One Earth
Perspective

Co-designing Indus Water-Energy-Land Futures

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The Indus River Basin covers an area of around 1 million square kilometers and connects four countries: Afghanistan, China, India, and Pakistan. More than 300 million people depend to some extent on the basin's water, yet a growing population, increasing food and energy demands, climate change, and shifting monsoon patterns are exerting increasing pressure. Under these pressures, a "business as usual" (BAU) approach is no longer sustainable, and decision makers and wider stakeholders are calling for more integrated and inclusive development pathways that are in line with achieving the UN Sustainable Development Goals. Here, we propose an integrated nexus modeling framework co-designed with regional stakeholders from the four riparian countries of the Indus River Basin and discuss challenges and opportunities for developing transformation pathways for the basin's future.

Introduction

The mid-21st century will see the global population increase from 7.7 billion in 2019 to 8.5–10 billion in 2050.[1,2] Scientific evidence increasingly indicates that humanity has already reached or even exceeded the carrying capacity of several of the Earth's ecosystems[3] and that future populations will face a range of climatic hazards, including notable global "hotspots" exposed to varying levels of risks.[4–6] The magnitudes of such risks are critically dependent on regional adaptive capacity to prepare for and manage changing risks.[7] Growing needs for food, energy, and water will only exacerbate existing socio-economic challenges.[8–10] The world's poorest and most vulnerable are disproportionately exposed to climate change[11,12] and hydro-climatic variability.[13–17]

Improving and sustaining human welfare is not an easy task, particularly in regions expected to see continued population and economic growth in the future. Looking ahead to 2050, 50% more food production will be required globally (a larger increase is expected in developing countries[18,19]), and electricity generation is expected to double as we achieve universal access to energy.[20] With increasing energy and food demands on top of population growth, water demands will also rise by more than 50%, particularly in developing countries.[17,21] Greater land, energy, and water resource demands pose growing concerns given that such resource pressures have historically acted as conflict multipliers and have occasionally lead to social unrest. Transboundary river basins have often been at the center of such conflicts.[22] Given these alarming projections, a "business as usual" (BAU) development pathway is no longer seen as acceptable. Decision makers and wider stakeholders are increasingly calling for new, more integrated, and inclusive development pathways that avoid dangerous interference with the local environment and global planetary boundaries. These urgent calls are also embodied in global policy frameworks such as the United Nations' 17 Sustainable Development Goals (SDGs).

The Indus River Basin (hereafter referred to as the Indus) covers an area of around 1 million square kilometers and connects four countries: Afghanistan, China, India, and Pakistan. It is home to more than 300 million people, who depend upon the basin's resources for water, food, and energy needs. The Indus is particularly critical to Pakistan's 160 million people because its waters are critical for irrigating 80% of Pakistan's 21.5 million ha of agricultural land,[23,24] and water flowing from Indus tributaries also support intensifying agricultural irrigation over North West India.[25] The Indus is also known as an area rich in biodiversity, particularly where it opens to the Arabian Sea,[26] and the river delta is a critical area for freshwater fauna and serves as a habitat for water birds.[27] With a rapidly growing population, an increasingly unpredictable monsoon-dominated climate yielding highly seasonal river flows dominated between May and September (>80%), and aridity levels 30% higher than those in the nearby Ganges river basin, the rising demands on the Indus' resources[28–30] are an increasing concern. Management and transboundary negotiations of these vital resources are further exacerbated by political tensions across its four riparian nations (Afghanistan, China, India, and Pakistan). At present, the Indus Waters Treaty, brokered by the World Bank in 1960,[31] is the mechanism that effectively allocates Indus waters to India and Pakistan. This treaty is considered to be one of the most successful water-sharing mechanisms in that it has settled many disputes via legal procedures within its framework. However, recent political tensions between India and Pakistan call into question the effectiveness of future dialog.[32] Intensifying climate change and emerging resource constraints pose new concerns to the treaty, which could require modernization of its provisions subject to the agreement of relevant stakeholders.

The existing studies of water, food, and energy nexus issues in the Indus fall short of providing a workable blueprint for a sustainable transition in the region. Their analytical scope is often narrower and sectorally focused on a single issue, such as water resource management, where inter-linkages are overlooked.[33,34] These studies are often focused on analytical and descriptive aims to identify resource constrains and implications, whereas less attention is given to the potential solutions that could be adapted to foster a sustainable transition.[35] In addition, given the deficiency in existing monitoring and information systems of the Indus, these studies tend to rely on global projections such as shared-socioeconomic pathways (SSPs), which lack important regional contexts such as political economy consideration.[36] As a consequence, local water-planning strategy is not understood given that an integrated system of food, energy, and water resources and drivers such as climate change, population growth, and technological development are not properly considered.[37] These planning efforts are also made difficult by complex water, energy, and land resource demands under the aforementioned political tensions among the riparian countries.[38]

Here, we propose a new approach—a framework, co-designed with stakeholders from each of the Indus states, that considers water, energy, and food resource assessments, bottom-up solution-focused scenarios, and integrated modeling—and discuss its potential to act as a model for implementing sustainable transformative solutions in transboundary river basins.

Co-designing with Indus Stakeholders

The Integrated Solutions for Water, Energy, and Land (ISWEL) project is a partnership between the International Institute for Applied Systems Analysis, Global Environment Facility, and United Nations Industrial Development Organization and aims to build an integrated framework of food, energy, and water resource assessment incorporating bottom-up and solution-focused scenarios co-designed with regional stakeholders from the four riparian countries. The stakeholder consultation period consisted of three meetings, and the number of bi-lateral and informal meetings took place between 2016 and 2019. The first stakeholder consultation in the Indus consisted of two national meetings in Delhi (India) and Lahore (Pakistan) in March 2018. The purpose of this initial consultation was to gain an understanding of the main sectoral and nexus challenges that the Indus is facing from the individual countries' perspective and to identify priority needs. These meetings were followed by a second round of consultation, which took place in Vienna (Austria) in May 2018 as part of the Third Indus Basin Knowledge Forum, in which representatives of all four riparian countries participated. The main outcomes included joint visions and the development of alternative pathways to meet the development challenges. The third meeting was in the form of a validation workshop, which took place in Kathmandu (Nepal) in August 2019 and was intended to substantiate the quantitative scenarios that were built on the basis of the narratives developed in the previous rounds.

A myriad of methods are available for stakeholder engagement in complex policy domains,[39–43] yet expanding these practices to an integrated assessment of nexus issues raises new challenges. Nexus framing significantly expands the stakeholder landscape to multiple policy arenas that are otherwise analyzed separately; past experience of the science-policy interface of complex resource-management issues, such as the Integrated Water Resource Management efforts, shows that in addition to uncertainty and surprises that are hard to discern in natural systems, political, economic, cultural, and institutional barriers also hinder a successful implementation of integrated policies.[44,45] Furthermore, given that underlying concepts and assessment tools for nexus issues are also relatively less developed, science and policy discussions will be more unfamiliar and uncertain for participating stakeholders who naturally think more squarely on cross-sector issues. The stakeholder engagement methods and analytical framework developed in the ISWEL project hence incorporate the notion of *knowledge brokering*—beyond informing and consulting decision makers and wider stakeholders, these iterative rounds of stakeholder consultation and integrated modeling assessment are aimed at engagement, collaboration, and capacity building of both researchers and end users of information.[46] Well-designed and implemented stakeholder engagement also creates greater ownership and use of project outputs, as well as greater understanding and capacity that allows for their effective uptake.

Complex Crossroads of Climate, Environments, and Policy

From the country- and basin-level consultations, stakeholders indicated a number of cross-sectoral and transboundary challenges. One of the most frequently mentioned was water-security concerns linked to rising food demands.[47,48] Agriculture, followed by municipal and industrial water supply across the basin, is by far the largest water consumer. Afghanistan's and Pakistan's economies are heavily dependent on agriculture, and this translates into the provision of allocation priorities being given to irrigation over other sectors.[34] This prioritization causes many disputes and results in inefficient hydropower management in countries such as Pakistan.[49] Nevertheless, as stated by the stakeholders, there is ample room to improve agricultural water management (through investing in new and upgraded irrigation infrastructure, increasing agricultural productivity, improving crop choices, and developing technical capacities of farmers).[50,51]

The impact of energy-related water demands and climatic changes to surface-water demand is also frequently mentioned. Afghanistan and Pakistan heavily rely on surface water (over 85% and 65%, respectively, of total abstractions), whereas in India the share is more even (52% of abstractions are derived from surface waters, and 34% are derived from groundwater).[52] All basin countries are focused on developing hydropower in the upper Indus, and climate change is expected to alter river flows originating in the Tibetan Plateau, including the upper Indus, with dwindling glaciers.[53,54] The entire Indus is characterized by changing and highly seasonal river flows such that 85% of the annual water flows are concentrated in the summer and only 15% are concentrated during the winter under changing climate, which most likely affects hydropower potential.[55] Pakistan is highly dependent on surface water flows coming from India, and its representatives were concerned by how these developments would affect the quantity and timing of water flowing into their country; glacier-fed river flows might start decreasing later this century given shrinking glaciers.[56] On the basis of the Indus Water Treaty, India is exploiting the hydropower potential of the Indus tributaries, all of which flow into Pakistan.[57] In particular, five projects (Miyar Nallah, Lower Kalnai, Pakal Dul, Kishenganga, and Ratle) are under construction, over which Pakistan has raised objections given that these could affect the flow regime of the Chenab and Jhelum river flows, from where Pakistan receives most of its surface water, whereas India has reiterated that its actions are not violative of the treaty or international norms. Likewise, much of the water flow coming into Pakistan is already allocated, which raises heightened concerns of water security. Pakistan also plans to develop its energy sector; hydropower is one preferred option, but it will require multipurpose strategies to avoid competition with priority uses (such as irrigation).[58] This requires optimal infrastructure to secure the availability of resources throughout the year, and this is yet insufficient in countries such as Pakistan, which has storage capacity of only up to 30 days (equivalent to 13% of annual flows).[59] In Pakistan, 45% of the annual flows come from snow and glacial ice melt,[60,61] and although uncertain, climate-change projections indicate an increase in the annual water flow in the near term (as a result of glacier melting) but a sharp decrease in the medium run, which will heavily affect water availability in the country.[62–65]

Furthermore, regional stakeholders also recognize the imminent threat to groundwater sustainability and its link to energy-related issues. Indian and Pakistani energy subsidies with large uncertainty in surface-water availability, for example, have contributed to unsustainable groundwater pumping.[66–69] The majority of water from the Indus is allocated to irrigation, and inefficient irrigation and a lack of drainage systems cause problems with soil salinization and waterlogging, undermining the agricultural productivity.[70,71] Most irrigated water is allocated to produce crops of low economic and nutritional value,[72] and the prioritization of water for irrigation is causing water conflicts with other users (e.g., urban, energy, and industry).[35] Access to clean, reliable, and modern sources of energy is a persistent gap in some of the riparian countries given that large parts of the populations, especially in rural areas, still rely on the use of biomass (fuelwood, animal dung, charcoal, and crop residues), which is causing soil degradation (the removal of animal dung and crop residues reduces soil capacity to restore and maintain its fertility), air pollution (both indoor and wide air pollution), and increased carbon emissions.[73]

The Indus Water Treaty is a bilateral treaty between India and Pakistan and defines the rules under which both countries can use and manage flows of the Indus.[74,75] This treaty, however, does not reflect all of the main and future challenges—such as climate change, population growth, environmental flow needs, transboundary aquifer management, and growing water needs from Afghanistan and China.[32,76] Some stakeholders highlighted the need to shift the focus of the treaty from allocation of flows to relocation toward actual demands and future consumption. However, other stakeholders noted that the same might not be implementable in practice and recommended against tampering with a treaty that was painstakingly drafted and has stood the test of time. As indicated in the workshops, using a benefit-sharing approach rather than an engineering river-dividing approach to water management between the two countries under the Indus Water Treaty could be considered as a way to deliver mutual benefits.[77,78] However, this is one view among many across different basin stakeholders. Many of the problems around water management in the Indus are related to the political tensions between India and Pakistan, and addressing them is critical given that 80% of the water flows in Pakistan are coming from India,[79] whereas the remaining 20% inflow from the Kabul river. Importantly, disputes over water are not only on the transboundary setting but also at the provincial level within both India and Pakistan.[80] In addition, water demands for agriculture and energy are also growing rapidly in Afghanistan and China, which poses a new challenge to the existing framework of the Indus Water Treaty.

Visions and Pathways to a Desirable Indus Future

Identifying pathways for the sustainable use of water, energy, and land resources (maximizing co-benefits while reducing sectoral trade-offs) is a complex task because different stakeholders have different values and priorities, resulting in multiple pathways, as indicated above. Moreover, multiple drivers at different scales ranging from local to global (e.g., climate change, political instability, population growth, migration, and socio-economic development) shape the development of basin pathways. Accordingly, we adopted a multi-scale approach to our participatory scenario design process. The "sphere of influence" as depicted in Figure 1 signifies that priorities and choices made by decision makers within the basin (at regional, national, and sub-national levels) largely determine preferred pathways to achieving water, energy, and land SDGs in the Indus. Yet such decisions of course are not immune to important global developments and the potential for external shocks. Hence, the "sphere of uncertainty" (Figure 1) adds significant challenges to the local planning process in the medium to long term.

On the basis of this conceptual framing, the ISWEL participatory scenario process identified and evaluated information in

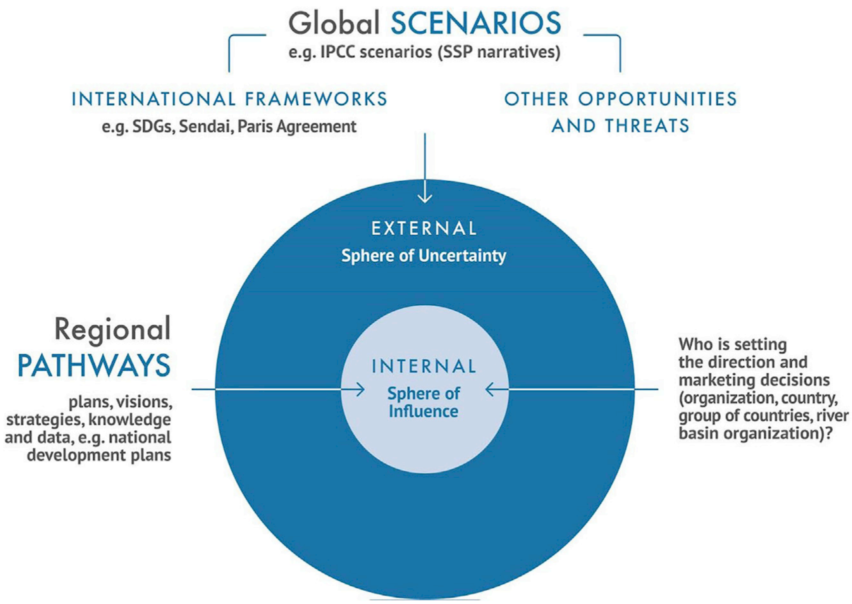

Figure 1. The Logic of Scenarios
Separating the sphere of uncertainty from the sphere of influence. Reproduced from the ISWEL progress report.[81] Summary videos for the co-design workshop with stakeholders are available at https://www.iiasa.ac.at/web/home/research/iswel/Outcomes.html.

two spheres: (1) aspirational targets regarding water, energy, and land; overall development goals for a basin in 2050; and solutions and trade-offs associated with alternative pathways to achieving these targets; and (2) whether these basin pathways are robust enough in light of different global and regional scenarios. In order to facilitate the identification of key narratives on water, energy, and food nexus issues, the team used the existing stakeholder-developed regional scenarios for South Asia[82] as a basis to design facilitation materials. The South Asia regional scenario defined stakeholder visions of the world in 2050, expressed narratives, and semi-quantified indicators of human capital; governance and institutions; science, technology, and innovation; political stability and conflict; economic structure; and demographics similar to the SSP scenario framework.[83–85] The information collected from the stakeholders also helped improve the portfolio of solution options that integrated assessment models subsequently simulated. The ISWEL scenario process included 24 participants from all four riparian countries and representing national and provincial decision makers, including governments, NGOs, academia, and policy think tanks.

From Visions and Pathways to Quantitative Scenarios

Börjeson et al.[86] provide a typology of scenarios based on the three principal questions that a user might inquire 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?" These are the so-called explorative scenarios, which are useful in situations of significant uncertainty—creative thinking and "out of the box" approaches are then needed for imagining possible "game changers" or "black swans." (3) "How can we get there?" These are the so-called normative scenarios, intended to support the achievement of certain visions. These visions specify which targets should be achieved, which outcomes should be avoided, or which impacts should be reduced.

For basin planning, the third type of normative approaches is often the most relevant to stakeholders because it allows for the exploration of preferred futures that articulate conflicting or shared values of diverse stakeholders and thereby help identify courses of action that can be taken to achieve alternative societal goals.[87] The ISWEL scenario-planning process hence adopted the normative approach to construct the stakeholder-led narratives, including visions and pathways. At the same time, the team also recognizes that the integrated modeling practice is firmly embedded by the IPCC framework with the underlying representative concentration pathways and SSPs and that the use of the IPCC scenario framework ensures a certain degree of comparability (and indicates which body of previous analytical results to build from) that is essential to making a systematic and reliable accumulation of scientific knowledge that can be translated into policy recommendations.

The ISWEL scenario approach hence reconciled these dual needs for consistency and contextualization, as depicted in Figures 2 and 3. The participatory scenario development and integrated assessment modeling are conceived as an iterative process in which visual aids (such as maps, cards representing investment options, and important drivers of change) are used to facilitate improved linking of the narrative formation process and subsequent modeling assessment (Figure 2). Scenario-building facilitation processes are carefully crafted so as to (1) provide transparency to stakeholders with regard to what inputs (e.g., challenges and solutions) can be included in the scenario narratives 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.

More specifically, as shown in Figure 3, we integrated the standardized IPCC scenario narratives (SSP 2: Middle of the Road) as the BAU regional pathway, and stakeholders also articulated the "what-if" normative policy pathways on the basis of the three alternative prioritizations of economy, society, and environment domains as desired futures (Figure 3).

Indus Water-Energy-Land Nexus Scenarios

The stakeholders' visions and pathway narratives were translated into quantitative scenarios that were then analyzed with our nexus modeling framework.[88] At the time of writing, the development of the nexus modeling framework is still ongoing, and local research partners are planning to implement the modeling framework across the Indus. Figure 4 shows an illustrated example of an integrated assessment in which new

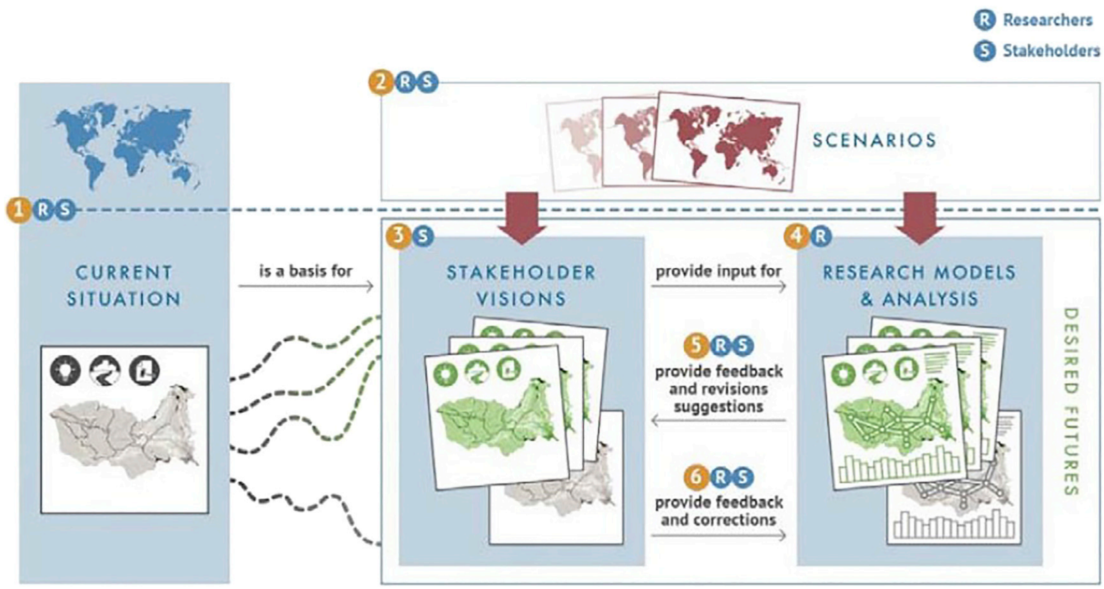

Figure 2. Summary of the Process Describing the Development of the Basin Scenarios
Reproduced form the ISWEL progress report.[81]

investment costs were estimated under the BAU scenario (corresponding to SSP 2) and an alternative sustainability scenario, based on stakeholder inputs, that can achieve multiple SDG targets, namely food (SDG 2), water (SDG 6), and energy (SDG 7). This illustrative example shows that planned investment under the BAU scenario is concentrated in the water sector (and to a lesser extent the energy grid). With limited investment in improving agricultural water use and renewable-energy development, the region would most likely face difficulties in achieving multiple SDG targets and the ever-growing water demands for irrigation.[89] Under the sustainability scenario, the region will see higher and more balanced investment to achieve multiple SDG targets; in particular, a large part of the new investments will be used for technology development to meet targets related to wastewater treatment and the sharing of renewable energy.

As this example shows, the analytical linkages between water and other sectoral models, such as agriculture and energy models, are critical to providing effective insights to uncover trade-offs and synergies. This is largely driven by the fact that improvements to agricultural productivity, for example, are closely intertwined with the development of irrigation.[90] Such an expansion is also considered an adaptation option in the face of climate change and is expected to strongly affect rain-fed agriculture given the limited land available under urban expansion.

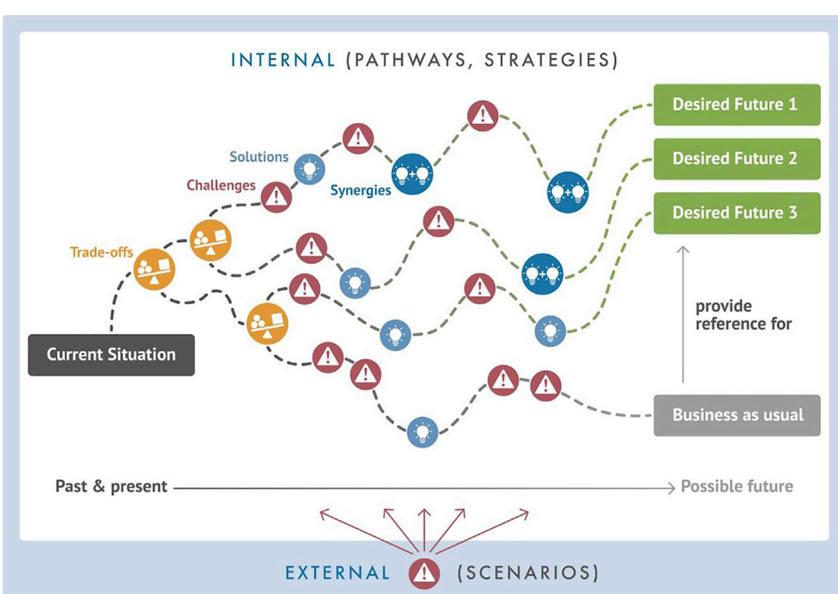

Figure 3. Example of Three Desired Regional Future Scenarios
Reproduced from ISWEL progress report.[81]

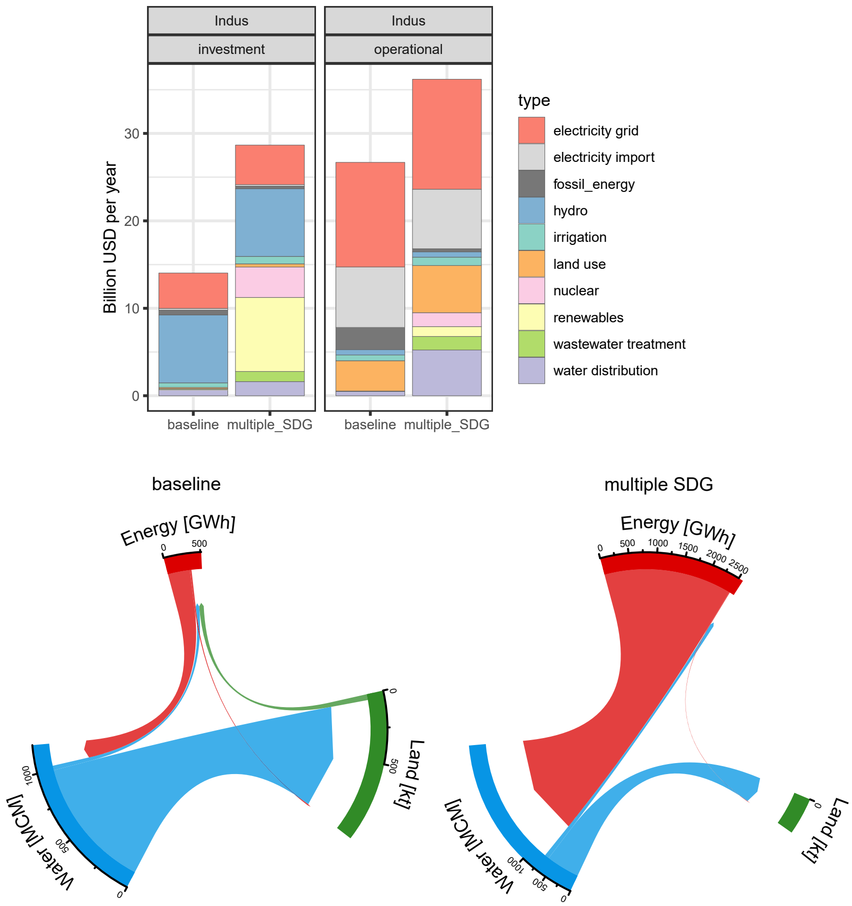

Figure 4. Modeled Outcome of Average Yearly New Investment Costs and Operational Costs

Modeled in a BAU or baseline scenario and a multiple-objective (water, energy, and land) sustainable scenario (top), as well as changes in total flow dependency among the different sectors in the two different scenarios (bottom) for the Indus.[88] Nexus flows (bottom) among energy, land, and water depict interactions such as electricity consumed for water technologies and for land management, water used in the energy sector or for irrigation, and amounts of crop residues converted to biomass.

However, although irrigation could help to achieve some key targets (SDGs 2 and 15), its increasing role challenges water availability (SDG 6), especially in the already water-stressed regions of the Indus. The water necessary for sustaining the environment (i.e., environmental-flow requirements) can be either protected (i.e., agriculture expands below sustainability thresholds) or unprotected (i.e., agriculture expands beyond sustainability thresholds). To estimate the potential environmental consequences of irrigation expansion, we calculate the unsustainable share of the total irrigation water demand, equivalent to the quantity of demand that exceeds the water flows necessary for the environment. Figure 5 compares the current and estimated future surface-water inflows against total water withdrawals in the basin. In the coming decades, withdrawals under current agriculture practice (i.e., BAU) and other water use will exceed the available surface water, compromising necessary water flows for the environment. In addition, water pollution from chemical fertilizers and quality issues such as high salinity will further exacerbate water scarcity in the Indus.

Finally, land and energy interlinkages are also crucial for the Indus region for a number of reasons. Bioenergy expansion, for example, is considered in the region as a key policy for climate-change mitigation. A growing demand for biomass for use in the energy sector will most likely reduce land that is available for competing uses, such as food production and nature conversation. An optimal energy mix, in turn, also depends on the quantity and price of available biomass together with the emission reduction potentials from the land-use sector. Changes in energy price will likewise affect the agricultural sector because energy is an important input in agricultural production. In India, groundwater irrigation has been largely supported by electricity subsidies in order to increase agricultural yields, lower food prices, and sustain the demand for agricultural labor. Energy is used directly (e.g., for field operations, irrigation, and drying) as well as to produce many important inputs used in agriculture, such as synthetic fertilizers and other agrochemicals, machinery, and seeds. Energy prices will increase with stringent climate policy (e.g., a carbon tax on fossil energy), and changes in energy prices are likely to have impacts on agricultural production costs and eventually on food (and biomass) prices.

Another key question that benefits from integrative analysis is how costs and technology diffusion for desalinated and wastewater-recycled water will evolve in water-scarce regions, therefore defining the supply of these nonconventional sources of water. Technology implementation such as thermal and membrane desalination, urban and manufacturing wastewater treatment, distribution and recycling, rainwater harvesting, smart irrigation technology, and rural water distribution yields co-benefits of sustainable consumption and production, such as minimizing the cost of achieving both clean water and energy goals. However, it is important to note here that social and cultural elements play an important role toward such technology dissemination given that wastewater treatment and sanitation are not new challenges (e.g., there are water, sanitation, and hygiene [WASH] projects in over 100 countries worldwide). Finally, in order to test the robustness of the chosen regional solutions, the model assessment can also be repeated under alternative external circumstances (i.e., scenarios of global shocks, such as price hikes and sudden economic downturns or alternative socioeconomic developments). Although a sustainability scenario (consistent with SSP 1) is often desirable, strategies designed by stakeholders should also be robust to unfavorable external conditions, and the

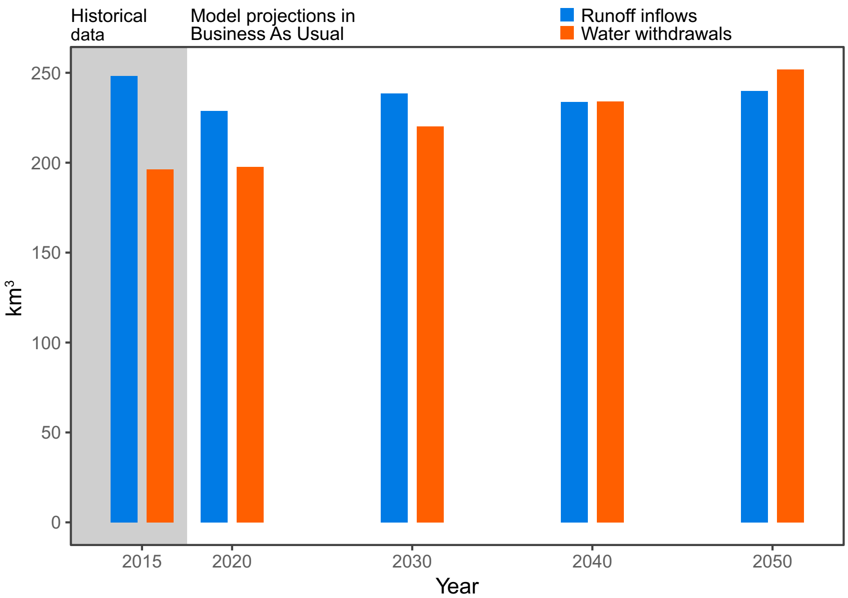

Figure 5. Historical and Model-Estimated Projections of Yearly Total Runoff Inflows and Total Water Withdrawals for the Indus Basin under the BAU Scenario

Based on agriculture, industry, and households for the Indus. Evaporation losses and fossil groundwater reserves are not considered.

implications that alternative global socioeconomic developments might have (on the basis of SSPs 2–5) on regional pathways should be evaluated carefully, and desired pathways co-designed by stakeholders and researchers can be revised to improve their feasibility and robustness through iterative interactions.

Nexus Modeling, Knowledge Sharing, and Capacity Building

Global and regional efforts to foster integrated policymaking for resource management has made mixed progress over the past few decades.[91] The renewed interest in the notion of water, food, and energy nexus opens up new opportunities for transdisciplinary collaboration. Yet, more efforts are certainly needed to enhance the conceptual bases for nexus framing, to clarify the most crucial sectors, to identify ways of linking science and policy domains, and to design appropriate and effective modeling and stakeholder-engagement processes. Such endeavors will require a greater scope of disciplinary inputs: in addition to the conventional mix of biophysical, engineering, and economic disciplines that are included in the integrated modeling efforts, a wider involvement of fields such as history, political science, anthropology, social psychology, and other disciplines will be key to bridging analytical gaps.[92] Global scientific discussions are ripe to integrate human behavior and governance into integrated assessment models,[93] but equally important are efforts to bring integrated assessment models (or model-based thinking) successfully into the day-to-day policy discussions and planning efforts. The ISWEL scenario co-design and integrated assessment modeling described here is our humble step in this direction. More than 50 participants from the four riparian countries participated in the ISWEL project, representing 32 different organizations within academia, regional and federal governments, think tanks, and non-governmental organizations. Tangible outputs of this project included three shared visions articulated for the Indus and quantitative analysis of resource-management options through integrated assessment modeling. In fact, more important than these are the intangible outcomes we hope to achieve—a greater emphasis on systems thinking in policy discussions and a network of like-minded researchers and practitioners committed to bringing changes to the region beyond the political, national, disciplinary, and sectoral divides.

We advocate that this framework can be extended to other transboundary river basins experiencing similar pressures. The ISWEL project is planning to implement the approach described here to the Zambezi basin in Africa, which shares a number of biophysical, socioeconomic, and governance similarities with the Indus. In order to fill the knowledge gap between global and regional narratives and scenarios to capture stakeholder needs and ambitions, a series of stakeholder workshop are again deemed necessary. The ISWEL strategies for addressing water, land, and energy concerns at the basin scale envisage cooperation and sharing of expertise and resources among various stakeholders who would be involved in preparing an action plan locally to address the common concerns in the basin. Therefore, there is a dire need to take the initiative to the next level to strengthen the trust between the policy and decision makers of the riparian countries and encourage them to address other festering problems confronting the region.

Although the integrated nexus modeling framework and associated stakeholder engagements described here still require many improvements, they have provided important insights into complex environmental issues that seem to be previously untouched. The ISWEL project has also provided capacity building for young Indus talents and researchers who will play an important role in future policy development to address the needs of a growing population in a region of increasing and complex water, energy, and food pressures.

DATA AND CODE AVAILABILITY

The integrated nexus modeling framework and the code are available from Vinca et al.[88]

CONSORTIA

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AUTHOR CONTRIBUTIONS

The ISWEL Indus Basin Team led the study with substantial inputs from Indus stakeholders coordinated by B.A.W. The paper was conceived and written by Y.W. with input from all authors. A.V. and S. P. led the development of integrated nexus modeling framework for the Indus. B.A.W. and P.M. led the engagement with stakeholders in the Indus with support from all authors.

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