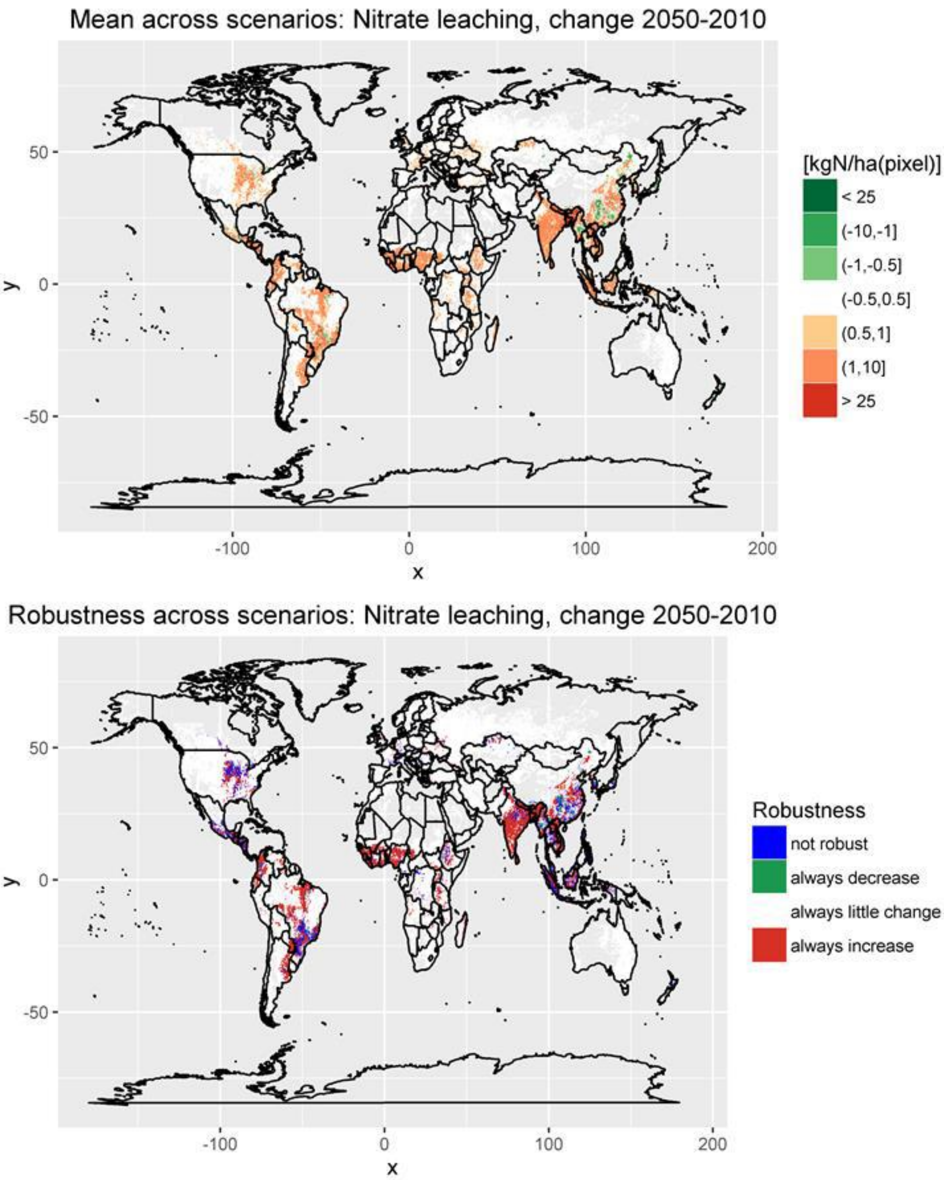


Figure 34 Illustration of hotspots of changes in reactive nitrogen flows (here nitrate leaching) associated with future changes in the extent and management of cropland.

Scenario projections of nitrogen flows take into account the expected increase in yield through technological progress (as an effect of assumptions of how GDP trends translate in R&D expenditures in the agricultural sector). Scenarios specific assumptions are also considered with respect to the amount of additional fertilizer is required to sustain these yield gains. Although all quantities are expected to increase in the future, results highlight contrasted trends with respect to additional fertilizer application translates into losses of reactive nitrogen to the environment (see Figure 35). These indicators were used for the hotspot assessment (output 2.2.1).

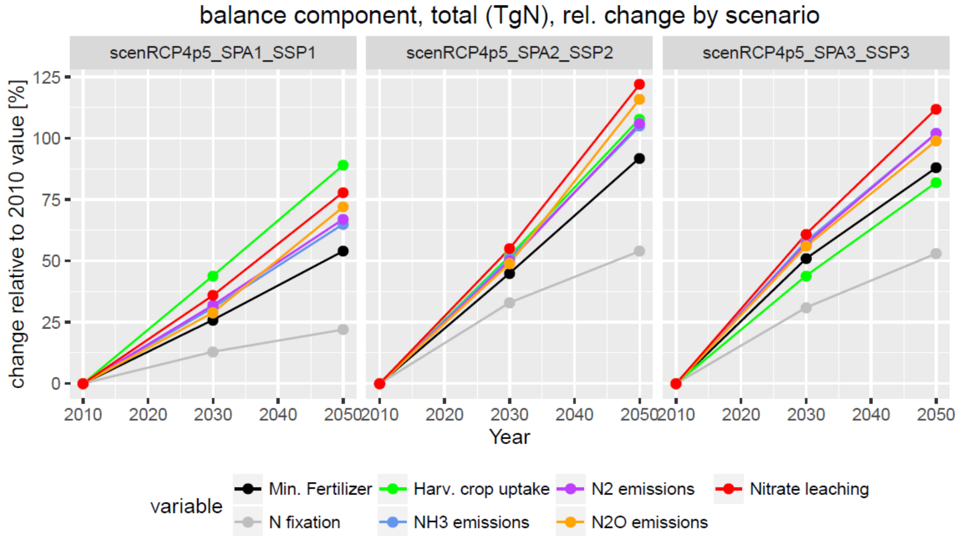


Figure 35 Illustration of global trends in nitrogen flows of cropland for 3 SSP scenarios (for RCP4.5).

BASIN

To model land/water use change and food security scenarios for the Zambezi and Indus river basin, the aim is to run GLOBIOM at the Simulation Unit (SimU) level, which is the highest possible resolution. SimUs are homogenous land use simulation units of between 10x10 and 50x50 km, defined by altitude, slope, soil, agro-ecological zone, and country boundary. Figure 36 show the SimU resolution for the Zambezi and Indus river basins in GLOBIOM.

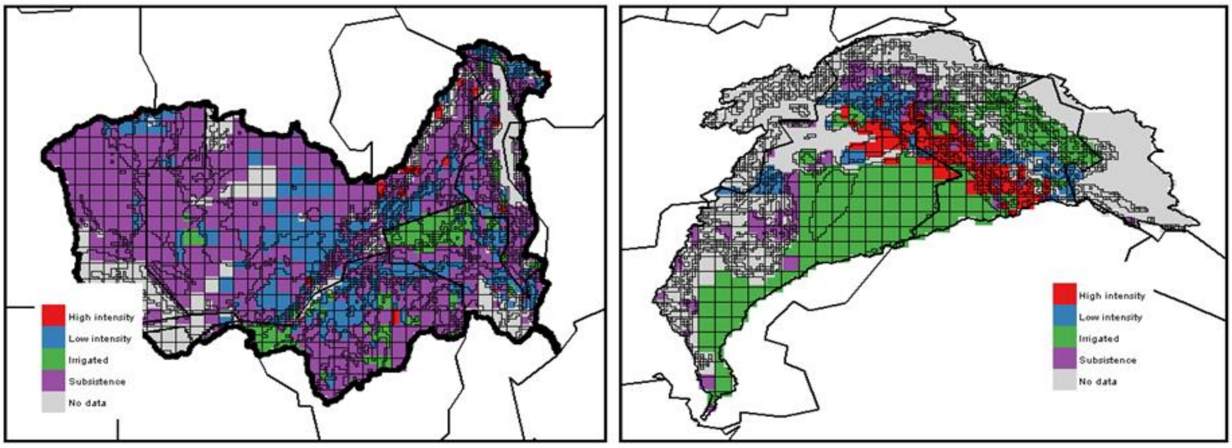


Figure 36 Zambezi (left) and Indus (right) river basin simulation units (SimU) by dominant crop management system

While spatial resolution of the supply side activities of the models is based on the land units described above, the resolution of the demand side activities such as food demand, trade, and regional prices remain at the regional level. To model the basins, the first step was to extract the countries within each of the basins from larger subcontinental aggregations to form new basin-country regions which allows to aggregate the economic activities and behaviors of the basin countries while still keeping within the global consistency of the model. For countries for which only a portion of the land area falls within the two case study basins, the country portions of the land area were allocated to appropriate hydro-basins, and which are then informed by basin-level information such as surface water availability. The normal version of GLOBIOM considers 30 regions, which means that two additional regions were added.

Using the new regional groupings, a set of exploratory scenarios were conducted to examine the behavior of the regions under future drivers from the SSPs and stakeholder development scenarios. The drivers we included in our exploratory scenarios included population, GDP, tech change, demand for water from other sectors such as domestic and industry and irrigation water application efficiency and increased water storage for three SSPs. We also combined these with impacts from climate change on crop yields, nutrient requirements and irrigation water requirements as well climate impacts on surface water availability. This is discussed in more detail for both the Zambezi and Indus basin in Section 2.1.

To better model future land use changes at a high spatial resolution, it is essential to have information on the location and size of crop areas in the base year (2000 and 2010). At the moment GLOBIOM uses global Spatial Production Allocation Model (SPAM) maps from the International Food Policy Research Institute (IFPRI) as input which are considered too coarse for a detailed regional assessment and discussions with stakeholders. To improve the base year land use data for GLOBIOM a downscaling model is developed that uses a similar approach as SPAM but is able to incorporate detailed information on the location of irrigated areas, high-resolution land use maps and subnational agricultural statistics too produce high-resolution (1x1 km) land use maps for around 40 crops in the base year. Additional information from national household surveys are used to validate the land use maps.

A first version of the model is ready and has been tested for Malawi for which high-quality data is available (Figure 37). The total procedure is coded in R and GAMS programing languages, which makes it relatively easy to add other Zambezi and Indus basin countries. Draft results for Zambia are currently being produced and a part of the necessary data (subnational agricultural statistics, land use maps and irrigation information) has already been collected for Zimbabwe, Angola and Tanzania.

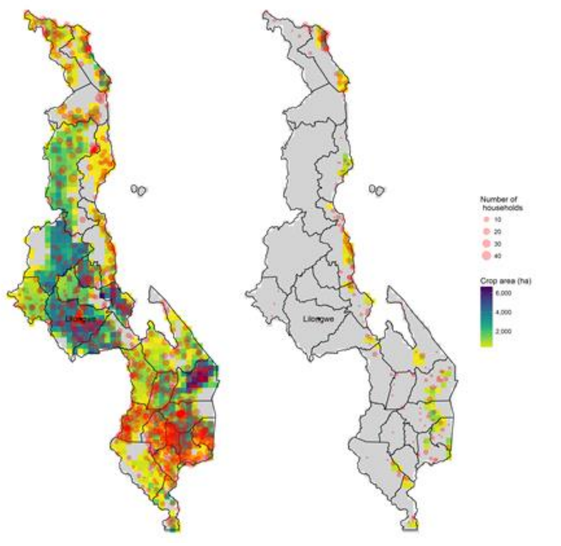


Figure 37 Maize and rice land use maps for Malawi compared with household survey information

Model Integration

Summary: The main output of component 1.2 is the development of a System Assessment Framework (SAF) capable of jointly modelling water, energy and land demands and cross sectorial impacts at the global and regional level. In order to build the SAF, within this task, respective WEL integrated assessment models have been developed at global and regional level. The long-established energy-economic model (MESSAGE) and the agro-economic system model (GLOBIOM) are both being upgraded in order to contribute to the integrated nexus modeling framework developed for the project. Similarly, a new global and regional scale hydrological model (Community Water Model; CWatM) has been developed to provide water system boundaries. One important innovative aspect within this task is to provide a global and regional scale hydro-economic model (ECHO) that represents water resource systems, infrastructure, management options and associated economic values in an integrated manner. ECHO includes an economic-hydrologic optimization procedure that aims to balance water demand and supply at the level of large-scale river basins worldwide, suited specifically for regional nexus assessment. After model development and improvement, all model will contribute to build the integrated system analysis framework.

Progress by Month 12: Currently, extensive discussion how to establish effective linkage among the WEL nexus models is underway. The main objective is to provide system boundary conditions and associated inputs for each model in order to examine potential feedback among the water, energy and land sectors. Within the system analysis framework future scenarios (pending with regional stakeholder activities and feedback) will be eventually used to evaluate possible integrated solutions for water, energy and land, considering potential trade-offs, synergies and co-benefits at the global and the regional scales (i.e., Indus and Zambezi). Integrated scenario and solution assessments will highlight hidden trade-offs, that may cause undesirable impacts on one sector. For example, increased demands for low-carbon biofuels may lead to higher water demands and land competition for food production, subsequently increasing water scarcity and reducing water availability for ecosystems.

After series of technical meetings, the ISWEL team has now established how best to integrate the four nexus models (MESSAGE, GLOBIOM, CWatM, and ECHO). Due to the complexity nature of individual nexus models, we have determined to establish the linkage among the models with key nexus model parameters related to agriculture, energy, water and economy such as agricultural water productivity, cropping practice, irrigation efficiency, water recycling, energy supply structure and associated water demands, hydropower, water supply and water stress, desalination, and wastewater (Figure 38). These examples of key parameter exchange among the nexus models, which will be harmonized under the same future scenario simulation in order to depict possible development and solution pathways, and associated trade-offs, synergies, and co-benefits for the Zambezi and the Indus. A technical parameter sheet was produced describing how the parameter exchange among the different nexus models is established. This technical parameter sheet serves a look up table how each model exchange different parameters, i.e. outputs of respective models serve as inputs for corresponding models, and vice versa. This soft-linkage is the first step to develop a fully coupled and integrated assessment tool, which could be explored in the next phase of the project.

The integrated model simulation for the Zambezi and the Indus is being developed and the current status is as follows. The nexus models will run twice. The first run serves as generating necessary output variables for corresponding models under the same future scenarios with harmonized key nexus parameters. The future scenarios for the Zambezi and the Indus will be developed in consultation with regional stakeholders, and the ISWEL modeling team will closely communicate with the stakeholder team. For the second runs, each nexus model obtains the input parameters from corresponding models (i.e., output parameters), for example, CWatM gets irrigation water demand from GLOBIOM, or energy water demand from MESSAGE. Then, all models run again with harmonized and exchanged parameters to see the feedback among the different nexus models. ECHO would need to work on possible future solutions or development pathways during this second run, to estimate, e.g. the investment costs required to reduce water scarcity under the business-as-usual scenario (tentative; pending with stakeholder feedback) to the sustainability scenario (tentative; pending with stakeholder feedback), or increasing food production from one scenario to another. These improvements and developments of respective WEL nexus models are well underway.

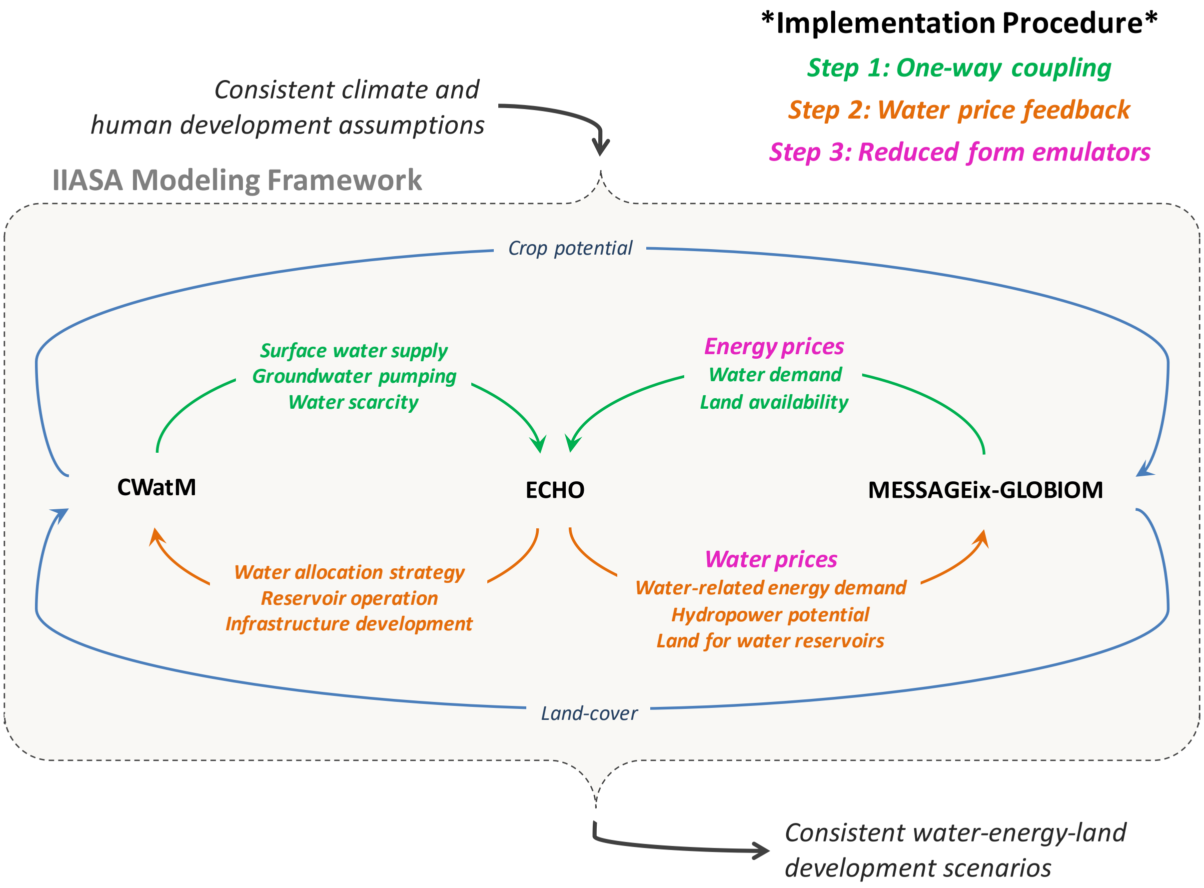


Figure 38. Architecture of the Systems Analysis Framework developed for ISWEL

Component 2. Exploring nexus solutions at global and regional scales

Outcome 2.1 Regional assessment of nexus challenges and solutions

Summary: The main output linked to this outcome is the identification of tangible strategies for improving regional decision-making across sectors and borders identified for two basins. Building such strategies will require engaging with stakeholders in the basins to: (1) define the regional challenges and potential solutions; (2) providing feedback on interim approaches and results; (3) translate final insights to policy and investment strategies that can help guide decision-making within their respective organizations on regional, national, and sub-national levels; and 4) identifying primary data to be collected in the future.

Progress by Month 12: Most progress during year 1 have been focused on desktop study of potential solutions, in particular the (multidimensional) assessment of technological solutions. The goal of this assessment is to perform a multidimensional analysis of a selected number of technologies that show relevant trade-offs/synergies between sectors, in order to provide data as an input to the regional assessment modelling of nexus solutions in the two basins.

Multidimensional assessment of technological options

Key *Outputs and milestones achieved*

- 3 spreadsheets (1 per technology) containing the results and data generated through the technological trends analysis.
- 1 spreadsheet containing the desalination nexus indicators database assessed for the three desalination technologies.
- A draft scientific paper describing the nexus indicators framework and the results of the assessment for the desalination technologies. This paper is expected to be finalized and submitted by early 2018.

The *objectives* set for this task and *attained results* are the following.

1. ***Initial identification and selection of a set of representative technologies***

The first objective was to establish a subset of representative technologies that can exert high potential impacts on the management of the water-energy-land nexus, either negative (high resource use, crossed-effects or environmental impacts) or positive (resource efficiency, synergies between technologies or reduced externalities). The selection criteria applied included the following: 1) technologies with relevance for the three nexus dimensions (water, energy and land use); 2) examples that span both supply and end-use technologies; 3) technologies that are well advanced in their formative phase and have reached some degree of market diffusion. A preliminary selection of two technological groups, desalination (supply technology) and irrigation systems (end use technology), comprise the first set of analyses. The selection was driven by data availability, the widespread applicability and the substantial changes and improvements possible in these two important nexus technologies.

2. ***Definition of analysis dimensions and a framework of indicators for technological nexus assessment***

The multidimensional analysis is organized in two sections: first, an analysis of technological trends and, second, an analysis of nexus trade-offs and synergies through a set of assessment indicators.

- Technological trends analysis

The analysis consists of the collection and representation of data on the historical evolution of several technological variables and the mathematical regression models that allow understanding of their dynamics and can be used for predictions of future development. The selected technological variables are the following.

Technology growth and deployment**:** the extent and timing of industrial growth and deployment by main market regions reached as well as the unit scale dynamics are described through technology diffusion growth curves.

Economic aspects including the following:

- *Time evolution of investment costs*: evolution of investment costs over time.
- *Economies of scale* represented as the evolution of capital costs in function of unit size or industry production capacity depending on the type of technology.
- *Learning by doing/using* makes reference to the improvements achieved through the continuous replication and improvement of the manufacturing process and/or use of the technologies. The effect of learning by doing/using on costs is estimated by representing the evolution of descaled investment costs - costs treated such that the effects of economies of scale are removed - over installed units and obtaining the learning rate.

- Indicators to assess technological nexus trade-offs and synergies

A framework and set of impact indicators that characterizes the nexus synergies and trade-offs generated by the selected technologies has been defined. The indicators span nexus resource inputs and outputs, including greenhouse gas emissions, and resource quality. The assessment is done through consultation of literature, global databases and ISWEL's team data, and presents the information in a consistent and homogeneous format. The outputs are compiled in a set of spreadsheet like databases for the different technologies.

3. Analysis of the first set of technologies – Desalination

Desalination technologies are mainly divided into two technological groups: 1) thermal technologies, which use thermal energy to heat and distillate saline water into desalinated water, and 2) membrane technologies, which use the capacity of membranes to retain salts and the differences in osmotic pressure as the basis for the desalination process. The multidimensional analysis of desalination has been focused on three technologies: Multi-effect distillation (MED) and Multiflash distillation (MSF) as main representatives of the thermal group, and Reverse Osmosis (RO), the most relevant within the membrane group. These three technologies have reached the highest technological maturity within the sector and together sum 92.7% of global installed desalination capacity (Alvarado-Revilla, 2015). Data for the analyses were obtained from GWI's Desaldata database.

A summary of the most relevant results obtained from the technological trends analysis is provided in **Figure 39**, **Figure 40**, and **Figure 41** and **Table 6** Economies of scale parameters for desalination technologies and **Table 7**.

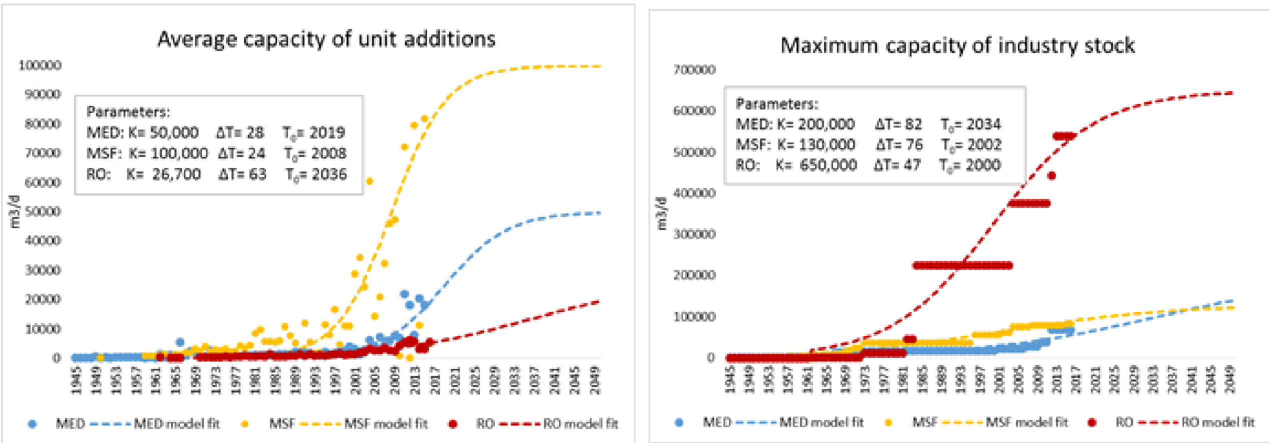


Figure 39 Diffusion of cumulative installed capacity (m^3/d) and installed units of desalination technologies

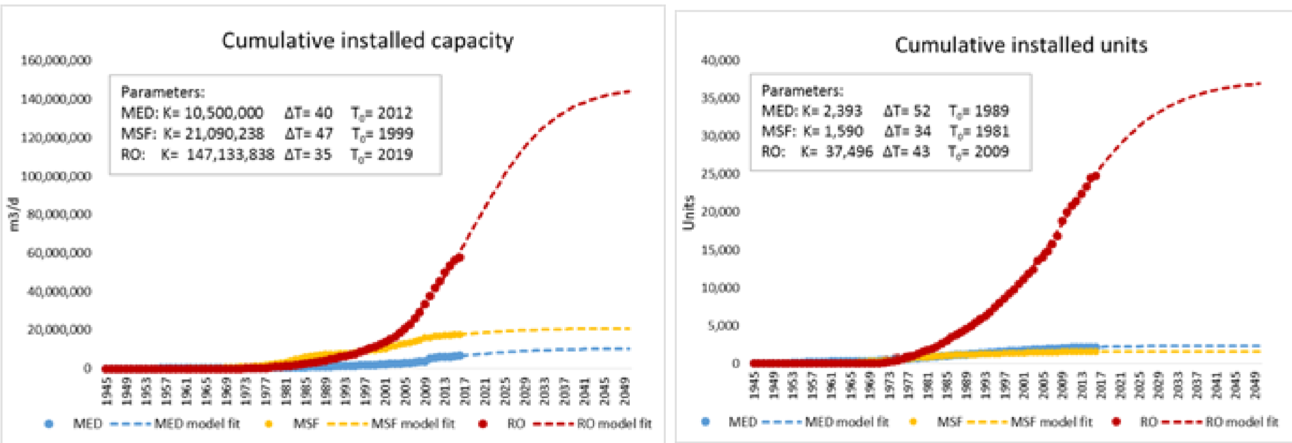


Figure 40 Scaling dynamics of desalination technologies

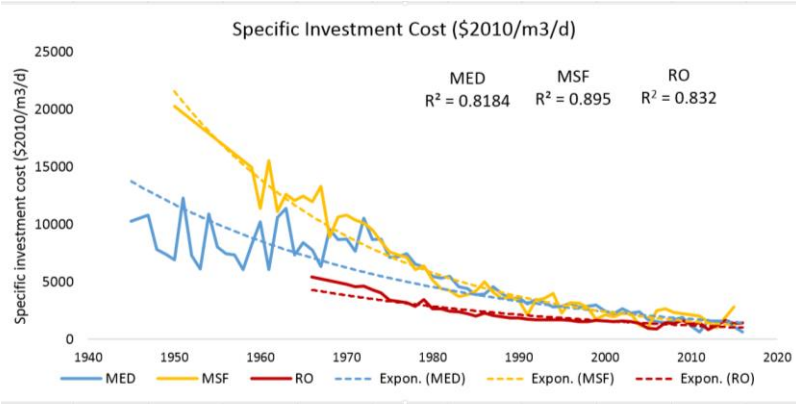


Figure 41 Temporal evolution of specific investment costs

Table 6 Economies of scale parameters for desalination technologies

Technology	Scale parameter	R^2
MED	0.71	0.72
MSF	0.82	0.88
RO	0.89	0.83

Table 7 Learning rates for desalination technologies

Technology	Initial stage		High growth period	
	Learning rate	R^2	Learning rate	R^2
MED	2%	0.35	22%	0.96
MSF	2%	0.46	30%	0.96
RO	1%	0.66	10%	0.95

Figure 39 and **Figure 40** show the historical growth data registered by the three desalination technologies at the industry and unit scales as well as the logistic functions fitted to the data and function parameters. The logistic fits (dashed lines) are extrapolated to 2050 providing a projection of future industry and unit size evolution. The analysis shows that MED and MSF are currently close to saturation, and will probably achieve their industrial deployment peak before 2030 with cumulative installed capacities of 10.5 and 21 million cubic meters per day respectively. Parallel, average size of unit additions are expected to continue the current growth trend towards large scale projects until stabilizing in the near future at capacity levels around 50,000 and 100,000 m3/d respectively. Results in tables 6 and 7 show that these technologies have benefitted from significant economies of scale (0.7 and 0.8 respectively, being 0.6 considered maximum economies of scale and values over 1 non-existing economies of scale) and learning rates (22% and 30% respectively) explaining the considerable specific investment cost reductions registered over the last 5 decades and reflected in **Figure 41**. Such an evolution and the closeness to saturation of these technologies suggests limited room for further learning in the future. Reverse Osmosis results point at an earlier stage in the technology lifecycle with more substantial growth and diffusion prospects. Following the technology growth curve, the intense increase in deployment of reverse osmosis projects should continue over the next two decades only approaching saturation by 2050 with cumulative installed capacities close to 147 billion cubic meters. Meanwhile, despite the unit upscaling process at the capacity frontier has been more pronounced than in thermal technologies, with a few giant projects

implemented, the average capacities of unit additions over time have increased at a much lower pace, and may stay around 20,000 m3/d by 2050. RO also exhibits lower economies of scale (0.89) than thermal technologies due to its modular configuration, and has experimented a learning rate of 10% presumably closely linked to a reduction in membrane costs and technical improvements. However, the prospective technology diffusion expected for the next two decades suggests that learning processes will continue to occur allowing for further capital cost reductions.

Using the obtained economies of scale and learning parameters, a series of cost projection scenarios to 2020, 2030 y 2050 were generated for the three technologies. In the baseline scenario assuming a logistic growth trend, projected costs would decrease by 12% for RO and by 10% for thermal technologies assuming no further learning for the latter. These projections were used in the MESSAGE-ECHO to conduct the assessment and related publication on SDG pathways (Parkinson et al., 2017).

N*ext steps* planned for year 2 include:

1. Submission for publication of scientific articles on desalination trends and nexus indicators applied to desalination.
2. Performance of the multi-dimensional analysis applied to irrigation technologies
3. Performance of the multi-dimensional analysis applied to a third technological set, preliminary wastewater treatment technologies.

Outcome 2.2 Global nexus hotspots and transformation pathways

Short description: The purpose is to apply the systems analysis framework developed in sub-component 1.2 to carry a comprehensive global assessment of global nexus hotspots and solutions. This global assessment will have two main applications. Firstly, the identification of multi-sectoral vulnerability hotspots and how these resource scarce hotspots may evolve under different socio-economic and hydro-climate scenarios as a result of the implementation of various response strategies (e.g. technological solutions). The second application is the exploration of nexus dynamics and how those might impact global transformation pathways.

Progress by Month 12: Efforts in year one has been dedicated to the development of a fast-track assessment of multi-sectoral vulnerability hotpots assessment under different climate and socioeconomic scenarios. A detailed description of the outputs of this assessment is provided below.

Global exposure and vulnerability to multi-sector hotspots

This hotspots section comprises two main components:

1. **Synthesis of the global multi-sector hotspots analysis**. This synthesis summarizes a more extensive piece of work that assesses global population exposure and vulnerability to multi-sector climate risks, across water, energy and land sectors. It is the first climate impacts assessment of its kind to use gridded projections of vulnerability, represented as an income level and developed in this project (Outputs of sub-component 1.1). More detailed version of this work is available in Annex 2, as a draft paper submitted for review (Annex 2a)) and the Supplementary Information to the paper (Annex 2b)).
2. **Discussion and proposed analysis for second phase of the nexus hotspots analysis.** This discusses the proposed analyses for individual sectors and indicators, different dimensions of vulnerability, country and basin scale analyses, dashboard development and more detailed policy analysis for solutions.

Background to climate impacts and vulnerability

The 21st century will see the global population increase from 7.5 billion in 2017 to an expected 8.5-10 billion in 2050 (KC & Lutz, 2014). Future populations will be exposed to a range of climate change hazards of varying intensities that will vary from place to place, with some 'hotspots' exposed to more risks than others, compounding the challenges (Diffenbaugh & Giorgi, 2012; Diffenbaugh, Giorgi, Raymond, & Bi, 2007; Piontek et al., 2014). Risks are not just dependent on the severity of climate change and subsequent hazards but critically on the population's spatial distribution (exposure) and their vulnerability and capacity to prepare for and manage changing risks (IPCC, 2012). Increasingly studies are showing that the world's poorest are disproportionately exposed to changes in temperature extremes (Harrington et al., 2016; Herold, Alexander, Green, & Donat, 2017) and challenging hydro-climatic complexity (Hall et al., 2014; Yusuke Satoh et al., 2017; Tramberend et al., 2017).

In 2011, there were an estimated 767 million people living in extreme poverty with income of less than $1.9 USD per day, with a total of 4.2 billion (bi) classified as vulnerable to poverty living on less than $10 USD per day (World Bank, 2017) vulnerable to poverty; this category and income level specifically captures the fraction of population that lack "economic stability and resilience to shocks that characterizes middle-class households" (López-Calva & Ortiz-Juarez, 2013; World Bank, 2013).

- The most optimistic scenarios project up to an 85% reduction in the vulnerable population to 616 million by 2050, for example with very good progress on the SDGs.
- However in a high inequality scenario, the vulnerable population could still be as high as 4.0 billion in 2050, even whilst the majority prosper (Gidden, Rao, Parkinson, & Riahi, 2017).
- Even with low to moderate levels of climate change of 1.5° or 2.0° global mean temperature (GMT) above pre-industrial conditions, the goals of the 2015 Paris Agreement (2015), the extent of exposed and vulnerable population in an unequal society could be substantial.

To understand the scale of this problem in the future, the exposure of future global and vulnerable populations to multi-sector climate impact hotspots must be assessed to inform effective, integrated policy responses.

Study framework

Our objective is to assess the exposure of global and vulnerable populations to overlapping multi-sectoral hotspots. This work investigates how multi-sector risk changes with higher levels of global mean temperature (GMT) rise and to what extent socioeconomic development and poverty reduction can reduce risks.

This work is assessed across the following dimensions:

- 14 indicators (see Table 8), developed for this project using state-of-the-art global models, grouped within 3 sectors (water, energy and land)
- Climate change scenarios for historical (1971-2000), 1.5°, 2.0° and 3.0°C global mean temperature rise above the pre-industrial conditions, applied to the indicator datasets
- 3 socioeconomic scenarios from the Shared Socioeconomic Pathways (SSPs 1-3), with projections of population, GDP and income available to 2100 and gridded to 0.125° resolution (approx. 10km at the equator)
- Exposure of the global population, and exposure of the vulnerable population (i.e. income < $10 /day) (other income levels will be done in follow up work)
- Global coverage at 0.5° (approx. 50km at the equator) resolution over land, with regional aggregations as per the IPCC 27 SREX land region definitions.

The general structure of this work and methods includes:

1. Development of 14 indicators across water, energy, and land sectors (**Table 8**).

2. Aggregation of the indicators and risks using new and established methods to produce sectoral multi-sector risk hotspot maps, compared for 1.5°, 2.0° and 3.0° changes in GMT above pre-industrial conditions (see **Figure 42** Sectoral score (0-3) maps for 2.0°C GMT warming scenario. On the left columns the individual indicators are shown. Right column is the sectoral scores. N.B. that only 4 of the 6 water indicators are shown.
3. Assessment of the exposure of the global and vulnerable population (income <$10 per day) using three socioeconomic projections from the Shared Socioeconomic Pathways (SSPs 1-3). Results are presented at global grid and IPCC region scales.

In this section the central scenarios based on a 2.0°C climate with 2050 population projections from SSP2 will be presented. For the multi-sector hotspots, the global and vulnerable exposure across SSPs and GMT change dimensions for 2050 were assessed to present a better understanding of the dynamics between socioeconomic development and risks at different levels of warming.

Table 8 Water, energy and land indicators and associated model combinations used in the study. GCMs is General Circulation Models, GHMs is Global Hydrological Models. See Annex 2a) Methods and Annex 2b) Supporting Information (SI) for full details and references.

Indicator	Description and methods	Models
Water		
Water stress index	Water stress index (w1) as a fraction of net annual human-economic water demands (irrigation, industry, households) relative to available renewable surface water supply (18), as derived in the Water Futures and Solutions initiative (19).	5 GCMs, 3 GHMs
Non-renewable groundwater stress index	Non-renewable groundwater stress index (w2) is calculated as the fraction of total annual groundwater abstraction that is non-renewable (abstraction in excess of recharge) using data from Wada and Bierkens (20).	HadGEM2-ES, PCR-GLOBWB
Drought intensity	Drought intensity (w3) change is calculated using daily river discharge deficit volume below Q_{90} over drought event duration, as derived in Wanders and Wada (21).	5 GCMs, 5 GHMs
Peak flows risk	Peak flows risk (w4) index is derived as locations where there is significant (50%+) ensemble agreement of a doubling or halving of the 20-year return period for river discharge, calculated using Generalized Extreme Value distribution fitting with a block-maxima approach as in Dankers, Arnell (22)	5 GCMs, 4 GHMs
Seasonality	Mean seasonality (w5) is the change in discharge seasonality index. Calculated as the coefficient of variation (standard deviation divided by the mean) of mean monthly discharge, it represents the variability of mean monthly discharge.	5 GCMs, 5 GHMs
Inter-annual variability	Mean inter-annual variability (w6), is the change in inter-annual variability index, calculated as the coefficient of variation of mean annual discharges, it represents the variability of mean annual discharge.	5 GCMs, 5 GHMs
Energy		
Lack of access to clean cooking	Lack of access to clean cooking (e1) fraction is projected from the reference energy scenarios for each SSP on a regional basis (23, 24), then downscaled using projected SSP Salamanca income distribution projections (14) by selecting the poorest population first within each country.	MESSAGE, SSPs, Salamanca
Heat event exposure	Heat event exposure (e2) is calculated as the sum of days from heat events lasting 3 or more consecutive days above the historical 99th percentile daily mean wet bulb air temperature. Only assessed at locations where T_{mean} p99 > 26°C and population density > 10 persons/km^2.	5 GCMs
Cooling demand	Measure of the absolute growth in annual cooling degree days (CDD) (e3) with a set point temperature of 26°C and population density > 10 persons per km^2.	5 GCMs
Hydroclimate risk to power production	Hydroclimate risk to power production (e4) index aggregates the combined hazard of four hydrological indicators, peak flows risk, drought intensity change, seasonality and inter-annual variability to a continuous hazard scale (as used with other indicators). This is multiplied by a capacity score according to the installed capacity in each grid square, using a global dataset of water-dependent thermal and hydro power plant capacity (25-27).	5 GCMs

Land		
Crop yield change	Climate change impact on crop yield (l1) is estimated by the EPIC crop model under for ISIMIP future climate change scenarios (28) for 18 crops and 4 crop managements systems and overlaid with the distribution of crops and systems estimated by GLOBIOM land use model (29) for year 2000 (30) and aggregated across crops and crop management pixels (using calorie content)	5 GCMs, EPIC + GLOBIOM
Agricultural water stress index	Agricultural water stress index (l2) measures the fraction of water stress driven by the agricultural sector by identifying locations where the monthly irrigated water demand is in excess of the water necessary for the environment or (environmental flow requirement, EFR) (31-33)	GLOBIOM + HadGEM2-ES + LPJmL
Habitat degradation	Habitat degradation (l3) is estimated as a % change from the share of land area within a pixel being converted from natural land to agricultural land (cropland and grassland) in the future as simulated by the GLOBIOM model (29, 34)and further downscaled ton 0.5° (35)	GLOBIOM + downscaling
Nitrogen leaching	Nitrate leaching from mineral fertilizer application over cropland (l4) is the flux of nitrate resulting from mineral fertilizer application to cropland and lost to surface water streams as simulated by EPIC (36) for 18 crops and crop management systems, and overlaid with GLOBIOM assumptions on future changes in crop yield and crop input use efficiency (37, 38) and downscaled GLOBIOM distribution projections of crop and crop management systems	GLOBIOM + downscaling + EPIC

Sectoral results

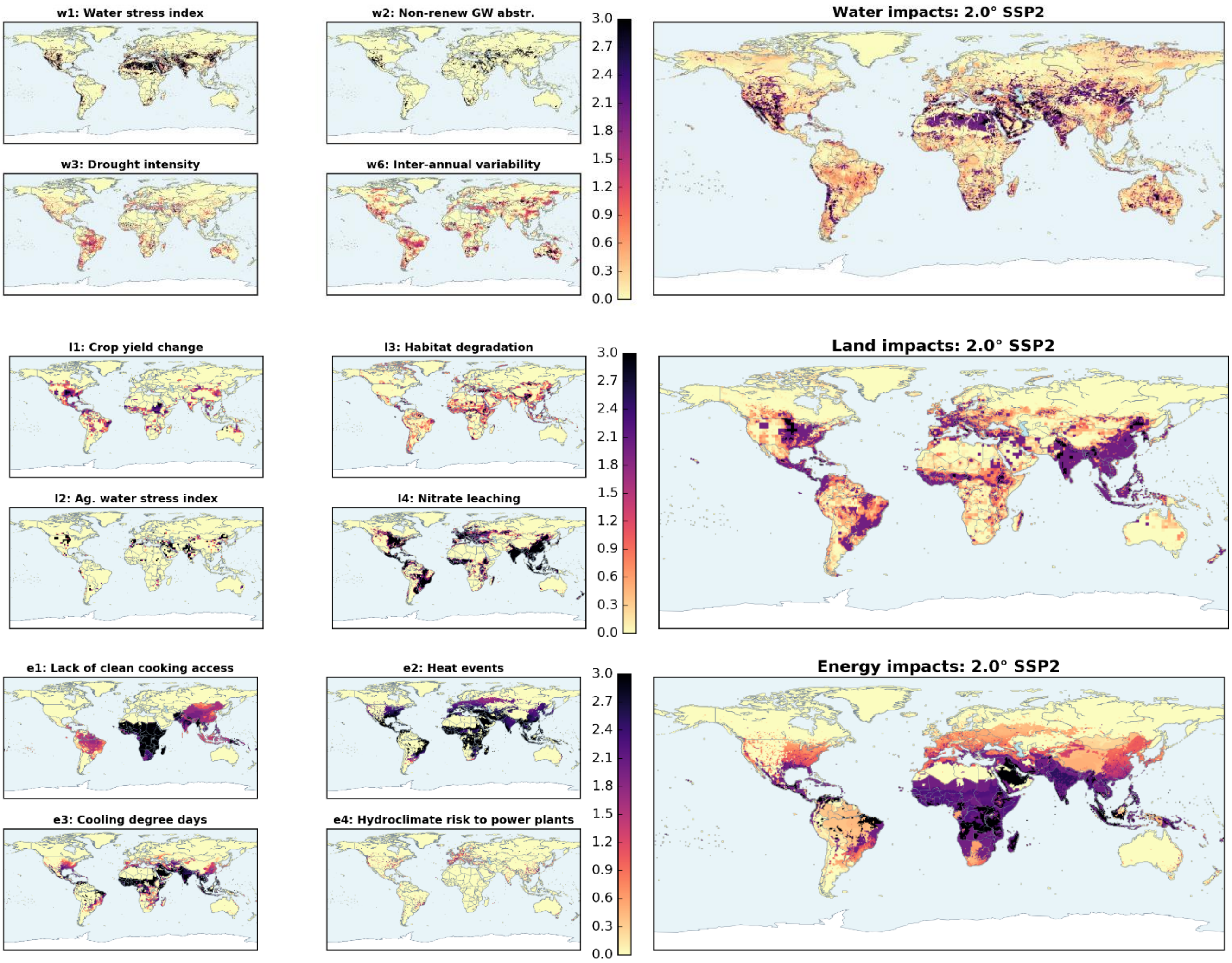


Figure 42 Sectoral score (0-3) maps for 2.0°C GMT warming scenario. On the left columns the individual indicators are shown. Right column is the sectoral scores. N.B. that only 4 of the 6 water indicators are shown.

Water sector indicators have a wide range of risks of varying spatial coverage. Results are driven both by small areas of concentrated, high score indicators (w1, w2, w4) and widespread areas of moderate risk (w3, w5, w6). Water stress (WSI) and groundwater stress indices are in part demand driven and tend to be spatially concentrated in population centres and intense water demand regions, with the latter less widespread than overall WSI. The more bio-physical indicators of drought intensity, inter-annual variability, and seasonality have more widespread risks and affect larger areas of land, including cropland and less populated areas. Arid areas for indicators w3 to w6 were masked out. Areas of particular concern include southwest North America, south east Brazil, north Africa, the Mediterranean, the Middle East, and west, south and east Asia.

Energy sector indicators are strongly driven by locations of higher air temperatures and population density. This is because of both the substantial air temperature changes expected that drive cooling energy demand and heat event exposure, particularly in the tropics. As wet bulb temperature was used for the heat event indicator, higher scores are widespread in warm humid climates. The hydroclimatic risk to power plants indicator is confined to a very small proportion of land grid squares (6%); however, the high correlation of power plants with population density means that the effects are not lost when measuring population exposure. Nonetheless, due to this indicator's sparsity, few locations by spatial extent present high levels of risk, aside from West Africa and Indonesia, driven by low clean cooking access, more heatwaves and higher cooling demands. Large areas present consistently low-medium levels of risk, such as sub-Saharan Africa, the Middle East, South and Southeast Asia and central America.

Land sector impacts are widespread and cover large portions of all continents except Australia. Nitrate leaching is most widespread with many locations exceeding sustainable levels. Reductions in crop yields and habitat degradation also drive the sectoral score. Locations of exploitation of water by the agriculture sector, or irrigation water use that is in excess of what should be left to support the environment, increases in areas already dependent on irrigated agriculture: North America, South Asia, and China. Overall, Midwest United States, southeast Brazil, Ethiopia and South Sudan, the Mediterranean and most of South and Southeast Asia, all present moderately high impacts.

Multi-sector climate risks and global exposure

Multi-sector risk (MSR) occurs at locations where two or more sectors surpass a tolerable level of risk. In this study, the minimum MSR to define a multi-sector risk was assumed to be 4.0. However, results at an MSR≥5.0, with sensitivity at 4.0 and 6.0 are presented (Annex 2b), SI Figures S12-14, S16-21).

For the multi-sector risk scores two main trends that emerge as global mean temperature rises (**Figure 43**). First, the area of land affected by climate risks grows in area, particularly large regions of populated areas (**Figure 43**, **Figure 44**a). At 1.5°C risks are predominantly in South Asia. Secondly, the risks intensifies in some locations, with more MSR heterogeneity and more pronounced differences between the 1.5°C and 3.0°C scenarios, as shown by the wider distribution in **Figure 44**a. For example, at 1.5°C, MSR scores between 4-6 are fairly uniform across small areas, whilst a 3.0°C GMT results in hotspots of high MSR, interspersed with wider areas of moderate risk. High risks occur primarily in Central America, east Africa and west Asia, the Mediterranean, the Middle East and parts of India and east China.

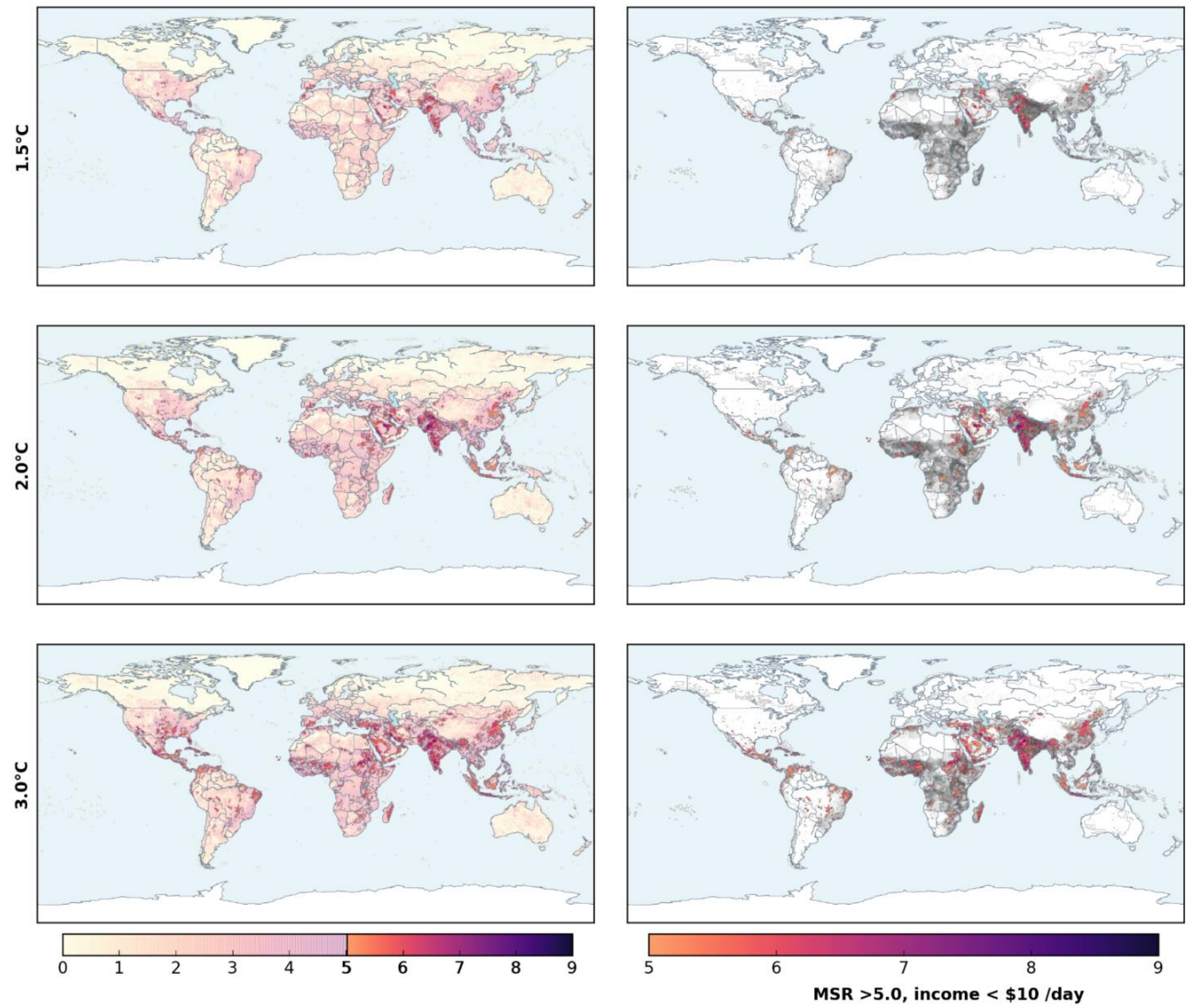


Figure 43 Multi-sector risk maps for 1.5, 2.0 and 3.0°C climates. Left column shows the full score range 0-9 (with transparency) and multi-sector risk score, MSR≥5.0, in full colour. Right column greyscale underlay is the SSP2 2050 vulnerable populations, with the MSR≥5.0 overlaid (only pixels > 4 vulnerable /km^2), indicating the concentrations of exposed and vulnerable populations (E&V). Moderate and high multi-sector impacts are prevalent where vulnerable people live, predominantly in South Asia at 1.5°C, but spreading to sub-Saharan Africa, the Middle East and East Asia at higher warming.

Comparing the macro-regions (Figure 44b), Latin America, Africa and SE Asia & Australasia have at least one region with worse population exposure than the global median (Caribbean, West Africa, Southeast Asia). The exceptions are Asia, where most regions have above global median exposure, and North America and Europe, where all have lower than median exposure. The least exposed region is Alaska and the most exposed regions are Southeast Asia, South Asia and Tibetan Plateau.

Global exposure and vulnerability

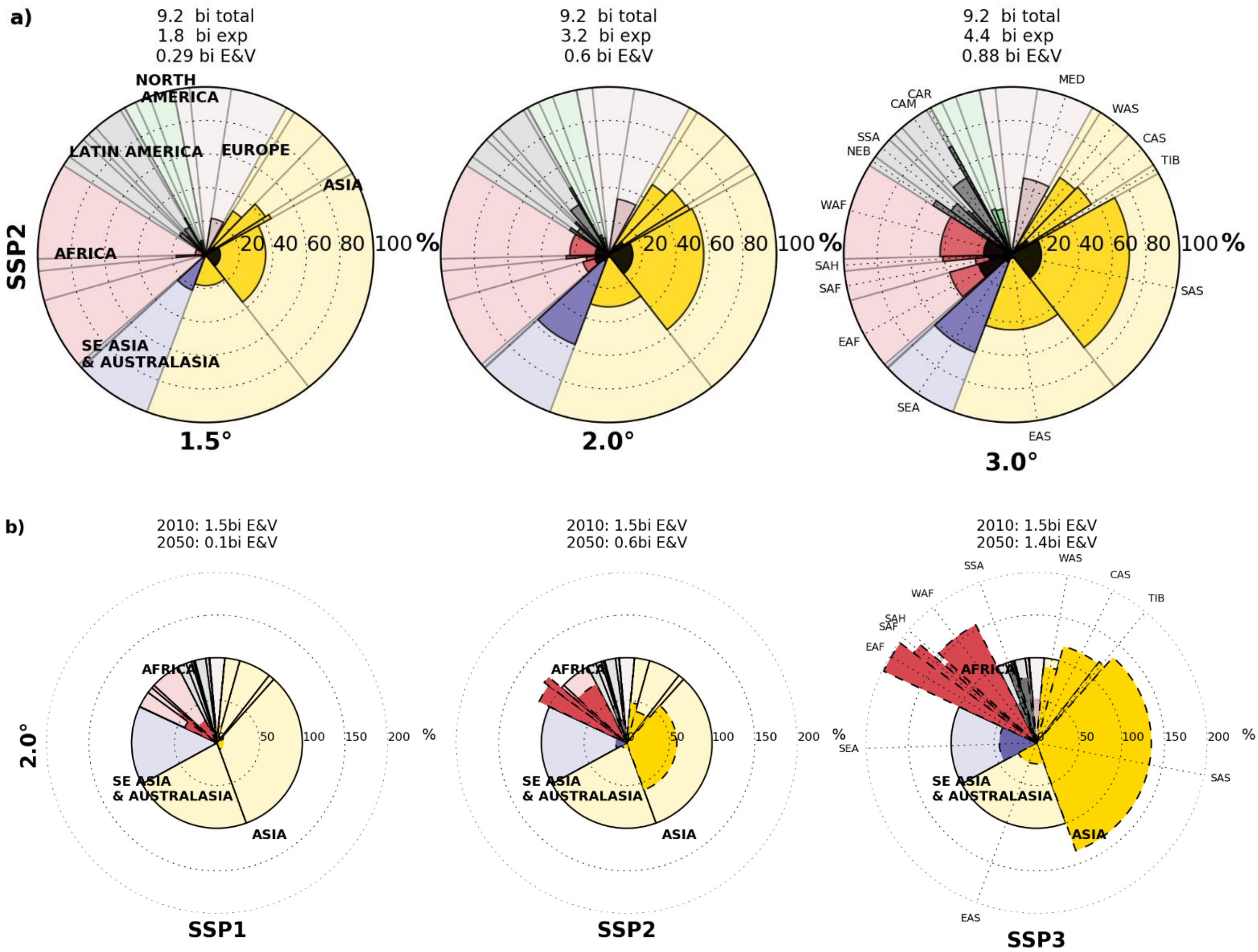


Figure 44 Global population exposure and vulnerability. Upper row (a) background is the total global population in 2050 for SSP2, whilst in the foreground, the fraction of exposed population (MSR ≥ 5.0, strong colours). Black shaded central segments are the exposed and vulnerable (E&V) population. For global exposure, GMT is the dominant driver over SSP population. However, the lower panel (b) shows how important socioeconomic development is for reducing the E&V population. It compares, for a 2.0°C climate, the E&V population in 2010 (background circle), with the projected E&V population in 2050 (foreground segments). Whilst poverty reduction in SSP1 almost eradicates the E&V population in most regions by 2050, SSP3 results in substantial increases compared to 2010 in Asia and Africa due to high levels of inequality

Considering the total global population exposure for MSR ≥ 5.0, the magnitude of global mean temperature rise has a considerably stronger effect than the differences in population growth from the SSPs. Between 1.5°C and 2.0°C, the total population exposure to multi-sector risks increase by 75%, even though there are differences in absolute numbers between the SSPs (Annex 2b) SI Fig S16-18). The level of exposed and vulnerable population (E&V) (black shaded areas **Figure 44**a) increases approximately by 100-133%. At 3.0°C warming, even though impacts are more severe, the number of E&V increases by similar absolute numbers, but less in relative terms. This is largely because the spatial extent of risks does not increase as much between 2-3°C as it does from 1.5-2.0°C (Figure 44). Nonetheless, there are still more vulnerable people exposed to more severe risks.

The benefits of poverty reduction are made clear when the E&V population numbers are compared for different SSPs (**Figure 44**b). Whilst SSP1, and to a large extent SSP2 project widespread poverty reduction, primarily across Asia and Africa, in SSP3 poverty and inequality barely any net improvements are observed between 2010 and

2050. What is achieved in Southeast and East Asia is offset by a growing poor population in Africa and South Asia. Multi-sector climate impacts in Africa and Asia are generally moderate, but some locations, particularly in South, East and West Asia, have some of the highest MSR scores and vulnerable populations (Figure 44). The result is that for SSP3 there is between 7-14x more E&V population compared to SSP1, concentrated in the African and Asian regions with between 25-100% more E&V in 2050 than compared to the 2010.

The largest co-benefits of poverty reduction and climate mitigation are felt by Africa and South Asia. Overall, there is approximately a factor of 20 difference of total E&V population between the best case (SSP1/1.5°C) and worst case (SSP3/3.0°C) scenarios combinations; with MSR=4.0 threshold the difference is factor 16.5, whilst for a high impacts threshold MSR=6.0 the difference is 40x (Annex 2b), SI Figures S16-21). This growing scale factor with MSR threshold shows that in a worst case scenario, higher fractions of a larger vulnerable population will be living in areas of particularly high risk.

Latitude also plays a role in the distribution of impacts (Annex 2b), SI Figure S23), consistently across a number of metrics. Whether assessed by mean score per pixel, cumulative score, land area-weighted or population-weighted impact, latitudes between 40°N to the equator fare worst, southern hemisphere quite poorly, north of 40°N above average. In general, the latitude analysis also shows that, on average, latitude actually has more influence on impact than the different levels of warming, but that differences between the warming levels become more important closer to the equator.

Conclusions

- Although global exposure to multi-sector risks (Figure 44) will affect a relatively small fraction of global land area, the risks to human populations will be large. Between 1.5-3.0°, the increase in exposed population to multi-sector risks more than doubles (1.8-4.4 billion for SSP2), regardless of the SSP. Both the scale of and the differences between these numbers underlines the multi-dimensional risks of climate change that will be experienced across the world regardless of wealth.
- Exposure in Asian regions is the most severe, on proportional and absolute terms, due to the high concentrations of population and the high multi-sector risks of those regions. Asian regions, Africa and Latin America face high proportions of exposed population compared to their total population.
- For populations vulnerable to poverty (E&V), i.e. population with daily incomes of <$10/day, the importance of socioeconomic development is undeniable. Socioeconomic pathways alter the number of E&V by an order of magnitude. Whilst approximately 75% of global exposure falls to Asian and African regions, they have 85-90% of the exposed and vulnerable population, approximately half of which in South Asia.
- As the most undeveloped region, Africa faces worse than most regions, especially in high inequality socioeconomic scenarios and high warming climate scenarios. In higher warming scenarios, African regions have higher fractions of the global E&V population, ranging from 8-21% at 1.5°C, to 29-54% at 3°C.
- The results also indicate that the poorest are also disproportionately impacted by multi-sector risks. Compared to a 1.5°C baseline, the number of exposed and vulnerable scales faster than the exposed population driven by both the warming level and the inequality levels. Further assessments to understand the distributional risks of climate change to different levels of vulnerability are required.
- Climate mitigation alone is not enough to reduce exposure to the world's poorest, who will still be vulnerable to impacts at 1.5°C. Action to rapidly reduce inequality, eradicate poverty and promote proactive adaptation through mechanisms such as the SDGs, would greatly reduce the size of exposed and vulnerable population, especially if co-benefits for climate mitigation also accrue.

Next tasks and activities

Most of the work to date has focused on developing the datasets and developing methods and tools for performing global multi-sector hotspots assessment. The first stage has tested this capability and the aggregation of the indicators and provided an insightful analysis at the global scale.

The next planned steps of the assessment are discussed in the following sections, although are flexible if new insights or recommendations for focus are received.

1. Detailed indicator and sectoral analysis

More detailed analysis of the water, energy and land sectors will be continued for each sector and includes further review of the scoring assumptions. More insights can still be gained from analyzing the water hotspots, energy hotspots and land hotspots in more detail. As already revealed in the analysis, not only are their spatial distributions quite different, but subsequently the exposure of land and population is different. The plan is to develop infographics to communicate these sectoral results better.

2. Climate exposure across dimensions of vulnerability

Up to now the assessment has only thoroughly investigated the exposure of the global population and the "vulnerable" population with income <$10/day. The next steps will involve assessing the changes in exposure at different income levels (e.g. $2, $5, $20) to determine to what extent poorer people are (or are not) more exposed than richer segments of society. This may help ton identify basins and countries where the poor are disproportionately impacted and may best benefit from targeted assistance and adaptation.

3. Basin / country level analyses

The analysis up to now (and presented) has been at 27 IPCC regions that aggregate land pixels within these regions. The team have developed the capability of testing different spatial aggregation options, primarily at the river basin scale, or alternatively country borders. The assessment at the river basin scale will provide an alternative perspective to the IPCC regions, and more suited to identification of nexus challenges. Such assessment will allow to identify the most critical river basins (e.g. table of Top 10 hotspot basins), by both sectoral and multi-sector risks, as well as understand how the Indus and Zambezi compare to other basins.

4. Dashboard development

The spatial data of the hotspots assessment should be well suited to presentation online on a dashboard communication tool. The team is beginning to test out potential online functionalities to understand how online presentation of the hotspots assessment can work as a communication tool, similar to WRI Aquastat, for example. This will provide an accessible presentation of the hotspots assessment with an interactive exploration of the implications for the different sectors.

5. Policy analysis and solutions

The analysis and indicators chosen have relevance to a number of key global development frameworks, primarily the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction. Work will continue to assess in more detail the linkages of our assessment to the goals and indicators of these frameworks (and others) to provide better context for the results.

Component 3: Capacity building and knowledge management

Outcome 3.1 Knowledge and capacity network

Summary: The main output is the establishment of connections and interactions among stakeholders from different organizations and sectors within the basins through the organization of a series of meetings and workshops. Engaging with local stakeholders is seeing as a key feature of this project and should be framed as a two-way process i.e. a process where ISWEL is able to support the development of capacities in nexus research and management, and at the same time the project also benefits from interacting with local/regional in order to have a better understanding of what are key challenges and possible solutions within the basins, as well from the exchange of information.

Progress by Month 12: The majority of the efforts during year 1 have been allocated to identify and establish contacts with existing nexus-related processes and/or leading organizations in the two basins. A description of the stakeholder process designed for the two basins is described below. The outcomes of the first consultation in the Zambezi are also presented.

Stakeholder Strategy

The stakeholder process developed has been designed to engage with a number of stakeholders representing different sectors and riparian countries within each of the basins, with the purpose of:

- Identifying basin challenges, priorities, and trade-offs in relation to water-energy-land nexus
- Build a range of stakeholder informed scenarios of water-energy-land futures to gain understanding of the consequences of different decisions and what opportunities exist to maximize sectorial and transboundary co-benefits
- Support the development of local capacities in nexus research and management
- Cooperate with other organizations and institutions pursuing the implementation of a nexus agenda

According to the project proposal, three stakeholder meetings are planned in each basin back to back with at least two capacity development workshops. The strategy described in the proposal has been further developed and the timeline adjusted given the initial difficulties to establish the partnerships with local organizations. Table 9 provides a summary of activities, expected outputs, possible partners and a timeline. A brief description of each activity is provided below. Table 9 provides a summary of the planned activities, partners and the (tentative) timeline.

The first activity, the so-called "*preparatory phase*", involves the search and establishment of partnerships with organizations leading ongoing process related to basin-wide planning and strategic development. Rather than initiating new processes, it was decided to place the efforts in engaging with good entry points i.e. organizations currently leading basin processes, which could uptake and benefit from ISWEL outcomes. For the Zambezi, it was rapidly identified that a key and suitable entry point to the basin was the Zambezi Watercourse Commission (ZAMCOM). Contacts were initiated in January 2017, and followed by several face-to-face meetings, including the participation of Simon Langan in a meeting organized by the ZAMCOM Secretariat in Tete (Mozambique) in February 2017. This partnership is being now formalized through a Memorandum of Understanding (MoU), which is in the process of being signed in due course. In the Indus, given the absence of a formal basin organization, the strategy has been to try and engage with existing basin process, specifically the Indus Basin Knowledge Platform, supported by the Word Bank, the International Water Management Institute (IWMI), and the International Center for Integrated Mountain Development (ICIMOD). Project Coordinator travelled in July

2017 to Colombo and participated in the first Indus Basin Knowledge Forum to introduce the ISWEL project and establish contacts with basin stakeholders. In parallel, contacts have also been established with country organizations in the Indus including Lahore University Management of Sciences (LUMS) in Pakistan and the Energy and Resources Institute (TERI) in India.

The second activity involves the organization of a *"warming-up"* meeting in each of the two basins with the following goals:

1) strengthening the relationship with local partners (e.g. ZAMCOM, IBKP) and meet with other stakeholders from different sectors and countries, to build new and established partnerships and discuss sectorial and country priorities; and

2) gain a better understanding of what are the key nexus challenges and potential solutions in the basin.

The next section describes the outcomes of the warming up meeting in Zambezi, held in Lusaka between 23-30 September 2017. In the Indus, the planning is to organize two separate country meetings, one in India with the support of TERI and one in Pakistan in collaboration with LUMS, to identify basin needs from their respective national perspectives. These meetings are planned for first trimester of 2018.

The third activity includes the development of a "*Scenario focus group"* workshop with regional experts (researchers and/or government representatives) on water, energy, and land, to discern future trends in resources demand and interlinkages under a range of different socio-economic and hydro-climate scenarios. Each of these scenario workshops will be organized back-to-back with a capacity building workshop. In terms of training, there are two main components considered:

- A) training for young researchers on the development and applications of the nexus modeling tools applied to each basin,
  B) training with regional decision makers using the Nexus Simulation game developed by IIASA followed by a simplified session with a focus on application of IIASA nexus modeling tools.

The 2 options can be combined with regional decision makers participating in option B while young researchers could participate in both, A and B.

In the Zambezi, ISWEL researchers are in dialogue with the Global Water Partnership (GWP) and the African Union Planning and Coordinating Agency (AU-NEPAD) exploring options for organizing the capacity development workshops together. Both organizations are leading projects on capacity development around the Nexus and have shown great interest in cooperating with IIASA. In the Indus, discussions are being held with IBKP and its partner organizations to co-organize the next Basin Forum and take the opportunity to organize the Scenario and Capacity Development workshop for the ISWEL project back-to-back.

The fourth activity includes a "*final meeting"* to present project results to basin partners and other basin organizations, and explore pathways to include ISWEL outputs into the national and/or basin development plans.

In addition to the planned meetings in the two basins, resources will be allocated to sponsor 1-2 talented Ph.D. students from regional research organizations (or citizens from any of the riparian countries), to visit IIASA and contribute to the ISWEL research that is being developed in each of the basins. This scientific exchange will be channeled through the Young Summer Professional Program (YSSP) that IIASA organizes every year. This YSSP provides annually 50 grants for talented Ph.D. students to visit IIASA during a 3-month period and develop a research project under the supervision of IIASA staff. The call for 2018 is currently open, and efforts have been placed to disseminate this opportunity among regional contacts and partner organizations.

Table 9 Implementation of the Stakeholder Process in the Zambezi and Indus

Phase	*Objectives*	*Key Outputs*	*Timeline*	*Key Partners*
Preparation	- Stakeholders analysis, - Initiating contacts with stakeholders and other nexus projects/initiatives, - Preliminary process design	- Draft the Stakeholder Strategy - Partnership with basin/national organizations ZAMBEZI Zambezi Watercourse Commission (ZAMCOM) INDUS Lahore Management Sciences University (LUMS) and The Energy and Resources Institute (TERI), World Bank, IWMI, ICIMOD	January-August 2017	
MEETING 1 *Warming up: building partnerships and Identifying nexus challenges*	- Building relationships: meeting stakeholders, identifying their needs - Building partnerships: other initiatives and projects engaging nexus stakeholders, - Identifying challenges, priorities, and tradeoffs.	- Strengthening existing partnerships and establish new ones ZAMBEZI GWP, AU/NEPAD/JRC, SADC, WWF - Identifying expert group for scenario development - Identifying young researchers (Ph.D. students, Post Docs) to participate in capacity development activities, - Harmonizing stakeholder process inputs and outputs with IIASA modelers from all programs. - Prioritization of nexus challenges in the basin	Zambezi September 2017 Indus March 2018	Zambezi ZAMCOM Indus LUMS & TERI
Meeting 2 *Scenario Focus group and Capacity development workshop*	- Scenario development (expert group) with support from young researchers (as a part of their capacity development), - Capacity development training on nexus modeling and scenario development (participants: young researchers), - Feedback from broader stakeholders group to improve scenarios.	- At least two qualitative regional scenarios (storylines) for the basin with additional quantification for selected key components matching the inputs to the IIASA models. - 8-10 young researchers being trained in the nexus.	Zambezi April 2018 Indus June 2018	Zambezi ZAMCOM, GWP, AU/NEPAD/JRC, SADC, WWF Indus World Bank, IWMI, ICIMOD
Meeting 3 *Final workshop*	- Presentation of scenario modeling results - Lessons learned, assessment of scenario integration into Zambezi Strategic Plan as well as planning processes of other stakeholders, - Capacity development – second stage. - Outlook: continuation and expansion of the process.	- Validated scenario results for the two basins - 8-10 PhD researchers being trained in the nexus.	Zambezi May 2019 Indus June 2019	ZAMCOM, GWP, AU/NEPAD/JRC, SADC, WWF Indus World Bank, IWMI, ICIMOD LUMS, TERI

First stakeholder meeting in the Zambezi

This section describes the activities and outputs of the first stakeholder meeting "Building partnerships and identifying nexus challenges" that ISWEL team organized in the Zambezi. As described in Section 1, the overall purpose of this meeting was to strengthen and build partnerships with regional and riparian organizations in order to: 1) identify priority issues related to cross-sectoral and transboundary cooperation in the areas of water, energy, and land; 2) engage with a number of organizations and experts that could support and contribute to the ISWEL project and benefit from its outcomes.

As a result of the discussions with ZAMCOM, the ISWEL team was invited to participate in the second Zambezi Basin Stakeholder Forum, held in Lusaka on 24-25 September 2017. This invitation was seen as a great opportunity to organize the first field mission to the Zambezi. Accordingly, between 23-30 September 2017, a small delegation of five ISWEL researchers (Simon Langan, Piotr Magnuszewski, Amanda Palazzo, Michiel van Dijk and Barbara Willaarts) and the project manager from UNIDO (Robert Novak), travelled to Lusaka to:

1. Participate and organize a session in the II Zambezi Basin Stakeholder Forum convened (ZAMCOM);
2. Hold eight bilateral meetings with Zambian and regional organizations working on water, energy, environment, and land;
3. Two technical visits to two hydropower plants (Kafue Gorge, Kariba Dam North)

a. Participation in the Second Zambezi Basin Stakeholder Forum

Forum background

The Second Zambezi Basin Stakeholder Forum "Benefits of Co-operation and Basin-wide Planning in the Management and Development of Shared Water Resources" took place between 25-26 September 2017 at the Intercontinental Hotel Lusaka. It was organized by ZAMCOM and attended by 120 participants, representing more than 40 regional and riparian organizations.

This Forum is a platform developed by ZAMCOM to support a wider involvement and engagement of riparian countries and organizations in the Zambezi basin-wide planning. The two other participatory instruments in place, include the National Stakeholder Coordination Committees (NSCC) and the Basin-wide Stakeholder Coordination Committee (BSCC).

Day one of the meeting was mostly devoted to introducing the progress of ZAMCOM activities upon two main fronts: 1) the development of the Basin Strategic Development Plan (2017-2019); and 2) the development of the Decision Support System (DSS) for the Planning, Management, and Development of Water Resources. The last session of the day was dedicated to discussing in working groups three priority topics:

1) What are the priority issues requiring transboundary water cooperation in the Zambezi?
2) What are the benefits of transboundary water cooperation?
3) What role should ZAMCOM play in the realization of benefits for cooperation?

Day two started again with parallel discussions on four main topics:

1) Building resilience through infrastructure development in the Zambezi
2) Institutional strengthening and capacity development for basin wide-cooperation
3) Improving data and information management in the Zambezi
4) Strengthening gender equity and social inclusion in basin-wide planning

The last session before the wrap-up was allocated for presenting the ISWEL project. Next section provides full details of the structure and outputs of the ISWEL session.

In the afternoon of day two, and as a part of the activities planned within the Forum, we had a guided technical visit to Kafue Gorge Dam.

<u>ISWEL session "Applying a Nexus Approach to generate new-synergies and resolve trade-offs for basin-wide planning"</u>

The session was structured into three main parts:

1) A short **introductory presentation** of the project to provide the overall framework and assumptions of the IIASA nexus approach. Given that the main theme of the conference was related to the discussion of benefits for cooperation, with a special focus on transboundary water cooperation, the emphasis was placed on the added benefits from cross-sectoral cooperation. This presentation was delivered by Piotr Magnuszewski and preceded by a short introduction by Simon Langan.

The presentation was followed by an **interactive group discussion** aimed at promoting the dialogue among the participants around the following two questions:

What are the main constraints for promoting cross-sectorial and transboundary coopetition in the Zambezi?
What are the main opportunities to overcome such constraint?

For this session, no pre-arrangements of the room were needed, as the existing setting was favourable. All participants sat in 10 roundtables, and each table had between 7-9 persons. Each table/group was provided with markers, flipchart paper and post-its of two different colours (orange and green) before the facilitators started describing the process. Flipchart sheets at each table were pre-divided into two main columns with two labels: constrains and opportunities.

This part of the session was facilitated by Amanda Palazzo and Barbara Willaarts. Both facilitators explained the process and requested the groups to discuss among themselves the two questions outlined above and write on the orange post-its the main constrains identified, and on yellow the opportunities to overcome the former ones. The facilitators decided not to pre-establish any group of categories of constraints and opportunities, in order to prevent possible framing of the issues, so that the ISWEL team could get a broad range of answers. Participants were asked to pair constraints and opportunities placing them in parallel next to each other i.e. one opportunity to one constraint.

Each group was asked to discuss and write their post-its. Facilitators walked through the room answering questions and clarifying doubts. Once finished, facilitators collected the 10 flipchart sheets with the post-its.

Given the short time allocated for the session, facilitators could not debrief on the outputs of the individual groups. Participants were informed that individual group outputs were going to be processed, clustered together and interpreted *a posteriori,* and results would be sent to ZAMCOM for its inclusion in the Stakeholder Forum Report.

2) The last part of the session included an **open discussion** with other organizations currently involved in nexus projects and initiatives in the basin and SADC region to explore potential avenues for collaboration. Specifically, with ongoing projects like AU/NEPAD Water CoEx and the SADC NEXUS Dialogue Project "Fostering Water, Energy and Food Security Nexus Dialogue and Multi-Sector Investment in the SADC Region".

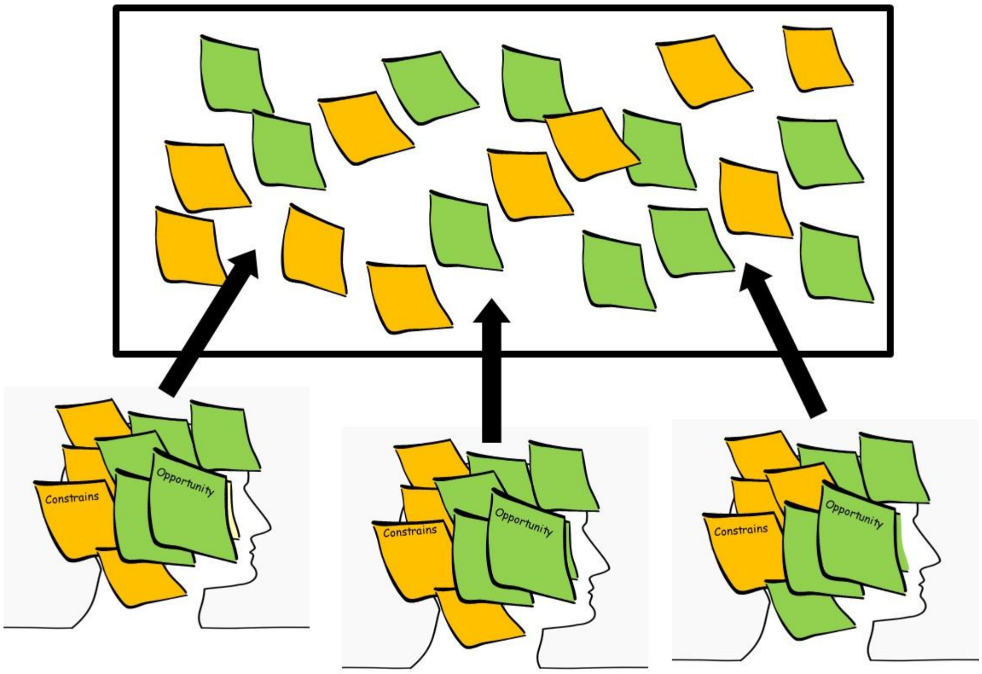
In terms of outputs, the information collected in the flipchart sheets was processed ex-post through a clustering analysis. With more time available, this exercise would have been done during the session with the participants, but due to the time constraints it was agreed to be processed after the meeting.

The clustering analysis is a technique frequently used in stakeholder analysis, and it is intended for grouping opinions, participants and views emerging from a participatory process as a mean to synthesize outputs. It can be done by the stakeholders based on their perceptions, opinions, and views of the topics under discussion, or it can be applied to the outputs of the process by researchers.

For the purpose of this exercise, post-its collected from the flipchart sheets were clustered, distinguishing between those referring to constraints (orange) and to opportunities (green). The criteria/categories for clustering were not pre-defined (bottom-up analysis) and post-its were grouped based on the similarities of its contents.

The clustering exercise was participated by four members of the IIASA team (Simon Langan, Michiel van Dijk, Amanda Palazzo and Barbara Willaarts) and consisted of two steps. To start, post-its pairs (challenge-opportunity) from all 10 flipchart sheets were first numbered (e.g. constrain 1 to opportunity 1, constraint 2 to opportunity 2, etc.). Once numbered, post-its were removed from the sheets and placed into a whiteboard and started to be moved individually by participants. This process took approximately 1 hour and involved several discussions among the participants in order to best classify these different post-its. Once grouped, clusters were reviewed jointly by the team and cluster names were proposed i.e. the categories under which constraints and opportunities were classified. Figure 44 summarizes the process.

A. Individual exercise of placing post-its on a white board.



B. Grouping and collective agreement on the emerged clusters and their names

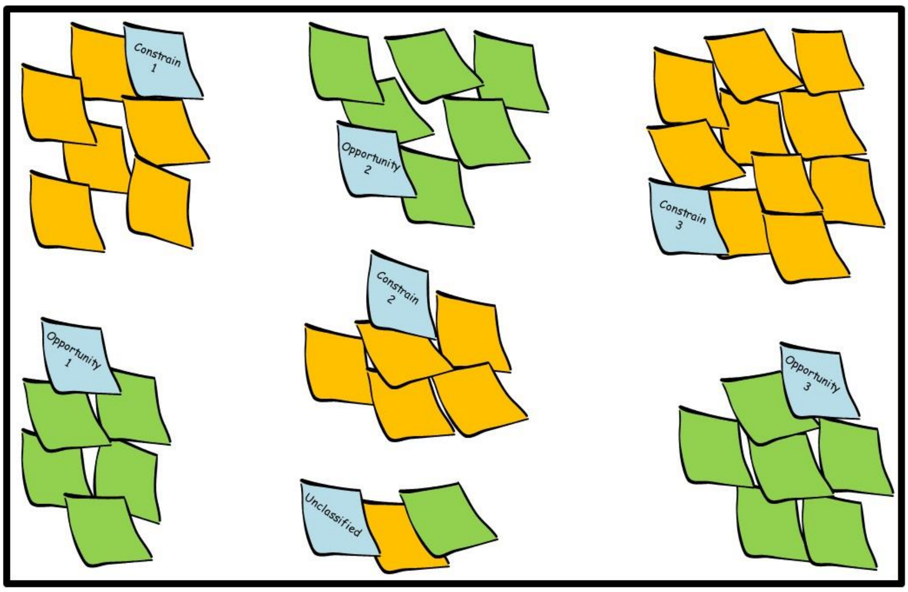


Figure 45 Summary of the clustering exercise developed to unfold the main constrains and opportunities to implement a nexus approach in the Zambezi basin.

The outputs of the clustering exercise are summarized in Table 10. The original texts from post-its have been preserved. A summary of the 'interpreted' outputs as well as cluster typologies is provided below.

Table 10 Main constraints and opportunities for fostering a cross-sectoral cooperation and nexus approach in the Zambezi Basin

What are the main constraints to implement a nexus approach?	What are the opportunities to overcome such constraints?
Resources	
Financial	
- Budget allocation and mandate	
- Lack of financial resources	- Sustainable Financing
- Limited financial capacity	- Willingness by development partners to support
- Inadequate resources	- Donor/CP willingness
Capacities	
- Inadequate knowledge on the linkages - Theoretical/ Don't appear practical - Lack of capacity - Institutional capacity lack	- Government promoting the linkages - Research may bring clearance on the issues - Capacity building programs - Capacity building under the umbrella of ZAMCOM
Technical	
- Lack of harmonized data and information - Lack of capacity	- Use of remote sensing - Training opportunities on the increase
Physical	
- Lack of equity in resource distribution	
- Spatial and temporal variability of natural resources	- Adequate natural resources
Technical/Financial	
- Differences in technical and financial capacities	
Cultural	
- Cultural aspects	- Integrate Cooperation
- Cultural differences	
- Language	
Gender	
- Lack of inclusive approach (including gender sensitive)	
Cross-sectoral cooperation	
Institutional setting and policies	
- Water, energy and food issues mandated to different institutions	
- Focal points for integration not existing	
- Lack of institutional coordination	- Integrated management
- Lack of coordination among the sectors	- Integrated approach for coordination
- Sector reforms at different stages	- Harmonize sector reforms
- Practical difficulties in breaking the silos	- Improves efficiency and sustainability - Job creation - Wealth creation
- Poor land management affects water flows, which also affects energy generation	- Investment in water resources management
- Institutional government silo mentality	- Available revised SADC Protocol on Gender, Development partnerships (articles 18-19 and 31) -

What are the main constraints to implement a nexus approach?	What are the opportunities to overcome such constraints?
- Different platforms dealing with nexus issues from different perspectives	- SADC Agricultural Regional Policy
- Lack of integration of where, when, and what is available to enable the nexus	- Industrialization strategy
- Public sector silos	
- Budgeting per ministries and departments	
- Conflicting and competing uses	
- Sectorial focus. E.g. ZAMCOM: water	- Sectorial programmes quite advanced and possible to integrate
- Inadequate collaboration between different water sector players across the region	- Regional peace in region (SADC)
- Inter-agency poor collaboration	- Inter-agency coordination mechanism
- Silo mentality	- Integrated approach
- Different priorities in national development plans	- Already existing synergies between energy, land and water. E.g. most countries water and energy are in the same ministry
- Barriers to land ownership	- Open transboundary land ownership
- Inadequate of institutional approaches to buttress the nexus approach	- Existence of regional institutional framework for cooperation
Transboundary cooperation	
National prioritization	
- Individual countries have different priorities	
- Different priorities for the Member States	- Harmonize priorities
- Different national contexts and priorities	- Regional Economic integration in motion
- Sovereignty	- Political will
- Hidden agenda, political issues, and sovereignty	- ZAMCOM integrated strategy
Institutional setting and policies	
- Barriers to trade	- Customs union
- Lack of coordination and implementing partners	- Harmonization of protocols among member states
- Different policies by sector and country	- Existence of institutions (e.g. SADC, ZAMCOM)
Benefit sharing	
- Weak ZAMCOM agreement, no explicit benefit sharing	- Amend ZAMCOM agreement to include benefit sharing, limit no harm rule
- Benefits of cooperation, there are no evidence	- Presence of research institutions in the riparian states

Based on the clustering exercise, the different barriers and opportunities to implement a nexus approach can be broadly grouped into five main categories: resources availability, cultural factors, gender factors, cross-sectoral and transboundary governance issues.

In terms of resources, there are several barriers or constraints, with financial resources appearing to be most acute. Budget allocation and especially limited resources for promoting this cross-sectoral cooperation are mentioned several times. Greater endorsement by donors and development partners is seen as an opportunity to overcome these barriers.

In terms of capacities, the existing inadequate knowledge about what the nexus means, and the yet little evidence of its practical application, were cited as the main barriers. Fostering capacity development programs, and in particular bringing in research and academia to shade light on the practical usefulness of this nexus approach, were given as opportunities.

From a technical perspective, there are data challenges and lack of technical skills. The use of new technologies like remote sensing can help to overcome part of the data gaps and support the harmonization of existing information data sources. The growing opportunities in training might contribute to addressing some of the technical challenges.

Lastly, unevenness in resource distribution and capacities (technical and financial) among riparian countries is also given as a key barrier. Opportunities on this front are still unclear.

Cultural factors, including language barriers, were identified as an important constraint to promote cross-sectoral cooperation across countries. The lack of an inclusive approach is regarded as a barrier to take the nexus approach into action.

Governance-related challenges, within and across countries, were the most numerous barriers to implement a nexus approach as recorded from the number of post-its collected. Nevertheless, a large number of opportunities were also proposed by the participants.

At the national level, the existing institutional setting, with ministries developing their separate, non-coordinated agendas is the most frequently identified constraint. The current budget allocation system and the conflicts between some ministries, incentivize the silo mentality and prevents the operationalization of the nexus management approach. Promoting greater integration is seen as a key opportunity, and possible pathways to this end include a more active role of SADC in the development of integrated policies, and at national level the development of mechanisms to support harmonization of the sector reforms that are currently taking place. In some countries, the interlinkage between sectors (e.g. water and energy) is tight, and this has led to the development of joint ministries on Energy and Water.

The (limited) transboundary cooperation is also cited as an important constraint to the implementation of the nexus management strategy. Riparian countries have different national development priorities and a strong sense of nation’s sovereignty. Lack of trust among riparian countries is also pointed out. These barriers result often in conflicting agendas with an accompanying absence of political will. The current institutional settings are perceived as inappropriate to buttress the nexus approach, although existing institutions like SADC and ZAMCOM have a potential to foster the co-operation across countries and sectors. Lastly, the need to provide solid evidence on the benefit sharing across countries will also contribute to foster co-operation and research can play an important role here.

b. Bi-lateral meetings with Zambian organizations

In addition to the participation in the Zambezi Stakeholder Forum, an important goal of the ISWEL first mission in the Zambezi was to engage and discuss with a number of regional and national stakeholders, and identify main nexus challenges and national priorities. Given that the Forum was hosted in Lusaka, the great majority of the meetings held where with sectorial Zambian organizations in the fields of water, energy, land and the environment. A total of eight bi-lateral meetings were held between 26-29 September with:

1. Zambian Electricity Company (ZESCO)
2. Water Resources Management Authority (WARMA), Zambia Ministry of Energy and Water Development
3. Department of Energy, Zambia Ministry of Energy and Water Development
4. Freshwater Program, World Wildlife Foundation, Zambia
5. Department of Agriculture, Zambia Ministry of Agriculture
6. Zambia Ministry of Development and Planning
7. Indaba Agricultural Policy Research Institute (IAPRI)

Annex 3 contains the minutes of the discussed points. A summary of the main outputs is provided below and refers to the key challenges each sector faces, as well as their development plans.

From an energy perspective:

- In urban areas, access to electricity reaches 25% of urban citizens, but in rural areas this access drops to 6%. Targets for 2030 include increasing access in urban areas up to 90% and to 51% in rural areas.
- Charcoal is the main source of energy in rural communities and responsible for much of the ongoing deforestation and erosion problems.
- Sedimentation is affecting hydropower performance downstream.
- Development of mini-grids is one of the strategies to promote electricity access in rural areas. However, there is a need to better understand what are the optimal grid configurations and how to best use existing ones. From a financial point of view, the participation of the private sector is required, although this will request an increase of tariffs and of the overall electricity demand in rural areas to make investments attractive.
- Zambia is currently facing power deficit. Short-term plans foresee the development of new 1000 MW (by 2022) and in the longer term an additional development of 3000 MW (2030). Hydro-power is currently the main source of electricity (90% of the current demand), and development plans include a diversification of the energy mix, where hydro-power will increase in absolute terms (additional 1500 MW) but its share in the future energy mix will be reduced to 75%. Through this diversification, the share of coal will increase up to 900 MW (13% projected energy mix), and solar PV as well by 700 MW (13% of the projected energy mix). Further development of renewable energies is constrained by the lack of data which prevents the development of feasibility studies for new projects.
- Climate change is perceived as a threat, but energy development plans barely touch upon this driver, despite the high vulnerability of hydropower to changes in flows.
- Mining is the main consumer of electricity (approx. 55%) and government plans are very much shaped to secure energy access to this sector, as it is also the largest contributor to the Zambian national GDP.

From a water-environment perspective:

- Zambian Water Resources Management Plan is not yet being implemented, nor the catchment management plans for the six main sub-basins. The only exception is Kafue Gorge. The absence of these plans makes the management of the basin's resources, including the matching of supply-demand and monitoring and enforcement of water user obligations, extremely challenging.

- Data and tools for water management and monitoring are still poor, and available data is of questionable quality (e.g. monitoring stations have low maintenance).
- The lack of capacities also prevents WARMA from taking a more active role in effectively managing water quality, which is a mandate in the Water Act, but has not been achieved so far.
- Permitting system is in place but not yet completely implemented. Partly due to the absence of a Groundwater Act. A Groundwater Act is now being developed but not yet enacted.
- Water allocation priorities for Zambia include: 1) non-commercial uses; 2) environmental flows; 3) commercial uses, including all socio-economic activities.
- There is a widespread mind-set that water which is not utilized for human and economic uses is wasted. There is a lack of understanding of the role that environmental flows can play in supporting development goals. This is partly caused by the lack of sound knowledge about ecosystem services.

From a land-food perspective:

- The great majority of agricultural crop production in Zambia is extensive (i.e. rain-fed and low-input) and is constrained by the biophysical conditions of the three main agro-ecological zones (AEZs) of Zambia which are based primarily on rainfall patterns. This makes the crop sector highly vulnerable to climate variability (droughts and floods). Shifting of the AEZs due to climate change may exacerbate the existing challenges affecting the agriculture sector. The Southern part is now mostly devoted to maize production, whereas in the Northern part cassava is most predominant due to the low productivity of the soils.
- Available data (e.g. soil maps) for estimating crop suitability and productivity potential are rare. Existing soils maps have a very low resolution.
- More than 70% of farmers are smallholders (< 2 ha) and 53% of the labour force is employed in agriculture, but agricultural policies often benefit medium-scale to commercial farmers. Smallholders are often reluctant to embrace new technology (conservation agriculture, hybrid seeds).
- Zambian Agricultural Research Institute (ZARI) has recently updated booklets on crop specific management recommendations. Government investments in R&D have focused heavily on maize, neglecting many other crops. Private sector in Zambia produces and sells hybrid seeds for maize (significant market in Eastern Africa), although an interest in private sector sales seeds for other food crops remains low.
- The Indaba Agricultural Policy Research Institute (IAPRI) and the National Statistical Office maintain two useful household surveys that focus on different aspects of the agriculture sector. The Rural Agricultural Livelihood Survey (RALS) provides a detailed look at small and medium scale farmers based on the 2010 census. The National Statistical Office of Zambia conducts a yearly survey of Zambian famers to collect information on the anticipated area, production, input use, prices, and food balance of major crops which is called the Crop Forecast Survey (CFS).
- Each ministry (including Ministry of Agriculture and National Development Planning) is responsible for developing their own climate adaptation plans; plans are not coordinated.

c. Conclusions and Next Steps

Based on the outputs of the Forum and the meetings held with Zambian organizations, a number of conclusions can be extracted and used to shape the next stages of the project as well as guiding the generation of outputs that are useful for the sustainable management of water-energy-land of the Zambezi.

- Most of the barriers to foster multi-sectoral cooperation i.e. nexus management, are governance-related. Ministries and riparian countries seem to be reluctant to cooperate in the development of multi-sectoral policies and investment plans and therefore mechanisms are not in place. Despite the efforts that have been allocated in the last years to assess the multi-sectoral investments opportunities, there is still not a clear understanding on the benefits of cross-sectoral cooperation and nexus management.
- Lack of capacities in terms of data and tools are also an important constraint for implementing sustainable WEL development plans in the basin. Development speed is unprecedented and there is a high political pressure to implement projects and plans, despite the limited knowledge and capacities already in place.
- Climate change is perceived as a substantial threat but it is not fully accounted for in all sectoral development plans (e.g. Energy). This is partly because there is no specific government unit in charge of developing national adaptation and mitigation plans. Most ministries deal with this issue individually, and perhaps not all perceive or understand the same level of threat.
- The linkages between environment and development are not well understood. The environment is seen as a barrier to development by some sectors. Further effort is required to develop sound environmental awareness and to provide evidence for the benefits of sustainable development.

The first stakeholder engagement led to a better understanding of challenges and priorities of Zambezi river stakeholders. It also allowed the IIASA team to build partnerships and plan the next steps with a stronger confidence and support from new partners. Specifically, the following steps will be undertaken:

- Given that there are two other main Nexus projects in the Zambezi and more broadly in the SADC region (SADC and GWP project on “Fostering a water, food and energy security nexus dialogue and multi-sector investment in the SADC region”, and AU/NEPAD project Network of Water Centers of Excellence initiative), it was agreed with the two leading organizations to co-operate and explore the possibility of jointly develop the next stakeholder consultation. This consultation will include a scenario workshop and a back-to-back capacity development training. IIASA will take the lead in drafting a concept note for this workshop, while GWP is offering its network to identify suitable participants and organizations, and it is likely that it can also provide some resources (financial or in-kind). The format in which AU/NEPAD could join these plans is now being discussed. AU/NEPAD also sees opportunities for jointly developing a capacity development workshop. The tentative timeline for holding this second consultation is April 2018 and the venue will have to be agreed and decided with all partners involved in the workshop, including ZAMCOM.
- The majority of the Zambian organizations interviewed are keen on having this integrated vision on future WEL demands and interactions. The technical expertise of the persons interviewed could be very valuable for the next stages of the project, including the scenario development workshop. WWF was also volunteering to support the ISWEL team in the development of the scenarios workshop, and particularly if environmental flows, and sustainable water use are prominently featured in scenarios. This organization is currently working with WARMA in the process of implementation of environmental flows.

The above steps lead to the next stakeholder consultation that, in order to be effective in contributing specific input to the IIASA models, has to be planned as an expert meeting, where identifying the right experts is critical to the meeting success. The main outcome of this next meeting will be scenario storylines with some of its part being quantified in order to guide model coupling with them.

A few scenarios will be considered describing general world trends that provide a context for the Zambezi river basin. Within these bounds a number of pathways describing the developments and activities within the basin will be constructed. All pathways assume sustainability as a target however they may differ with respect to both interpretation of the sustainability conditions as well as difficult tradeoffs that need to be decided along the way.

The process will consist of the following steps:

- Characterizing current situation,
- Setting desirable goals,
- Identifying tradeoffs,
- Development and selection of nexus solutions,
- Building pathways.

At least two summary narratives will be prepared that describe pathways from the current situation to future goals. A narrative contains a combination of different solutions that is arranged chronologically – it connects and integrates different elements into a consistent storyline. Pathways narratives will be prepared as consistent storylines (narratives) that contain the above elements (goals, gaps, tradeoffs, solutions, and co-benefits). They will be grounded in the reality of the river basin. They will be ambitious but realistic – not only describing the desired end state but also the way to reach it, explaining what were the main challenges and how were they overcome. A list of important knowledge gaps and uncertainties will be listed. Finally, some elements of these storylines will be expressed in numerical values providing a more specific input to the quantitative scenarios to be built by IIASA based on workshop narratives.

Outcome 3.2 Capacity building for system analysis and nexus decisions

Summary: In addition to the stakeholder meetings and workshops planned in the basins, it was agreed to organize at least two capacity building workshops back-to-back with the second and third meeting in the two case studies. The overall purpose of these trainings is to build on IIASA extensive expertise in system analysis and model development to develop local technical capacities for nexus management and research. In addition to these capacity workshops, exchange programs with researchers from the basins will also promoted. The long-standing Young Scientists Summer Program (YSSP) will be used as a starting point for facilitating the training of young researchers from the basins into the nexus, and where possible be engaged into the development of the ISWEL project.

Progress achieved by Month 12: Most efforts so far have been focused in disseminating the YSSP call that is currently open for 2018 applications and actively search for good PhD candidates working in the basin. ZAMCOM, GWP and NEPAD have disseminate the YSSP opportunities for 2018 among their networks in the Zambezi, and LUMS has done the same thing in the Indus.

Outcome 3.3 Dissemination and outreach

Summary: This section describes the efforts conducted by the ISWEL team in disseminating the outputs of the ISWEL projects in scientific conferences, high level panels and through publications

Progress achieved:

Participation in Scientific Conferences

1. Wada, Y (2017). "Towards integrated solutions for water, energy, and land using an integrated nexus modeling framework" Conference Proceeding presented at "American Geo-Sciences Union Fall Meeting" New Orleans 11-15 December. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/207928

2. Burek P, Satoh Y, Greve P, Kahil T, Byers E, Langan S., Wada Y. (2017) "Improving Water Resources Management on Global and Region Scales – Evaluating Strategies for Water Futures with the IIASA's Community Water Model" Conference Proceeding presented at "American Geo-Sciences Union Fall Meeting" New Orleans 11-15 December. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/219908

3. Parkinson, S., Kahil, T., Wada, Y., Krey, V., Byers, E., Johnson, N., Burek, P., satoh, Y., Willarts, B., Langan, S., Riahi, K. (2017). "Hydro-economic modeling of integrated solutions for the water-energy-land nexus in Africa" Conference Proceeding presented at "American Geo-Sciences Union Fall Meeting" New Orleans 11-15 December. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/275056

4. Burek P, Satoh Y, Greve P, Kahil T, & Wada Y (2017). "Development of a community driven global water model" Poster presented at "European Geo-Sciences Union" Vienna 23-28 April. http://pure.iiasa.ac.at/14536/

5. Byers E, Gidden M, Maussion F (2017). "Working with big, multi-dimensional geoscientific datasets in Python: a tutorial introduction to xarray" Session convened during "European Geo-Sciences Union" Vienna 23-28 April. http://meetingorganizer.copernicus.org/EGU2017/session/25651

6. Wada, Yoshi (2017). "Recent advancement in estimating global, continental and regional scale water balance components" Session convened during "European Geo-Sciences Union" Vienna 23-28 April. http://meetingorganizer.copernicus.org/EGU2017/picos/24112

7. Konadu DD, Howells M, Byers E.A, Smith P, Richards KS (2017). "Energy and environmental system interactions – Policy and modelling" Session convened during "European Geo-Sciences Union" Vienna 23-28 April. http://meetingorganizer.copernicus.org/EGU2017/session/22842

8. Renner M, Greve P, Berghuijs W, Coenders-Gerrits M, Gudmundsson L (2017) "Advances and applications of the Budyko water and energy balance framework" Session convened during "European Geo-Sciences Union" Vienna 23-28 April. http://meetingorganizer.copernicus.org/EGU2018/session/26944

9. Palazzo A, Havlík P, van Dijk M (2017). "Future energy, food, and water trade-offs in the Zambezi river basin: a model analysis" Conference Proceeding presented at Global Food Security Conference, Cape Town 3-6 December. http://globalfoodsecurityconference.com/

10. Greve, P, Kahil T, Mochizuki J, Schinko T, Langan S, Wada Y (2017). "Global assessment of water policy challenges under uncertainty in water scarcity projections" Conference Proceeding presented at ILEAPS Science conference, Oxford 11-14 September. https://custom.cvent.com/30FF68BC7F924C829EC42F83CADECD93/files/30c9d2d5908d471393afe193e148165d.pdf

11. Kahil T, Parkinson S, Burek P, Satoh Y, Langan S, Wada Y (2017). "Economic costs of reduced water availability under climate change: Application of IIASA global hydro-economic modeling framework" Conference Proceeding presented at Impacts World 2017, Postdam 11-13 October. https://www.impactsworld2017.org/program-speakers/

12. Palazzo A, Havlík P, Leclere D, van Dijk M, Deppermann A (2017). "Hotspots in land and water resource uses on the way towards achieving the Sustainable Development Goals" Conference Proceeding presented at Impacts World 2017, Postdam 11-13 October. https://www.impactsworld2017.org/program-speakers/

13. Byers E, Gidden M, Burek P, Havlik P, Krey V, Langan S, LeClere D, Palazzo A, Parkinson S, Rogelj J, Satoh Y, Wada Y, Willaarts B, Riahi K (2017). "Future exposure and vulnerability to multi-sector hotspots" Conference Proceeding presented at Impacts World 2017, Postdam 11-13 October. https://www.impactsworld2017.org/program-speakers/

14. Byers E, Gidden M, Burek P, Havlik P, Krey V, Langan S, LeClere D, Palazzo A, Parkinson S, Rogelj J, Satoh Y, Wada Y, Willaarts B, Riahi K (2017). "Multi-sector climate impacts assessment for water, energy and land" Conference Proceeding presented at "Inter-Sectoral Impact Model Intercomparison Project Meeting, Postdam 9-10 October. https://www.isimip.org/

15. Wada, Y (2017). "Sustainable global groundwater management for human security" Session convened at Japan Geoscience Union Meeting 2018, Makuhari Messe 20-24 May. https://confit.atlas.jp/guide/event/jpguagu2017/session/MZZ40_22PM1/detail?lang=en

16. Kahil T, Parkinson S, Burek P, Satoh Y, Greve P, Fischer G, Tramberend S, Langan S, Wada Y (2017). "Economic costs of reducing unsustainable groundwater use: Application of IIASA global hydro-economic modeling framework" Conference Proceeding presented Japan Geoscience Union Meeting 2018, Makuhari Messe 20-24 May. https://confit.atlas.jp/guide/event/jpguagu2017/subject/MZZ40-12/date?cryptoId

17. Wada, Y (2017). "Trans-scale Solutions for Sustainability" Conference Proceeding presented at Kyoto International Symposium by RIHN, Kyoto 20-22 December. http://www.chikyu.ac.jp/rihn_e/

18. Wada, Y (2017)." Towards integrated solutions for water, energy, and land using an integrated nexus modeling framework" Conference Proceeding presented at UNESCO Knowledge Forum, Paris 18-20 November. http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/Draft_Agenda_Knowledge_Forum_Water_Security.pdf

19. Matthew J. Gidden, Simon C. Parkinson, Narasimha D. Rao, Keywan Riahi (2016). Spatial Downscaling of Urban and Rural Income and Inequality for the Shared Socioeconomic Pathways" in Ninth Annual Meeting of the IAMC 2016, Beijing, China, Dec. 2016. http://www.globalchange.umd.edu/iamc/events/ninth-annual-meeting-of-the-iamc-2016/

20. Matthew Gidden, Edward Byers, Peter Greve, Taher Kahil Simon Parkinson, Catherine Raptis, Joeri Rogelj, Yusuke Satoh, Michelle van Vliet,, Yoshide Wada, Volker Krey, Simon Langan, and Keywan Riahi (2017). Hydroclimatic risks and uncertainty in the global power sector, "European Geo-Sciences Union" Vienna 23-28 April. http://meetingorganizer.copernicus.org/EGU2017/EGU2017-15648.pdf

Participation of ISWEL Executive team members in High Level Panels

1. ISWEL presentation at the Vienna Energy Forum (May 2017, Vienna)
2. COP23 Session on Energy Policy Trade-offs within the Broader Sustainable Development Challenge
3. COP23 Side Event on The Water-Food-Energy NEXUS.
4. World Water Week2016 key Note on "Operationalizing the water-energy-food nexus" at the Stockholm 2016"
5. "Accelerating Sustainable Energy for All in Landlocked Developing Countries through Innovative Partnerships" co-organized by UNIDO and SE4ALL

Peer Review Articles (submitted or planned to be submitted in 2017)

1. Matthew Gidden, Shinichiro Fujimori, Maarten van den Berg, David Klein, Steven J. Smith, Detlef P. van Vuuren, Keywan Riahi (under review). *A Methodology and Implementation of Automated Emissions Harmonization for Use in Integrated Assessment Models*. Submitted *to Environmental Modelling & Software*

2. Nils Johnson, Peter Burek, Simon Parkinson, Edward Byers, Martina Flörke, Petr Havlik, Mohamad Hejazi, Volker Krey, Simon Langan, Nebojsa Nakicenovic, Amanda Palazzo, Alexander Popp, Michiel van Dijk, Michelle van Vliet, Detlef van Vuuren, Yoshihide Wada, David Wiberg, Caroline Zimm, and Keywan Riahi (submitted*). Global models and the Land-Energy-Water Nexus: Status, Challenges and Opportunities*. To be submitted to *Global Environmental Change.*

3. Edward Byers, Matthew Gidden, Peter Burek, Kristie Ebi, Peter Greve, Petr Havlik, Nils Johnson, Taher Kahil, Volker Krey, Simon Langan, David Leclère, Michael Obersteiner, Amanda Palazzo, Shonali Pachauri, Simon Parkinson, Narasimha Rao, Joeri Rogelj, Yusuke Satoh, Yoshihide Wada, Barbara Willaarts, Keywan Riahi (under review). *Global exposure and vulnerability to multi-sector climate change hotspots*. Submitted to *Environmental Research Letters.*

4. Matthew Gidden, Narasimha Rao, Simon Parkinson, Keywan Riahi (submitted). *Spatially explicit urban and rural poverty estimates under different global socioeconomic futures*. Submitted to *Nature Sustainability.*

5. *Taher Kahil, Simon Parkinson, Ted Veldkamp, Yoshihide Wada (in preparation). Developing a continental-scale hydro-economic model for integrating water-energy-land nexus solutions. To be submitted to Water Resources Research*

6. Yusuke Satoh, Yoshihide Wada, Edward Byers, Kei Yoshimura, Yadu Pokhrel, Hyungjun Kim, Taikan Oki (in preparation). *Developing a continental-scale hydro-economic model for integrating water-energy-land nexus solutions.* To be submitted to *Water Resources Research*

7. Peter Greve, Taher Kahil, Junko Mochizuki, Thomas Schinko, Yusuke Satoh, Peter Burek, Guenther Fischer, Sylvia Tramberend, Simon Langan, Yoshihide Wada (in preparation). *Global assessment of water management challenges under* uncertainty in water scarcity projections. To be submitted to *Nature Sustainability*

8. Peter Greve, Ted Veldkamp, Taher Kahil, Peter Burek, Yusuke Satoh, Yoshihide Wada (in preparation). *Supply vs. demand-driven changes in water scarcity*. To be submitted to *Environmental Research Letters*

9. Amanda Palazzo, Petr Havlik, Hester Biemans, Yoshihide Wada, Michael Obersteiner, Pavel Kabat, Fulco Ludwig (in preparation). *Balancing food security and water for the environment under global change*. To be submitted to *Global Environmental Change*

10. Amada Palazzo, Michiel van Dijk, Petr Havlik (in preparation). *Future energy, food, and water trade-offs in the Zambezi river basin: a model analysis*. To be submitted to *Regional Environmental Change*

11. Amada Palazzo, Michiel van Dijk, Petr Havlik (in preparation). Climate change, water scarcity and food security in South Asia: global-to-local analysis. To be submitted to *Regional Environmental Change*

12. Amanda Palazzo, Petr Havlík, David Leclere, Michiel van Dijk, Andre Deppermann (in preparation). *Hotspots in land and water resource uses on the way towards achieving the Sustainable Development Goals*. To be submitted to *Global Environmental Change*

Component 4: Project Management

Summary: This component is devoted to project monitoring and evaluation. Tasks associated to this component include 1) reporting; 2) internal coordination to ensure project outcomes are achieved in due time; and 3) organize at least one meeting per year with the Project Steering Committee (PSC) to ensure the policy relevance, budgetary and scientific adequacy of the project and its progression.

Progress by Month 12: Internal coordination is assured through the organization of bi-weekly research and management meetings. To ensure the project coherence, consistency and relevance, a number of meetings have been organized with the PSC. These included two skype calls and one meeting that took place in Vienna in June 2017. Annex 4 includes the meeting report and below is provided a summary of the main recommendations made by the PSC members. Also, ISWEL Executive team met with UNIDO Energy Director to discuss ISWEL progress and cooperation among the two organizations. A list of planned activities and meetings have been also drafted and it is enclosed at the end of this section.

Summary of the First Meeting with the Project Steering Committee

The meeting took place during 8-9 June 2017 at IIASA. This was the first of the three annual face-to-face meetings planned during the project life time, and was attended by 18 IIASA staff, currently involved full- or part-time in ISWEL and by the six members of the PSC: Leena Srivastava (TERI University), Astrid Hillers (GEF), David Grey (University of Oxford), Youba Sokona (South Centre), Robert Novak (UNIDO) and Nebojsa Nakicenovic (IIASA Directorate).

This meeting has been preceded by two conference calls (12 December 2016 and 21 April 2017), which provided an introductory overview to ISWEL. The specific goals of the meeting were:

- Providing a comprehensive overview to all PSC members on the project scope, goals, timeline, planned outcomes and outputs.
- Present and discuss in detail the ongoing work within the different project components and tasks. In particular, the progress achieved so far with the modeling (global and regional), the stakeholder engagement strategy, the challenges upfront and the planned outcomes for 2017.
- Receive feedback from the PSC members to improve the usefulness and impact of the research developed
- Utilize the knowledge, experience and network provided by the diversity PSC members' background to design appropriate strategies and responses to overcome existing challenges.

The meeting lasted one and half day and was arranged into four sessions (Project Overview, Regional Assessment, Global Hotspots Assessment and Stakeholder Engagement). Each session was introduced by presentation by the IIASA team and followed by a discussion. Time was also allocated at the end of the meeting for the PSC members to deliberate a number of specific recommendations to enhance the relevance and applicability of ISWEL both for, global and regional decision making.

The PSC provided extensive comments on the approaches and activities in progress. Table 11 provides a summary of the overall recommendations and a list of actions planned or undertake to address them.

Table 11. Recommendations provided by the Project Steering Committee and summary of actions undertaken

Recommendation	Action uptake
1. Working towards a better definition of project outputs and outcomes, particularly within the basins	The definition of the global outputs, in particular the approach to develop the hotspot assessment (Output 2.2.1), has been discussed extensively in the past few months. As described in Section 3 substantial progress has been made in the framing of this assessment and the first sets of results have been produced. A scientific paper has been submitted and if accepted, the global hotspot assessment on global population exposure to multi-sectorial climate risks, will likely be included in the Special 1.5° Report the IPCC is preparing. With regards to the regional outputs, significant efforts have been placed in building partnerships with basin organizations and stakeholders representing all different sectors (Output 3.1.1). As described in this report in Section 3, outcome 3.1, first consultations in the Zambezi delivered important opportunities for continued engagement in the next steps of the process. The stakeholder engagement strategy planned for the Zambezi, describing activities and specific outputs/outcomes, has also been elaborated. The next steps will include the drafting of the concept note on meeting 2 (Scenario Focus Group (output 1.1.1) and Capacity Development Workshop (output 3.2.1a). In the Indus Basin, the approach to be followed is similar to reach Output 3.1.1.
2. Better framing of nexus challenges in Low latitudes	This recommendation has been taken into account at two levels. - Directly involving stakeholders in the identification and prioritization of nexus challenges within the basins. In the Zambezi, one of the main goal of the first consultation held in September 2017, was to collect the view and impressions from local stakeholders on what were the main nexus challenges within the basin, and what were the main constraints and opportunities for nexus management. In the Indus, the project will follow the same approach. - Within the modeling framework, spatially-explicit socioeconomic projections of income levels have been produced for the first time. In particular, the datasets are produced at income levels of $2, $10 and $20/day to capture different levels of poverty and vulnerability These vulnerability datasets have been taken into account in the hotspots assessment. First analysis of global hotspots uses the $10, "vulnerable to poverty" income threshold. Further analysis will assess more income levels to assess impacts at different levels of vulnerability. The indicators used in the hotspots assessment cover a broad range of challenges and stressors applicable to the global population, and these can be developed further. This is an exciting and innovative element to the work and we were highly appreciative of the discussion the PSC initiated allowing us to produce the first assessment that incorporates both vulnerability and exposure.
3. Early engagement with stakeholder to adequately	The ISWEL team acknowledged the concerns the PSC team had in relation to this issue and substantial progress has been made since June 2017. In the Zambezi Basin, the first consultation stakeholder

Recommendation	Action uptake
frame regional problems, demands and challenges.	consultation took place between 23-29 September, hosted by ZAMCOM in Lusaka (details are provided in Section 3, Outcome 3.1). This consultation included the organization of a session in the Zambezi Stakeholder Basin Forum. The session and overall the participation in the Forum gave the ISWEL team the opportunity to introduce the project to a wide audience and discuss with stakeholders the major opportunities and constraints stakeholders have. This we are using to foster co-operation across sectors and countries and have a better understanding on what opportunities ISWEL can bring to the region. It also allowed the team to interact with ZAMCOM and organizations currently dealing with Nexus aspects (e.g. SADC-GWP Nexus dialogue, and AU/NEPAD Center of Excellence in Water Sciences project) to build relationships and discuss avenues for co-operation e.g. joint-development of workshops and capacity building trainings. In parallel to the participation in the Forum, the team also had bi-lateral meetings with Zambian organizations to exchange views on the challenges and national priorities these ranged from ministry of planning to power generation and WWF. Following up from this mission, the ISWEL team is now producing a concept note for the Scenario Workshop and back to back a capacity building workshop in discussions with GWP and the JRC to explore opportunities to jointly develop these activities. On the Indus, the political sensitivities in the region have contributed to the delay of the starting of the process, but in the last two months' substantial progress has been made. We now have two entry points into the Basin (Lahore University of Management Sciences, and The Indus Basin Knowledge Platform) that are willing to support and engage in the development of the stakeholder process. Efforts over the last few weeks has been placed in the identification of stakeholders from different sectors and countries, that could be invited to the different consultations we are organizing. We have now a consolidated database and we are working in the organization of the first consultation and warm up meeting, that is planned for February-March 2018.
4. Key aspects to take into account in the global hotspots assessment include: - Identification of areas where attaining WEL-related SDGs (e.g. 2, 6, 7, 13 and 15) could be challenging. - Governance, fragility and migration aspects are very	The hotspots assessment has from an early stage taken into account how the SDGs could be incorporated – but it is challenging because projections for the SDG indicators do not always exist. Nonetheless, the initial multi-sector assessment does include a number of relevant indicators relating to: food security (2), water security (6), clean energy access (7), climate change mitigation (13) and land sustainability (15). Further work will also investigate other policy-relevant frameworks such as the Sendai Framework for Disaster Risk Reduction. There is scope to incorporate Governance and fragility when the hotspots analysis is processed at the country and basin levels, for which there are a few indicators that can be used. Modelling of migration is extremely complex, and whilst nexus hotspots may be push factors, pull factors (city opportunities) are generally acknowledged to be much stronger are considered in the socioeconomic urbanization scenarios of the SSPs

Recommendation	Action uptake
important drivers and are not yet considered - Nexus Risk Index would be a good feature - Charcoal and fuelwood not considered - Policy relevance of the analysis	Charcoal and fuelwood is now considered in the clean cooking access indicator and is particularly important for the "low-latitude" nexus The policy relevance of the analysis is covered through a number of design choices: use of the SSPs; RCPs and 27 IPCC regions such that results are relevant, consistent and comparable with other assessment frameworks; assessment at 1.5/2.0/3.0°C for relevance to the Paris Climate Agreement; use of indicators with relevance to multiple SDGs; framework flexibility of outputs at country, basin and other spatial decision-making units.
5. ISWEL should be a solution-oriented project, but providing global WEL solutions seems a rather ambitious plan, as this will require a throughout analysis of technological, physical and institutional conditions of every country and region.	As described above, the global analysis is meant to be a comprehensive assessment pointing at regions around the world where problems and conflicts might emerge under a number of scenarios and test how a series of standard solutions may work, but it is not meant to provide specific recommendations for all different regions. In the regional assessment, exploring the solution space is feasible and here significant effort will be placed in both, understanding what the challenges and problems area and what solutions make more sense given the local and regional context. Importantly this will involve dialogue and iterative consultations with the regional stakeholders.
6. Capacity development is a core element in ISWEL project but better definition of the extent of this activity is required.	Capacity development in the context of ISWEL will be addressed in two ways. - Developing training workshops as agreed in the proposal (output 3.2.1a). Training options in the Zambezi have been discussed and currently there are two main proposals: A) training for young researchers on the development and applications of the nexus modeling tools applied to the Zambezi river basin, and B) training with regional decision makers using the Nexus Simulation game developed by IIASA followed by a simplified session with a focus on application of IIASA nexus modeling tools. The 2 options can also be combined with regional decision makers participating in the second while young researchers could participate in both. - Promoting the scientific exchange of researchers (output 3.2.1b). IIASA offers every year grants to join the so-called "Young Summer Student Program (YSSP)" These grants are meant for mid-stage PhD students to develop a 3-month research projects at IIASA during the summer in collaboration with IIASA researchers. YSSP offer a perfect opportunity for researchers within the two basins, to visit IIASA and engage in the development of research projects in the context of ISWEL and related to the two basins. The ISWEL team has engaged in active dissemination among basin partners of the 2018 call for applications (now open). Active search of potential good candidates is also in progress.

Summary of planned activities for 2018

Type of meeting	Details & Timeline
Management	Annual Project Steering Committee meeting. 16-17 April at IIASA
Stakeholder Engagement-Zambezi	Preparatory meeting for Zambezi Scenario Workshop. 5 February 2018, Harare. Participants: ZAMCOM, IIASA, GWP, AU/NEPAD
Stakeholder Engagement-Zambezi	Zambezi Scenario and Capacity Development Workshop. April 2018. Location and exact dates TBC
Stakeholder Engagement-Indus	First meeting "warming up" in India (End March 2018). Hosting-organization TERI First meeting "warming up" in Pakistan (End March 2018). Hosting-organization LUMS
Stakeholder Engagement-Indus	Second Meeting" Scenario and Capacity Development Workshop". June, Vienna in partnership with World Bank, ICIMOD and IWMI

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5. Annex

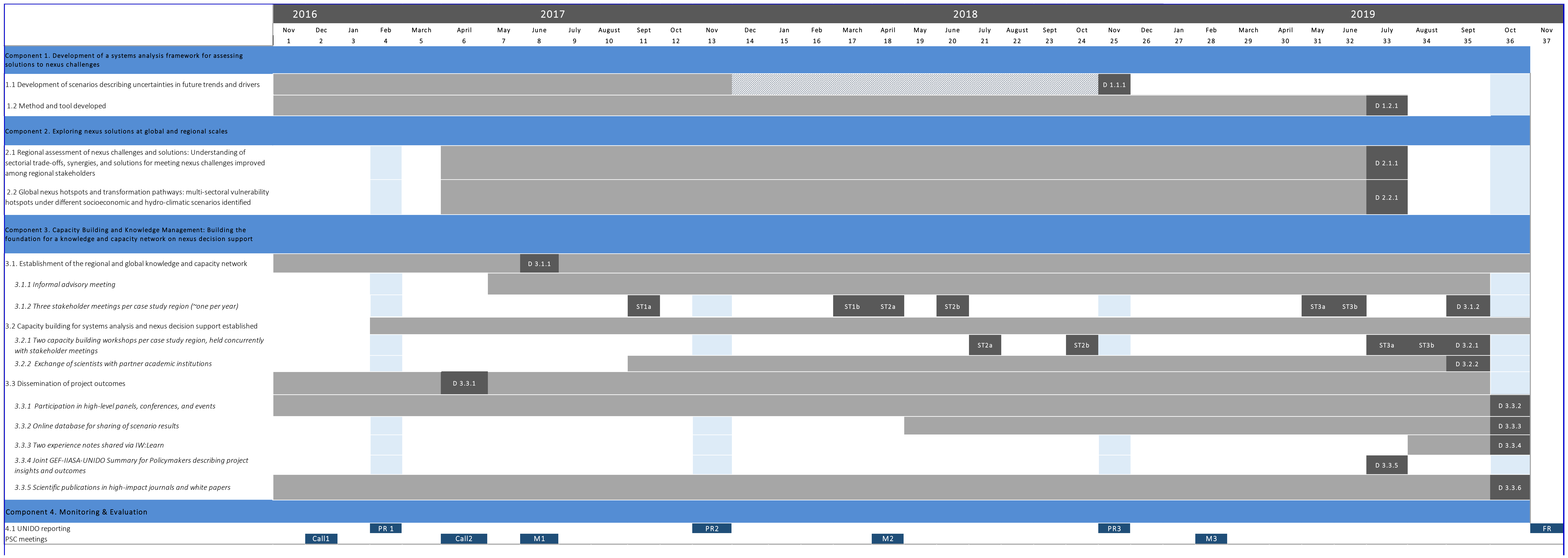
Annex 1: Work Plan

Annex 2: Hotspot Paper submitted

Annex 3: Zambezi Mission Report

Annex 4: Report -Annual Project Steering Committee Meeting 2017

Annex 1: Work Plan



ST = Stakeholder Meeting (region a/b), D = Report/Deliverable/Publication, M= meeting, PR= Progress Report, FR=Final Report

Planned Deliverables ISWEL

D 1.1.1 Report describing the stakeholder-informed regional scenarios for exploring nexus challenges, drivers and solutions (*December 2017)*

D 1.2.1 Report/Paper describing the model development and integration into system assessment platform (*July 2019*)

D 2.1.1 One Summary for Policy Makers (SPM) for each case study on tangible strategies for improving regional decision-making across sectors and borders identified (*July 2019*)

D 2.2.1 Summary for Policy Makers (SPM) on Global assessment of multi-sectorial hotspots and transformation pathways (*July 2019*)

D 3.1.1 Database with stakeholder contacts for the global consultation and the two case study areas (*June 2017*)

D.3.1.2 Report describing the stakeholder process and the outcomes of the regional workshops (*September 2019*)

D 3.2.1 Presentations and report of the capacity building workshops uploaded into the project website (*September 2019*)

D 3.2.2 Report describing the results of the scientific exchange program and their contribution to ISWEL (*September 2019*)

D 3.3.1 Project Website (*April 2017)*

D.3.3.2 Report summarizing the participation in high level panels, workshops and conferences related to ISWEL project (*October 2019*)

D 3.3.3 Open access web tool and platform to share scenario results and related databases for investors and stakeholders (*October 2019*)

D 3.34 Two shared experiences available online for the IW:learn (*October 2019*)

D 3.3.5 Three edited Summary for Policy Makers (SPM) (global and for the two case studies) available online (*July 2019*)

D 3.3.6 At least six scientific peer publications related to ISWEL outcomes submitted (*October 2019*)