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Integrated Solutions for Water, Energy and Land

Progress report III

Period (1 November 2017- 31 October 2018)

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1. Background

This report summarizes the progress achieved by year two (November 2017-October 2018) 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 main outputs and highlights achieved during the reporting period (Months 12-24). 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" provides a technical description of the activities that have been developed and the next steps planned.

2. Executive Summary

Purpose

The overall goal of the project is to develop tools and capacities to support the sustainable management of water, energy and land, through the development of a truly integrated “nexus approach”. The project takes a global approach, but it also focuses in on two transboundary basins facing multiple development and environmental challenges: The Indus and the Zambezi basins.

The global assessment seeks to develop an integrated view of the risks that different regions of the world might face to meet key water, energy and land-related development and environmental targets, and the exposure and vulnerability of world populations to them. In addition, the project seeks to identify strategies and solutions for achieving sustainable pathways for water, energy, and land (WEL) taking into account a range of possible climate and socio-economic futures. Dissemination of the global outcomes is carried out through the development of web-visualization tools, and a wide range of publications including policy briefs, policy reports and peer review papers. These outcomes are expected to support international organizations and donors in identifying investment risks and opportunities, support global policy making, and more widely contribute to the scientific debate on sustainable development pathways.

Within the basins, the project seeks to develop tools and processes that can be utilized, improved and adapted by basin researchers and regional planners to build a common understanding of what are the benefits of applying a WEL nexus approach in national/basin planning as oppose to sectoral development plans, and provide evidence-based information on what cost-effective solutions exist to for riparian countries to jointly meet WEL development and environmental goals. Building capacities around nexus research and management is also a key feature of this project, and efforts are being devoted to train basin researchers and planners in the use of the nexus tools (models and participatory exercises), as well as facilitating spaces for cross-sectoral engagement and knowledge exchange around the nexus. Together this dual track approach will help building an enabling environment that can facilitate better management of the water, food, and energy sectors, and hopefully unlock and optimize the sustainable development agenda of the basins.

The progress achieved during year 2

The enabling environment that is being develop in the project relies on the development of tools (models and processes) that can help countries and basins for long term and integrated planning of WEL, maximizing co-benefits from aligning development agendas and highlighting potential trade-offs.

Building on the technical and scientific expertise of IIASA (together with input from UNIDO, GEF and the Project Steering Committee), in the course of the last 24 months, the project team has invested significant efforts to complete the development of an analysis modeling framework (AMF) to generate evidence-based information on WEL nexus opportunities and constrains. This AMF represents and connects the biophysics and economics of WEL systems, and it is composed of five models that are, dependent on the actual use case, combined in different ways: The Hydrological Community Water Model (CWatM), the water quality model (MARINA), the hydro-economic model (ECHO), the energy-economic model MESSAGE*ix* and the agro-economic model GLOBIOM. Two of the models describing the water system (CWatM, and ECHO) have been newly developed within this project. Likewise, MARINA model, which was originally developed by Wageningen University and Research, has been updated to improve the temporal and spatial representation of nutrient loads within the basins. MESSAGE*ix* and GLOBIOM were developed previously and coupled in the course of past projects, but have being upgraded to improve the representation of sectorial interlinkages, in particular by adding a representation of the water sector, and to enhance their spatial resolution. The overall goal underpinning the development of this AMF is that it is flexible (i.e. models can be plug and plug out depending on the questions to be addressed), scalable (i.e. applicable at multiple scales), and transferable (i.e. applicable to different locations) (outcome 1.2, Table 1). At the time of this reporting the AMF has been completed.

During the past 12 months, progress on the global assessment included: further development of the global hotspot work presented last year, completion of the global AMF and one first application to assess global transformation pathways for some WEL related Sustainable Development Goals (SDGs). On the former, global hotspot wok has now being expanded to assess the multi-sectoral risks and vulnerability exposure of the 275 major river basins across the world. In terms of impact and operationalization, the global hotspot assessment carried out last year has been featured in the IPCC Special Report on Global Warming of 1.5°C.[1] Dissemination of this work includes a web-interphase "hotspots explorer", currently in development that will also made freely available all the underpinning datasets.

In terms of the assessment of global solutions, the global AMF developed relies on three models: MESSAGE*ix*, GLOBIOM and the CWatM. MESSAGE*ix* and GLOBIOM have been enhanced to include a reduced-form, regionally-specific representation of the global water sector, i.e. by a hydro-economic component. Linkages established among these models provides a method to explore a number of policy relevant questions, including potential trade-offs as well as solutions/pathways to achieve multiple SDGs and the (multi)sectoral implications of climate change mitigation and adaption policies. This AMF has been applied to demonstrate the co-benefits of attaining sustainable consumption and production (SDG 12) in terms of minimizing the cost of implementing clean water and energy goals consistent with SDGs 6 (water), 7(clean energy) and 13 (climate).

Within the basins, significant progress has also been achieved, both in terms of engagement activities as well as with the tool developments. In the Indus, the project team has organized 3 meetings in the course of 2018: two national consultation meetings (Delhi, India and Lahore, Pakistan, March 2018), and one basin meeting (Vienna, May 2018). The basin meeting consisted of an ISWEL scenario workshop with approximately 40 participants for two days followed immediately by a wider stakeholder workshop with approximately 100 participants drawn from the riparians as well as wider international interests from research, NGO and funder/donor organizations. This event was co-organized with the International Centre for Integrated Mountain Development (ICIMOD), the International Water Management Institute (IWMI) and the World Bank (WB). These meetings have contributed to: 1) Connect and build partnerships with a wide range of stakeholder organizations in the basin; 2) identify main water-energy-land nexus challenges; and 3) co-develop 3 alternative basin visions and pathways (stakeholder driven scenarios) (Outcome 1.1, 2.1 and 3.1., Table 1). Also as part of the Indus assessment, the modelling team completed the regional representation of the nexus in the AMF and populated the models through use of the required databases (Outcome 1.2, Table 1). The hydrological model CWATM was calibrated to adequately represent water flows in the Indus basin and provided input into the newly developed MESSAGE*ix*-Indus model that integrates a representation of energy, water and land activities. This integrated NExus Solution Tool (NEST) is now ready to be used for running the stakeholder driven scenarios and the identification of tangible policy solutions and investment strategies that can facilitate the Indus nexus management (Outcome 2.1, Table 1). In terms of developing capacities (Outcome 3.2, Table 1), the project team organized one-day training on integrated assessment tools back to back with the basin meeting held in Vienna. Also, IIASA hosted during the summer a researcher from Lahore University of Management Sciences (Pakistan) as part of the Young Summer Professional Training Program (YSSP). To support the wider dissemination and outreach of the YSSP contribution to the Indus nexus assessment, IIASA will fund his attendance and participation to the upcoming 2018 American Geosciences Union conference to be held next December. The partnering with ICIMOD, IWMI and WB represents a significant input to wider dissemination of the work within the WEL community of both research and implementers as well as representing significant financial leverage for the resources brought to support the meeting.

[1] http://www.ipcc.ch/report/sr15/

In the Zambezi, efforts during the past year have also been focused in completing the basin AMF and continuing the engagement activities started in 2017. Since January 2018 IIASA team has co-organized one stakeholder meeting and participated in two meetings convened by Zambezi Watercourse Commission (ZAMCOM). The IIASA-led stakeholder meeting took place in Harare in 9-11 July 2018, and consisted of a 2-day Scenario Workshop and 1-day training on Scenario processes. The training was attended by 11 International Master students from Zimbabwe University and was intended to provide them with an overview on different approaches for scenario planning process and some skills to support the IIASA team during the stakeholder scenario workshop. The scenario workshop brought together 28 participants from 21 different organizations (federal government, donors, NGOs) and 7 riparian countries, representing all three sectors. As with the Indus, the main outcomes of this meeting have translated into: 1) 3 different shared future visions and pathways or the basin, 2) greater understanding on the countries sectoral and nexus challenges and priorities, 3) a pre-agreement with ZAMCOM in which the resulting scenarios will be used to feed into the development of the Zambezi Strategic Development Plan (ZSDP). To strength the partnership with ZAMCOM, ISWEL team also joined two important meetings in the course of 2018: 1) a coordination meeting early February in Harare intended to align and finding synergies among organizations leading nexus-related projects, and 2) the III Zambezi Basin Stakeholder Forum, that took place in Lilongwe on 8-9 October. Project team will also participate in the next Zambezi Technical Committee (ZAMTEC) in February 2019 to discuss the feasibility of including the scenario process developed for ISWEL into the ZSDP. Based on the challenges and priority needs collected from the stakeholder meetings, the Zambezi AMF has been developed using five models (CWATM, MARINA, ECHO, MESSAGE-Access, and GLOBIOM), and populated with the available regional and global data. The Zambezi AMF is now ready to quantify the basin scenarios using the information provided from the stakeholder workshops.

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, videos). Over the past year, the ISWEL team has participated in 16 scientific meetings, and 6 high level panels and/or side events. Also, ISWEL team participated in the 9th International Waters Conference organized by GEF in Marrakech (November 2018) through a number of activities, including running the nexus simulation game and an overview presentation about the ISWEL project. These together with 16 publications (of which 6 are high impact peer review research papers), 1 policy brief, and 2 videos describing the stakeholder engagement activities are supporting the dissemination of the ongoing 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 second meeting with the PSC took place on 17-18 April 2018 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. PSC members like David Grey, Astrid Hillers and Robert Novak attended and contributed to the Indus meeting in Vienna/Laxenburg. Also, Robert Novak joined the IIASA team in the stakeholder meetings held in Lahore, Vienna and Harare.

Milestones and outcomes for the period

A summary of the main outcomes and outputs produced between November 2017 and October 2018 is given below.

- The assessment of multi-sector vulnerability hotspot analysis undertaken at the global level has been expanded now to the 275 major river basins across the world
- Work on the global hotspots analysis developed during the previous reporting period has been featured in the IPCC Special Report on the Impacts of Climate Change at 1.5°C. Specifically, data tables detailing the number of people at risk within each scenario, region, indicator and sector.

- The modelling team has completed the development of one global and two basin assessment modeling frameworks (AFMs). These AMFs are calibrated and ready for deployment.
- 3 workshops organized with the stakeholders from the Indus (Delhi, Lahore, and basin wide in Vienna) and 1 stakeholder workshop organized in the Zambezi (Harare). The meetings have facilitated:
    - Wide engagement with basin stakeholders: 34 organizations joined the Indus meetings and 21 in the case of the Zambezi.
    - The identification and prioritization of basin sectoral and transboundary nexus challenges, which have been drafted as a stakeholder report.
    - Development of 3 contrasting visions and development pathways for each basin and based on the stakeholder preferences
    - Two training workshops on the use of nexus modeling tools and scenario planning processes
    - The amplification of the project impact thanks to the engagement into existing processes. In the Indus by inputting and leading a wider process like the Indus Basin Knowledge Forum. In the Zambezi, part of the ISWEL work is now being considered in the formulation for the strategic work plan within ZAMCOM.
- 6 peer review published, 1 policy brief, and 2 working papers.
- Two videos highlighting the stakeholder process are available on the web.
- Attendance to 16 conferences and 6 high level panels/side events, in which the work from ISWEL was presented to a range of audiences
- One PhD researcher from Indus has been extensively exposed and trained in the use the Indus AMF (3 months as a YSSP) and sponsored through the project to disseminate his work in international forums.

Overall progress and deviations with respect to the work plan

The project is continuing to make good progress. Overall the work is in line with the work plan of the proposal and updates discussed in February 2017 (Annex I). The details of the outputs obtained for the reporting period (1 November 2017- 31 October 2018) against the components are detailed in Table 1.

Table 1. Targets, outputs in year two, 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	Indus Scenario Workshops held in Month 20 Zambezi Scenario Workshop held in Month 21, Three scenario narratives describing future visions and regional change pathways per basin	Yes. Output 1.1.1 was initially planned to be delivered in Month 14. Due to the delays in the organization of the scenarios workshops Output 1.1.1 for the two basins is expected to be ready by Month 28.
Outcome 1.2 Method and tool development					
Output 1.2.1 Nexus modeling tool developed and presented with preliminary results: Tool will illuminate trade-offs among sectors and explore solutions for achieving multiple development and environmental objectives	Indicators	Timeline	Targets (as described in the proposal):	Key outputs/milestones for the period:	Deviations with respect to initial planning
	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)	One global and two basin assessment nexus tools	Yes Three tools as opposed to one single tool

<table>
<tr><td colspan="6">Component 2. Exploring nexus solutions at global and regional scales</td></tr>
<tr><td colspan="6">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</td></tr>
<tr><td rowspan="2">Output 2.1.1 Tangible strategies for improving regional decision-making across sectors and borders identified for two selected regions</td><td>Indicators</td><td>Timeline</td><td>Targets (as described in the proposal)</td><td>Key outputs/milestones for the period:</td><td>Deviations with respect to initial planning</td></tr>
<tr><td>Identification and documentation of key regional insights (yes/no)</td><td>Month 5-33</td><td>Joint GEF-IIASA-UNIDO Summary for Policymakers (SPM)</td><td>Summary of key sectoral transboundary challenges for each basin</td><td>NO</td></tr>
<tr><td colspan="6">Outcome 2.2 Global nexus hotspots and transformation pathways: multi-sectorial vulnerability hotspots under different socioeconomic and hydro-climatic scenarios identified</td></tr>
<tr><td rowspan="2">Output 2.2.1 Global assessment of multi-sectorial hotspots and transformation pathways</td><td>Indicator</td><td>Timeline</td><td>Targets (as described in the proposal)</td><td>Key outputs/milestones for the period:</td><td>Deviations with respect to initial planning</td></tr>
<tr><td>Global assessment of multi-sectorial hotspots and transformation pathways (yes/no)

Identification and documentation of knowledge and data gaps (yes/no)</td><td>Month 5-33</td><td>Documentation and communication of key insights from global assessment in publications and SPM

Inclusion of knowledge and data gaps in SPM</td><td>IIASA Working paper published on Sustainable Transformation Pathways for achieving SDG6,7, 12 and 15.</td><td>NO</td></tr>
<tr><td colspan="6">Component 3. Capacity Building and Knowledge Management: Building the foundation for a knowledge and capacity network on nexus decision support</td></tr>
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Outcome 3.1 A foundation of a regional and global knowledge and capacity network established					
	Indicator	Timeline	Targets (as described in the proposal)	Key outputs/milestones for the period:	Deviations with respect to initial planning
Output 3.1.1 Establishment of connections and interactions among stakeholders from a wide array of institutions, sectors and countries; including expert advisory meetings	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) Number of informal expert advisory meetings conducted	Zambezi: Second consultation (scenario workshop) completed Participation in two additional expert meetings with ZAMCOM and other partners. 21 stakeholder organizations consulted in total Indus: Partnerships established with LUMS (Pakistan) and TERI (India). Alliances established with IWMI, ICIMOD and World Bank First (national) consultations completed Second consultation (scenario workshops) completed 34 stakeholder organizations consulted in total	NO Despite the delays in the organization of the stakeholder consultations last year, this year all planned activities have been organized and there is no deviation with respect to the remaining project timeline
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	Zambezi: Training on Scenario Development Process with 11 international students from IWRM Master Program from Zimbabwe University Training on Nexus challenges and transboundary cooperation through NEXUS simulation game. Indus: Training on Tools and models for nexus management during the Indus Basin Knowledge Forum. Number of participants: 25 approx. Training on Nexus challenges and transboundary cooperation through NEXUS simulation game.	NO
Output 3.2.1.b Exchange of scientists/experts with partner institutions, organizations	Number of scientists/experts exchanged	Month 1-35	At least one scientist/expert per case study region	1 student from Pakistan participating in the 2018 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 16 Scientific conferences and 6 High Level Panels/Research to policy Meetings	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	Participation on the 9th International Waters Conference	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)	1 Policy Brief published "The big difference of half a degree"	NO
Output 3.3.1.e Scientific publications and white papers	Number of publications	Month 1-36	At least eight scientific publications and/or white papers submitted over the life of the project	13 Peer-review papers (6 published, 3 under review, 4 in preparation) 2 IIASA Working papers published	NO
Component 4 Project Management					

Reporting	Annual progress report delivered (yes/no)	Month 1-36	At least one progress report per year	Third Progress Report (Month 12-24)	NO
(External) project oversight	Annual meeting with the Project Steering Committee	Month 1-36	At least one meeting per year	Annual Meeting 17-18 April 2018	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 output 1.1.1 (stakeholder informed basin scenarios) requires in the first place the development and processing of quantitative and spatially explicit projections of global climate (e.g. temperature, precipitation) and socio-economic (e.g. population, GDP, income) drivers under different development pathways. The source of these projections are the Representative Concentrations Pathways (RCPs) and the Shared Socioeconomic Pathways (SSPs) developed for the Intergovernmental Panel on Climate Change (IPCC). These quantitative projections (scenarios) describe contrasting and plausible future climate and socioeconomic mega-trends, and are used to assess the biophysical (land productivity), hydro-climate (water availability, and variability) and resource demand globally in a spatially explicit manner (0.5-degrees resolution). For the two basins, the SSPs and RCPs provide the context to define the regional change pathways, which are being defined in collaboration with stakeholders to further include regional drivers, possible solutions as well as improved regional datasets.

Progress by Month 24: The past 12 months have been mostly devoted to complete the main components that are needed to develop the quantitative basin scenarios: 1) the basin modeling tool (Outcome 1.2) and the stakeholder meetings and partnerships established that helped identifying basin drivers and potential solutions against different development and climate pathways (Outcomes 2.1 and 3.1). The research team is now discussing how is best to integrate the rich and diverse information collected from the meetings into the modeling framework. A description of the approach that is being discussed is provided below. Modelled basin scenarios are expected to be ready by the first trimester of 2019 and presented for validation to the stakeholders in the two basins.

Development of basin scenarios

Approach

Countries across the globe have committed to a number of policy targets e.g. IPCC Paris agreement, UN Sustainable Development Goals (SDGs), Sendai Agreement, as examples. Achieving these and other national-specific targets will require that countries and basins define specific strategies and policies. This implies that there is not one but multiple pathways to reach common targets within and across countries and basins, and each one might deliver positive outcomes but also entail unavoidable trade-offs.

Identifying pathways to manage sustainable water, energy, and land resources for the Indus and the Zambezi basins is a complex task, as different stakeholders have different values and priorities and therefore multiple (if not infinite) pathways could materialize. Also at the same time and beyond stakeholder's values and priorities, there are many drivers operating at different scales (from sub-national to global) that can have large influences in shaping the development basin pathways but are also very uncertain, particularly when it comes to long term planning (e.g. climate change, political instability, population growth, migration, socioeconomic development).

Accordingly, the rationale for the basin scenario process designed for ISWEL starts from the understanding that decisions regarding what pathways would lead to achieving water, energy and land security in the two pilot basins are largely determined by the priorities and political choices made by policy makers (state and non-state actors) within the basin and at different levels: regional, national and sub-national level. This "sphere of influence" (see Figure 1) stays within the basin but it is crucial to realize that there are many drivers of uncertainty that might have large implications for meeting the basin development targets. This "sphere of uncertainty" adds significant challenges to any planning process, particularly in the medium to long term, preventing any realistic possibility of forecasting, and making the case for scenarios (i.e. what would be the outcomes of implementing contrasting policy options to meet desirable futures from the stakeholders' perspectives and how would those change assuming different global and regional development trajectories).

The participatory scenario process (Outcome 3.1) was designed with the intention of gathering sufficient information from stakeholders in the two spheres: 1) aspirational targets regarding water, energy and land overall development goals for each basin in 2050 and pathways to get there (including solutions and trade-offs), and 2) whether these basin pathways are robust enough in the light of different global scenarios (i.e. a world that resembles the one we know today (BAU) or a world that is radically different). The information collected from the stakeholders also helped improving the portfolio of solutions and policy options that models will simulate.

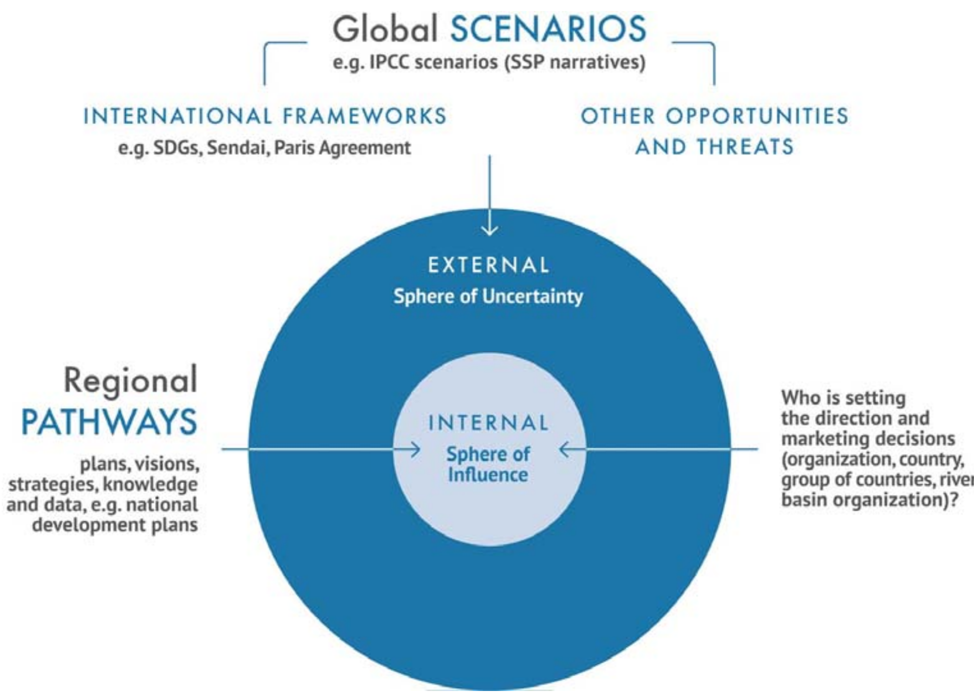


Figure 1. The logic of scenarios: separating the sphere of uncertainty from the sphere of influence.

The details of the participatory exercise developed in each basin are described in Component 3, Outcome 3.1. The main outcomes of this exercise include a detailed spatial representation of challenges and solutions (pathways) for at least three desirable futures in each basin, and a (rough) timely on when changes and solutions would be implemented to reach the basin visions. These outcomes are described in detail in the following links: Zambezi[2] and Indus[3].

Box 1 and 2 summarize the narratives underpinning the visions and pathways developed with the basin stakeholders. These storylines represent three contrasting, but still desirable, futures for the basins, where the differences mainly stem from the development priorities stakeholders identified i.e. sustainable development through economic development in the first place, or through the promotion of social wellbeing, or instead through environmental protection.

[2] https://drive.google.com/drive/folders/12GYr4Z2_liFX2EBI84RTuiCOA-Uax3he?usp=sharing
[3] https://drive.google.com/drive/folders/11ACxJwHHWQbhEuLOyj42S7gOC03nj0lT?usp=sharing

Box 1. Narratives for the INDUS basin

Economy

Under this vision, the transboundary (regions and countries) economic cooperation is the key driver that can lead to economic growth of the Indus basin. Such cooperation among the riparian countries should reduce conflicts on: 1) water sharing and resources management: 2) existing conflicts at the borders; 3) disagreements among provinces; and 4) implementation of environmental conservation protocols. The key challenge is how to convince the riparian countries to cooperate. It is not obvious how to achieve this, however, the potential pathway for the region assuming transboundary cooperation would look as follows.

One very first step to improve the economic cooperation would require reducing the barriers to movement of people, goods and services. This can be achieved by fostering the free trade agreements starting from the South Asian Association for Regional Cooperation (SAARC) and the China–Pakistan Economic Corridor (CPEC) and involving in them all four riparian countries. SAARC need to be strengthened, and China needs to be involved. CPEC China-Pakistan economic corridor (not limited only to transport but also other infrastructures) could be extended to include Afghanistan and India. Further trade agreements may be needed including establishing a customs union and easing visa constraints as options. Besides international agreements, it is important to expand the existing transport infrastructure – roads, railways, ports, etc. – in the basin.

Water is a critical resource for socio-economic development and to meet current and future demands, there is a need to increase storage facilities (big and small dams), in combination with other measures like improved groundwater use efficiency in agriculture or the development of storm water drainage and sewer systems in urban areas. Measures to improve water quality are also essential with a special focus on those aiming to address salinity. Rivers should also support trade through creating navigating channels. Allocation rules need to be reconsidered as agricultural and industrial water uses should not constrain urban water supply systems.

Agriculture is a key economic sector and will continue growing but under the premise of increasing its productivity, in terms of its economic revenues, job creation and more efficient use of water resources (surface and groundwater). Irrigated areas will continue expanding and the upgrading of irrigation technologies (swift towards drip and sprinkler irrigation) and crop diversification will contribute to buffer the growing water demands. Rain-fed agriculture can also be expanded to new areas. In order to reduce dependency on oil import, oil-seed production should be improved. Cotton and livestock production should also increase. It is of crucial importance to improve the market access for farmers and introduce price harmonization. Many ways to support rural population should be implemented in addition to agricultural support e.g. tourism development and creation of non-farm jobs in rural areas.

Energy production is critical for economic development – the focus should be on Upper Indus with the increase of energy production and its efficiency. With an obvious attention to hydropower (big and small) it is also important to promote renewables (big and small) as well as grid interconnection between the countries. Transboundary energy cooperation is required for efficient energy sharing and system cost minimization – i.e. a joint hydropower projects production in one country delivering energy also for a neighbor country.

The modernization and growing competitiveness of the agricultural sector should be accompanied by the industrialization of some parts of the basin to better balance the regional development. The issues of capital, labor, and land availability should be carefully considered. Among the specific industries with a development potential are: manufacturing, mining, textiles and others. The economy should be ready for low carbon future. However, the commitment for climate action is different among countries, as low emitting countries like are currently not very committed to reducing its emissions.

Social changes and transitions are affecting many economic issues. The most important are introducing some measures for population growth control, improving education access and achievements, especially for women, provide many opportunities for capacity building, increasing gender inclusion in many sectors especially in decision-making. Urban development should be based on sound water management and infrastructures (described earlier). Pollution should be handled efficiently including both solid waste processing and wastewater treatment. All new buildings should be designed with water and energy efficiency solutions. Environment is an underlying basis of the economy. Following the Paris Agreement, it is important to improve climate change monitoring system (climate gauge stations). Water monitoring should also be improved with further enhancing of the flow gauging systems. Vital ecosystems should be protected. Afforestation should be promoted in the northern area and close to the rivers and environmentally friendly engineering implemented.

Environment

A prosperous Indus basin requires ensuring a sustainable use and conservation of its natural capital, including its water and terrestrial ecosystems. Implementation of this vision requires the presence of strong facilitating factors including: leadership, funds, leveraging of NGOs, political will, and facilitation of stable geopolitics. The water cycle dynamics determining the river flow, maintained by groundwater, glaciers melt, and monsoons, need to be understood and respected in policy development and implementation. There is a strong need for coordinated strategy and capacity building involving all stakeholders.

Improving the management of water ecosystems requires significant investments in implementing water quantity and quantity monitoring systems. Storage infrastructure like dams should be planned considering carefully the potential effects on the river systems. Risk of sedimentation impact of big dams should be accounted for in feasibility studies and prevented. Dams construction and operations should also be aligned with the flood management measures (dual purpose infrastructure). Actions should prioritize the improvement and optimization of the existing infrastructure before planning for new developments. Strategic storage dams should be carefully planned in critical points. Groundwater storage and groundwater recharge should be considered as an alternative for the construction of new dams. Wastewater recycling and reuse should be applied broadly to manage aquifer recharge (MAR). Water should be zoned and priced to achieve the above objectives. Better water allocation should be designed – it should be more evenly distributed among sectors (less to agriculture and more to cities and industries), while return flows can be reused downstream to increase environmental flows and feed downstream ecosystems (including Indus delta). Full scale implementation of the water allocation scheme is possible only through water accounting in the monitoring stations that need to be expanded. Widespread salinization resulting from intensive irrigation is a huge problem. Irrigation efficiency policies through water efficiency systems in agriculture can lead to rebound effects and an increase in total irrigated area that offsets the water savings. To avoid this, it is necessary to apply side measures such as a cap in total irrigated area. High efficiency-precision agriculture is critical to achieve water objectives. It should be based on: 1) selection of seed varieties and efficient cultivation practices; 2) application of digital technologies including smart sensors and tele-connection via smart phones; 3) efficient application of water and fertilizers;4) rehabilitation of irrigation canals (reduction of system losses),5) sprinklers and drip irrigation; 6) reducing fertilizer use and introducing organic agriculture; 7) hydroponic crops; and 8) management of canopy density and height, as well as specific species combination to generate synergies and maximize yields.

Renewable energy generation to complement hydropower: solar (Kashmir, Balochistan and areas close to Kabul; Rajasthan is already implementing it.) and wind (significant potential for wind in Rajasthan).

Protected zones should be created in sensitive ecosystems or areas (forest and wetlands) of great ecological value to avoid degradation by tourism or urban expansion. Biodiversity can serve as an indicator of water quality status and improvement (e.g. Dolphin as a natural indicator of healthy water quality). Existing laws on species, habitats and designated protected areas should be enforced. Sustainable tourism should be promoted to counteract the problems created by the current massive tourism. Green corridors could be established for power generation and then used for sustainable tourism activities. UNESCO Geoparks system could serve as an example of protected zones. It requires protection policies and investment in security systems. Income from ecotourism could support indigenous people. Coastal areas should also be protected. Coastal mangroves, which has been proven to increase atmosphere water moisture and thus promote and stimulate upstream precipitation, should be restored. Fishery zones should be implemented, sedimentation avoided, and environmental flows increased. A buffer zone beyond the basin boundaries should be considered to assess the effects on and interactions with the surrounding socio-economic-environmental systems e.g. food trade to Delhi and rest of India, energy policies in China and development (mining) plans and policies in Afghanistan.

The following flood adaptation measures should be considered: 1) Interconnected early warnings system (both for flood and landslide); 2) Create riparian zone where it is forbidden to live;3) Moving people outside these regions (To find affordable places);4) Sustainable urban planning respecting the flood plains; 5) Need for an agreement of cooperation and collaboration among countries (especially India-Pakistan) and data sharing in order to reduce the need for infrastructure and generate a smart network; and 6) Early warning systems in place across the whole basin.

Industry development should be considered carefully. Low carbon transport system should become the standard. Improvements of urban environment should be identified and implemented including: 1) implementation of solid waste recycling and appropriate treatment systems;2) investing in waste to energy systems; 3) constructions of green-efficient buildings; and 4) promoting of electric vehicles.

A bigger participation and integration of the whole society is needed including government, NGO, population, enterprises. Communities living in the mountains, who are the natural ‘glacier keepers’, should be involved and supported. Clean Water Act should be enforced. Other environmental laws, actions and regulation rules should be enforced. Laws should be

introduced ensuring appropriate measures in case of strong environmental damages – they should be treated as environmental crimes. Water pricing scheme should be designed and enforced.
Cultural and behavioral changes towards more sustainable practices should be promoted including norms and attitudes for improved hygiene and waste management. Expectations and pressure for pollution mitigation should be enhanced. Investments are needed in education to improve the population awareness about the importance of the environment. Investment in capacity building are needed at different levels including in particular: 1) exchange between students; and 2) creation of Indus Research Centre and Network.

Society

The most important components of the social vision includes: 1) Transboundary management (community & technology driven); 2) Resilient Communities; 3) Supporting Indus Entrepreneurs; 4) Technological Revolution; 5) Joint Transboundary Governance; and 6) Easier mobility. Indus basin should agree on its customized Indus Development Goals with time horizon until 2050.
This pathway is strongly based on better transboundary collaboration – both technology and community driven. It is characterized by smart technological progress, with specific solutions addressing the major challenges in the basin. Technology is creating and enabling new possibilities, for example new developments in ICT such as open data sharing, using data warehouses, and satellite telemetry can strongly improve the capacity and functions of existing and new infrastructures by, for example, applying them to early warning systems. The necessary transition to these new technologies requires a new generation of science and technology education.
Water problems in Indus are complex and in order to improve for both soft and hard Infrastructure is needed. Irrigation is crucial for agriculture and in order to sustain rural population, the area for irrigated cotton, sugarcane, wheat, and rice need to be expanded. This needs to be accompanied with substantial investments in drainage to reduce waterlogging. In the areas where groundwater is low, its recharge need to be carefully managed for example using wetlands ecosystem services. There is a strong need for smart irrigation techniques to increase the water use efficiency. Some areas located far from canals and rivers, like Thal and Sindh, already use drip and sprinkler irrigations techniques, but it needs to be broader. Floods pose more and more serious risks and they need to be handled jointly by the riparian countries using transboundary flood management. Water treatment should be implemented more broadly to improve access to drinking water. Water demand in cities can be managed by using for example urban wastewater recycling.
Salinization is the biggest threat and needs to be controlled. It won't be possible without increasing agricultural water use efficiency. An important contribution may come from transboundary community management combined with easier regional mobility including country borders. Such management could lead to the exchange of best agricultural practices leading to improved water management and efficiency. Other specific include improving animal house boundaries and building roads and increasing agriculture import into Gilgit Baltistan.
One of the more promising solutions to increasing energy production in the Indus basin is based on the benefits sharing approach in relation to hydropower construction and use. Small storage dams should be built in Jhelum and Balochistan. New run off the river power plants should be built in Kashmir Small run of the river power plants can be built in many places of Upper Indus. Large storage area dams should be constructed in KPK province. With growing energy demand hydropower should be complemented with coal power plants.
Agriculture should be balanced with industrial development – both traditional textiles industries as well as food processing industries. To this end, special economic zones can be used.
Improving social indicators shouldn't lead to further environmental problems. In particular, minimum environmental flows should be maintained, both transboundary and within countries.
The progress in achieving a sustainable Indus future is relying strongly on improving governance in the region. Transboundary institutional mapping, identifying exemplary resilient communities, and sharing of their best practices, that can be based on article 7 of the Indus Water Treaty (benefits sharing), can lead to significant progress, especially with respect to energy production and distribution. Drought, floods and other disaster risks should be managed transboundary by establishing regular data sharing and cooperation of the National Disaster Management Authorities (NDMA) in the riparian countries. A broad group of stakeholders (experts) from the riparian countries should be granted the observer status for better understanding of the common problems, sharing existing and formulating new, joint solutions. Examples of such innovative practices include both community and individual (entrepreneurship) level instruments: e.g. community water budgets and wells entrepreneurship (e.g. water ATMs) linked with the private data providers. However, regulations will not suffice without also improving compliance to water and environmental regulations. Public awareness of water issues can be enhanced by authorities and clear communication strategies to spread resilient practices.

Box 2. Narratives for the ZAMBEZI basin

Economy

In the Economy-based Scenario, Zambezi has made the leap to become a competitive economy thanks to investments programs that contributed to secure access to key natural resources and foster the physical and economic integration of the riparian countries. The leap is achieved with the deployment of a large investments to increase energy security and electricity access mostly through the construction of at least 13 new multipurpose-use dams across the Zambezi river and its tributaries and the maintenance and upgrading of existing infrastructures. In the more remote areas, hydropower is replaced by other renewable energy like solar power and wind power. Investments are also geared towards upgrading the agro-sector and improving food security, including the expansion of the irrigated areas, the replacement of canal for drip irrigation, the diversification of crop production (food and non-food crops), the development of greenhouses for production of high value crops, and pest control. Investments in improving water monitoring systems and water quality also contribute to more effective management of available resources and reduce vulnerability to floods and droughts. Water transfers from the Congo Basin into Upper Zambezi and Kafue contribute to buffer water scarcity during droughts. Improved communication infrastructures (railway, roads, airports) and country agreements facilitate the economic integration of the Basin.

Environment

Zambezi Basin has become a competitive, equitable and green–based economy: as a result of a strong cooperation among countries in the benefit-sharing framework. The leap is achieved with the deployment of a large-scale program that prioritizes the rehabilitation of degraded lands, the conversion of most pristine and fragile ecosystems into conservation areas (wetlands, terrestrial forests, mangroves) and improving the management of existing protected area network. This green investment constitutes the pillar over which eco-tourism economy flourishes in the Basin. Revenues of eco-tourism are shared among state countries but also among rural communities, and Community-based natural resources management becomes a reality to improve the livelihoods of many people living in the rural areas. Green infrastructure is insufficient to meet the water and energy demands by an increasing population, therefore, existing hydropower projects continuous but operations are adapted to secure environmental flows downstream. New energy demands are being met through the development of solar power, which also represent a more efficient option to increase electricity access among the disperse rural community in the basin. Growing water demands are also met thanks to the un-tapped groundwater potential in the Zambezi. To ensure appropriate governance of this hidden resource, efforts are invested in implementing an effective GW management plan at the basin scale which also considers artificial recharge to sustain the resource availability in the longer term. In addition, several policies are implemented in order to improve the water sanitation and reduce the pollution of surface waters. To reduce the risks of extreme floods, early warning systems and flood mitigation plans are implemented and coordinated by ZAMCOM. Agricultural productivity raises as well as farmers' income and overall food security levels increasingly. This is achieved through significant efforts and resources into R&D and the implementation of large-scale Climate SMART agricultural programs. Preserving Indigenous knowledge becomes an important target for maintaining cultural heritage but also because it represents a key source of knowledge for climate change adaptation and mitigation.

Society

Riparian countries of the Zambezi experience significant improvements in meeting its most important development goals. This leap has been made possible thanks to implementation of an ambitious transboundary cooperation plan, that includes joint investments to improve supply as well as communication infrastructures, as free trade agreements. This mechanism of sharing costs and benefits allows countries to meet jointly their development targets for both urban and rural population. Investments will be first allocated to increase access to electricity, mostly through the expansion of hydropower stations and solar power in the most remote areas, as well as developing the power grid to cover all populations. Making electricity available for all will facilitate the economic development and improve livelihoods particularly in the rural areas. Additional resources will be invested in improving the agricultural sector, through the development of technical capacities and access to credit. This will help eradicating hunger and lifting rural populations out of poverty. Trade agreements will also help to boost the agricultural market. Industrialization will also take off and continue developing towards 2050. As a result of the higher demand and use of natural resources, environmental and monitoring policies are implemented to reduce the pollution associated to industries and the conservation of forest areas in the headwaters, to prevent dam sedimentation as well as for floods control.

Translating the stakeholder's visions and pathways into quantitative scenarios

The overall process on how the stakeholder information is translated into the modeling scenarios is summarized in **Figure 2**. The stage where we are currently is Step 4 i.e. matching the stakeholder information with the model capabilities to define the boundary conditions of what can actually be considered in the modeling framework developed.

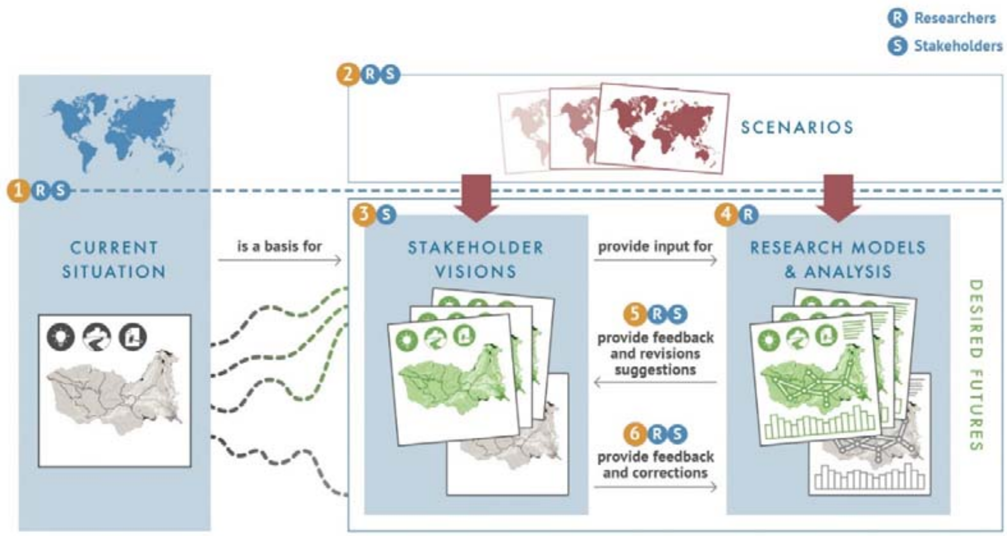


Figure 2. Summary of the process describing the development of the basin scenarios

The departure point in Step 4 is that the information collected from the stakeholders as well as the modeling tools developed are suitable for exploring different types of basin scenarios. The choice of one or other scenario type depends on the type of questions that want to be addressed (see Box 3).

BOX 3. Schools of scenarios

Börjeson et al. (2006) provide a typology of scenarios based on the three principal questions that users may want to ask about the future.

1. What will happen?

These are predictive scenarios that are trying to elicit probable futures. They are strongly based on current trends or other sources of reliable information about the incoming changes.

2. What can happen?

Explorative scenarios are useful in situations of significant uncertainty – then creative thinking, 'out of the box' approaches are needed to imagine possible 'game-changers' or 'black swans'.

3. How can we get there?

To answer this question, normative scenarios are used supporting the achievement of a certain vision. The visions specify which targets should be achieved or which outcomes should be avoided, or impacts to be reduced. This type of question is usually in the center of interest for most stakeholders. They less interested in potentialities and more in setting a positive direction.

One should note that if we try to harmonize this classification with the clear separation of scenarios and pathways (Figure 1), questions 1 and 2 can lead to development both scenarios and pathways whereas question 3 is indicating that pathways are used since the focus in on sphere of influence.

In the ISWEL project, both in the Indus and in the Zambezi, stakeholders are clearly focused on developing pathways to desired futures and that's why we have used the normative approach (question 3 in the box) to designing and implementing stakeholder workshops. As outputs, they have produced a series of normative pathways, with three different priorities. This way we have managed to generate outstanding engagement and enthusiasm among participant (evident in participants' feedback).

At the same modeling practice is strongly affected by the IPCC framework with the underlying SSPs. There is a substantial body of data collected and processed, generated model runs and analyses of results that would be hard to ignore. Additionally, the IPCC/SSP framework provides comparability essential to making a systemic and reliable scientific progress that can be translated into the policy recommendations. This raises the need to provide a bridge between the normative stakeholder pathways and explorative, model-based, scientific pathways (Figure 2). We intend to cross this bridge by developing a model-based business-as-usual regional pathway (based on the SSP2 – Middle of the Road) and, in the next step, constructing a series of 'what-if' policy pathways based on the same priorities (Economy, Society, and Environment) as the stakeholder scenarios. Such an approach will combine an explorative character of the IPCC scenarios with normative elements, represented by specific policies in their corresponding pathways. The policies included will be based on the corresponding stakeholder pathways.

To this end, a process is now being designed to match the information coming from the scenario workshops with the modeling capabilities. This matching exercise will serve to: 1) provide transparency to stakeholders in regards to which input (challenges, solutions, etc.) can be included into the modeling framework; and 2) provide an internal reference of which scenario elements are important and, at the same time, can be a part of the model pathways. Figure 3 provides an example of the matching exercise that is currently being developed.

Dimensions	Workshop Scenario Elements	Modeling capabilities of the Nexus tool
Demography	Population (growth)	✓
	Urbanization (level)	✓
	…..	
Human Development	Education	✓
	Access to drinking water	✓
	Access to clean energy	
	…..	
Economy and lifestyle	Energy demand	✓
	Cooling demand	
	Land demand	✓
	Tourism	
	….	
Technology	Drip irrigation	✓
	Rainwater harvesting	
	Coal power	
	…..	
Environment	Forests	✓
	Wetlands	
	Environmental flows	
	Protected areas	

Figure 3. Example of a matching exercise to bridge information from the stakeholders with modeling capabilities

Next Steps: Finalize the planning of the list of pathways to be explored and develop a procedure to translate stakeholder information into model inputs and targets. This discussion will take place in November 2018, as it is expected that basin quantitative scenarios will be completed during the first trimester of 2019 before heading into the basins for final consultations.

Outcome 1.2 Method and tool development

Summary: In addition to the scenarios, the main output of this project component is the development of a nexus tool (output 1.2.1). The nexus tool developed is, in reality, an analysis modeling framework (AMF) or 'tool-box' that integrates the following models: The hydrological Community WATer Model (CWatM), the water quality model (MARINA), the hydro-economic model (ECHO), the energy-economic model (MESSAGE*ix*) and the agro-economic model (GLOBIOM). The main features of the AMF is that it is scalable (i.e. can be applied to address issues at multiple scales, from global to regional), flexible (i.e. depending on the issues to be addressed models can be plug-in and plug-out), and it is transferable (i.e. applicable to different locations). Building the AMF implied a two-step process: 1) the development or upgrade of sectorial models to better incorporate the nexus connections; and 2) the coupling of the different models. Year 1 of the project was mostly dedicated to the development of the new sectoral models (CWATM and ECHO), and the upgrading of existing ones (MARINA, MESSAGE*ix* and GLOBIOM) to better represent the sectorial linkages and/or temporal and spatial scales. Year 2 has been dedicated to assembling the different models to create specific AMF for addressing the global and basin scale nexus issues.

Global Assessment Modeling Framework

Progress by Month 24: The global AMF is now nearing completion and consists of a model chain integrating three tools: MESSAGE*ix* covering the energy sector and respective infrastructure development decisions; CWatM representing the water-related impacts on land surface; and GLOBIOM representing the land sector and land use activities. Figure 4 describes the boundary conditions and associated input models to examine potential feedback the three sectors.

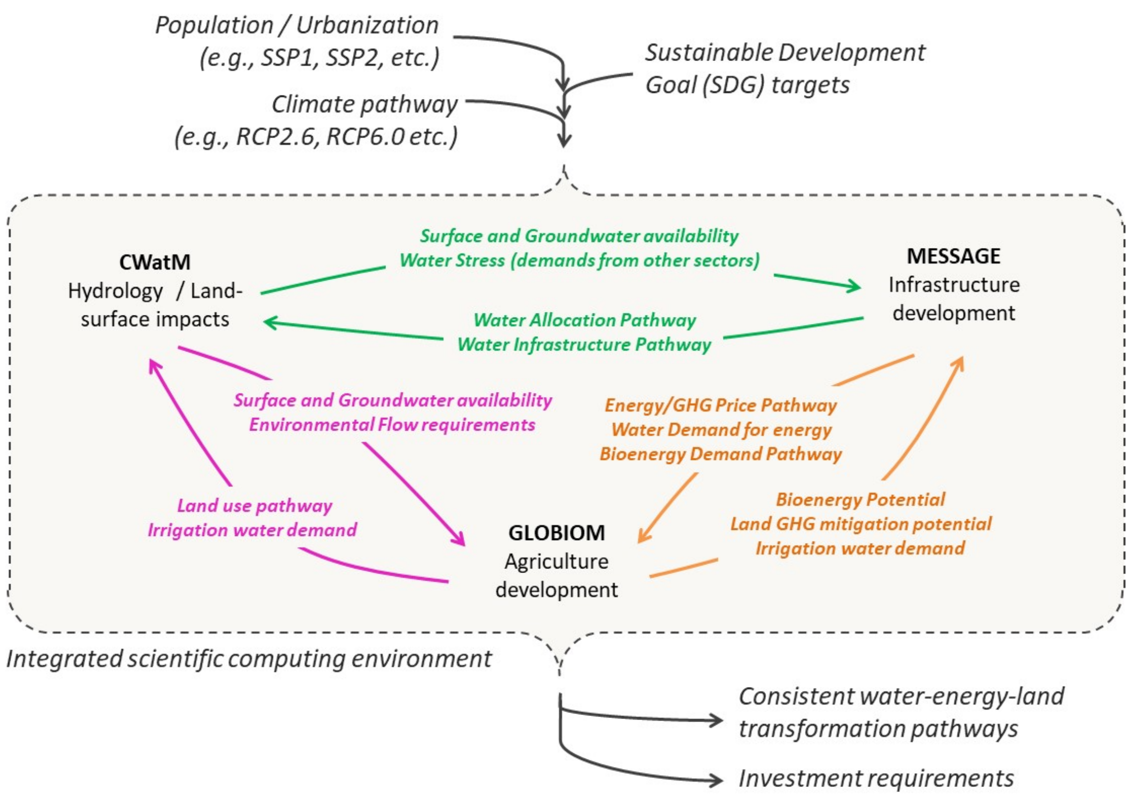


Figure 4. Architecture of the Global Systems Analysis Framework

The global AMF is being designed in such a way that it allows exploring different policy questions, including potential trade-offs as well as solutions/pathways to achieve multiple sustainable development goals (SDGs) or the (multi)sectoral implications of climate change mitigation and adaption policies. These policy options can be model assuming different socio-economic and climate developments. Table 2 provides a summary of the policy dimensions that are currently integrated into the global tool.

Table 2. SDGs targets that can be explored through the global system analysis framework

Sustainable Development Goals	Indicator	Targets
Food Security (SDG2)	Total calorie intake	Developing countries: undernourishment below 1% Developed countries: animal calorie intake does not exceed 430 kcal/capita/day
Clean water and sanitation (SDG6)	Access to piped water	Universal access in urban areas to 100 liters/capita/day and 50 liters/capita/day in rural areas
	Wastewater collection	Half of the return flows are treated
	Sustainable water withdrawals	(1) Ensure sustainable extraction of surface water for use by irrigation with protections for the minimum environmental water flow requirements (2) Limit all water extraction for use by irrigation of groundwater defined as unsustainable (3) Reduce in share of agricultural water demand exceeding unprotected environmental water flows
Affordable and Clean Energy (SDG7)	Access to electricity	Universal access to electricity and 50% of the energy mix coming from renewable energies
Responsible production and consumption (SD12)	Reduced animal calorie intake	Maximum of 430 kcal/capita/day for those countries exceeding the threshold
	Food waste	Food waste halved respect to current records At least 25% of urban return flows recycled
	Recycling of return urban flows	Improved behaviour leads to 30% reduction of water demands
	Water intensity	Domestic, urban and agricultural water use decrease by 30% through improved behaviour
	Energy demands	Energy demand decreases by 40% thanks to improved consumer behaviour and efficient technologies.
Climate Action (SDG13)	Global Greenhouse Emissions	Compliance with the Paris Agreement and limiting Global Warming to 1.5 Degrees
Protection of terrestrial land and its biodiversity (SD15)	Highly biodiverse areas[4]	At least 17% of global highly biodiverse areas being conserved

[4] Highly biodiverse areas refer to areas where three or more biodiversity priority schemes overlap (Conservation International's Hotspots, WWF Global 200 terrestrial and freshwater eco-regions, Birdlife International Endemic Bird Areas, and WWF/IUCN Centres of Plant Diversity and Amphibian Diversity Areas).

To operationalize the sectorial linkages, the energy and agricultural and forestry models include a reduced form (simplified) representation of the sectors that the other models are representing in detail. For example, MESSAGE*ix* includes a parametric representation of GLOBIOM which allows the energy system to "see" the feedbacks of the agriculture and forestry sectors to certain policies. Similarly, a reduced form, regionally-specific representation of the global water sector is included in MESSAGE*ix* which accounts for future shifts in global water use patterns driven by a combination of socioeconomic changes, and links these projections and policies to water availability, and the cost, energy and emissions impacts of future infrastructure systems.

A description of the interlinkages between the different model components is provided below. Section 2.2 describes a first application of how the global AMF has been applied to model the costs and characteristics of global future pathways aiming at balancing SDG 2 (food) SDG 6 (water), SDG7 (energy), and SDG13 (climate).

Water-Land interlinkages (CWatM –GLOBIOM)

The interlinkages between water and the land models has been improved to address critical questions currently under debate like- what options exists to improve agricultural productivity to achieve food security (SGD2), while supporting the conservation of terrestrial ecosystems (SDG15) and the achievement of water security targets (SDG6)? These questions can be explored taking into account different climate and socioeconomic global scenarios, to illustrate a range of possible solutions and investments that will contribute to maximize outcomes and highlight potential trade-offs.

The need to further investigate these linkages is largely driven by the fact that improvements to agricultural productivity are often been linked to the development of irrigation. Such an expansion is also considered an adaptation option in the face of climate change, expected to strongly affect rain-fed agriculture (Leclère et al., 2014; Müller et al., 2011; Roudier et al., 2011). However, while this measure could help achieving some key targets (SDG2 and SDG15), an increased role for irrigation poses challenges for water availability (SDG 6), particularly in water stressed regions.

To address these linkages, GLOBIOM is used to model the supply and demand of agricultural products at a high spatial resolution in an integrated approach that considers the impacts of global change (socioeconomic and climatic) on food, feed, and fiber markets. GLOBIOM models the conditions and investments required to transform rain-fed cropland into highly productive and efficient irrigated cropland, taking into account the biophysical availability of water, the growing competition for water from other sectors (domestic, energy, industry, and the environment) as well as the impacts that upgraded and expanded irrigation systems have on regional crop production, land use change and emissions, as well as food security and resulting water demands for irrigation.

The information on surface and groundwater availability, as well as the water demands by the different sectors and environmental needs is provided to GLOBIOM through the hydrological model CWatM. Projections on water availability and socio-economic and environmental demands are supplied by CWatM at a high spatial resolution taking into account the land use and land cover information provided by GLOBIOM as well as the changing socio-economic and climate drivers (RCPs and SSPs).

In GLOBIOM, demand for water for irrigation is sourced from groundwater or surface water, however agriculture is always considered the residual user of water, after water for environment and other economic uses have been satisfied. The water necessary for sustaining the environment (environmental flow requirement) can be considered as protected or unprotected. When the water flows are unprotected, agriculture is not limited to sustainability thresholds. We calculate the unsustainable share of the total irrigation water demand which is the quantity of demand that exceeds the water flows necessary for the environment. The share of unsustainable water demand for irrigation also considers the share of water sourced by unsustainable groundwater extraction, which globally accounts for almost 20% of the total irrigation water demand (Wada et al. 2012).

In an iterative process, these changes water availability estimated by CWatM and sectoral demands are then passed back to GLOBIOM to further inform the availability of water for use by agriculture. Developments of the agricultural sector including expansion of irrigated area and water withdrawals for irrigation are included in the hydrological processes of CWatM which determines the resulting impact of how water is retained, used, or transferred to downstream users across a landscape.

Land-Energy interlinkages (GLOBIOM-MESSAGE*ix*)

Linkages between GLOBIOM and MESSAGE*ix* have been established previously with the purpose of: 1) representing feedback loops between the energy and the land system regarding market interactions in response to climate change mitigation policies, and beyond that 2) evaluating the implications of climate change mitigation policies on several land-related development targets (namely SDGs 2, 12, 6 and 15).

The rationale for representing market interactions among the energy and land systems originates from the fact that bioenergy expansion is considered a key climate change mitigation policy. Thereby, a growing demand for biomass from the energy sector will reduce land that is available for other uses such as food production or nature conversation. Vice versa, an optimal energy mix depends on the quantity and price of available biomass and the emission reduction potentials from the land use sector.

To reflect this interdependency between the land use and energy sector in the modelling chain, in a first step, a scenario surface is quantified with GLOBIOM along two important determinants from the energy sector: carbon prices and biomass demand prices. To this end, scenarios with different combinations of exogenously implemented carbon- and biomass demand prices are calculated in GLOBIOM. As results, biomass supply potentials and marginal abatement cost curves from the land use sector are gained. This scenario surface (so called "GLOBIOM emulator") is available offline. It allows MESSAGE*ix* to virtually implement a reduced form of GLOBIOM directly into the optimization process and take feedback reactions on prices and emissions from the land use sector immediately into account. The final bioenergy demand and required carbon tax (given a certain climate target) are then fed back into GLOBIOM to calculate the final impacts on the land use sector.

The described link between MESSAGE*ix* and GLOBIOM has been the first one to be established among these two models and it has been extensively tested in several projects. However, the described approach so far only considered the climate policy dimension (carbon & biomass prices). Other important dimensions, such as the impact of changing energy prices on agricultural production, or the impacts of climate mitigation on land-use related SDGs, had been neglected until now.

The impact of energy prices changes on the agricultural sector may become especially crucial in ambitious climate change mitigation scenarios. Ambitious mitigation scenarios are likely to increase energy prices through the implementation of climate policy (e.g., a carbon tax on fossil energy). Energy, in turn, is an important input in agricultural production. It is used directly (e.g. for field operations, irrigation, drying) as well as to produce many important inputs used in agriculture such as synthetic fertilizers and other agro-chemicals, machinery, seeds etc. Thus, changes in energy prices are likely to have impacts on agricultural production costs and eventually on food (and biomass) prices.

To reflect this additional interlinkage between the energy and land use sectors also in the model chain, energy demand for agricultural production has been identified and cost for energy in agricultural production has been made explicit in GLOBIOM, facilitating another interface with MESSAGE*ix*. To this end, a new database has been developed which contains quantitative energy use and prices for all different production activities/regions represented in GLOBIOM, split by energy carrier.

Additionally, to enable the energy system model to integrate the climate policies within a broader development agenda, a revised emulator was generated by GLOBIOM to include in addition to the climate policy dimension also SDGs targets with respect to food security (SDG2), dietary patterns and food waste reduction (SDG12), irrigation water use (SDG6), and biodiversity protection (SDG15). The revised emulator thus considers these different SDG objectives (see Table 2) and hence allows the MESSAGE*ix* energy system model to develop climate stabilization pathways that do not jeopardize these SDGs.

Energy-Water interlinkages (MESSAGE*ix*-CWaTM)

Linkages between the energy and water model have been established in order to: 1) improve the representations of the water availability and constrains into the energy modeling system, and 2) assess the water requirements (of conventional and non-conventional sources of water) and return flows resulting from the use of different energy technologies and efficiency improvements. Full technical description of the linkage can be found in Parkinson et al. (2018).[5]

Water requirements and return flows for different energy technologies have been calculated following the approach of Fricko et al. (2016). Each technology is prescribed a water withdrawal and consumption intensity (e.g., m^3 per kWh) that translates technology outputs optimized in MESSAGE*ix* into water requirements and return flows. This assessment allows exploring how different energy improvements translate into improvements of the water intensity. A key feature of this work is the optimization of plan cooling technology options for individual power plants, which allows MESSAGE*ix* to choose the type of cooling technology for each power plant and track how the operations of cooling technologies impact water withdrawals, return flows, and thermal pollution.

MESSAGE*ix* representation of the water system includes three different sources of freshwater supplies: rivers and aquifers, desalination, and wastewater recycling. Projections on freshwater supply from rivers and aquifers for energy production are provided by CWatM and its calculation takes into account the renewable water availability fraction and the water demands of the agricultural, municipal and manufacturing sector. These water supply projections take into account improvements in water use efficiency, increased water demands by different sectors, including future connections of populations to an improved water source. Furthermore, MESSAGE*ix* incorporates assumptions regarding how technology diffusion for desalinated and wastewater recycled water will evolve in the future in water stress regions, and therefore supply estimates for these non-conventional sources of water. Technologies incorporated into the water module of MESSAGE*ix* include: thermal and membrane desalination, urban wastewater treatment, rural wastewater collection and treatment, urban /manufacturing wastewater recycling, urban/manufacturing water distribution, and rural water distribution. The establishment of these linkages has allowed so far to assess co-benefits of implementing sustainable consumption and production (SDG 12) in terms of minimizing the cost of implementing clean water and energy goals consistent with SDGs 6, 7 and 13.

[5] http://pure.iiasa.ac.at/id/eprint/15231/

Indus Assessment Modeling Framework

Progress made Month 12-24: The past twelve months have been dedicated to completing the development of the Indus AMF, the so-called Nexus Solutions Tool-NEST, improving the representation of modelling framework to adjust it to the basin context as well as populating the model and calibrating the data. The Indus AMF includes two modelling tools, the CWATM and a version of the MESSAGE*ix* model that incorporates fully integrated and reduced-form of the water and land use systems. These tools are used iteratively to transfer feedback on water availability (CWATM to MESSAGE*ix*) and water uses (MESSAGE*ix* to CWATM). Both tools access the same harmonized Geospatial database to guarantee consistency.

Description of the tool

The NEST tool simulates the expansion, retirement and operation of technologies to meet user-specified demands for water, energy and agricultural products across different sectors, and quantifies the impact of these development scenarios on the environment ensuring robust performance across specified indicators. NEST is supported by a geospatial database and interactive, web-based results processing tools. The geospatial database houses all relevant input data used for model parameterization and calibration.

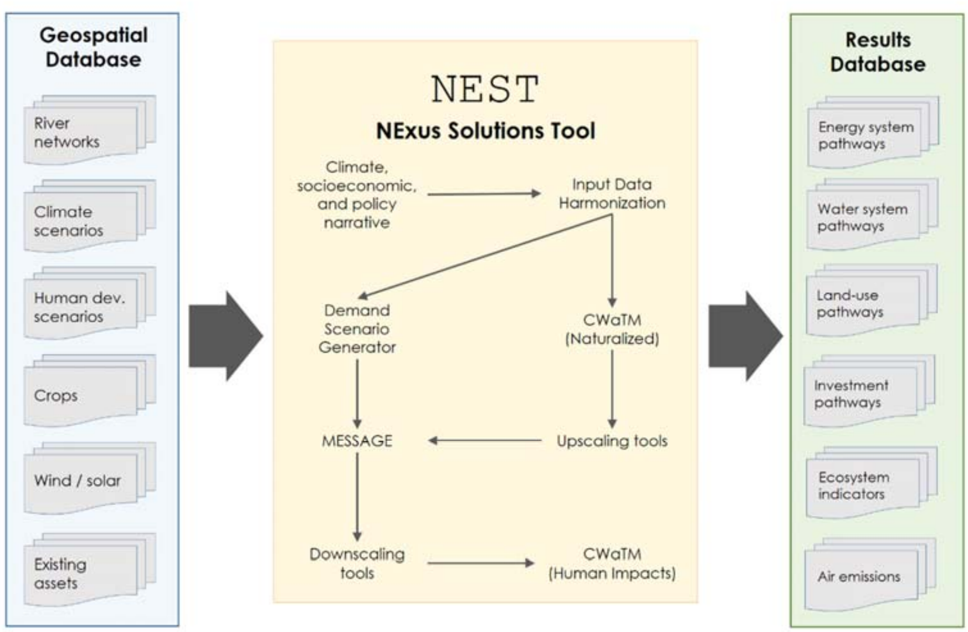


Figure 5. Structure of the NEST framework

NEST is implemented to explore long-term pathways spanning multiple decades because many of the modeled decisions involve infrastructure with long lifecycles (e.g., a new power plant can last for around 30 years). Moreover, relevant sustainable development policies for water, energy and land systems usually focus on achieving targets many decades into the future in order to address adaptation to long-term sustainability challenges (e.g., the SDGs aim for achievement by 2030). Technologies must also have the capacity to balance monthly variations in supply and demand to ensure systems can cope with seasonal variability.

Geographic scope

River basins are the fundamental spatial unit used in NEST, and are defined by geographic areas where all incident precipitation converted to runoff is directed towards a single outlet to the sea (or inland lake). River basins can be delineated using the HydroBASINS global dataset. Using hydrologically corrected digital elevation data from NASA's Shuttle Radar Topography Mission at 15 arc-second resolution, watersheds (or sub-basins) are delineated in a consistent manner in HydroBASINS at different scales.

In NEST, river basins are disaggregated into sub-basins to enable consistent tracking of within-basin surface water flows. To enable a transboundary perspective, NEST further intersects the sub-basin boundaries with country administrative units, e.g., from the Global Administrative Areas database (GADM). A reduced-form network is estimated between Basin Country Units (BCU) using flow-accumulation data from HydroBASINS at 15 arc-seconds. The construct for the Indus river basin in South Asia is depicted below (Figure 6).

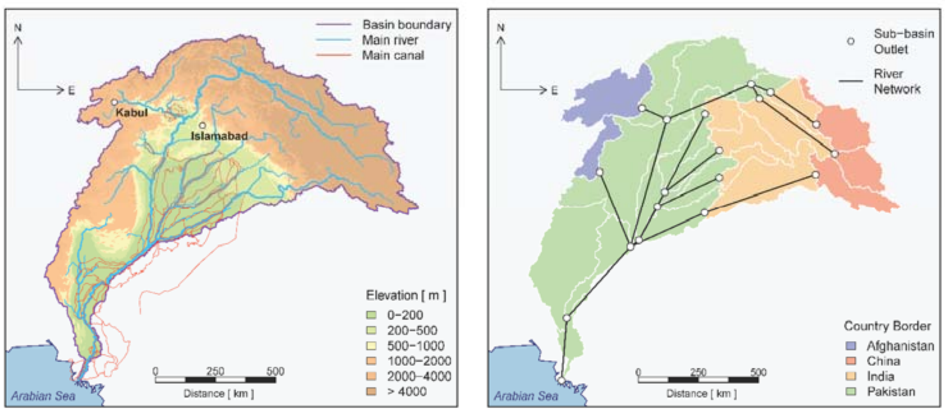


Figure 6. Main rivers and canals in the basin (left), Basin Country Units (BCUs) and reduced-form river network

Geospatial Database

As mentioned above, geospatial data has been collected and elaborated for the different sectors of the countries of the Indus basin, aggregated at different scales and inputted to CWatM and MESSAGE*ix*, respectively working at 5' and BCUs resolutions. Other than river network and water reservoir data, the geospatial database includes human development indicators, such as population, information on crops historical land use and yields (GAEZ-FAO Data Portal), and data on renewable potential used to calculating exclusion zone and hourly capacity factors for common photovoltaic and wind turbines (Pfenninger et al., 2016; Staffell et al; 2016). Spatial data, together with other aggregated data, such as technology parameters, are manipulated and used as input to CWatM or MESSAGE*ix*, or used to generate demand trends for electricity, water requirements or crop products (see Figure 7).

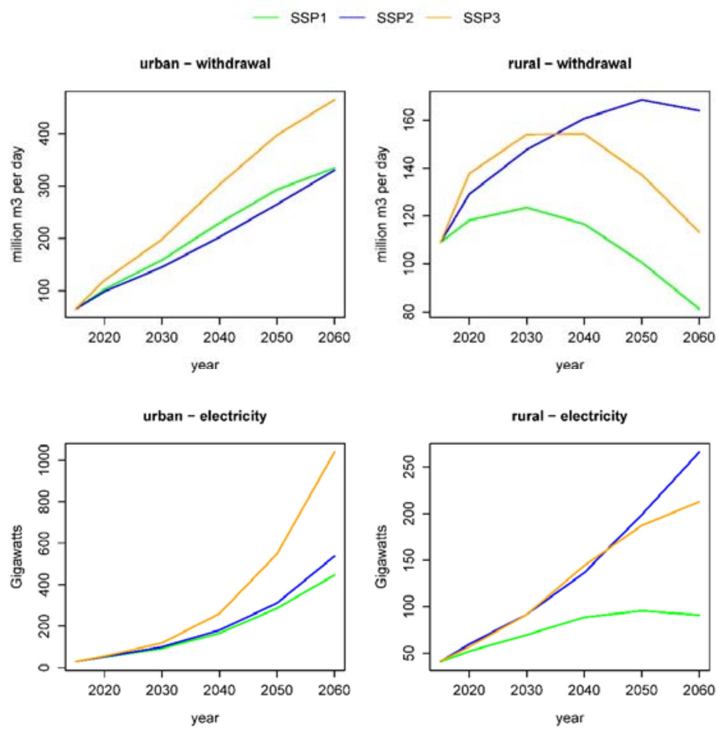


Figure 7. Aggregated electrcity and water demand for the whole Indus-basin region

Infrastructure transformation

System transformation is simulated using the MESSAGE*ix* framework. A diverse portfolio of water, energy and land technologies are defined and characterized by input and output efficiencies (i.e., the rate at which a particular commodity is consumed or produced during technology operation), costs (investment, fixed and variable components), and environmental impacts (e.g., greenhouse gas emissions untreated wastewater, etc.).

In MESSAGE*ix*, water from different sources (surface, ground and saline) is converted and allocated across sectors (urban, rural, energy and agriculture). Simultaneously, return-flow volumes are managed, including opportunities to recycle wastewater streams within and between sectors. Likewise, river flow and conveyance between spatial units is optimized. Nexus interactions across sectors are accounted for explicitly, including the energy required for pumping and treating water, and the water needed for crops and electricity generation. Hence, the water system pathways in NEST adapt to future changes in agriculture and energy systems.

The energy system representation in NEST is focused on electricity supply mainly because of current global trends towards end-use electrification. The portfolio of power plants includes most types of fossil and low-carbon power generation. Thermal power plant technologies are distinguished by cooling technology, with the choice of cooling technology impacting the plant's economics and efficiencies. Transmission between BCUs and distribution to end-users is explicitly modeled in the framework using a simple transport representation commonly found in large-scale energy models. Rural, urban and agriculture end-users of electricity are distinguished in the model.

The land system using the MESSAGE*ix* reference scheme primarily focuses on cropping systems. The model is able to choose the type of irrigation technology and crop type in each basin country unit (BCU). Irrigation technologies differ in terms of their investment costs and water/energy efficiency. Yield varies with the amount of irrigation in each month. On-farm energy and water requirements are estimated from data observed in the literature. Distinction is made between the type of energy carrier supporting agriculture activities (e.g., grid, diesel generation and distributed PV). Finally crops residues can be converted into different types of biomass, used in the energy sector.

Scenario & Policies

NEST is a tool for scenario analysis. Each scenario is distinguished by a unique narrative, which locks-in climate, socioeconomic and policy outcomes that in turn drives harmonization of input data. Scenarios comprising different narratives (i.e., input data assumptions) are compared to explore tradeoffs, synergies and uncertainties associated with alternative future outcomes.

Current applications rely heavily on data harmonized for the Shared Socioeconomic Pathways (SSPs): population, economic activity and urbanization projections scenarios that bridge uncertainties in the future capacity of society to mitigate and adapt to climate change. A reference, or baseline scenario, represents business as usual pathways, where growth and climate/environmental effort match the continuation of historical and current trends. Existing policies are also implemented, such as the Indus Water Treaty.

In addition to the Baseline, a number of environmental, techno-economic or social policies can be implemented to explore different resulting investment pathways, identify areas or sectors with critical issues or resource scarcity. Among the portfolio of policy options that can be explored are the opportunities to optimize the development of the energy sector, including access to clean energy (electricity) and reduced emissions, irrigation (options to increase water use efficiency to reduce the overall water demand of agriculture and the salinization problems associated to it), and possible strategies for multi-purpose management of dams (energy, irrigation, urban and industry water supply).

As first step, different Sustainable Development Goal will be implemented, modifying model input data or adding constraint to achieve policy targets on energy, water, food production and climate action.

Ultimately, stakeholder engagement processes within the ISWEL project have led to the definition of three different visions for the region that focus and prioritize issues respectively on economy, environment and societal aspect (equity, education, etc.). Qualitative information gathered during workshops with stakeholders has been assessed and converted into model language. The next step is to harmonize the characteristics of these visions with more standardized and globally recognized policy objectives (SSPs and SDGs).

Preliminary results

The main outputs from NEST include the MESSAGE*ix* results providing projections over the planning horizon of the technology capacities, outputs and environmental impacts for each geographic region delineated in the model. MESSAGE*ix* data and results can be accessed and modified via the ix modeling platform, which enables version control and the ability to access and modify data online. Moreover, NEST generates water resource use and availability projections at a daily time-scale and 5 arc-minute spatial resolutions consistent with CWaTM. To facilitate efficient browsing and sharing of the data with both technical and non-technical end-users, NEST is accompanied by an interactive web-based results explorer. Figure 8 shows an example or preliminary result concerning investments in the different sectors (left) and a preview of the interactive web-based result explorer (right).

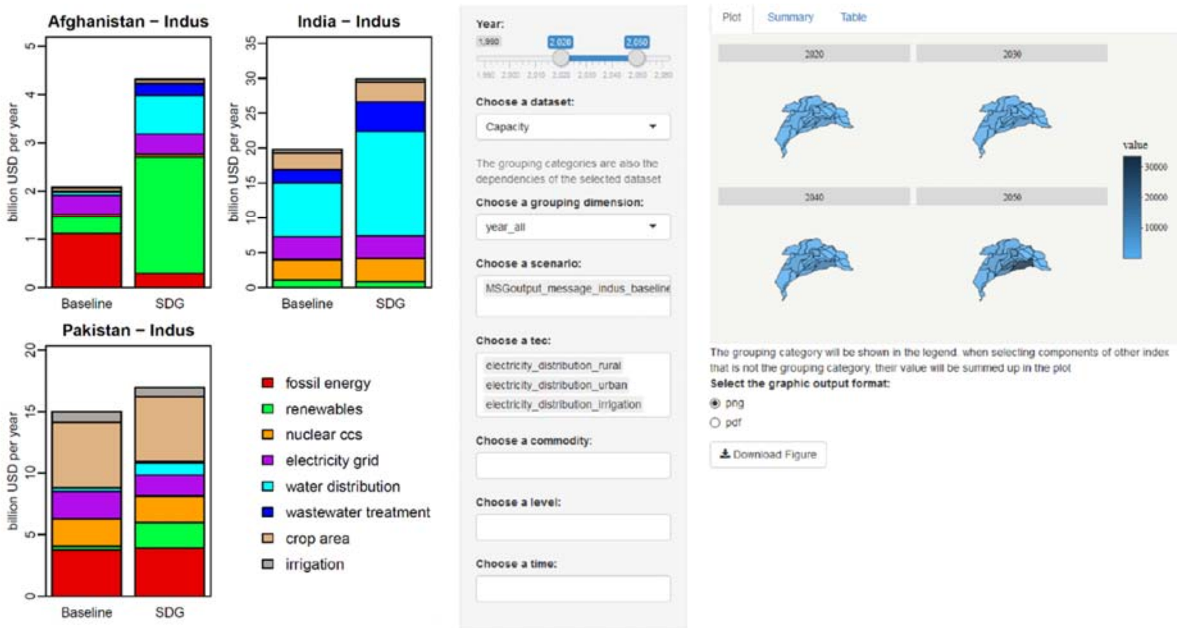


Figure 8. Average investments in different sectors in China, India and Pakistan for the Baseline and SDG 6 scenarios (left); preview of the web results explorer (right).

Next steps: The immediate next steps include the population of the NEST tool with the translated information obtained from the scenario workshops to run the three stakeholder visions and pathways.

Zambezi Assessment Modeling Framework

Progress made by Month 24: The past 12 months have been dedicated to improving the representation of Zambezi AMF to adjust it to the basin context as well as populating the model and calibrating the data. The Zambezi AMF integrates the models: CWATM, MARINA, ECHO, MESSAGE-Access, and GLOBIOM. These models have been (soft) linked to represent the connections among sectors in the Zambezi based on the challenges identified in the stakeholder meetings (Outcome 2.1).

Description of the tool

The five models integrating the Zambezi AMF use the same harmonized input data (base maps and scenario assumptions), and they are (soft) linked to so that relevant output of one model is used as input into the other model (e.g. the demand for irrigation water projected in GLOBIOM is used as an input into ECHO to assess the available water supply for hydropower). The exchange of information between models during the optimization and processing runs ensures that nexus challenges, trade-offs and synergies are modelled adequately.

Table 3 provides a summary and the main features of the models integrating the Zambezi AMF. Figure 9 depicts the linkages between the models. Each arrow shows the exchange of information between two or more models. A description of these interlinkages and how they relate to the nexus challenges in the Zambezi river basin is provided below.

Table 3. Zambezi model summary

Name	MESSAGE-Access	CWATM	ECHO	GLOBIOM	MARINA
Full name	MESSAGE-Access	Community water model	Extended Continental-scale Hydroeconomic Optimization model	Global Biosphere Management Model	Model to Assess River Inputs of Nutrients to seAs
Focus	Household energy model	Hydrological model	Hydro-economic model	Land use model	Water quality model
Reference	Poblete-Cazenave and Pachauri (2018)	Burek et al. (2017)	Kahil et al. (2018)	Havlík et al. (2014)	Strokal et al. (2016)
Model characteristics	Structural behavioral choice model; Simulation-based estimation	Distributed hydrological model Including water supply and demand	Bottom-up linear optimization model; Minimization of investment and operating costs of a wide variety of water management options	Partial-equilibrium model; Maximization of consumer surplus; Coverage of crop, livestock and forestry sectors	Quantifies river export of nutrients by source at the sub-basin scale as a function of human activities
Unit of analysis	Region with global connection with MESSAGEix	Simulation unit (5x5 to 30x30 arc min); Aggregation to sub basins	Sub-Basin	Simulation unit (5x5 to 30x30 arc min).; Global with regional detail for Zambezi.	Simulation unit: Sub-basin; Spatial coverage: regional
Key input data for calibration	Household surveys of the regions of interest	Observed river discharge	Observed or simulated discharge at sub-basins; Observed mix of water resources use by sector	Land cover map (GLC2000); Crop distribution map (SPAM); Crop and livestock data (FAOSTAT); Irrigation by source surface water/ groundwater	Annual load and annual mean concentration at sub-basin outlets and river mouth
Model output (key NEXUS indicators)	Household demands for cooking fuels, in particular, charcoal and firewood	Water resources availability (runoff, discharge, groundwater recharge) and water demand	Water withdrawals by sub-basin, sector and source; Optimal combination of water management options (including investment in new water infrastructure); Energy, land, and cost implications of water management options	Agricultural land use; Food security indicators; LULUFC GHG emissions; Irrigated area; Resource demands for various agricultural and forestry sectors by sub-basins (water, land); Irrigation management by systems and costs for expansion, upgrade, and depreciation	Annual mean concentration

Water-land linkages (CWATM-ECHO-MARINA-GLOBIOM)

Stored surface waters in the Zambezi are primarily managed to secure hydropower production. The planned expansion of hydropower capacity overlap with the development of new irrigation projects, which eventually will compete for the same waters. There circumstances might pose a challenge for future energy production and agricultural productivity growth. Similarly, there is a risk that the increase in the demand of water from hydropower, irrigation as well as industry and household consumption will have a negative impact on the environment as water availability becomes limited, which will have large implications for the eco-tourism sector development plans. To capture these water land linkages, models have been coupled to simulate the potential trade-offs emerging from these sectorial plans, as well as potential solutions pathways.

The CWATM hydrological model is used to calculate the surface and groundwater availability, as well as the socio-economic water demands and environmental flow requirements. The model is also able to account how future water demands will evolve in response to socioeconomic change and how water availability will change in response to climate. Sectoral water demands in CWatM are estimated using a range of methods. Monthly domestic and industrial water demands are estimated using the approach followed in several previous studies (Hanasaki et al., 2013; Hejazi et al., 2014; Y. Wada et al., 2016). Irrigation demand is calculated using GLOBIOM based on optimized crop pattern, estimated crop water requirements, assumptions on irrigation efficiency, and the availability of water resources to irrigation (i.e., total water availability minus water demand of other sectors and environmental flows requirements) (Sauer et al., 2008; Pastor et al., 2014). The calculations of the different water demands use harmonized projections of population, GDP, and technological change from the Shared Socioeconomic Pathways (SSPs) database.

To assess the impacts of poor water quality the MARINA model (developed originally by Wageningen University) has been used to estimate annual nitrogen concentrations (which can be potentially downscaled to seasonal or monthly concentration). These loads are estimated based on the water availability information provided by the CWatM. In addition to the calculation of nutrient loads, information has been collated on nitrogen standards for different sectors to categorize the suitability of water use by different users. Standards for drinking water, irrigation and environmental flow are mainly based on WHO (2017), FAO (Ayers & Westcot, 1985) and UNEP (2016) guidelines, respectively. Both information sources are key for determining the optimal water allocation pathway within the hydro-economic model ECHO.

ECHO is a bottom-up linear optimization model, which includes an economic objective function and a representation of the most relevant biophysical and technological constraints (see Kahil et al. 2018). The objective function of ECHO minimizes the total investment and operating costs of a wide variety of water management options over a long-term planning horizon (e.g., a decade or more), to satisfy sectoral water demands across sub-basins within river basins. The ECHO optimization approach can be classified as a normative optimization because it goes beyond improvements in the management of existing facilities, towards projections of the capacity and activity levels of various water management options, based on the assumption that water users seek to minimize the cost of water supply and demand management subject to constraints. The optimization procedure in ECHO uses a perfect foresight formulation, which provides the most optimal transition for the water system across the studied spatial and temporal ranges under anticipated future climate, socio-economic and policy changes.

ECHO includes representations of essential biophysical and technological features at the sub-basin level. These include representations of various water supply sources (surface water, groundwater, and non-conventional water such as desalinated water), sectoral demands (irrigation, domestic, manufacturing, and electricity), and infrastructure (surface water reservoirs, desalination plants, wastewater treatment plants, irrigation systems, and hydropower plants). The GAMS optimization software is used for ECHO development and scenario simulations. The optimal solution generated by ECHO provides spatially explicit information on a least-cost combination of water management options that can satisfy sectoral water demands looking at water, energy, and land sectors.

A diverse range of water management options are represented in ECHO, including supply and demand options that span over the water, energy and agricultural systems. The supply-side management options are surface water diversion, groundwater pumping, desalination, wastewater recycling, and surface water reservoirs. Surface water diversion, groundwater pumping, and desalination all transform raw water resources (surface water, groundwater, and seawater) into freshwater suitable for consumption within the different sectors (irrigation, domestic, manufacturing, and electricity uses). Wastewater recycling enables upgrading of wastewater originating from domestic and manufacturing sources to suitable quality for different purposes. Surface water reservoirs store water across several months for later multipurpose uses. The demand-side management options include different irrigation systems (flood, sprinkler, and drip), and various options to improve crop water management in irrigation and water use efficiency in the domestic and manufacturing sectors.

The land use model GLOBIOM optimally allocates available land (5x5 arcmin spatial resolution) among production activities in the agricultural and forestry sector to maximize the sum of producer and consumer surplus, and subject to resource, technological, and policy constraints for the period 2010-2050. This land use/cover map is used by the CWatM to simulate the water availability taking into account the various demands. This information is passed back to GLOBIOM to produce the final land cover/use map, which will be exchanged back with CWATM, as well MARINA, and ECHO. Specific developments in the expansion or conversion of irrigated areas by systems are passed to ECHO.

The development of the productivity, water and nutrient requirements of crops considered in GLOBIOM are shared with CWATM, MARINA, and ECHO. The exchange of this information allows estimating the impacts on water quality linked to agricultural development as well as irrigation production costs, and land prices, which are used by ECHO to determine the benefits and costs associated with irrigation activities and the economic value of water for irrigation.

Energy-Water linkages (MESSAGE-ECHO)

Energy development plans in the Zambezi are largely driven by the expansion of hydropower. Using the information on the existing capacity of hydropower facilities and future projections (based on the stakeholder information and national reports), ECHO estimates the water demands of actual and future hydropower developments (including evaporation) and the costs. This information together with the projections of the water demands and costs from the other sectors, is used by ECHO to explore optimal solution pathways to meet the multiple water, energy and land development goals.

Energy-Land (MESSAGE-Access-GLOBIOM)

Access to clean energy (electricity) in rural areas is extremely low in most of the Zambezi riparian countries (< 5% of population with access). Charcoal is yet the main source of energy for households, and responsible for much of the ongoing land degradation and emissions. Energy demand in rural areas is expected to continue growing as a result of population growth. To assess the future trade-offs between energy demand and land use, the MESSAGE-Access and GLOBIOM models have been linked.

For this situation we are using the MESSAGE-Access model which is a residential energy and technology choice model, which interacts with the global energy system model, MESSAGE. It is used to assess pathways to achieve universal access to modern energy by accelerating the transition to clean cooking fuels and electrification. In the context of the Zambezi, MESSAGE-Access provides a strong modeling framework for analyzing effective policy choices to improve the penetration of modern cooking fuels among the poor and electrifying rural areas. It is the first model to explicitly account for heterogeneous economic conditions and the preferred energy choices of poor populations living in rural and urban settings. The current version of the MESSAGE-Access model (Poblete-Cazenave & Pachauri, 2018) is designed to analyze how household with different characteristics present different preferences energy and technology. Unlike previous models in the literature, we make no a priori assumptions about preferences between fuels. Additionally, we account for the full range of price and income responses, as to better capture income and substitution effects between clean and non-clean fuel options.

The choice model is embedded within the new version of IIASA MESSAGE*ix* (Huppmann et al., 2018) - a global-scale, multi-region, energy system model. The linkage with the larger MESSAGE*ix* energy system model allows for residential energy use to be influenced by macro feedbacks from the larger energy system, particularly via energy prices. Additionally, forecasts of population (Samir and Lutz, 2014), GDP (Crespo Cuaresma, 2017) and inequality (Rao, Sauer, Gidden, & Riahi, 2018) from the different Shared Socioeconomic Pathways (SSPs) are used to estimate paths of transitions towards cleaner energy sources in line with these different scenarios.

Accordingly, demand for household energy is modelled by MESSAGE-Access. Using information from household surveys of countries in the region, preferences for different fuel options are estimated and translated into demands that depend on fuel prices and household income. Future demands for biomass (I.e. firewood and charcoal) are projected in line with SSPs scenarios of income and inequality, as well as prices from MESSAGE. GLOBIOM uses the demand for firewood and charcoal production from MESSAGE-Access to project potential deforestation.

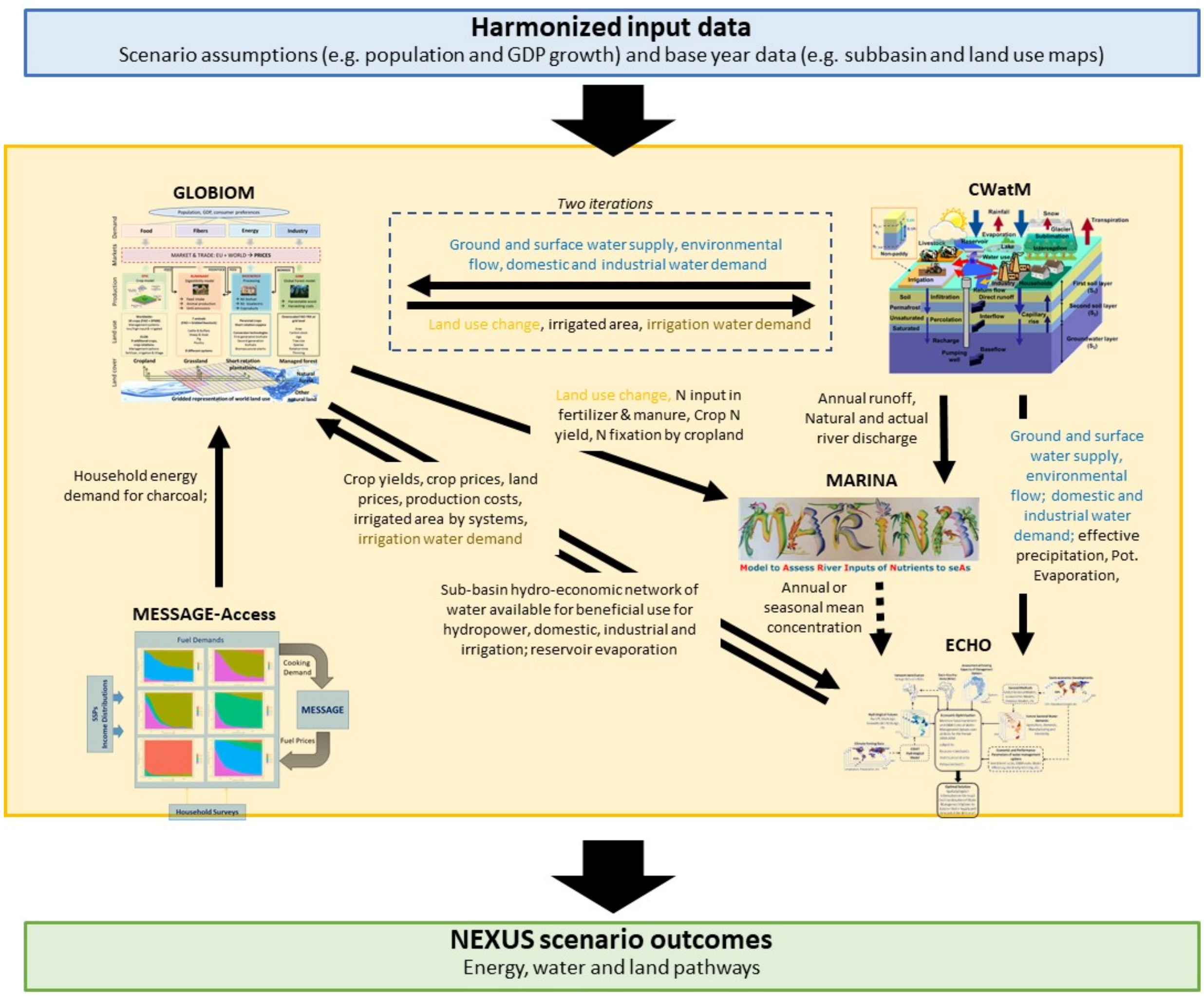


Figure 9 Zambezi Assessment modelling framework

Geographical scope

The spatial boundary conditions of the Zambezi AMF are defined by the the Zambezi river basin delinitation provided by ZAMCOM, which has been further refined by splitting a number of subbasins into smaller basins: Kariba into 4 sub-subbasins (7,8,9,10), Kafue into 2 (11,12) and Tete into 4 (16,17,18,19) (Figure 10, Table 4). The GRanD and HydroLake databases (Lehner et al., 2011; Messager et al, 2016) are used to provide charactersitics of exisiting reservoirs and lakes.

a)

b)

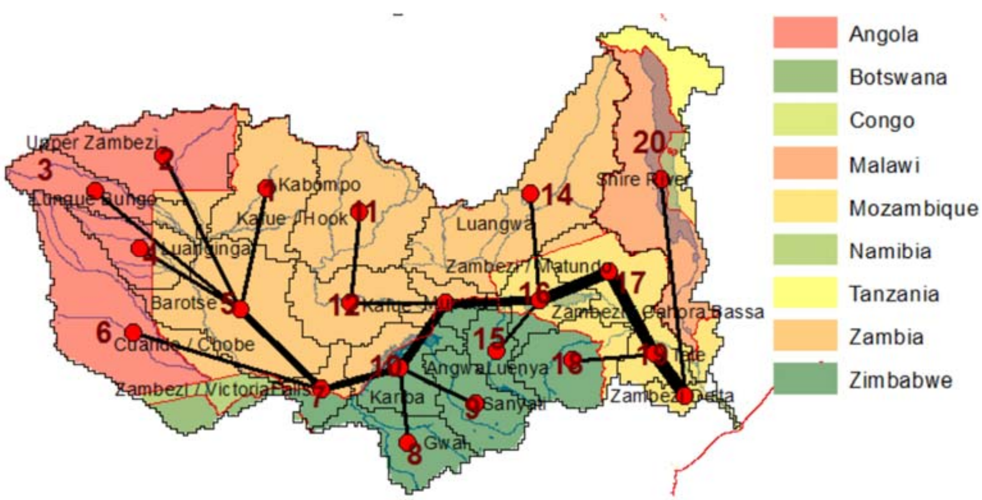


Figure 10 Zambezi official sub-basins and river network (a), Basin Country Units (BCUs) and reduced-form river network. Source: Source: ZamCom (http://zamwis.wris.info/) and authors.

Table 4 Definition of sub-basins

Sub-basin	Name	Incoming (Flows)	longitude	latitude	Upstream area
1	Kabompo		23.29	-14.20	72233
2	Upper Zambezi		23.21	-14.12	93657
3	Lungue Bungo		23.13	-14.29	47031
4	Luanginga		22.87	-15.13	41899
5	Barotse	1;2;3;4	25.12	-17.71	362040
6	Cuando/Chobe		25.12	-17.77	154950
7	ZambeziVictoriaFalls	5;6	26.80	-18.04	538300
8	Gwai		26.87	-18.04	43740
9	Sanyati		28.88	-17.04	45040
10	Kariba	7;8;9	28.89	-16.21	681426
11	Kafue_Hook		26.04	-15.04	96630
12	Kafue	11	28.63	-15.88	154000
13	Mupata	10;12	30.11	-15.62	857796
14	Luangwa		30.38	-15.47	149488
15	Angwa		30.61	-15.70	25130
16	Zambezi_after_CahoraBassa	13;14;15	32.88	-15.53	1065000
17	Zambezi_Matundo	16	33.63	-16.20	1120700
18	Luenya		33.71	-16.47	54500
19	Tete	17;18	35.21	-17.70	1205891
20	Shire River		35.29	-17.63	160932
21	Zambezi Delta	19;20	36.20	-18.78	1378490

Datasets

An important objective of building the AMF was to ensure that input data across the different models was harmonized, and to the extent possible populate the models with regional data where available. Table 5 summarizes the main data sources that are currently being use to populate the models.

GLOBAL

To ensure that the analysis and projections of the five linked models are consistent, an effort has been made to harmonize the input data. Two types of input data can be distinguished. The first type is scenario assumptions, which include socio-economic drivers, including population growth and economic development as well as climate change scenarios. All models use the scenario matrix approach (van Vuuren et al., 2014) that has been recently developed by the integrated assessment community to assess the impact of climate change under a range of plausible socio-economic futures. The two main axes of the matrix are: (1) the level of radiative forcing of the climate system (as characterized by the representative concentration pathways, RCPs) and (2) a set of alternative plausible trajectories of future global socio-economic development (described as shared socio-economic pathways, SSPs).

The RCPs have been used to project the magnitude and extent of climate change (Taylor et al., 2012), including change in temperature and precipitation. The climate change projections are used directly and indirectly by the five models in the Zambezi model framework. For example, CWATM uses precipitation, temperature and radiation projections, among others. ECHO, GLOBIOM and MARINA indirectly use the climate projections by using runoff and discharge originating from CWATM. Moreover, GLOBIOM takes crop and grassland yield projections from a vegetation growth simulation model EPIC that, in turn, models the future change in grassland yield, crop yield, crop water and nutrient requirement resulting from temperature and precipitation changes.

The SSPs consist of two elements: a narrative storyline and a quantification of key drivers (O'Neill et al., 2017). The SSP database (SSP Database, 2016) presents projections for two main drivers: population growth and economic development up to 2100 for each of the SSPs. SSP projections are used to estimate domestic and industrial water demand, which are used by CWATM, GLOBIOM and ECHO. These projections are used by MARINA to estimate nitrogen input to rivers from domestic wastewater and by GLOBIOM to project future food and fiber demand, as well as investments and advancements in agricultural productivity. Using an econometric relationship of the future development of per capita income and historical development of crop yields, GLOBIOM estimates the intrinsic technological improvement in crop and livestock yields.

For the eight countries in the Zambezi river basin, a revised set of drivers is used based on outputs from the stakeholder scenario development exercise. For all countries outside the Zambezi river basin, the SSP database is used to quantify a range of NEXUS drivers, including the demand for water, energy and land, that are closely related to the level of income.

REGIONAL

In order to estimate future investment needs, the existing capacity of the different water management options implemented in ECHO is assessed at the subbasin level using various databases. The capacities of existing surface water reservoirs are estimated by aggregating facility-level data from the GRanD database (Lehner et al., 2011). The capacity and production of major hydropower plants in the Zambezi basin are estimated based on several previous studies (Spalding-Fecher, Joyce, & Winkler, 2017; Tilmant et al., 2012; World Bank, 2010). The existing capacities of surface water diversion and groundwater pumping infrastructure are identified using historical gridded water withdrawals and groundwater extraction rates from (Wada et al., 2010, 2011). These withdrawals are aggregated to the level of the subbasins, and the maximum monthly withdrawal in the historical time series plus a 10% reserve margin is used to define the capacity in each subbasin. Wastewater treatment capacities are defined using estimates of return flows from the domestic and industrial sectors and national data on water treatment level from AQUASTAT database. For countries without data, the water treatment level is estimated by matching each country to another with similar gross domestic product (GDP) per capita. The existing water treatment capacity is estimated in each subbasin by multiplying the estimated water treatment level by the volume of domestic and industrial return flows for the base year (2010).

GLOBIOM represents the spatial and temporal nature of water demand and supply by building on the work from (Sauer et al., 2010), which considered the suitability of four main irrigation systems for crop production by examining the biophysical conditions and economic suitability of crops for irrigation. The current distribution of irrigated area among the irrigation systems is based on the suitability but also considers the country level statistics available from (Jägermeyr et al., 2015). The four irrigation systems are characterized by a corresponding water application efficiency (WAE), which also varies by region (Sauer et al., 2010). A resulting average water application efficiency is calculated for each sub-basin as a weighted average of the system WAEs in that region, weighted by the areas allocated into each system in that sub-basin and passed to ECHO. Projected water application efficiencies are based on exogenous assumptions from (Hanasaki et al., 2013), a paper which quantified water efficiency assumptions under the SSP scenarios. The assumptions are translated into the GLOBIOM model as a 0.15% per year improvement in water application efficiency in the SSP2 scenarios, a 0.30% per year improvement in the SSP1 (high water efficiency) scenarios, and a 0% improvement in SSP3 (low water efficiency) scenarios.

Irrigation water requirements at the monthly level are calculated using the globally gridded crop model EPIC, which simulates the biophysical processes of crop production under biophysical conditions and crop management systems. Irrigation water requirements are also harmonized in the base year to match the water demands from Aquastat (FAO, 2017), using the irrigated cropland area dataset available from SPAM (You & Wood, 2006), to inform the irrigated area by crop and the current distribution of irrigated area among the irrigation systems.

Water supplying irrigation in GLOBIOM is split into three categories: irrigation sourced by surface water, groundwater, and irrigation sourced by non-renewable sources and is based on the spatially explicit map at 0.5° spatial resolution of irrigated areas sourced from groundwater from Siebert et al. (2010).

Monthly surface water and groundwater availability is simulated at a 5x 5 arcmin spatial resolution using the CWatM. To use at the appropriate sub-basin spatial resolution for GLOBIOM, MARINA and ECHO, the mean monthly runoff is estimated by aggregating according to the average discharge rates in each river basin.

Table 5 Summary of data sources used in the Zambezi AMF

Typology	Data	Description	Models directly using the data
Global			
Socio-economic	Population	population with SSP growth scenarios	CWATM, GLOBIOM, ECHO and MARINA
	GDP	economic development with SSP scenarios	CWATM, GLOBIOM, ECHO and MARINA
Climate	Precipitation	rainfall from GCM with RCP scenarios	CWATM, EPIC
	Temperature	air temperature from GCM with RCP scenarios	CWATM, EPIC
	Radiation	solar radiation from GCM with RCP scenarios	CWATM, EPIC
Others	Land cover map	Global Land Cover 2000 (GLC 2000)	GLOBIOM
	wastewater treatment	Level of wastewater treatment from WHO/UNICEF Joint Monitoring Programme for Water Supply; wastewater treatment capacity from AQUASTAT	MARINA, ECHO
	nitrogen deposition	dry and wet nitrogen deposition on land from ISIMIP	MARINA
Regional			
Physical	basin characteristics	basin specific data, e.g., sub-basin, reservoirs/lakes	CWATM, ECHO and MARINA
Energy	hydropower production		ECHO
Land Use	land cover map	high-resolution maps for the region	GLOBIOM
Agriculture	Sub-national agricultural statistics	gridded harvested area by crop	GLOBIOM and CWATM
Energy	Household survey data	Energy demand, agricultural input use	GLOBIOM, MESSAGE-Access

Next steps: The immediate next steps include the population of the NEST tool with the translated information obtained from the scenario workshops to run the three stakeholder visions and pathways.

Component 2. Exploring nexus solutions at global and regional scales

Outcome 2.1 Regional assessment of nexus challenges and solutions

Summary: The main output of 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 24: The past twelve months have been dedicated to continuing the engagement with the basin stakeholders through the organization of a number of meetings (3 for the Indus and 2 in the Zambezi). These meetings have contributed to have a further understanding on the basin sectoral challenges ad definition of a preliminary set of nexus challenges as well as priorities. This information has been used to shape the basin tools (Outcome 1.2, Output 1.2.1) to address the key questions regarding water, energy, land development goals. A summary of the main sectorial challenges is provided below. **Error! Reference source not found.** synthetizes the main nexus challenges identified in the two basins.

ZAMBEZI

The first stakeholder meeting (Lusaka, September 2017) provided a good overview of the wide ranges of financial, governance, socio-economic, cultural and physical challenges that the Zambezi faces when it comes to the understanding and management of the water-energy-land nexus (see a summary in Box 4, and further details in Second progress report, 2017). The knowledge gained from this first meeting helped to inform the AMF. However, this required some further investigation (mostly via online search of background documents and bi-lateral discussions with stakeholders) to establish a prioritization in terms of what the project (within its timeline and capacities) could and should address.

Box 4. Key challenges hampering cross-sectoral and transboundary cooperation in the Zambezi Basin

Financial: Lack of resources represents an important constrain when it comes to encourage and support this cross-sectoral cooperation

Capacities: Inadequate knowledge about what the nexus means and little evidence about its practical application. This applies to stakeholders but also is only an emerging topic within academia and research organizations.

Technical: Lack of data and monitoring systems. Also, insufficient sharing mechanism of data across sectors and countries represents a main barrier to further develop any strategy and knowledge around the management of the nexus. Efforts should be allocated in building technical capacities as well as means to harmonize and share data across.

Cultural factors, including language barriers, were identified as an important constraint to promote cross-sectoral cooperation across countries.

Governance-related challenges, within and across countries, were the most numerous barriers to implement a nexus approach. Institutional silo setting, different or misaligned priorities, as well as financial constrains are among the most important challenges from a governance perspective. The (limited) transboundary cooperation is also cited as an important constraint given the lack of experience in the benefit sharing frameworks. Climate change is perceived as a substantial threat but it is not fully accounted for in all sectoral development plans (e.g. Energy). Although the different ministries need to deal with the development of adaptation and mitigation plans individually, not all perceive or understand the same level of threat.

Table 6. Summary of key nexus challenges identified in the Zambezi and Indus Basins.

	Water-Energy	Water-Land/Food	Energy-Land/Food
Zambezi	The basin is still facing an important energy deficit. Energy development plans are focused on further expansion of hydropower, particularly to improve access to clean energy (electricity) to urban areas and industry. Issues at stake: There is no clear consideration of the Climate Change impacts linked to these plans, and the prioritization of water infrastructure for single purpose use is and will continue causing problems (e.g. with other users like irrigators, downstream countries, non-compliance of environmental flows).	Agricultural productivity is very low and development plans include the expansion of irrigation. Issues at stake: increasing irrigation water demands might create conflicts over water in some parts of the basin. Also, expanding irrigation might contribute to increase productivity of farmers with access to markets, but it is unclear how this measure can help lifting subsistence farmers out of poverty and give them access to markets.	Access to clean energy (electricity) is low but particularly in rural areas (below 5%). Issues at stake: Charcoal is used as the main source of energy in rural areas, and responsible for much of the ongoing deforestation and land degradation. Erosion linked to ongoing deforestation is also caused sedimentation in dams, undermining the hydropower potential, and thus the electricity supply for urban areas. Rural electrification with renewable energies (e.g. solar) is regarded as more complex to manage (and finance) than large scale projects (big dams).
Indus	The basin is still facing an important energy deficit. Upstream countries (mostly India and Afghanistan) are focused on developing hydropower potential in the upper Indus. Issues at stake: little consideration of how Climate change might impact hydropower potential. Pakistan is highly dependent on surface water flows coming from India, and it is concerned how these developments will affect the quantity and timing of water flowing into their country. Pakistan also needs to develop its energy sector, and hydropower is one strong option, but will require multi-purpose strategies to avoid competition with priority use (irrigation). Energy subsidies in India have also contributed to unsustainable groundwater pumping, causing groundwater depletion and exacerbating soils salinization problems.	Majority of the waters from the Indus are allocated to irrigation. Issues at stake: Inefficient irrigation and lack of drainage systems is causing large problems of soil salinization and waterlogging, ultimately undermining the agricultural productivity. Most irrigated water is allocated to produce crops of low economic and nutritional value (rice and wheat). Prioritization of water for irrigation is causing important water conflicts with other users (e.g. urban, energy, industry).	Access to clean, reliable, and modern sources of energy is persistent gap in some of the riparian countries. Issues at stake: large part of the populations, especially in rural areas still relay on the use of biomass (fuelwood, animal dung, charcoal, and crop residues), which is causing soil degradation (removal of animal dung and crop residues reduces soil capacity to restore and maintain its fertility),and air pollution (indoor but also wide air pollution), and increased carbon emissions.

The Lusaka meeting also provided some insights on the specifically sectoral challenges. These where further investigated to map a number of priority challenges across the water, energy, and land sectors. The second stakeholder workshop (Harare, July 2018) also helped to confirm the issues described below.

Energy challenges

1. Access to energy. Only a small percentage of the population has access to electricity, and those having access are mostly urban/industrial centers. Access to electricity in urban areas differ from country to country but still remains under 80%. In rural areas the situation is worsen, with minimum access (5%) in countries like Malawi, Angola and Zambia.
2. Sources of Energy: Rural areas mostly rely in the use of charcoal and fuel wood, which is responsible for much of the ongoing deforestation and erosion problems, as well as health issues. Sedimentation of dams is partly related to this problem, which ultimate affects hydropower performance. Overall between 50-70% of the energy required for cooking across all countries comes from biomass fuels. Electricity in urban areas is mostly supplied by hydropower.
3. Energy production: the majority of the countries, except for Angola and Mozambique are net energy importers (much of which comes from South Africa in the form of fossil fuel generated thermal). Larger percentages of the national production relays in renewable energies (hydropower and particularly biomass). This energy mix is not efficient from an emissions perspective due to the high reliance on biomass.
4. Energy development plans:
   - Most of the efforts and investments plans are oriented to further develop the hydropower sector. This will contribute to increase energy security within the basin countries and export clean energy to neighboring countries like South Africa contributing to reduce meet emission reductions. The challenge here is that impacts of Climate Change are not well accounted due to high uncertainty and it might have counteractive impacts in the long run for the energy sector, but also for environment and other water users.
   - Development of other renewable energies (solar, wind, small hydro-, mini-grids) is also in the agenda. Rural areas will largely benefit from these development plans, although it encounters some problems, including the financing of the rural electrification, the lack of feasibility studies which prevent from having a clear picture of the energy potential, and the complexity of the implementation and management of such sparse infrastructures as oppose to large scale projects (big dams).

Water challenges

1. WASH (Water, Sanitation and Health): Access to water and sanitation is low within the basin countries. Basic access to water remains below 60%, with rural areas not averages below 50%. Access to sanitation facilities remains also below 40%. Overall, investments in water infrastructure are low.
2. Water users: agriculture and hydropower (evaporation) are by far the largest water consumers in the basin. Available estimates indicate that agriculture consumes annually 1,500 Mm^3 and water evaporation from hydropower up to 1,700 Mm^3. Consumptive water use of urban (200 Mm^3), industry (25Mm^3) are in comparison rather small. Aluminum smelters are the largest industrial water consumer and also the main source of (surface) water pollution. 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.

3. Water sources: irrigation, urban water supply and industrial activities mostly rely on surface water, whereas rural areas and small scale agriculture largely rely more on groundwater use. There is however an untapped potential for groundwater use and recharge.
4. Limited storage capacity combined with the prevailing climate variability and change deeply affects the water availability and becomes a key driver of water insecurity.
5. Water governance: despite the fact that many countries are developing water resources management plans, in many cases those are not implemented. There is also a need to strength national capacities for effective river basin management and to integrate these further with and through ZAMCOM
6. Water development plans:
    - Large scale investments in water infrastructures to support the expansion of hydropower and irrigation schemes. The intention is that such infrastructure developments will be subjected to proper environmental impact assessments (EIAs). The existing and future projects are being integrated into the Zambezi Strategic Development Plan.
    - Develop appropriate simulation models to simulate influence of dam operations to downstream users. ZAMCOM is currently implementing the Zambezi Water Use System (ZAMWIS), which aims to address part of the gaps existing related to tools and data sharing.
    - ZAMCOM through the Zambezi Strategic Development Plan is also seeking to identify the nexus challenges in order to align the investment priorities.
    - Optimize multi-purpose management of existing reservoirs

Agricultural challenges

1. Agriculture represents a key socio-economic sector for the basin. In some countries like Malawi, Mozambique, Zimbabwe, and Tanzania, this sector accounts for more than 20% of the national GDP.[6] The majority of the economic revenues from agriculture in these countries relate to the production and exports of cash crops (cotton, tea, tobacco). This sector is providing employment to a large part of the population in the basin, especially in countries like Angola, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe, although the majority if the farmers are small holders engaged in primarily <1ton/ha production.
2. Irrigated agriculture is still symbolic in the context of the basin (less than 6% of the total cultivated land). There is however, the ambition to further expand irrigation to enhance the productivity of agriculture. These irrigation schemes will most probably benefit market-oriented agriculture. Off-farm Infrastructure (communication infrastructures, storage, etc.) also needs to improve are there significant food loses.
3. Improving agricultural productivity should contribute to the development of farming economy and livelihoods but also improve food and nutritional security. The questions of what crop patterns and subsidies are required to achieve this double goal remains an important challenge.

[6] The share of agriculture to the national GDP differs widely among riparian countries. < 10%: Angola and Botswana; 10-20%: Zambia and Namibia; 20-30%: Mozambique and Zimbabwe; 30-40%; Malawi and Tanzania.

INDUS

The first consultation in the Indus basin took place in the form of two national meetings (Delhi, March 2018, and Lahore, March 2018). Both meetings contributed to set the scene in relation to the main challenges the basin faces from the two country perspectives. The second consultation (Vienna, May 2018) consisted of a basin meeting including all four riparian countries, and one of the main outcomes included a joint discussion of the basin current challenges and future outlook.

The information gathered from the three meetings has been arranged and further developed with literature review inputs, to summarize the main sectoral and nexus challenges that riparian countries are facing. The challenges have been grouped around three main sectors to provide an overall picture for the basin.

Energy challenges

1. India and Pakistan are both facing important energy shortages. To address this gap, India has decided to exploit the hydropower potential of the Indus tributaries, all of which flow into Pakistan. In particular, there are five projects (Miyar Nallah, Lower Kalnai, Pakal Dul, Kishenganga and Ratle) being built, over which Pakistan has raised objections, since these could impact the flow regime of the Chenab and Jhelum river flows, from where Pakistan receives most of its surface water.
2. Pakistan is also looking into further developing hydropower to address the energy gap. Yet, 40% of the electricity is provided through hydropower. However, operations in the existing 3 dams in Pakistan are managed to secure access of water for irrigation, which has counterproductive effects for hydropower development and other sectors.
3. Access to clean, reliable, and modern sources of energy is persistent gap in some of the riparian countries. In countries like Pakistan, 31% of the population are still lacking access to modern energy services, such as electricity, and about 63% of the population still relying on traditional biomass for cooking.

Water challenges

<u>Resource availability and use</u>

1. The climate in the basin is characterized by a high seasonality, with 85% of the annual water flows concentrated in the summer and only 15% during the winter. This requires optimal infrastructure to secure the availability of resources throughout the year, and this is yet insufficient in countries like Pakistan, which are highly dependent on the Indus water flows and which yet only have storage capacity of up to 30 days (equivalent to 13% of annual flows).
2. In terms of water users: agriculture is by far the largest water consumer, followed by municipal and industrial water supply across the basin. Afghanistan, but also the, Pakistan economies are very dependent on agriculture, and this translates into the provision of allocation priorities being given to irrigation over other sectors. This, in turn, causes numerous disputes (e.g. Islamabad facing water shortages, because water is first allocated for irrigators). This prioritization in Pakistan is also resulting in inefficient hydropower management. As shared in the stakeholder meetings, there is ample room for improving agricultural water management (through investments in new and upgraded irrigation infrastructure as well as development of technical capacities of farmers).
3. In terms of water sources, Afghanistan and Pakistan heavily rely on surface water (over 85% and 65%, respectively of total abstractions), while in India the share is more even (52% of abstractions derived from surface waters and 34% from groundwater). As indicated by both Indian and Pakistan stakeholders,

water planning should be more focused on improving groundwater management and storage and not only focus on improving appropriation and storage of surface flows.

4. Existing monitoring and information systems on water availability and use are very deficient, which makes it very difficult to have accurate estimates on existing availability and use as well as making future projections and options that match the demand. Despite all the efforts, the available water balances of the basin are very uncertain and part of this is due to the lack of high quality data on precipitation and glacier dynamics.
5. Drivers like climate change and population growth are not being properly considered in the water planning strategies, and their consideration is of critical importance. For instance, in Pakistan 45% of the annual flows comes from snow and glacial ice melt. Climate change projections indicate an increase in the annual water flow in the years to come (resulting from glacier melting) but a sharp decrease in the medium run, which will heavily impact water availability in the country. Likewise, much of the water flow coming into Pakistan is already allocated, which raises many concerns as demands keep increasing. Particularly, when Population in Pakistan has multiplied by 10 (35 million in 1960s to 350 in 2050).

Governance

6. The Indus Water Treaty is a bi-lateral treaty between India and Pakistan that defines the rules under which both countries can use and manage flows of the Indus across the two countries. This treaty, however, does not reflect all of the main and future challenges (climate change, population growth, growing water needs from Afghanistan and China). Some stakeholders highlighted the need to shift the focus of the treaty from focusing on allocation of flows to focus on actual and future consumption and relocate accordingly. As indicated by some participants of the workshop, using a benefit sharing approach rather than an engineering river-dividing approach to water management between the two countries could deliver significant benefits.
7. Many of the problems around water management in the Indus basin are related to the political conflicts existing between India and Pakistan. From India perspective, the country is complying the agreements made under the Indus treaty. They argue that they are using less water on Eastern rivers than what agreed under the treaty. In Pakistan, water demand has been growing tailored to the flow excess that India was allowing, but India is now intended to make use of its total share, which puts Pakistan in a very challenging position. Addressing these conflicts is critical as 80% of the water flows in Pakistan are coming from India. The remaining 20% of the remaining water inflow comes from the Kabul river.
8. Disputes over water are not only on the transboundary setting but also at the provincial level within both India and Pakistan.
9. In India, energy subsidies scheme disincentives farmers from increasing water use efficiency, and this is the main cause of groundwater depletion. In fact, by increasing water use efficiency, most of the irrigation could be covered with surface waters, releasing the pressure on groundwater. A key question is where the investments should come from to upgrade the irrigation system.
10. Lack of coordination between water and agricultural government departments within the riparian countries, despite close relationship that exists between the two sectors. In Pakistan, 95% of surface waters is used for irrigation, and only 35% of the water diverted into canals reach the farms. The diverted waters that are lost usually contribute to artificial groundwater recharge and are responsible for much of the waterlogging problems. The inefficient irrigation practices and the lack of adequate drainage systems are also causing important soil salinization problems, which in turn are having large impacts of crop production and overall agricultural productivity

11. Groundwater is mismanaged despite the role it plays addressing much of the current water shortages (e.g. for urban users). So far there is no accounting on water extractions and 90% extractions are pumped with diesel pumps.
12. The lack of water monitoring systems and enforcement makes also very complicated to manage water effectively and this also causes leads to overexploitation.

Agricultural challenges

1. Agriculture represents a key socio-economic sector for many of the riparian countries, specially Pakistan, Afghanistan and India. The Indian part of the basin is critically important from a food security perspective as it represents India's breadbasket. Pakistan's Punjab also represents the country's food basket. In fact, 95% of the irrigated land of Pakistan is located within the basin, and this sector contributes to 20% of the national GDP and provides employment to more than 40% of the population.
2. Government interventions in the agricultural markets have forced the progressive specialization of the basin agriculture into low value crops that very water intensive and of low nutritional value (e.g. wheat and rice). This crop specialization translates into a mono-cropping system (winter wheat and summer rice) which has decreased the cultivated area of other less water intense crops like pulses, millet, vegetables and fruits. The generation of food surpluses for rice and wheat, has negative consequences for crops' price and lastly on farmers 'economy. Also, this cropping pattern has implications beyond, as the burning of paddy crops residues is creating significant air and soil pollution problems.
3. Agricultural (economic) productivity is overall low across the basin and there are significant opportunities to increase it. But it is also important to realize that countries' economies need to be diversified as their development cannot rely on agricultural-based economies.
4. Soil degradation of agricultural land resulting from erosion, salinization, and pollution resulting from intensive use of inputs, are major challenges influencing agricultural productivity. Solutions to address these challenges require revisiting the subsidy schemes for energy, fertilizers, reform of commodity prices, and overall improving marketing and distribution of agriculture. This will also require revisiting the trade barriers.

Next steps: With the completion of Outcome 1.1 it will be possible to identify a preliminary set of policy options addressing some of the nexus priorities described above as well as investment strategies to inform decision making in each of the basins. This we see as a key component of moving towards implementation. These strategies and moves towards implementation will be presented and discussed with stakeholders for feedback and validation. This discussion with stakeholders would allow also to identify data needs for future assessments in the basin.

Outcome 2.2 Global nexus hotspots and transformation pathways

Short description: The purpose of this component of the work is to apply the global systems analysis framework developed in sub-component 1.2 to carry a comprehensive global assessment of global nexus hotspots and solutions. This global assessment has 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. The second application is the exploration of nexus dynamics and how those might impact global transformation pathways as a result of the implementation of various response strategies (e.g. technological solutions).

Global hotspot assessment

Progress by Month 24: The hotspots assessment has continued to develop into this year of the project, in a number of areas. Some of this work focuses on the scientific assessment itself, whilst other activities look to enhance the impact and relevance of the underlying assessment to different audiences and applications, such as IPCC and feeding into regional assessment framework. Section (a) provides an update on the global hotspot publication follow on. Subsequent subsections follow on directly from the proposed workplan for the hotspots in the 2017 report.

a. Update on the hotspots journal article and related activities

At the time of the previous report submission, the first paper on the hotspots assessment had just been submitted to a journal for peer-review. The reviewers encouraged more presentation of the uncertainties related to the study, and this led to more comprehensive analysis inclusion in the published paper. The paper was published in the fully Open Access journal Environmental Research Letters in May 2018, in the "IPCC SR1.5 Special Collection" and "BRACE1.5°C: Climate Change Impacts of 1.5°C and 2.0°C Warming" special issue. The release of the paper was accompanied by a IIASA press release. The paper was featured on numerous websites and social media, with a Twitter reach in excess of 300,000 accounts. A 4-minute video abstract, accessible to a broad audience was produced, and to date the paper has been downloaded approximately 4,500 times.

Due to its global scope, wide range of indicators and unique datasets, new methods and policy-relevant findings, the hotspots paper features in the latest IPCC Special Report on the Impacts of Climate Change at 1.5°C, released in early October. Both Chapters 3 & 5 feature numerous citations of the work, and the authors were asked to produce a bespoke Figure (3.18) and Table (3.4) for Chapter 3 (page 117-118) of the report.[7]

b. Detailed indicator and sectoral analysis

Regarding the individual indicators and sectors, a number of analyses have been undertaken to enhance understanding of the underlying drivers.

Alongside the hotspots paper, and not included in the original analyses, data tables were produced detailing the number of people at risk within each scenario, region, indicator and sector, information subsequently featured in the IPCC report Table 3.4 (Table 7 below).

[7] http://www.ipcc.ch/report/sr15/

Table 7. Detailed exposure and vulnerability by indicator and scenario (IPCC SR1.5, Chapter 3, 2018, Table 3.4).

SSP2 (SSP1 to SSP3 range), millions	1.5°C		2°C		3°C	
Indicator	Exposed	Exposed & Vulnerable	Exposed	Exposed & Vulnerable	Exposed	Exposed & Vulnerable
Water stress index	3340 (3032-3584)	496 (103-1159)	3658 (3080-3969)	586 (115-1347)	3920 (3202-4271)	662 (146-1480)
Heatwave event	3960 (3546-4508)	1187 (410-2372)	5986 (5417-6710)	1581 (506-3218)	7909 (7286-8640)	1707 (537-3575)
Hydro-climate risk to power production	334 (326-337)	30 (6-76)	385 (374-389)	38 (9-94)	742 (725-739)	72 (16-177)
Crop yield change	35 (32-36)	8 (2-20)	362 (330-396)	81 (24-178)	1817 (1666-1992)	406 (118-854)
Habitat degradation	91 (92-112)	10 (4-31)	680 (314-706)	102 (23-234)	1357 (809-1501)	248 (75-572)
Multi-sector exposure						
2 indicators	1129 (1019 – 1250)	203 (42 – 487)	2726 (2132 – 2945)	562 (117 – 1220)	3500 (3212 – 3864)	707 (212 – 1545)
3 indicators	66 (66 – 68)	7 (0.9 – 19)	422 (297 – 447)	54 (8 – 138)	1472 (1177 – 1574)	237 (48 – 538)
4 indicators	5 (0.3 – 5.7)	0.3 (0 – 1.2)	11 (5 – 14)	0.5 (0 – 2)	258 (104 – 280)	33 (4 – 86)

One question that sometimes arises is on our understanding of to what extent the indicators correlate with each other. We undertook a covariance analysis to understand the correlation between indicators and sectors, and for different socioeconomic scenarios. The covariance analysis revealed generally low correlation between indicators, particularly in populated areas, indicating that the resulting challenges will need multiple strategies, as opposed to tackling key pairs of highly co-dependent indicators (supplementary information of the paper). Understanding the uncertainty structure (Figure 5 of the paper) has also contributed to important analytical improvements and interpretation of the results. Whilst model and internal uncertainties (from GCM, Impact Models (IM) and Score Range (SR)) contribute most to impact uncertainties over land, irreducible scenario uncertainty (GMT and SSP) becomes significantly more important in every indicator when assessing specifically the exposed and vulnerable populations. This reiterates the importance of understanding, and improving the socioeconomic conditions in hotspot locations, as being an effective way of both reducing risks to vulnerable people with lower levels of uncertainty. Notwithstanding, improving model performance in highly populated regions is critical to reducing the uncertainties.

Additionally, as part of this activity we have developed a table of key hotspot risks for each region, as a quick reference guide (see Annex II). This information may be turned into an infographic or poster.

c. Climate exposure across dimensions of vulnerability

The initial assessment investigated the exposure of the global population and the "vulnerable" population with income <$10/day. As previously proposed and recommended in feedback from our stakeholders (including the PSC), we have continued with assessing the changes in exposure at different income levels (e.g. $2, $5, $20). This helps determine to what extent poorer people are (or are not) more exposed than higher income segments of society. We are still working on this analysis to investigate the risks at different income levels and show the distributional consequences of climate change. Preliminary analysis has been undertaken, however the results are highly sensitive at lower income levels.

d. Basin level analysis

The original analysis was assessed and presented across 27 IPCC regions that aggregate land pixels within these regions. More recently the team have developed the capability of analysis at different spatial aggregation options, primarily at the river basin scale.
The analysis, comprising 275 river basins across the world, helps identify the most critical river basins from multi-sectoral perspective. It was developed to be able identify both on absolute and proportional basis (with respect to population) the most impacted basis.

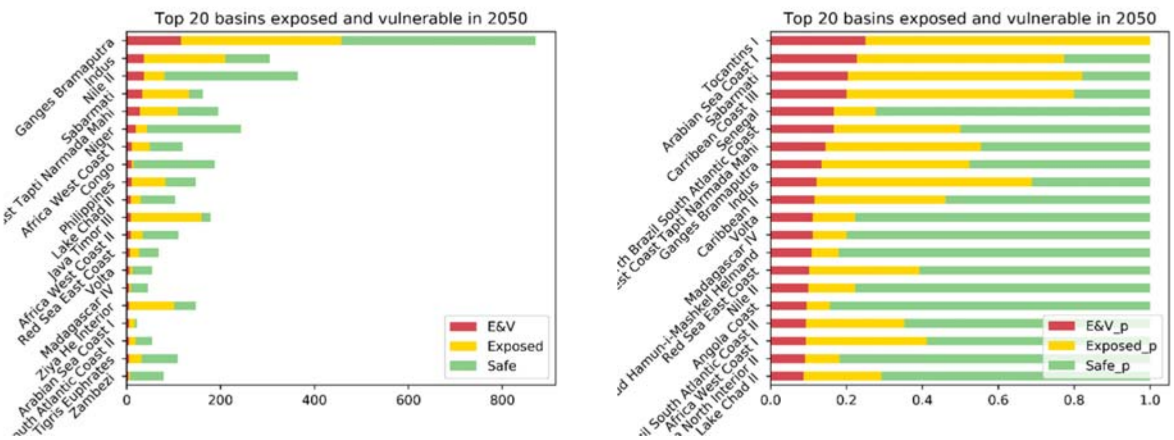


Figure 11. Left bar chart shows the basins most exposed in absolute numbers, whilst right bar chart shows the basins with the highest proportions of exposed and vulnerable population.

Work continues on this theme, developing new methods to categorise basins according to the risks they face, for example according to the sectors most impacted.

e. Dashboard development

Development of a website with a hotspots dashboard is underway, including detailed design of the interface. Design brief for the website has been submitted to a number of independent web developers and agencies and we are awaiting quotes and feedback. Some of the work will also be done by in-house web developers, who have recently completed the Scenario Explorer for the IPCC Special Report on 1.5°C. A functional prototype of the website is expected for the forthcoming PSC meeting in first trimester 2019.

The website is currently expected to feature three main components:

- Stories: Stories will be interactive, scrolling webpages that will follow a storyline according to themes, for example, *Water sector*, *Global River basins, the Indus River basin,* or *Socioeconomic change*. The storyline features text, pictures and interactive graphs to communicate the case study at hand.
- Explorer: The Explorer will feature a large, zoom enabled and interactive map (like Google Maps), where the user can select different scenarios and indicators used in the hotspots assessment, to spatially visualize the impacts.
- Dashboards: Users will also be able to create custom Dashboards, upon which users can select and visualize different datasets in a variety of styles and formats. This will allow them to create and compare their own analysis.

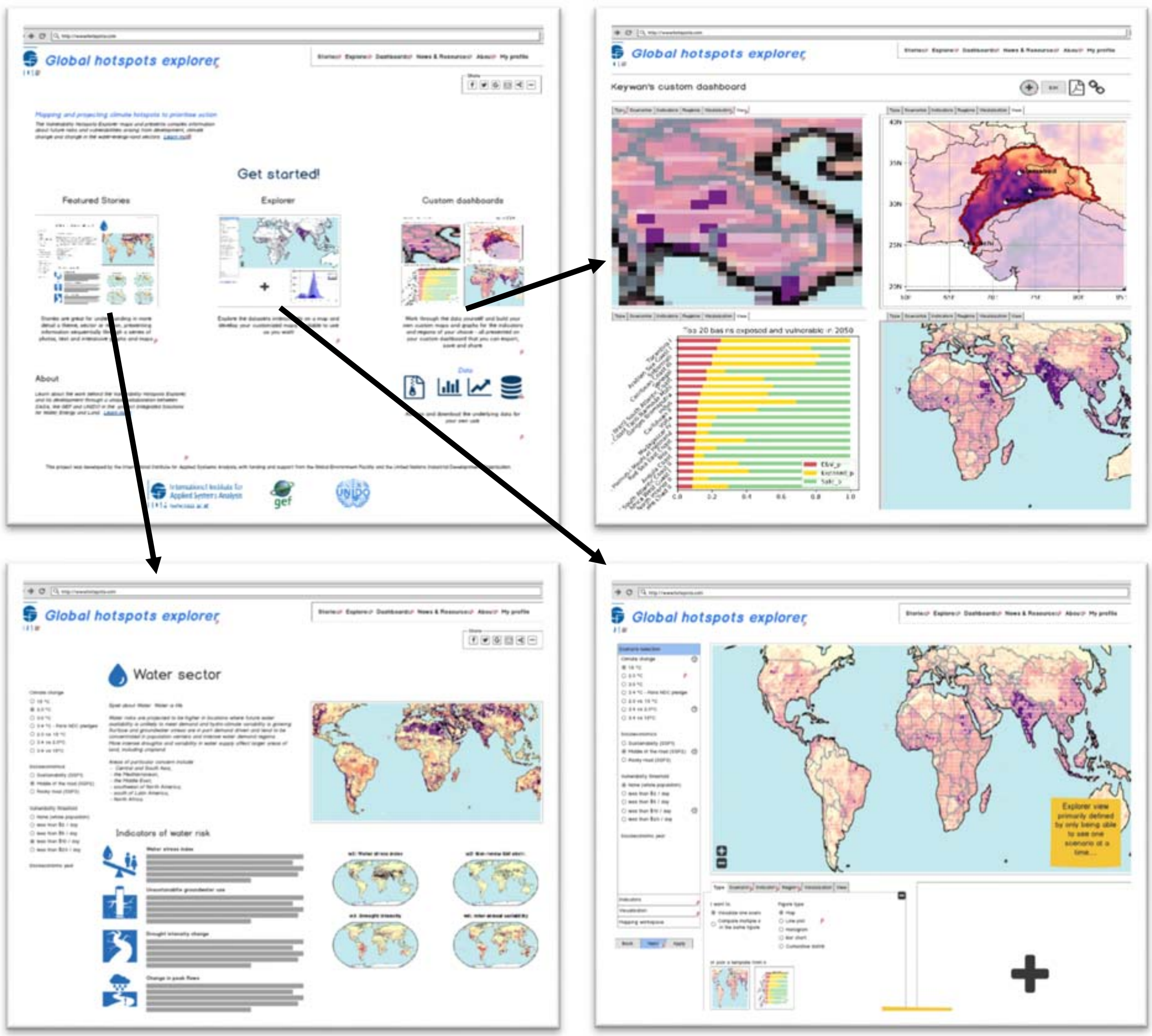


Figure 12. Mockups of the different website components. Anti-clockwise from top left: Homepage; Water sector story page; Explorer page; Custom dashboard page.

f. **Policy analysis and solutions**

Following publication of the journal article, a Policy Brief for this component of research has been developed (draft version in Annex III). Titled “The big difference of half a degree”, the policy brief explains the substantial differences for people impacted in hotspots, between global warming of 1.5°C and 2.0°C, the two temperatures in the Paris Agreement. It underscores the need for ambitious climate mitigation and benefits of achieving 1.5°C global meant temperature, alongside the inevitable impacts that will even occur at 1.5°C. It also shows the importance of vulnerability reduction through sustainable socioeconomic development, targeted in hotspot locations.

This policy brief will be completed in time for the official launch of the IPCC report in December 2018 at the UNFCCC COP24 meeting in Poland.

Next tasks and activities: The planned activities for the next 12 months include:

1. Development of the hotspots website
2. Completion of the basin scale hotspots analysis, and probably subsequent paper
3. Further analysis at different income and vulnerability levels

Global transformation pathways

Progress by Month 24: During the past 12 months, efforts have been concentrated in completing the Global AMF (Output 1.2.1) and develop a number of analysis (Output 2.2.1). In particular, the work carried out included an analysis of the costs and characteristics of global pathways consistent with multiple SDG indicators. The rationale stems from the understanding that despite strong linkages among the Sustainable Development Goals (SDGs) there is a lack of analysis providing global pathways balancing multiple objectives. This limits our ability to anticipate critical interactions across sectors and to design policies that tap into synergies while avoiding tradeoffs. The analysis highlights robust co-benefits of sustainable consumption and production (SDG 12) in terms of minimizing the cost of implementing clean water and energy goals consistent with SDGs 6, 7 and 13.

Balancing clean water-climate change mitigation trade-offs

We incorporated a quantitative representation of multiple SDG indicators into the Global SAF. This SAF provides a consistent global picture of interlinked water-energy-land systems transformation under assumptions surrounding future societal development and climate change. The implementation is framed around human population and economic activity projections for the 21st century aligned with the Shared Socioeconomic Pathways (SSP) (Fricko et al, 2017). The technological representation of the SAF enables the quantitative interpretation of the SDG targets for energy, water and climate as scenario outcomes and provides a tool for estimating the implementation costs. The SDG targets included in the analysis are outlined below, with the implementation detailed in previous work (Gruebler et al., 2018; McCollum et al., 2018, Parkinson et al., 2018).

SDG targets and IAM implementation

6 CLEAN WATER AND SANITATION

SDG6 (Clean Water & Sanitation): By 2030, each geographic region in the IAM achieves universal access to piped water and wastewater collection, and half of all return flows are treated. A minimum per capita freshwater allocation of 100 liters per day is achieved in urban areas and 50 liters per day in rural areas. Technological diffusion constraints related to financial barriers are relaxed to reflect increased access to project financing during implementation of the SDGs. Implementation is described in Parkinson et al., (2018).

7 RENEWABLE ENERGY

SDG7 (Affordable & Clean Energy): By 2030, each geographic region in the IAM achieves universal access to electricity, and the share of renewable energy in the global energy mix increases to more than 50%. Massive improvements in energy efficiency are made in response to a combination of technological and behavior changes, leading to a net reduction in power demand by 2030. Implementation is described in McCollum et al., (2018).

12 RESPONSIBLE CONSUMPTION

SDG12 (Responsible Consumption & Production): By 2030, each geographic region in the IAM recycles a minimum of 25% of the urban return flows, and transitions towards exclusive use of re-circulating and air cooling options for thermal power generation. Domestic, industrial and agricultural water use intensity also achieves a further 30% reduction relative to the baseline demands through assumed improvements in behavior. Energy demands are also much lower (40% in 2050 relative to 2010) due to transformation towards efficient energy technologies and responsible consumption behavior. Implementation is described in Gruebler et al. (2018) and Parkinson et al. (2018).

13 CLIMATE ACTION

SDG13 (Climate Action): Global greenhouse gas emissions from energy and land systems across all geographic regions in the IAM are consistent with the Paris Agreement goal of limiting global warming over the 21st century to 1.5 °C. Implementation is described in Fricko et al., (2017).

Figure 13 SDG targets implemented in the analysis

Results

The scenario achieving multiple SDG indicators is compared to a business-as-usual (BAU) scenario and a BAU transformation scenario featuring the 1.5 ˚C target (i.e., no additional SDG-related constraints). Figure 14 depicts selected global indicators calculated across the scenarios tested. Global freshwater withdrawals decrease in the SDG scenario to 2,400 km^3 per year in 2030. This represents a 28% decrease compared to the BAU scenarios and more than a 25 % reduction relative to the estimated extractions in 2010. This reduction in withdrawals would significantly improve environmental flows, and also avoids water resource and supply expansion in regions with existing infrastructure. The volume of wastewater that is returned to the environment from the municipal and manufacturing sectors untreated (**Figure 15**b) also decreases to less than 200 km^3 per year in the integrated SDG scenario, representing a 38% decrease versus the other scenarios and a 47% reduction relative to 2010. The reduced pollution will also contribute to improved downstream water quality. At the same time the SDG scenario is achieving rapid decarbonization in line with SDG 13, where the emissions drop to near-zero by 2070 (Figure 14 c). The decarbonization is driven in the by embedded policies consistent with the SDG 7 targets, namely by combining renewable electricity and energy efficiency investments.

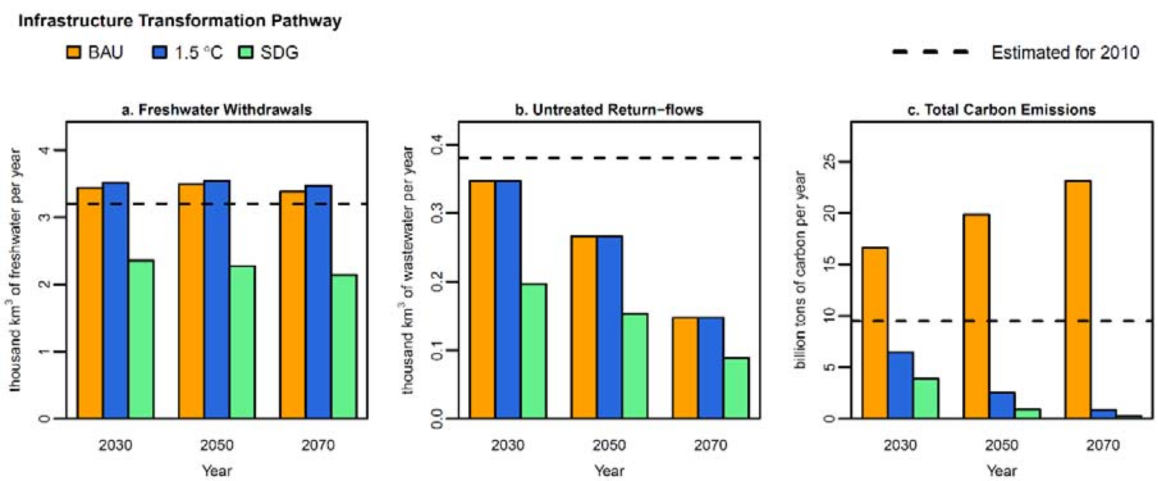


Figure 14: Global indicator pathways simulated with the AMF under three scenarios: 1) business-as-usual (BAU); 2) business-as-usual plus an additional emission budget (1.5 ˚C); and 3) the integrated pathway (SDG) featuring multiple indicators aligned with SDGs 6, 7, 12 and 13. Return-flows do not include irrigation.

Corresponding global costs for the implementation of water and electric power generation in each scenario is summarized in Figure 15. In the water sector, most investment is needed to develop, maintain and replace piped water and wastewater collection infrastructure, particularly in developing regions currently lacking infrastructure (e.g., South Asia, Latin America and Sub-Saharan Africa). The SDG scenario features accelerated investments into water treatment infrastructure, which is used increasingly to support water efficiency targets and demand growth in water-stressed developing regions. Efficiency investments are an important part of the SDG 6 solution portfolio, leading to the reductions in withdrawals depicted in Figure 14 In the long-term (i.e., 2070), more sustainable consumption and production behavior consistent with the SDG 12 targets provides foundation for reduced water supply costs when compared to the other scenarios featuring a continuation of current consumption trends.

Results for electric power supply (Figure 15c and d) indicate a rapid shift towards an investment market dominated by renewable energy technologies in the SDG pathway. Power supply in the SDG scenario is supported primarily with a combination of wind, solar and hydropower technologies, whereas conventional fossil technologies play a more central role in the BAU 1.5 ˚C pathway due to increasing use of negative emission technologies in response to increasing electricity consumption. The low electricity demands achieved in the integrated SDG pathway and consistent with the SDG 12 sustainable consumption narrative provides massive savings in the power sector in the form of avoided investment in power generation infrastructure. Increased electricity consumption to support water infrastructure is balanced with low-carbon electricity sources, but these additional constraints do not create significant challenges under sustainable consumption behavior. Comparing investments across sectors indicates water and power infrastructure require similar efforts in the SDG scenario, but that power costs dominate under the BAU and 1.5˚C pathways due to increasing electricity consumption.

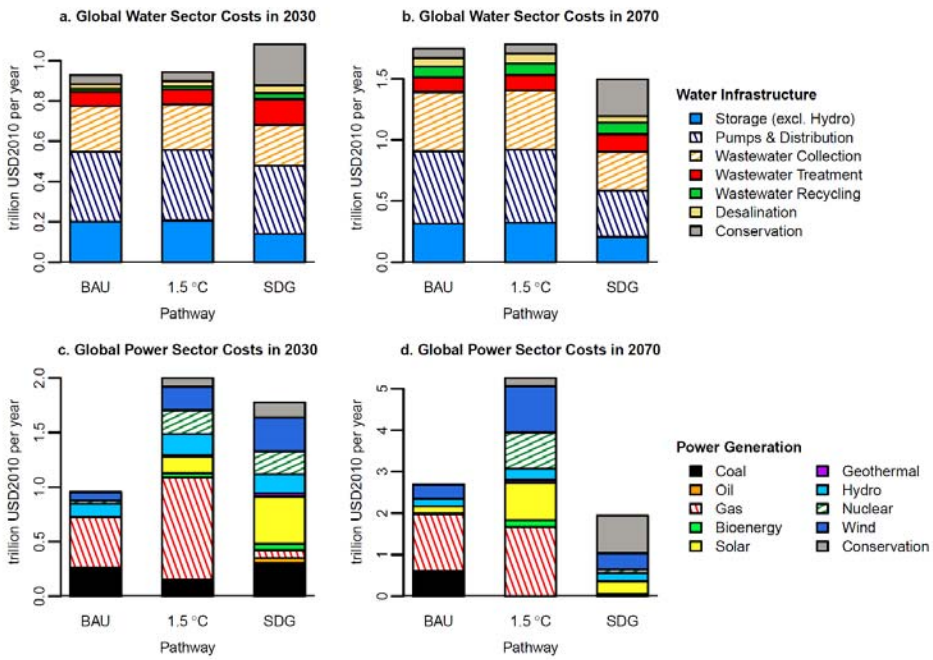


Figure 15 Global infrastructure costs (sum of investment, fixed and variable components) simulated with the IAM under the three development narratives (BAU, 1.5 ˚C and SDG). a) Global water sector costs in 2030; b) global water sector costs in 2070; c) global power sector costs in 2030; and d) global power sector costs in 2070.

Conclusions

The Global AMF developed can provide critical insight into interlinked SDG objectives. The case study analysis of global infrastructure transformations consistent with multiple water, energy and climate SDG indicators reveals the important role of integrated water-energy planning and sustainable consumption in enabling low-cost implementation. Integration of SDG indicators across sectors and scales is essential to unraveling interactions, and it is therefore important for future analysis to incorporate a broader range of SDG targets.

Next steps: Based on the improved sectorial linkages between the global modeling tools, MESSAGE*ix*, GLOBIOM and CWatM, it is planned to explore interactions between the water, energy and land sectors to simultaneously achieve the targets specified under the related SDGs. The focus of this research will be on identifying solutions that foster synergies while managing trade-offs across the three sectors. Compared to the analysis described above, in particular a better representation of the land-related SDGs, i.e. SDG2 (hunger), SDG15 (biodiversity) as well as the agricultural component of SDG6 (irrigation water use) will be major improvements of the new analysis.

Component 3: Capacity building and knowledge management

Outcome 3.1 Knowledge and capacity network

Summary: The main output of this sub-component of the work has been the establishment and strengthening 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 stakeholders from the different riparian countries and sectors is 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 colleagues 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 24: During the past year we have had a number of meetings with stakeholders in the two basins. These workshops and meetings have provided solid insights on what are the main challenges each of the basin are currently facing (see Outcome 2.1) as well as what are the possible pathways that stakeholders have identified to overcome those challenges and meet their development goals (see Outcome 1.1).

Indus engagement activities

The project team has organized three meetings in the course of 2018: two national consultation meetings (Delhi and Lahore, March 2018), and one basin meeting (Vienna, May 2018) co-organized with the International Centre for Integrated Mountain Development (ICIMOD), the International Water Management Institute (IWMI) and the World Bank. A summary of the meetings, participants and outcomes is provided below.

Meeting 1: Identifying challenges and priorities needs regarding water, energy, and land in India and Pakistan

This first Indus meeting turned into two separated country meetings: Delhi (23 March 2018) and Lahore (26-28 March 2018). The purpose of the two consultations was to strengthen and build partnerships with national organizations from the two countries and, given the political sensitivities, identify in a neutral environment what are the country perspectives on the sectoral and transboundary challenges.

The strategy developed to organize these and the subsequent meeting included the establishment of partnerships with local research organizations well connected within their respective countries and at the same interested in stayed engaged in the project. The entry point and local partner for India is The Energy Resources Institute (TERI), and for Pakistan, Lahore University of Management Sciences (LUMS). Each of these organizations supported the ISWEL team with the organization of the country meetings. The India meeting was attended by 4 IIASA staff (Keywan Riahi, Volker Krey, Simon Parkinson, and Barbara Willaarts). The meeting in Pakistan was attended by 4 IIASA Staff (Simon Parkinson, Piotr Magnuszewski, Simon Langan, and Barbara Willaarts) as well as by the UNIDO project manager and PSC member, Robert Novak.

In the two cases, the specific objectives of the meetings were:

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 selected organizations and experts that could support and contribute to the ISWEL project in the next stages and benefit from its outcomes.

The outcomes of the two meetings translated into: 1) identification of main sectoral challenges regarding WEL (Outcome 2.1), and 2) identification of stakeholders that later joined the scenario workshop. Meeting in India was attended by 23 participants, from 13 different organizations. In Pakistan, the meeting was attended by 34 participants from 15 different organizations. In the two meetings, stakeholders participating included academia, regional governments, think tanks, NGOs, and federal government. Table 8 provides a summary of the organizations participating the two meetings.

Table 8. Organizations participating in the first national consultations

Country	Organization participating
Pakistan	Lahore University of Management Sciences (LUMS) Ministry of Planning, Development and Reforms Planning and Development, Gov. Punjab Planning and Development, Gov. Baluchistan Planning and Development, Gov. Khyber Pakhtunkhwa LEADS Pakistan Meteorological Department (PMD) Pakistan Council on Research of Water Resources (PCRWR) Pakistan Agricultural Research Council (PARC) US Pakistan Center for Advanced Studies in Water, MUET Climate Change, Alternate Energy and Water Resources Institute (CAEWRI) Pakistan Business Council Water and Power Development Authority (WAPDA) Ministry of Planning, Development and Reforms
India	The Energy and Resources Institute-TERI Council on Energy, Environment and Water (CEEW) Department of soil and water conservation-Government of Punjab Indian Council for Research on International Economic Relations/IWMI Indian Institute of Technology (IIT) - Kharagpur Institute of Defense studies and Analysis (IDSA) Integrated Research and Action for Development (IRADe) International Development Research Center (IDRC) National Institute of Hydrology (NIH) National Institution for transforming India (NITI)-Aayog Technology Information, Forecasting and Assessment Council (TIFAC) TERI School of Advanced Studies The Celestial Earth United Nations Development Program (UNDP)

Meeting 2: Developing water, energy, and land nexus scenarios for the Indus Basin

With the aim of supporting knowledge generation and sharing for the sustainable management and future of the Indus, IIASA in partnership with International Centre for Integrated Mountain Development (ICIMOD), the International Water Management Institute (IWMI) and the World Bank convened two interlinked events from May 29th through June 2nd 2018 in Vienna and Laxenburg: a Scenario Workshop on "Developing Visions and

Future Pathways for the Indus Basin" and the Third Indus Basin Knowledge Forum, whose theme for this year was "Managing Systems Under Stress: Science for Solutions in the Indus Basin."

The nature for linking these two events dates back to the Second Indus Basin Knowledge Forum that took place in Colombo in July 2017. Back then IIASA, took the commitment to lead one of the ten action points agreed at the Colombo meeting and also an integral component of ISWEL project: the co-development of future scenarios for the Indus Basin taking into account different global developments and climate scenarios.

The 2-day Scenario Workshop was facilitated by eight IIASA staff, and supported by three members of the project steering committee (David Grey, Astrid Hillers, and Robert Novak). The overall aim was to go one step beyond the first consultations held earlier in the year and bring together experts and stakeholders from the four riparian countries, to jointly discuss this time desirable futures and pathways in the Indus basin and its riparian countries for the management of water, energy, and land. The workshop was based on a scientific approach but it also aimed to produce policy relevant results. The specific objectives of this meeting included the co-development in partnership with sectorial experts from all four riparian countries of:

- ✓ 3 different visions and pathways to desirable futures for the Indus basin taking into account different global developments and climate scenarios.
- ✓ Enhanced and shared understanding on the implications of different investments in the basin and their consequences cascading through the WEL sectors.

Participants in the Indus Scenario Workshop

Table 9 Summarizes the list of organizations participating in the Scenario Workshop.

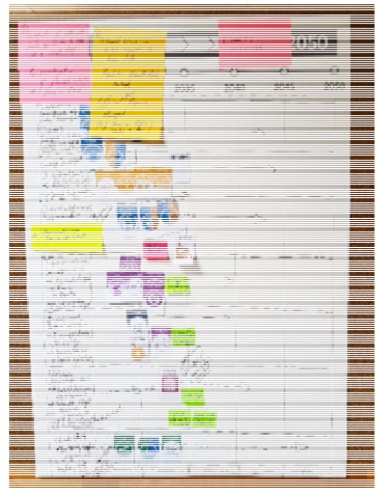
Country	Organization
Afghanistan	Environmental Conservation Specialist Organization of Afghanistan (ECSOA)
	Ministry of Energy and Water
China	National Climate Centre and Chinese Academy of Sciences
	Xingjiang Institute of Ecology and Geography
	National Climate Centre
India	Indian Institute of Technology (IIT) - Kharagpur
	The Celestial Earth
	Government of Punjab
	TERI School of Advanced Studies
	National Institute of Hydrology
	The Energy Resources Institute (TERI)
	University of Kashmir
	National Institute of Hydrology
	National Institution for transforming India (NITI) - Aayog Researcher
Nepal	The International Centre for Integrated Mountain Development (ICIMOD)
Pakistan	Lahore University of Management Sciences (LUMS)
	Lead Pakistan
	Planning Department-Government of Punjab
	U.S. Pakistan Center for Advanced Studies in Water
	Upper Indus Basin Network
	Ministry of Science & Technology
United Kingdom	Oxford University
USA	The Massachusetts Institute of Technology Institute (MIT)
	The Global Environment Facility (GEF)

The outcomes of the Indus Scenario Workshop consisted of:

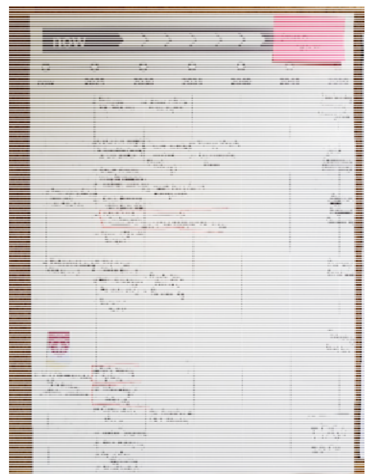
1. Three visions for the Indus basin, differentiated by the value preferences of the stakeholders, composed of spatial representation of development as well as sectoral challenges, and a range of potential solutions (technological but also behavioral, and policy related).
2. A timeline describing the different steps at which solutions and challenges will have to be implemented/addressed.

The narratives describing the visions and pathways are included in Section 1.1 and the report containing the processed information can be found online here. Pictures of the visions and pathways drawn by stakeholders are shown next. Two short videos of the process and how it feeds into a wider basin consultation process (IBKF) can be viewed here.

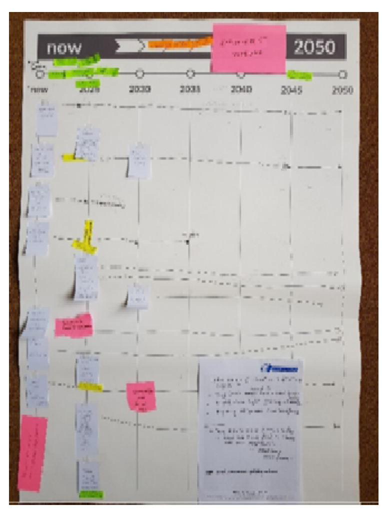
Economy Vision INDUS



Society Vision INDUS



Environment Vision INDUS



The participants' evaluation questionnaire indicated that almost all participants (with a few neutrals, no one disagreed) either strongly agreed or agreed that the workshop:

- met stated objective
- has stimulated learning and sharing of knowledge
- has been useful and relevant for their work

Below we present one, among many overwhelmingly positive comments in the feedback from participants:

> *"I am impressed with the openness of all participants to sit together and craft a collective vision. It demolishes a notion that south Asia is not ready to move forward, we just have to identify the right nodes of change, action and policy decisions supported and ignited by science."*

Zambezi engagement activities

The first consultation meeting (Meeting 1 on identifying basin challenges, took place in September 2017). Since then, the ISWEL team has participated in two basin meetings convened by the Zambezi Watercourse Commission and organized one Scenario Workshop. The two meetings where ISWEL team participated included:

1. Coordination meeting with partner organizations working on nexus initiatives in the Zambezi Basin. This meeting was convened by ZAMCOM with the intention to align current efforts and build on the work done across projects to support their activities, namely the Zambezi Strategic Development Plan (ZSDP) and the Zambezi Water Resources Information System (ZAMWIS). The meeting took place in Harare on 5 February 2018, and was attended by Piotr Magnuszewski (IIASA) and at least 4 other organizations, included, SADC, WWF, NEPAD/JRC, ETH-Zurich, WATER-NET. The outcomes of the meeting included a pre-agreement between IIASA and ZAMCOM to:
    a. Designing and facilitating a participatory scenario development workshop using a policy exercise approach.
    b. Providing feedback to the process of developing of Zambezi strategic plan through the outcomes of participatory scenario development.
    c. Training (train-the-trainer) of the new group of facilitators to be able to run the scenario development process using a policy exercise approach.
    d. Developing capacity building and training activities in the basin in coordination with other regional initiatives
2. Participation in the III Basin Stakeholder Forum "Water, Energy, Land Nexus for Socioeconomic development in the Zambezi Basin". The ISWEL team was invited to provide a keynote presentation to share the developing work. The meeting was attended by Amanda Palazzo (IIASA), and took place in Lilongwe 8-9 October 2018. During the meeting, ZAMCOM officially invited IIASA to join the bi-annual ZAMCOM Technical Committee meeting on November 22nd in Harare to present the scenario approach and preliminary results of the exercise developed during the scenario workshop of July.

Meeting 2: Developing water, energy, and land nexus scenarios for the Zambezi Basin

This purpose of this workshop as with the one organized in the Indus was to build on the first meeting bringing together experts and stakeholders from the eight riparian countries, to jointly discuss desirable futures and pathways for the Zambezi basin and its riparian countries with regards to water, energy, and land. The specific goals were the same ones presented as for the Indus. The meeting co-organized with ZAMCOM and was attended by 6 IIASA staff (Simon Langan, Piotr Magnuszewski, Amanda Palazzo, Michiel van Dijk, Beatriz Mayor, and Barbara Willaarts), and UNIDO project Manager, Robert Novak.

The 2-day workshop was attended by 24 stakeholders from seven riparian countries (Tanzania was not represented) and it was based on scientific approach but it also aimed to produce policy relevant results. The outcomes of the workshop translated into:

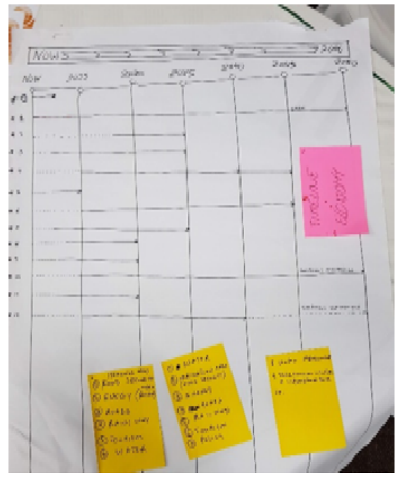
- ✓ Development of 3 visions and pathways to desirable futures for the Zambezi
- ✓ Enhanced and shared understanding across riparian countries participants and the ISWEL team national challenges and implications of different investments in the basin and their consequences cascading through the WEL sectors

Table 10 provides a summary of the national and international organizations that attended the Harare meeting. The majority of stakeholders were federal government representatives and some international organizations (The World Bank, WWF).

Table 10 Organizations participating in the Zambezi Scenario Workshop, Harare 10-11 July

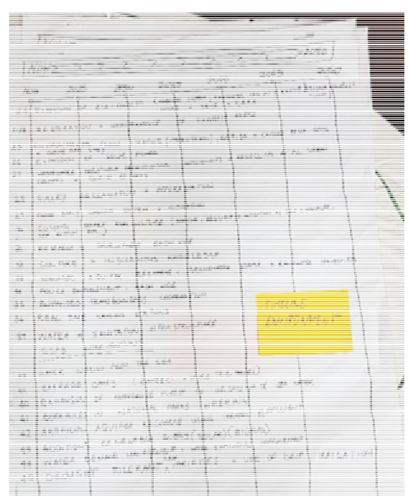
Country	Organization
Angola	Ministério da Energia e Águas
	Instituto Nacional de Recursos Hídricos (INRH)
	Governo provincial do Moxico
Botswana	Department of Water Affairs
	Department of Crop production
	Ngwato Land Board
Malawi	Energy Department
	Department of Water Resources
Mozambique	ARA Zambeze
Namibia	Zambezi Regional Council
	Namibia Water Corporation
	Ministry of Lands
Zambia	Ministry of Water Development, Sanitation and Environmental Protection
	Department of Energy
	Ministry of Agriculture
Zimbabwe	SARDC
	Department of Water Resources Planning and Management
	University of Zimbabwe
International	World Bank
	WWF
	Zambezi Watercourse Commission

Economy vision ZAMBEZI



Society vision ZAMBEZI

Environment Vision ZAMBEZI



The participants' evaluation questionnaire indicated that, similarly to the Indus workshop, almost all participants (with a few neutrals, no one disagreed) either strongly agreed or agreed that the workshop:

- met stated objective
- has stimulated learning and sharing of knowledge
- has been useful and relevant for their work

Among the multiple positive feedback messages from participants we present two of them below:

"The workshop allowed the bringing in of all the problems and challenges being experienced in the basin on the table. The workshop hence gave the platform to view the different aspects of the basin as one whole picture. It also strengthened the aspect of cooperation between the riparian states i.e. they cannot operate in isolation."
"The workshop was well organized and very relevant to the current situation in the Basin. It provided room for more engagement and good platform to open to a wider audience."

Scenario Process: Development of desirable pathways and visions

This section provides a short summary of the participatory scenario process developed using the Zambezi example to illustrate the dynamic.

STEP 1: Reviewing current situation in the Basin and its major challenges

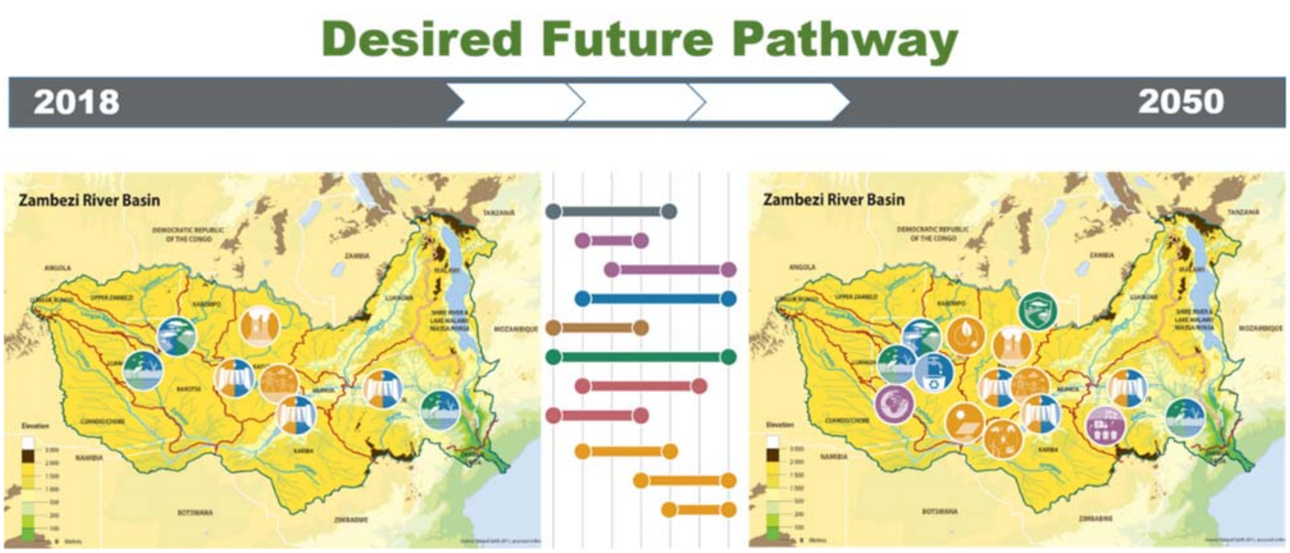
The process started with characterizing the current situation of a basin, represented in a simplified visual format. To this end, a predefined set of materials such as maps and cards with descriptions of infrastructure, economic activities and resources uses were provided to facilitate discussions. These materials are carefully selected to provide sufficient information and knowledge without narrowing down participants' scope of exploration and breadth of choices – they could always add additional elements be it physical, social, economic or environmental. Such visual representation provided an opportunity for better understanding and a deeper discussion of key issues among stakeholders. Participants developed this representations of the current situation separately for different riparian countries (Angola, Botswana, Namibia, Malawi, Zambia, Mozambique, Zimbabwe).

STEP 2: Developing future pathways: "business as usual"

Based on this joint assessment of the current situation (developed in the previous step), participants developed "business-as-usual" pathways – i.e. a series of changes of the existing situation that is likely to happen if current policies will continue. These changes were represented visually by adding or changing existing elements on the map. Additionally, the changes (new investments or initiatives) were represented separately with the timeline depicting the pathway from "now" to the future.

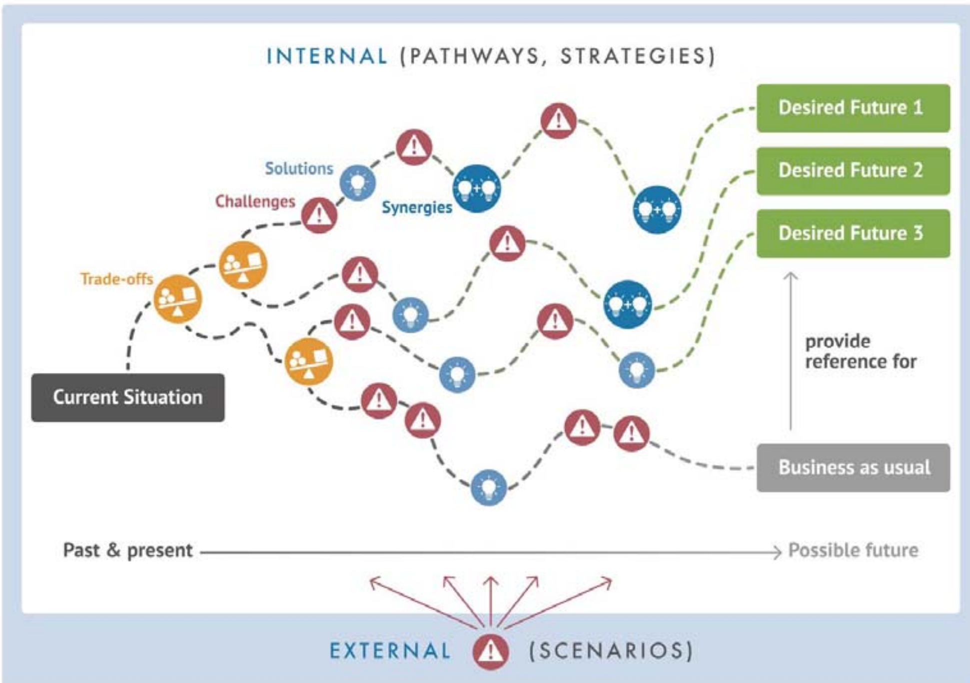
STEP 3: Developing Zambezi visions (desired futures) and pathways leading to them

Three visions of "desired futures" were developed together with their corresponding pathways. Unlike the business-as-usual that continues existing policies and directions, the desired futures started from clear, ambitious but realistic visions of what can be achieved. Three different groups worked assuming 3 different priorities: economy, society, and environment respectively. The focus on priorities were not supposed to eliminate other important concerns - all the visions were aimed to be desired and holistic. They included both hard (e.g. infrastructure) and soft (e.g. behavioral change) elements. The pathways leading to the crafted visions were represented on the timeline including specific initiatives and investments.



STEP 4: Improving the robustness of pathways – addressing challenges from global scenarios

In order to test robustness of the chosen solutions under unfavorable external circumstances (scenarios) it is also beneficial to consider some undesired global scenarios. The differences between alternative global scenarios are represented with a set of externally imposed challenges along the analyzed regional pathways. Although a sustainability scenario (consistent with SSP1) is often attractive, strategies designed by stakeholders should also be robust to unfavorable external conditions. Implications of other global scenarios (based on SSP2-5) on regional pathways will be considered and pathways will be revised to improve their feasibility.



Next steps: The information gathered will be used to further developed and shape the Nexus model tools (Outcome 1.2) and develop the quantitative scenarios for the Zambezi Basin (Outcome 1.1). The results of the models will be presented in spring 2019 during in both basins to provide an opportunity for further revising and improving visions and pathways.

Outcome 3.2 Capacity building for system analysis and nexus decisions

Summary: In addition to the stakeholder meetings and workshops, 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) has been 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 by Month 24: In the course of the last 12 months ISWEL team has organized two trainings with basin stakeholders and provided one grant to a student from Lahore University Management Sciences (LUMS) in Pakistan to participate in the YSSP at IIASA from July-September 2018 and work hands-on ISWEL Indus.

Capacity development Zambezi

Training on "Approaches to Scenario Planning process", Harare 9 July 2018

On July 9th, one day prior to the Stakeholder Scenario workshop, IIASA team ran one-day training approaches and methods to scenario planning. This training was tough for 11 Master students from the Integrated Water Resources Management Program of the University of Zimbabwe, with the purpose of, providing them with an overview on different approaches to scenario planning, and train them in the scenario process IIASA was running the day after with the stakeholders so that they could support the facilitation team and have a hands-on experience.

Prior to the training, and as s sort of ice breaker into the water-energy-land nexus and transboundary basin cooperation, IIASA researchers run the Nexus simulation game. for and specifically provide them with some training to support the IIASA team during the Stakeholder Scenario Workshop that was taking place the two days after.

Capacity Development Indus

Training on "Integrated Assessment Models for WEL Nexus planning" Laxenburg, 1 June 2018

During the IBKF hold in Vienna in May-June, IIASA modelers team also organized a training with the purpose of introducing a number of the models and resources used at IIASA that support decision making, policy analysis and capacity building across the water, energy and land sectors at a range of scales.

Key developers of the models gave presentations and presented examples on the use of the tools and they can be used can be used in the wider community to support local decision making and capacity building. Specific examples about their use in the Indus Basin were discussed.

Young Scientist Summer Program

Through the summer of 2018, three young researchers contributed to the development of the ISWEL project through the IIASA Young Scientist Summer Program.

Ansir Ilyas from Lahore University of Management Sciences (LUMS) was sponsored through ISWEL to participate in the 2018 YSSP program and collaborated with the Energy Program supporting the development of the Indus nexus tool. The main goal of his research stay was for him to get trained in the use of the tool and support to its development by:

1. Investigating and gathering local data on the various cross-sectoral issues in the Indus River Basin that arises between couplings of the water and energy sectors.
2. Connect these two resources with optimal solutions (technologies and management strategies) that counter the tradeoffs between water and energy usage for human development
3. Implement long-term scenarios with an existing basin-scale version of the MESSAGE and identify the future demand projections.

As a result of his stay at IIASA, Ansir will be presenting at the upcoming American Geosciences Union (AGU) his work with the financial support of ISWEL.

Fabio Amendola Diuana, from COPPE/UFRJ, Brazil, joined the Energy program for the summer 2018 and supported ISWEL Indus modelers. His participation was sponsored directly with IIASA funds and his contribution focused on enhancing the basin-scale modelling tool developed for the Indus basin by improving its flexibility and transferability to other basins. Key objectives of this research included:

1. Determining the suitable spatial representation of the model and automating the implementation for new basins;
2. Development of multi-scale mapping tools for combining global and local datasets, depending on availability;
3. Validating the results between Python-GAMS and R-GAMS versions;
4. Develop a rapid prototyping of models for implementation in other basins; and
5. Implementing scenarios to test the suitability of the model to capture key interactions across sectors.

His work has contributed to make the basin tool more flexible so that it can be deployed to other basins and used by other researchers and regional planners. Fabio continues to collaborate with IIASA on this project and will continue developing the tool through his PhD studies, by applying the tool to multiple river basins in Brazil.

Mengru Wang, from Wageningen University and Research, joined the Water Program to analyse nitrogen (N) sources and trends of riverine N export in the Indus and the Yangtze river basins between 2010 and 2050. Her participation was also sponsored directly with IIASA funds, and her analysis provides insights in how future trends in coastal N pollution are affected by socio-economic activities (based on three Shared Socio-economic Pathways) and climate-change induced hydrological changes (based on two Representative Concentration Pathways). The results on the main sources of N export by sub-basins are a good basis for developing effective options to reduce coastal N pollution from the two basins. Her research is of high quality and policy-relevance. Therefore, we aim for a strong peer reviewed paper with planned submission before May 2019.

As part of the ISWEL project, this is the first effort to estimate and project N export for the Indus basin using a sub-basin approach. This is part of the efforts to include water quality into the integrated modelling framework built for the ISWEL project. The approach to couple WUR and IIASA models for water quality assessment, in particular MARINA (WUR), CWatM (WAT Program) and GLOBIOM/EPIC (ESM program), will be extended for another project INMS. The N model for Indus will be further used to assess the impacts of regional development scenarios, based on stakeholder engagement outcomes from the ISWEL project.

Next steps: Continuing developing capacities around the use of the tools and processes developed in the project is a key target for 2018. The Executive Team is now discussing the launch of a small call to grant young researchers and stakeholders from the two basins, to come over to IIASA for a 6 to 9-weeks training in the use of the AMF. The plan is to grant at least one person from the Zambezi, and a second person from the Indus, preferably from India (as the 2017 YSSP was from Pakistan).

Outcome 3.3 Dissemination and outreach

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

Progress by Month 24: a summary of the participation in scientific and science to policy meetings, together with the scientific publications and working papers, is provided next. In summary, during the past 12 months the ISWEL team has participated in 15 scientific conferences and workshops and 3 high level panels. In terms of publications, the team has published 5 peer review papers and another 7 are currently under preparation. Other publications include one policy brief, and two IIASA working papers.

Participation in Scientific Conferences

1. Byers E, Parkinson S, Balkovic J, Burek P, Ebi K, Gidden M, Grey D, Greve P, et al. (2018).Global climate and development hotspots assessment: Asia under pressure. In: 5th Asian Energy Modelling Workshop, 10-12 September 2018, Singapore.
2. van Dijk M, You L, Mosnier A, Havlik P, & Palazzo A (2018). Generating high-resolution national crop distribution maps: Combining statistics, gridded data and surveys using an optimization approach. In: 30th International Conference of Agricultural Economists (ICAE), August 2018, Vancouver, British Columbia, Canada.
3. Burek P (2018). Global Hydrological Model Community Water Model (CWATM). In: Indus Basin Knowledge Forum (IBKF), 31 May-2 June 2018, Laxenburg, Austria.
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5. Tang T, Strokal M, Wada Y, Burek P, Kroeze C, van Vliet MTH., Langan S (2018). Sources and export of nutrients in the Zambezi River basin: status and future trend. International Conference Water Science for Impact, 16-18 October 2018. https://www.wageningenwaterconference.com/
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2. Langan, Simon (2018). Addressing Water-Energy-Food Nexus Hotspots in Transboundary Basins, Side Event co-organized with the World Bank, in cooperation with GEF, IIASA and UNEP. World ater Forum, Brasilia 21 March 2018
3. Langan, Simon (2018). Pollution-driven water scarcity for ecosystems and human uses worldwide, Special Session organized by IIASA in collaboration with Wageningen University, Stockholm World Water Week, 26 August 2018, Stockholm.
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10. 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*
11. 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*
12. 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*
13. 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*
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Other dissemination materials (webpage, Videos, social media)

As a result of the consultations held in the two basins and the workshops co-organized with other organizations, a number of dissemination videos and photo albums have been developed and made available online.

INDUS

Indus Basin Knowledge Forum and ISWEL Scenario Workshop: https://vimeo.com/298242677
Flickr Album of Indus Basin Knowledge Forum and Scenario Workshop:
www.flickr.com/photos/iiasa/albums/72157696919597184/with/29494219718/

ZAMBEZI

Video on Zambezi Strategic Development Plan and ISWEL Scenario Process: https://drive.google.com/open?id=1OX1i4re8ZXrI-iRgrfJep6ZF9oauyP6Q

Video on Nexus Simulation Game: https://vimeo.com/292958316

Next steps: Following the contractual obligations, the ISWEL team will produce along 2019 two IW Learn experiences, one per basin. Contacts have been already established with the person responsible for this at GRID-Arendal. In addition to this, during the last year of the project the team will produce at least two more policy briefs, one per basin, summarizing the main findings and policy recommendations. This dissemination plan will be completed with the publication of a number of peer review articles currently under development.

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. Co-ordination between UNIDO and IIASA and IIASA and GEF is largely done on a one to one basis, largely led by Langan on behalf of IIASA.

Progress by Month 24: Internal coordination is provided 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. In the final year of the current phase of the work it is suggested that to complement formal meetings a series of semi-formal more regular e-meetings (skype etc) be established between: a) IIASA and UNIDO and b) IIASA with GEF and UNIDO.

Summary of the 2018 Annual Meeting with the Project Steering Committee

The meeting took place during 18-19 April 2018 at IIASA. This was the second of the three annual meetings planned during the life time of the project, 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).

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 2018.
- 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 1.5 days 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 undertaken.

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

Main comments	Action undertaken
There is a need to clearly define what is the vision for the project. In short, what are we aiming to deliver? How do we expect those outputs will be used? and most importantly who will use those?	The project team has developed 1-page document synthetizing what ISWEL is about, what should deliver, and for whom (See Annex IV). The purpose sub-section within the executive summary also provides a short but clear statement of what is ISWEL and what do we aim to deliver. The progress report will also contribute to understanding more clearly the steps that the ISWEL team is undertaking to materialize the vision. Nevertheless, we would like to argue that ISWEL it is about developing tools and capacities that can inform and support the management of the nexus at the global and basin levels. At the global level, this comprises of developing web-based visualization tools that are populated with scientific information that allows understanding what opportunities and constraints exist to meet multiple WEL-related development goals and what regions and peoples will be exposed to the largest risks. In the basins, ISWEL aims to develop models, participatory processes and technical capacities that can increase the understanding of what is meant by the nexus, why it matters and provide some preliminary evidence-based information on the cost-effectiveness of applying nexus approach in national/basin planning as oppose to sectoral development plans. In the coming months we will generate and disseminate a ‘resource pack’ which highlights these tools in presentations, policy briefs and links to the underpinning evidence and citations The stakeholder that we are targeting: Global level: international organizations like IPCC and UN agencies Indus Basin: scientific community and regional planners Zambezi Basin: Zambezi Watercourse Commission, scientists
Global assessment is insufficient to address many of the development challenges we are facing as decision making occurs mostly at national and subnational scales. The approach adopted in the project to downscale into the basins is correct but this comes with a risk, as the granularity increases (problem size, diversity and number) and this is a novel approach for IIASA requiring the test of new approaches. Crucial issues to bear in mind in the basin studies:	The driver motivating the ISWEL project is exactly the premise that solutions need to be tailored to the context where they need have to be implemented, particularly because some of the resources that we are looking at (e.g. water) need to be managed at regional/basin scales. Whereas IIASA has a long expertise in global science, this project (as other ongoing projects at IIASA) is a great opportunity to further advance in the development of tools (models and processes) that can serve the main mission of IIASA, produce science that is relevant for policy and decision making, at national and sub-national scales. The tools that are being developed in ISWEL are therefore prototypes that will be further improved by stakeholders in the basins, but also by the scientific team in future projects.

Main comments	Action undertaken
1. Adequate engagement with stakeholders is crucial to understand the priorities and seek for users/beneficiaries of the project outcomes. 2. The resulting tools need to be useful and flexible i.e. stakeholders need to be able to improve and change them, and this also requires investing in developing the technical capacities. 3. Complexity in the basins is determined by biophysical and socio-economic challenges, but very importantly by governance and politics. Project team needs to be very aware of this and navigate through this complexity.	Evidence of the efforts that we have been undertaking to develop these basin tools, include: 1) Implementation of an ambitious stakeholder engagement strategy, which so far has allowed to interact and get feedback from a range of stakeholders and organizations in the Zambezi and in the Indus, that has included academics, NGO's, sectoral interests from all riparian countries in these very different transboundary basins. The success is also evidenced by the very positive feedback we received from the stakeholders. Also, ZAMCOM is exploring how to include use the scenario process developed for ISWEL into the Development of Scenarios in the Zambezi Strategic Development Plan. 2) The project has allowed us to develop not one nexus model, but three different models (one global and two for the basins) that have been assembled as analytical modelling frameworks (AMF). The reason for this diversity is rooted in the idea that a global nexus tool is not suitable to address the complexity of regional challenges, and at the same time, the tools also need to be tailored to the specific context of the basins and the users, hence the use of AMF. 3) It was very obvious in the Indus meetings, that politics play an important role when addressing the basin challenges and searching for possible solutions. Therefore, we invested significant efforts in organizing consultations in neutral spaces to foster dialogues among non-political actors that have often very limited opportunities to meet, to exchange views on the role of science and knowledge sharing to address the basin nexus challenges.
Within the basins, there is a clear need to identify what are the nexus challenges from the stakeholder's perspective, prioritize them and inform in a transparent and clear manner which challenges will be addressed, which ones not, and who can benefit/use the outcomes/outputs. The tools should be tailored to assess the problems and explore solutions and not the other way around (finding problems that fit solutions)	The interaction with stakeholders has taken a number of approaches to identify needs and priorities. Specifically, in addition to the workshops organized by the ISWEL team, ISWEL team members have attended and participated in several meetings organized by basin stakeholders, and have reviewed the relevant documentation. Together this has allowed a good mapping of the sectoral challenges the two basins are facing, as well as the identification of specific nexus challenges. Efforts have also been concentrated in establishing a number of priority nexus research areas that we will be looking at (see Table 7) and communication process that allows stakeholders to understand how much of the information they provided is considered in the modeling exercise and how it was utilised (e.g. Figure 3).
The complexity of the problems addressed is expanded due to the high uncertainty linked to the data used (because of its poor quality and often sparse and insufficient). It is very important that project	This is very clear for the team, and at the time of communicating project outcomes efforts will be devoted to understand and discuss the sources of uncertainty. As indicated above, the ultimate mission is not to deliver/impose solutions to very complex

Main comments	Action undertaken
outcomes and solutions provided are communicated adequately, underpinning the complexity and uncertainty linked to it.	problems, but rather use the results to promote dialogues about how the tools can be improved and what are the data needs. At a global level the team have recently published a paper (Greve et al., 2018) which outlines the sources of uncertainty in the different types of models (GCM, GHM and scenarios). We anticipate following this up with a further paper of other sources of uncertainty including data.
Clarification on the type of tools that will be produced and delivered is required. Also, for whom are these tools intended	The tools ISWEL is intended can be classified into three categories 1) Open-source hard-models, suitable for stakeholders with a strong technical background like scientist or planners interested in using them for scientific or planning purposes. 2) Participatory tool-kit that can help stakeholders to discuss nexus challenges, and develop common understanding of future visions and pathways (e.g. simulation games, scenario policy exercise) 3) Visualization tools that translate complex scientific information into easy-to-understand format. These tools include the hotspot explorer and the Nest tool (Indus) which will also have a visual interphase of model results. We have run exercises to enhance capacity of stakeholders in the first two of these. We will continue to develop this in the coming year and also for the visualization tool once near completion
There are elements in the problem framing of the basins which have not yet been given proper attention e.g. urbanization and water quality issues.	Water quality is now being addressed in both of the basins. Modelling tools are being developed from existing approaches (MARINA model). However, despite the magnitude of the problem, there is very little data that can be used to carry out a proper assessment, but nevertheless a preliminary assessment of nutrient loads (N, P) is now being included in the Zambezi AMF. In the Indus, progress has been made (YSSP worked on developing the Indus MARINA model) but it still needs to be integrated into the Indus AMF. Urbanization is considered within the models to the extent that projections of future populations differentiate urban versus rural populations and changes in resources demand are also accounted in a temporal and spatially explicit manner.

Summary of planned activities for 2019

Type of meeting	Details & Timeline
Management	Annual Project Steering Committee meeting. First trimester 2019 Bi-monthly e-meetings UNIDO/GEF/IIASA
Stakeholder Engagement-Zambezi	Final Workshop and capacity development training: March 2019. Location: Basin
Stakeholder Engagement-Indus	Final Workshop and capacity development training: April 2019. Location: Basin
Final meeting with PSC: presentation of project results	Various options: 2019 COP meeting, 2019 UNIDO conference in central Asia

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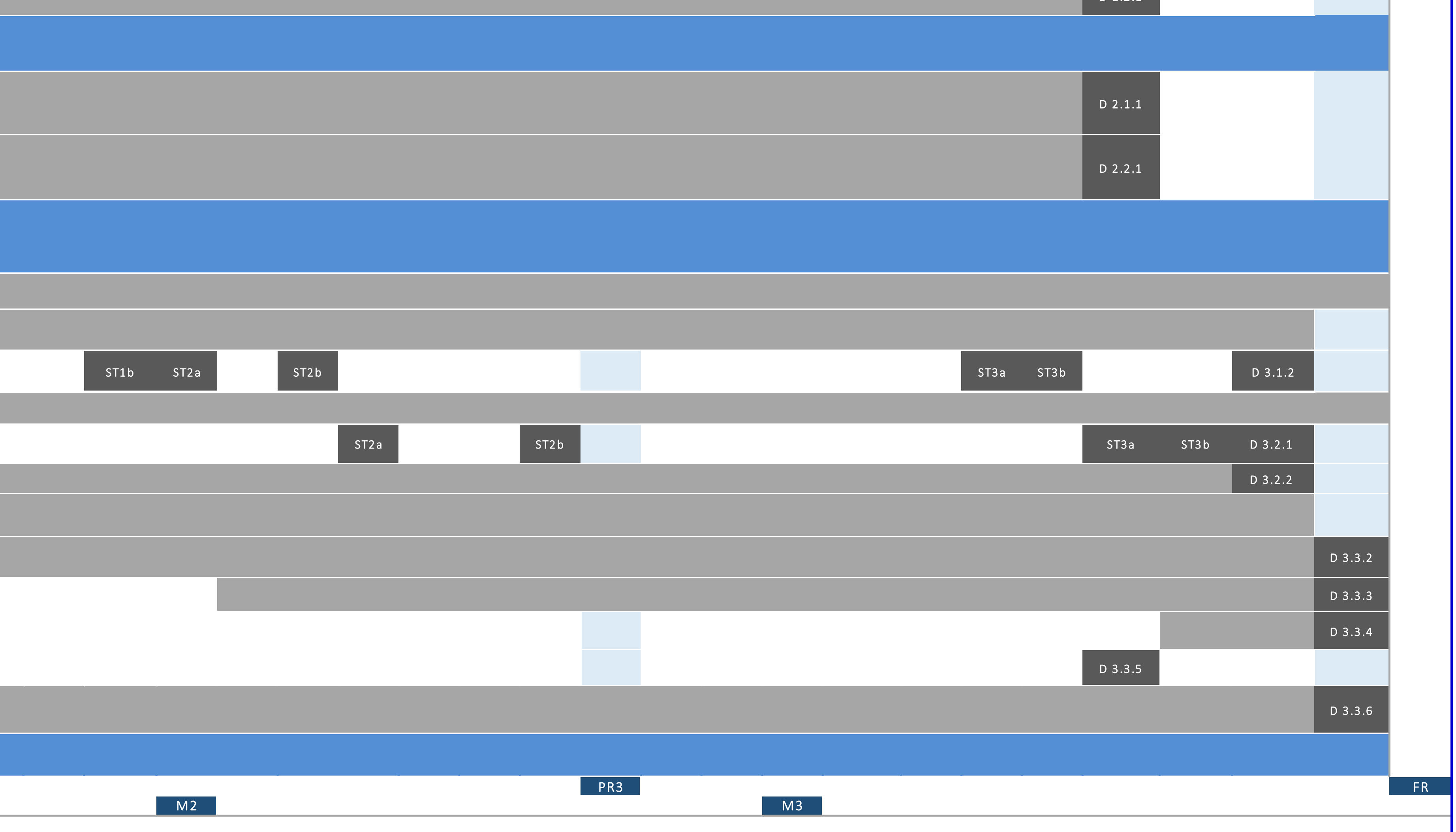
5. Annex

Annex I: Work Plan

Annex II: Key hotspot risks for each region

Annex III: Policy Brief "The big difference of half a degree"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Project: Integrated Solutions for Water, Energy & Land

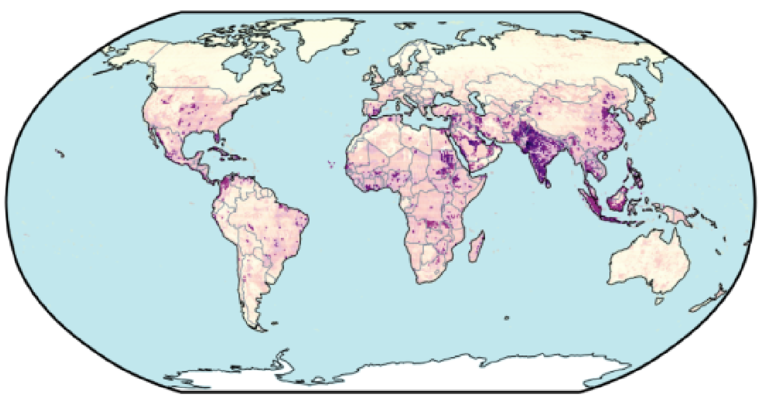
Annex II: Key hotspot risks for each region

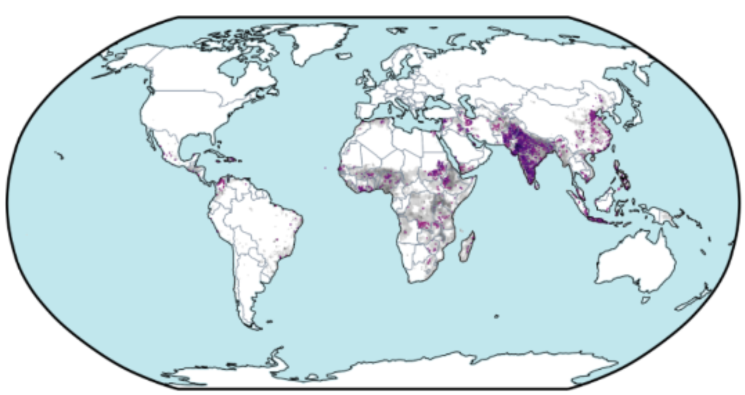
Global Hotspots Assessment

Regional impacts summary

ISWEL 3rd Progress Report to UNIDO

October 2018





Global multi-sector hotspots in a warming climate, for the whole population (upper) and for vulnerable population (lower). Adapted from Byers et al 2018.

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Region	*Multi-sector hotspots*	*Vulnerability*	*Key sectoral impacts*
ASIA			
Key hotspots: *Northwest India, Pakistan (Indus basin), northeast China*	• Most of India and Pakistan, • central Afghanistan, • northeast China including Beijing and Tianjin • east coast China incl. Shanghai and Wenzhou • Sichuan province	Particularly high in most regions, excluding coastal Chinese cities. Especially high in Pakistan, India, Afghanistan, Bangladesh, Myanmar	**Water**: North and northeast China driven by high water stress (both low availability and high demands) and variability. West and northwest India, and Pakistan, driven by high demands and seasonality. **Energy:** Most of south Asia characterised by low clean cooking access and growing cooling demands, high humidity and heat stress events. China, India and Japan face hydroclimate risks to power plants. **Land:** Large areas impacted by Nitrate leaching. Ag water stress and crop yield reductions in west India. Habitat degradation in central-southern China
SOUTHEAST ASIA AND AUSTRALASIA			
Key hotspots: *Indonesia, central Thailand*	• Central Thailand and Cambodia • Hanoi/central region of Vietnam • Most parts of Indonesia, especially Sumatra, Java and Kalimantan	Particularly high in most regions, especially rural regions	**Water**: High water stress and variability in Java, Indonesia, and patches of Australia **Energy:** Growing cooling demands, high humidity and heat stress events and moderate access to clean cooking drive high energy sector scores throughout Thailand, Malaysia and Indonesia. **Land:** Large areas impacted by Nitrate leaching and severe habitat degradation throughout southeast Asia.
MIDDLE EAST AND NORTH AFRICA			
Key hotspots: *Syria, Iran, Sudan, Nile delta*	• Persian Gulf and Red Sea coastal areas • North and West Iran, e.g. Lake Urmia • North Syria and southeast Turkey • Coastal/north Egypt, Nile delta • Central and north Sudan • Western Ethiopia • Yemen	High in almost all areas except Turkey, parts of Egypt and Saudi Arabia	**Water**: Almost all areas in high water stress **Energy:** Growing cooling demands and heat stress events result in moderate energy scores along north African coast and middle east. **Land:** Minimal impacts except upper Nile in Sudan, the 'Holy Land', coastal Algeria and northwest Iran.
SUB-SAHARAN AFRICA			
Key hotspots: *Upper Nile basin, Sudan, Ethiopia, Nigeria, Coastal Ghana and Cote D'Ivoire,*	• Lake Victoria • Central Tanzania • Burundi • North Zambia • South DR Congo • South Zimbabwe • East coast Madagascar	High in all areas	**Water**: Water stress in parts of west and south Africa, with growing drought intensity, seasonality and interannual-variability in central, west and southern regions of Africa. High variability means that hydroclimate challenges are already high, but changes are difficult to detect. **Energy:** Low clean cooking access, high humidity, rising temperatures and growing

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Region	*Multi-sector hotspots*	*Vulnerability*	*Key sectoral impacts*
Zambezi basin countries	• Johannesburg region, South Africa • Central Nigeria and Lagos • Coastal Ghana and Cote D'Ivoire • Coastal Guinea and Senegal • Cabo Verde Additionally at 3°C: • Rest of west Africa • South Sudan • Madagascar • Tanzania • Kae Victoria region		hydro and thermal power characterise significant energy challenges throughout SSA, particularly in central and western regions. **Land:** West, central north (equator to the Sahel) and east African regions (from the Horn to Mozambique) face generally widespread moderate-high impacts from habitat degradation and nitrate leaching. Crop yield reduction expected to be severe in the upper Nile, with moderate patches in west, the Horn and Zambezi river basin countries.
LATIN AMERICA			
Key hotspots: *Southeast Brazil, northeast brazil, Colombia, southern Mexico and the Caribbean*	• North east Brazil, Maranhao, Piaui • Rondonia state, Brazil • East Paraguay • Buenos Aires metr. area • Salta-Jujuy region • Central Bolivia (Santa Cruz de la Sierra) • Coastal Ecuador and Colombia, Medellin • Coastal Venezuela, Maracaibo-Valencia regions • Panama • Southwest Mexico, Guadalajara, Guanajuato, Sonora • Most Caribbean islands including Cuba, Haiti and Dominican Republic. Additionally at 3°C: • Costa Rica • Most of Mexico • Parana river basin • Tocantins, Brazil • Rio de Janeiro, Sao Paulo metr. areas, Brazil • Santiago-Valparaiso region, Chile	Low-medium vulnerability in most populated areas. Higher in northeast Brazil, Bolivia, Colombia, Venezuela, and central America.	**Water:** Except for Mexico and Chile, a general abundance of water and low populations result in very low water stress aside from some key metropolitan areas. Nonetheless, large parts of southern and western Brazil, Bolivia, Paraguay, Peru, north Mexico and central American islands face growing intensity of droughts, seasonality and inter-annual variability with will complicate water management. **Energy:** Large parts of the continent from Uruguay to Costa Rica have low-moderate populations lacking clean cooking access, whilst central America and the east coast of Brazil will have growing cooling requirements and heat stress events. A high reliance on hydropower and high hydroclimate variability means southeast Brazil (in particular near Rio and Sao Paulo), Peru and Colombia face risks to water-dependent electricity supply. **Land:** Southeast and parts of northeast Brazil, northeast Argentina, Colombia and most of Central America face moderate land sector challenges, driven by crop yield reductions, Nitrate leaching and habitat degradation.

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Region	*Multi-sector hotspots*	*Vulnerability*	*Key sectoral impacts*

NORTH AMERICA

Key hotspots: *Gulf of Mexico, Mississippi basin, mid-west U.S.*	• Patches of central mid-west • Florida • Southern California Additionally at 3°C: • Arizona • Inland California • Mississippi river basin • Gulf of Mexico states • Carolinas • Southern mid-west states	Very low	**Water:** Western United States perpetually faces water stress and growing variability, as does the east albeit not water stressed. **Energy:** Moderate-high energy sector risks in the east and Gulf of Mexico regions are driven by rising temperatures and large dependence on thermal power plants. **Land:** Moderate-high impacts are widespread in the east, mid-west and Mississippi basin, due to reductions in crop yields, some areas of agricultural water stress and considerable Nitrate leaching.

EUROPE

Key hotspots: *South east Spain*	• South east Spain • Bosphorous of Turkey Additionally at 3°C: • Rhone valley, France • Southern Italy • Albania • Greece • Western & central-west Turkey	Very low	**Water:** Southern Europe around the Mediterranean, particularly Spain and Italy, face high water stress and growing drought intensity. **Energy:** Low-moderate scores for energy sector are driven by a high number of thermal and hydro power plants in southern Europe, growing cooling demands and more heat stress events. **Land**: Moderate land impacts are more widespread in southern and central Europe driven by agricultural water stress and Nitrate leaching.

This research was funded by IIASA, the Global Environment Facility (GEF) and the United Nations Industrial Development Organization (UNIDO).

Between 1.5°C and 2°C – the big impacts of half a degree

IIASA research shows substantial benefits of climate mitigation and achieving the 1.5°C target, as well as where action is most urgently required to reduce the vulnerability of the world's poorest to unavoidable climate impacts.

→ With the world already around 1°C warmer than pre-industrial averages, achieving the 1.5°C target of the Paris Agreement could almost halve the number of people exposed to hotspots of climate risk compared to a warming to 2°C.

→ At 1.5°C of warming, 16% of the global population–1.5 billion people–are expected to live in climate change hotspots. At 2°C, this almost doubles to 29% of the global population–2.7 billion people. At 3°C of warming, that figure almost doubles again, to 50% of the population, or 4.6 billion people.

→ Asian regions, Africa, and Latin America face high proportions of exposed population compared to their total population.

→ Exposure in Asian regions is the most severe, even at 1.5°C, in proportional and absolute terms, due to the high concentrations of population and the high multi-sector risks of those regions.

→ Africa fares worse than most regions, especially in high inequality socioeconomic scenarios and high warming climate scenarios. At 1.5°C, the vast majority of exposed and vulnerable population is in Asia, while at 3°C, 27-51% are in African regions.

→ Targeting socioeconomic development in hotspot areas is particularly important for reducing vulnerability in places where impacts are expected to be most severe.

→ Ambitious sustainable development in hotspot areas could reduce the number of people who are exposed and vulnerable by an order of magnitude, from 1.5 billion to 100 million.

→ Proactive adaptation through mechanisms such as the Sustainable Development Goals would greatly reduce vulnerability to shocks like climate hazards that frequently prevent people escaping poverty.

→ Policies and investments aiming to keep global temperature limits below 2°C, will deliver the greatest benefits.

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The problem

The Paris Agreement, which was signed by 195 nations in 2015, articulates a long-term goal of "keeping the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C". While there is much evidence on the risks of higher levels of global warming, the differences between 1.5°C and 2°C change are less well understood.

There is increasing evidence that the world's poorest are disproportionately exposed to climate risks, including changes in temperature extremes and challenging hydro-climatic complexity. Those in poverty are much more vulnerable to climate change impacts, which also prevent them from escaping poverty. Knowing where and how many vulnerable people are at high risk is important for creating policies to mitigate the situation.

Is half a degree important?

IIASA research conducted as part of the Integrated Solutions for Water, Energy, and Land (ISWEL) project found substantial benefits for keeping global mean temperatures as low as 1.5°C.

According to the results which featured in the recent IPCC Report on Global Warming of 1.5°C, avoiding a 2°C increase could almost halve the number of people exposed to multi-sector impacts from 2.7 billion to 1.5 billion. In addition to reducing both the population exposed and severity of impacts in highly populated parts of Asia, exposure to multi-sector risks is avoided in large parts of Africa, particularly in East and West Africa. Subsequently, the number of low income (i.e., those with an income of less than US$10 per day), vulnerable people exposed is also greatly reduced from 0.5 billion to 0.29 billion.

Study framework

The objective of the study was to assess the exposure to and vulnerability of future populations to overlapping multi-sectoral hotspots. State-of-the art models were used to assess the future trends of 14 indicators of development and climate-induced challenges linked to three sectors–water, energy, and land. Three climate change scenarios were used representing global mean temperature rises of 1.5°C, 2°C, and 3°C compared to pre-industrial conditions. In addition, high-resolution projections of population, Gross Domestic Product (GDP), and income were developed for three socioeconomic scenarios ranging from sustainability successes to development failures.

Water risks

Water risks are projected to be higher in locations where future water availability is unlikely to meet demand and hydro-climate variability is growing. Surface and groundwater stress are in part demand driven and tend to be concentrated in population centers and intense water demand regions. More intense droughts and variability in water supply affect larger areas of land, including cropland. Areas of particular concern include Central and South Asia, the Mediterranean, the Middle East, southwest of North America, south of Latin America, and North Africa.

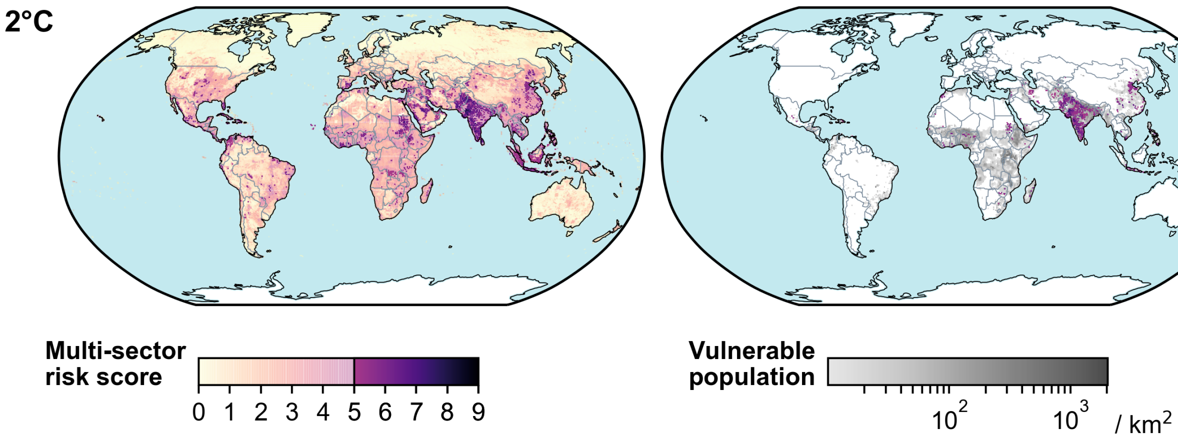
Energy risks

Higher energy risks are very much concentrated around the tropics and overlap with locations of higher air temperatures and population density. This is because of rising air temperature changes that drive cooling energy demand and heat event exposure, particularly in the

Water	*Energy*
Water stress index	Clean cooking access
Non-renewable GW abstraction	Heat event exposure
Drought intensity	Cooling demand growth
Peak flows risk	Hydroclimate risk to power
Seasonality	
Inter-annual variability	

Land	*Socioeconomics*
Crop yield change	Population density
Environmental flow exploitation	Income Levels
Habitat degradation	
Nitrogen leaching	

Indicators that were modelled to assess risk across the sectors.



Left: Multi-sector hotspots exposed above the risk score of 5 in a 2°C climate. Right: Multi-sector hotspots in locations with low income vulnerable population (exposed & vulnerable).

tropics. Areas of particular concern include Indonesia and West Africa, where exposure is driven by low clean cooking fuel access, more heatwaves, and higher cooling demands. Large areas across the tropics present consistently low-medium levels of risk.

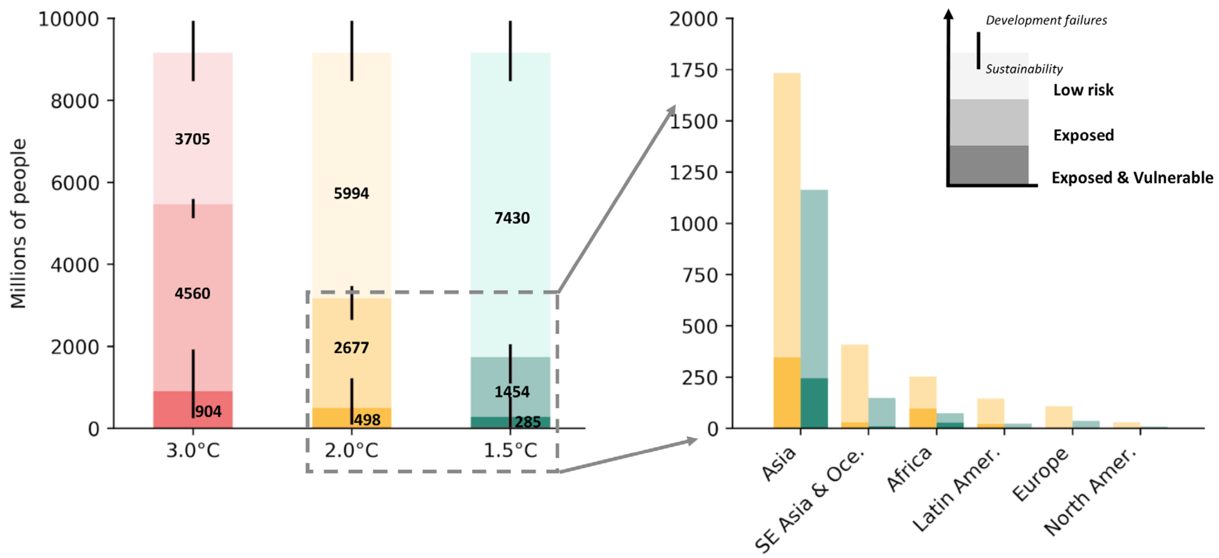
Land risks

Land sector impacts are widespread and cover large portions of all continents, particularly in agricultural areas. Nitrate leaching to watercourses from agricultural fertilizer use is a widespread risk with large areas exceeding sustainable levels. Crop yield reductions and habitat degradation are also expected in some places. Unsustainable irrigation water use increases in areas already dependent on irrigated agriculture, including China, North America, and South Asia. Areas of particular concern include the Midwest United States, Southeast Brazil, Ethiopia and South Sudan, the Mediterranean, and most of South and Southeast Asia.

Multi-sector risk

Multisector risk occurs at locations where two or more of the above sectors include multiple indicators surpassing tolerable levels of risk, such as locations that are expected to face various land and water challenges. At higher levels of warming, growth in both the size and intensity of hotspots can be expected.

First, the area of land affected by multi-sector risks increases fivefold when moving from a 1.5°C to 3°C



Even a 2°C temperature increase results in a high proportion of global population exposed (2.7 bi), particularly in Asia.

With 2°C impacts on today's population, the number of exposed and vulnerable would be 1.3 bi. With targeted poverty, vulnerability, and inequality reductions, this can be decreased to 0.5 bi or lower in 2050.

temperature increase (from 3% to 16%). Most of these hotspots overlap with the areas of high population density. At 1.5°C, hotspots emerge predominantly in South Asia. At 2°C, hotspot areas also include larger areas of South- and East Asia, East- and West Africa, and Central America.

Second, the risk scores intensify in some locations between the 1.5°C and 3°C scenarios. Areas with particularly high multi-sector risk scores include Central America, East Africa and West Asia, the Mediterranean, the Middle East, and parts of India and East China.

About this research and the ISWEL project

The International Institute for Applied Systems Analysis (IIASA) is leading the Integrated Solutions for Water, Energy, and Land (ISWEL) project in partnership with the Global Environment Facility (GEF) and the United Nations Industrial Development Organization (UNIDO). The main goal of the project is to explore cost-effective solutions to jointly meet water, land, and energy demands under different development and climate pathways.

The hotspots assessment involved more than 20 researchers from IIASA across the Energy, Water, and Ecosystem Services and Management programs. The work was led by Edward Byers (byers@iiasa.ac.at) and this policy brief has been additionally supported by contributions from Ansa Heyl, Barbara Willaarts, Simon Langan, and Keywan Riahi.

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