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Developing a Comprehensive Water-Energy Model for the Syr Darya River Basin Using WEAP and LEAP Modeling Software

NARRATIVE REPORT

CONTENTS

BACKGROUND

The USAID Regional Water and Vulnerable Environment Activity (hereafter, the Activity) is a five-year project that aims to strengthen water cooperation among Central Asian countries to increase stability, economic prosperity, and healthy ecosystems. The Activity is implemented by a Tetra Tech ARD Inc. branch in the Republic of Kazakhstan.

One of the objectives of the Activity is to facilitate and promote the Robust Decision Support (RDS) process among stakeholders at the level of the Syr Darya and Amu Darya River basins, which will support strategic planning and decision-making towards sustainable development of the region. The RDS process is accompanied by the development of an integrated water-energy-food-ecosystems (WEFE) and macroeconomic model for these basins and associated countries.

The modeling approach is to combine a water planning model, built with the Water Evaluation and Planning (WEAP) modeling platform, with an energy planning model, built with Low Emissions Analysis Platform (LEAP) and Next Energy Modeling system for Optimization (NEMO), and a macroeconomic model, Macro, which is designed to work with LEAP. The LEAP/NEMO, WEAP, and Macro models are run iteratively to convergence (see Figure 1).

The Stockholm Environment Institute in the USA (SEI) is the developer of these models and the main partner of the Activity to implement this task.

This report focuses on the results achieved for the Syr Darya River Basin modeling.

NOTE: *All the data used for the modeling is publicly open data from national agencies and international datasets. Scenarios were developed in consultation with national partners of the basin countries and may differ from current country/industry development trends. Numbers in modeling results may differ from the actual situation in the countries, but these results reflect development trends. The development of an integrated water-energy model by means of WEAP and LEAP modeling tools was carried out to demonstrate the benefits of using such tools in its integration to improve long-term and integrated planning.*

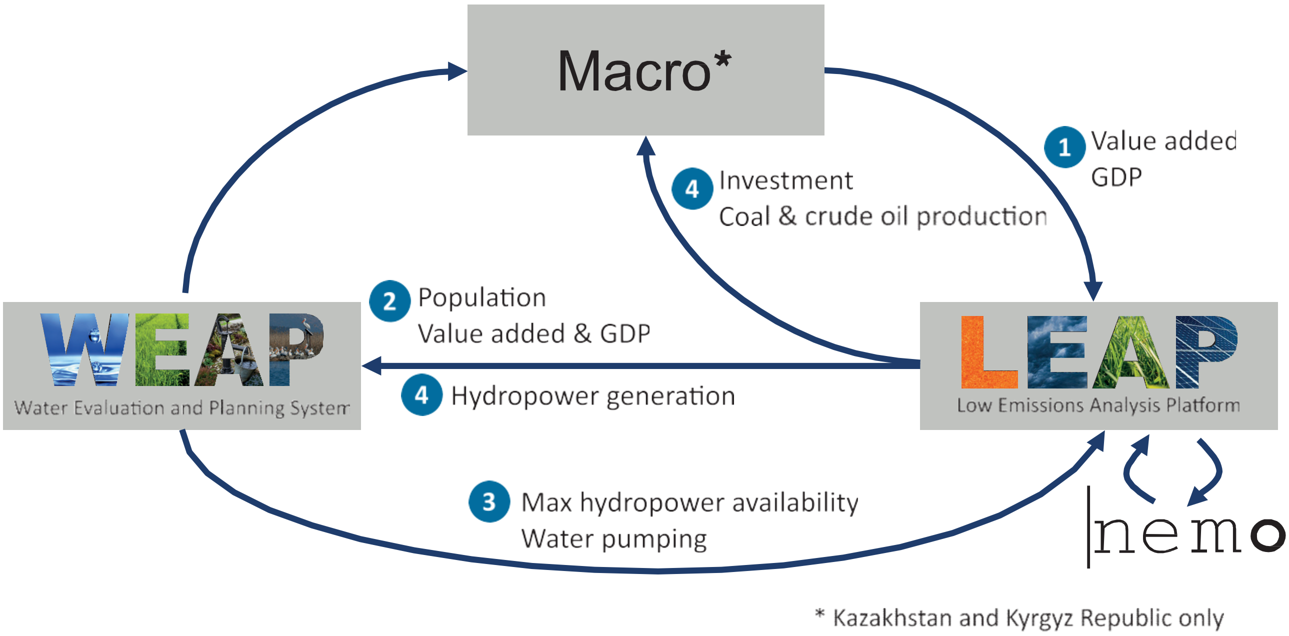

Figure 1: ***Iterative solution of LEAP, WEAP, and Macro: Models are run to convergence.***

I. ROBUST DECISION SUPPORT PROCESS

The RDS Process is based on a theoretical scheme for making decisions under uncertainty, which, in turn, arose out of the RAND (Research and Development Corporation) program for strategic decision-making under profound uncertainty.

The peculiarity of the RDS process is that traditional systems and approaches to decision-making do not take into account critical uncertainties such as climate change, demographic processes, economic development, etc., where there is no consensus on the probability of specific future changes.

The Activity applies the RDS process to the problem of water, food and energy planning in the face of climate change and other clear uncertainties in a way that directly meets the principle of integrated water resources management (IWRM), which is the need for joint planning of water resources in watersheds.

A key feature of applying the RDS process is recognizing and intentionally incorporating analysis of external factors such as climate change, as well as additional factors such as population growth and economic development,into the assessment of potential trade-offs and synergies associated with specific adaptation actions for water and energy management. Struggling with the uncertainties associated with these external factors, decision-makers engage in an iterative process to identify actions that can be taken at the Syr Darya and Amu Darya River basins scale to reduce the vulnerability and increase the resilience of their water and energy systems.

In general, the RDS process is presented below (Figure 2).

The main task of the RDS process under theActivity is to build capacity and involve stakeholders in the Syr Darya and Amu Darya river basins at all stages - starting from defining objectives, formulating problems, considering potential options for policy and engineering measures and infrastructure investments, as well as choosing specific socio-economic scenarios that would be of most interest to the countries of the region.This will contribute to a cross-sectoral understanding of the rational solutions that need to be taken to improve water, energy, food and environmental security in the region within the countries and regionally and, most important for the Activity – to understanding and recognition of benefits from using such a complex approach for better, well-informed and complex decision-making.

Within the Activity, the RDS was implemented through regional dialogue between the WEFE sectoral ministries – water, energy, environment, and agriculture, as well as ministries of foreign affairs, research and strategic institutions from all four Syr Darya basin countries – Kazakhstan, Kyrgyz Republic,Tajikistan and Uzbekistan.

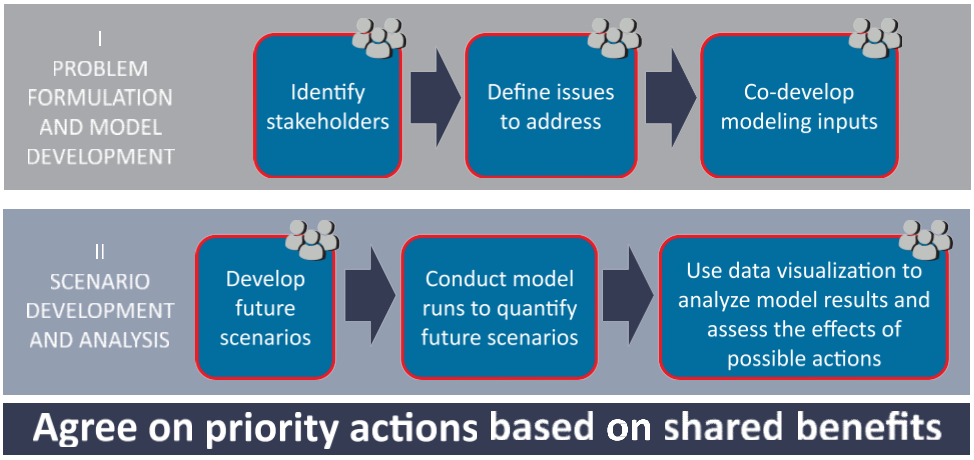

Figure 2: ***RDS process***

2. MODELING TOOLS

2.1. Water Evaluation and Planning (WEAP)

2.1.1. General overview

The WEAP software has been under development by Stockholm Environment Institute (SEI) for nearly 20 years.The software provides a comprehensive suite of tools for simulating water resources systems including rainfall-runoff hydrology, water resources infrastructure, agricultural, urban, and environmental demands, and the ability to apply complex operating rules and constraints to the water allocation problem. The water allocation problem is solved using linear programming (LP) defined by user-specified demand priorities and water supply preferences. The software is well-documented and has a well-developed training tutorial provided on the WEAP21 website. Comprehensive information on the software and download links are available at www.weap21.org.

2.1.2. WEAP scope and structure

WEAP allows for a fairly high level of disaggregation to describe water supplies and demands. In practice the data structure of the model is determined by the research or policy questions that are being addressed.This commonly starts with questions pertaining to how best to allocate water to competing users, which may include different water use sectors (i.e., domestic, municipal, industrial, agricultural, hydropower, environmental, etc.) as well as water users in different parts of the basin. Thus, the first level of data disaggregation determines which water use sectors should be included in the model. The next level of data disaggregation is to determine how each of these water use sectors should be spatially disaggregated.The spatial disaggregation is generally determined by water sources. For example, agricultural areas that divert water from the mainstem of a river may be considered separately from agricultural areas that divert water from a tributary flowing into the main river. Similarly, the domestic demands can be separated in a way that each take water from the same river, where downstream users are affected by the level of upstream abstraction.

These considerations are reflected in the data structure used to develop the national WEAP model for Syr Darya. For this model, the following water use sectors and associated demand drivers were considered:

- **Domestic:** population, per capita water use
- **Irrigated agriculture**: crop types, cropped areas
- **Industry**: production units, water use per unit
- **Hydropower**: electricity demands
- **Ecosystems:** based on ecosystem needs

These demands were defined for six demand regions within the Syr Darya. An example of how these demands are represented in WEAP for each demand region is shown in Figure 3 below, where red circles represent water demands, green circles represent sub-catchments, green squares represent groundwater, blue dotted lines represent rainfall runoff and groundwater recharge, blue solid lines represent rivers and streams, orange lines represent canals, green lines represent surface water diversions and/or groundwater pumping, and red lines represent return flows.

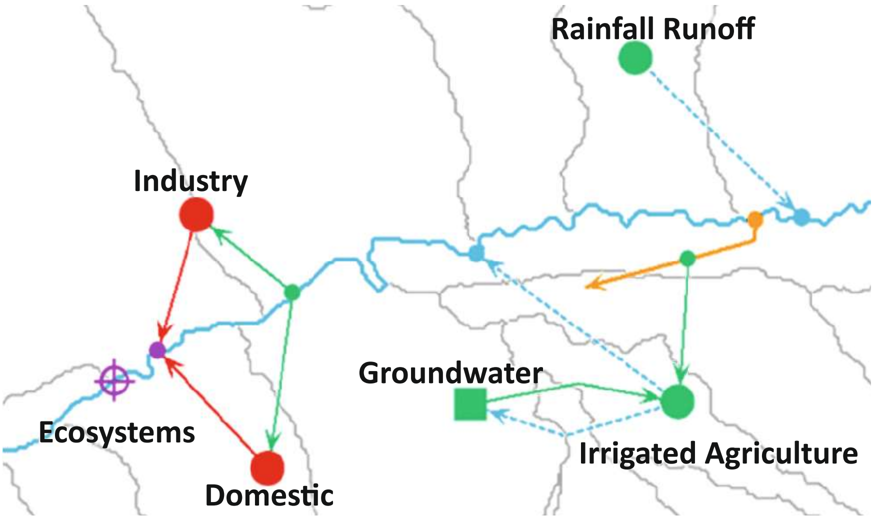

*Figure 3. **Representation of water demands in WEAP***

The spatial disaggregation of the basin into sub-catchments for the purpose of modelling basin hydrology followed a similar approach. For this, first the key locations were identified for which the river flows need to be estimated.These was primarily determined by existing and planned infrastructure, including dams and river abstraction locations, as well as the inflow locations of the main tributaries.This resulted in dividing the Syr Darya basin into fifteen sub-catchment areas, which are presented below in Figure 4.

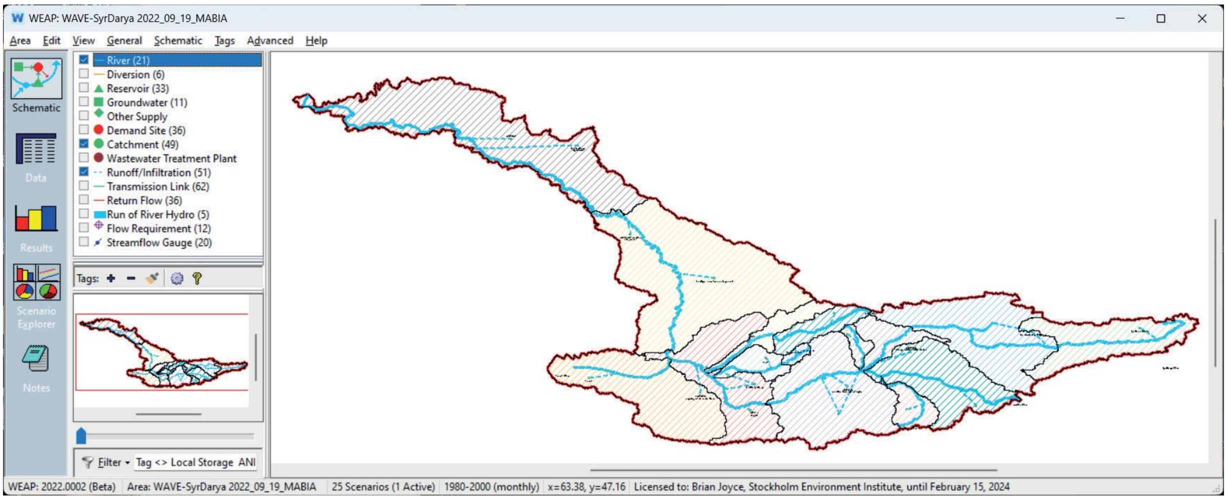

*Figure 4. **Spatial disaggregation of Syr Darya River basin into sub-catchments***

WEAP is a demand-driven model and, as such, provides a lot of flexibility in how data can be structured to characterize water use. This can range from highly disaggregated end-use oriented data structures to highly aggregate analyses. Typically, the data will be organized around water use sectors, including households, industry, and agriculture, each of which might be broken down into different subsectors, end-uses and water-using devices.The structure of the data can be adapted to different purposes, based on the availability of data, the types of analyses to be conducted, and preferences.WEAP also allows for the creation of different levels of disaggregation in each demand site and sector.

There are 19 water demand sites in theWEAP model for the Syr Darya River Basin.These water demand sites are disaggregated by sectors (domestic, industry, and agriculture) and countries (Kazakhstan, Uzbekistan, Kyrgyz Republic, and Tajikistan). Since key data on agriculture, population and industry is typically reported at the national and province levels, demand sites in WEAP were represented to closely resemble province boundaries. In some cases, data for different provinces was aggregated into one demand site in WEAP. This approach was also used by (Hunink, Lutz, and Droogers 2014) on a previous WEAP model for the region. The allocation of provinces to basins and WEAP demand sites was done based on the geographical location and information from CAWater-info.net, which reports water related statistics by country, province and basin. Water demand sites in WEAP are shown in Figure 5 and Table 1 below.

Table 1. ***Water demand sites***

Water demand	Kazakhstan (KAZ)	Uzbekistan (UZB)	Kyrgyzstan (KGZ)	Tajikistan (TJK)
Domestic (DOM)	▪ DOM_KAZ_Kyzylorda ▪ DOM_KAZ_Turkestan_Shymkent	▪ DOM_UZB_Andijan_Namangan_Fergana ▪ DOM_UZB_SyrDarya_Tashkent_Jizzakh	▪ DOM_KGZ_Naryn_JalalAbat_Osh_Batken	▪ DOM_TJK_Sogd
Industry (IND)	▪ IND_KAZ_Kyzylorda ▪ IND_KAZ_Turkestan_Shymkent	▪ IND_UZB_Andijan_Namangan_Fergana ▪ IND_UZB_SyrDarya_Tashkent_Jizzakh	▪ IND_KGZ_Naryn_JalalAbat_Osh_Batken	▪ IND_TJK_Sogd
Agriculture (AGR)	▪ AGR_KAZ_Kyzylorda ▪ AGR_KAZ_Turkestan_Shymkent	▪ AGR_UZB_Andijan_Namangan_Fergana ▪ AGR_UZB_SyrDarya_Tashkent_Jizzakh	▪ AGR_KGZ_Naryn_JalalAbat_Osh_Batken	▪ AGR_TJK_Sogd

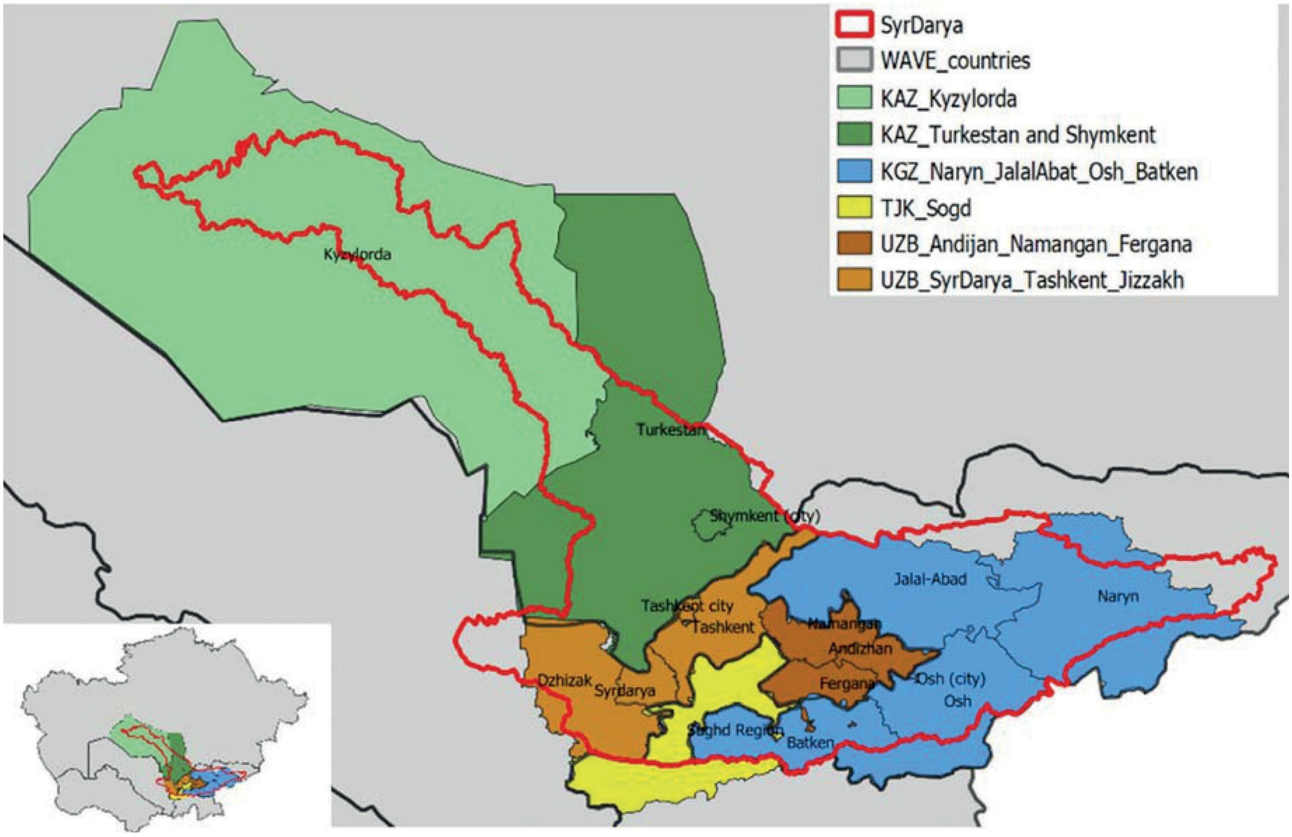

Figure 5. ***Division of provinces over WEAP demand sites***

2.2. Low Emissions Analysis Platform (half line space here)

2.2.1 General Overview

The model is built on the **Low Emissions Analysis Platform (LEAP)**, a software tool for modeling energy systems, pollutant emissions, sustainable development goals, and related externalities. LEAP is developed by SEI and is one of the most widely used energy system modeling tools in the world. The LEAP community of practice includes nearly 60,000 members[1], and dozens of countries rely on LEAP to produce energy strategies, climate change mitigation plans, low emission development plans, and similar policies. For example, 61 countries have used LEAP to prepare their Nationally Determined Contributions (NDCs) to the Paris Agreement.

LEAP, along with WEAP, is the most important element of the model's software platform. The model uses LEAP to simulate final energy demands, pollutant emissions, and most sources of energy supply. For electricity supply, however, an additional piece of software is involved: the **Next Energy Modeling system for Optimization (NEMO)**. NEMO is a high performance, open source energy system modeling tool also produced by SEI. It is designed to integrate with LEAP as a graphical user interface. The model uses NEMO to simulate electricity supply by least cost optimization. It is configured so users do not need to interact with NEMO directly; instead, LEAP runs NEMO when the model is calculated, and outputs from NEMO are shown in LEAP's results interface.

NEMO formulates an optimization problem for electricity supply that it then solves with a third-party solver program. NEMO is compatible with a variety of solvers, including open source and commercial/proprietary options. For the Syr Darya analysis, the SEI team used two solvers at different times – **Gurobi** and **HiGHS**. Gurobi is a commercial solver and generally requires a paid license, while HiGHS is open source and freely available. The team used HiGHS primarily when running the model in capacity building workshops with stakeholders. Gurobi was utilized when conducting integrated runs with the water and macroeconomic models, as its superior performance was an advantage in this context.

Each part of the model's software platform – LEAP, NEMO, and the solvers – has documentation online that describes its operation in detail. These resources are available at the following links:

- LEAP – https://leap.sei.org/
- NEMO – https://sei-international.github.io/NemoMod.jl/stable/
- Gurobi – https://www.gurobi.com/
- HiGHS – https://highs.dev/

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The model is a full energy system model for the countries of the Syr Darya Basin: Kazakhstan, Kyrgyz Republic, Tajikistan, and Uzbekistan. It simulates the production, consumption, and exchange of all energy carriers (fuels) in these countries, including fi energy demands[2], energy transformation activities and intermediate energy demands, primary energy extraction, and energy imports and exports. Each of the four Syr Darya countries is represented as a separate region in the model, and most energy demand and supply sources/activities are geographically aggregated at this level.An additional geographic distinction is used for agricultural energy demand, demand for water pumping, and hydropower, however. In these cases, the model distinguishes between demand or supply inside the Syr Darya Basin and outside the Basin.

The model covers years between 2010 and 2050. In general (but depending on the variable), results for 2010-2019 are based on historical data, and results in other years are projections. The default time step in the model is annual, and most energy demand, energy supply, and other results are calculated on an annual basis. Electricity is an exception: electricity demand and supply are modeled using 288 time slices per year, representing a typical 24-hour day in each month.

In addition to geography, the modeling of final energy demands is broken down by sector, subsector, and fuel. The following sectors are represented:

- Agriculture
- Commercial
- Industry
- Residential
- Transport

1 https://leap.sei.org/default.asp?action=stats.

2 Demands by energy end-users (i.e., users that are not energy producers).

The demand modeling also covers demand for international bunkers, energy inputs to non-energy processes (e.g., petrochemical feedstocks), statistical differences in energy balances, and other unclassified final energy demands.

Within each country, the supply side of the model is organized by energy-producing sector or industry, technology, and fuel. The main sectors are the following:

- Biomass production
- Blast furnaces
- Brown coal briquettes production
- Charcoal production
- Coal anthracite mines
- Coal bituminous mines
- Coal lignite mines
- Coke ovens
- Electricity production
- Hard coal briquettes production
- Heat production
- Natural gas production
- Oil production
- Oil refineries

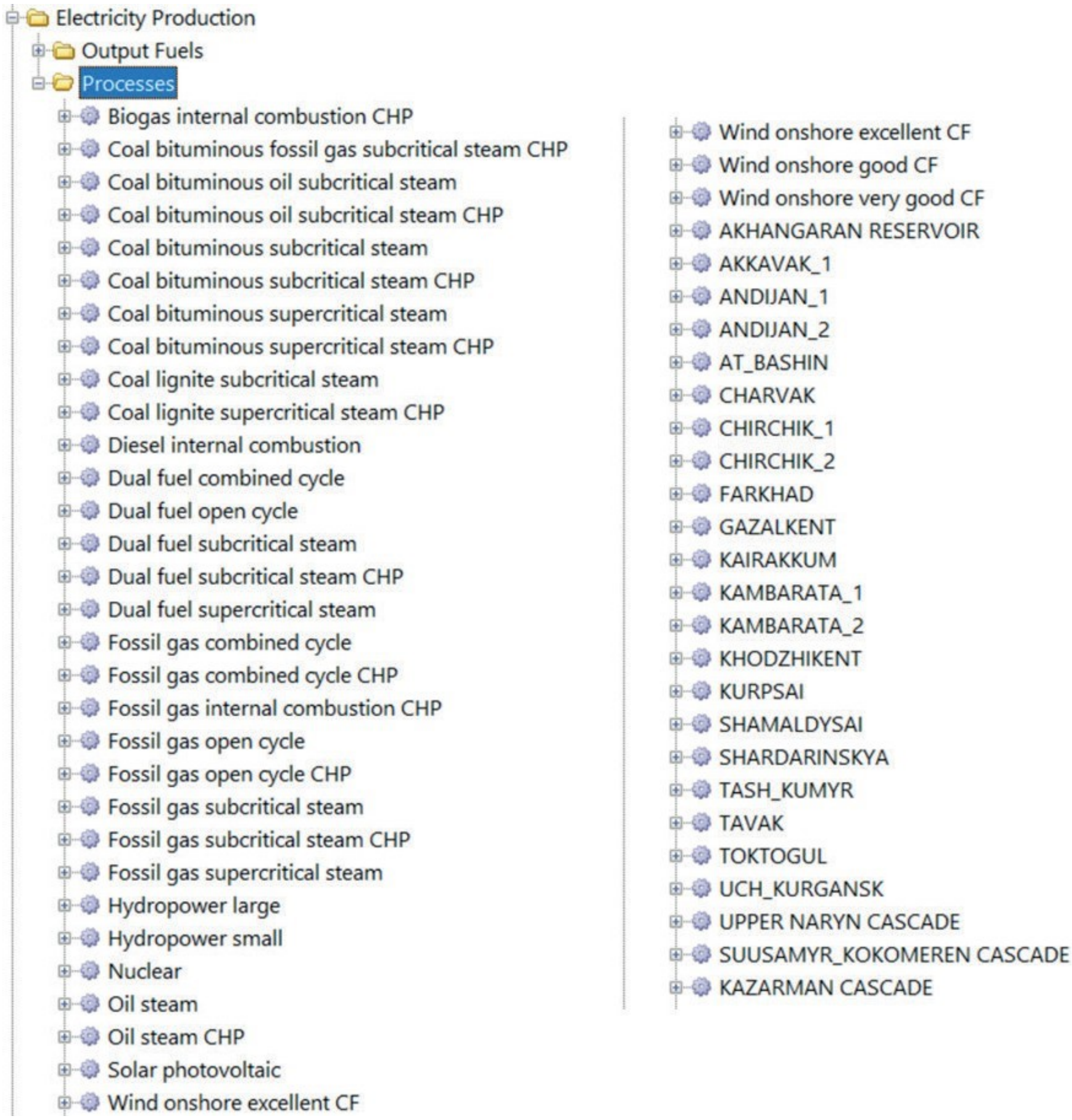


Figure 6: ***Structure of electricity production sector***

The supply model also represents changes in energy stocks or inventories; transfers of energy between supply sectors;own use by energy-producing industries;and losses of energy in transmission,distribution, and transport.

SEI paid particular attention to electricity supply when constructing the model due to this sector's importance in the Syr Darya Basin. Each existing, planned, or potential large hydropower facility in the Basin is separately represented in the model (24 in total). Other power production facilities are aggregated by technology; 33 such technologies are represented, including fossil fuel, nuclear, solar, wind, and biogas technologies. Figure 6, which is a screenshot from LEAP, shows the internal structure of electricity production sector in the model. The figure provides a full list of all power production facilities and technologies in the model, although it should be noted that LEAP hides facilities and technologies in regions where they are not used/do not exist.

The model tracks endowments of primary energy resources (both renewable and non-renewable) as well as energy imports and exports by fuel. LEAP uses this information when calculating energy balances in each modeled year.

In addition to energy consumption and production, the model quantifies emissions of major greenhouse gases from the energy system. These include carbon dioxide, methane, and nitrous.

2.3. Macro (macroeconomic model)

Macro is an open-source macroeconomic model. It is designed to be used with LEAP through the LEAP-Macro extension. It is thoroughly documented online;[3] the code is open-source and can be obtained through GitHub.[4]

Importantly, Macro is an economic simulation model, but it is not an economic planning model. Rather, the purpose of LEAP-Macro is to make internally consistent economic scenarios for LEAP. In a standard LEAP model, economic activity levels are specified externally (e.g., GDP and sector value added). But energy investment – calculated by LEAP – contributes to GDP. That creates a two-way link between the energy sector and the rest of the economy. In LEAP-Macro, economic activity levels are simulated, while energy investment contributes to aggregate demand. As illustrated schematically in Figure 6, in a standard application, LEAP and Macro are run iteratively until they converge. For the present project, LEAP, Macro, and WEAP are run iteratively as shown in Figure 7.

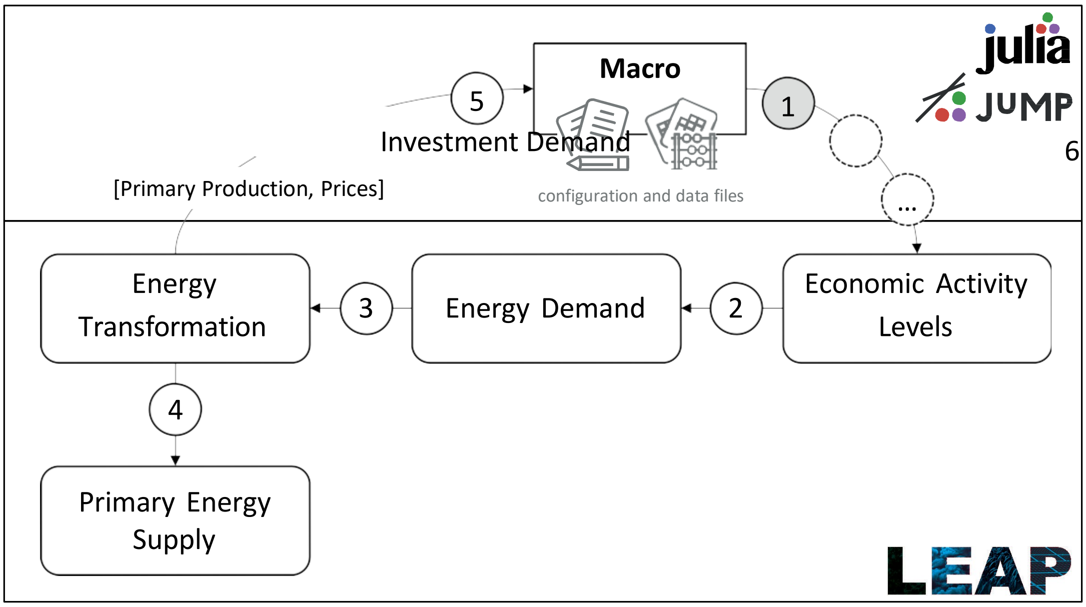


*Figure 7: **The LEAP-Macro link***

3 https://sei-international.github.io/LEAPMacro.jl/stable/
4 https://github.com/sei-international/LEAPMacro.jl

The Macro model is built upon a set of accounting relationships, which are initialized using national supply and use tables (see Figure 8). The model then simulates a sequence of dynamic interactions. Details are available in the online documentation. For the purposes of this report, the sequence can be summarized as: First, expected and historical demand, both domestic and export, drives investment; investment also depends on profitability, which depends on wages and prices for goods and services. Second, investment adds to total final demand. Third, demand for intermediate goods and services combines with final demand to yield domestic demand, which drives the economy forward.

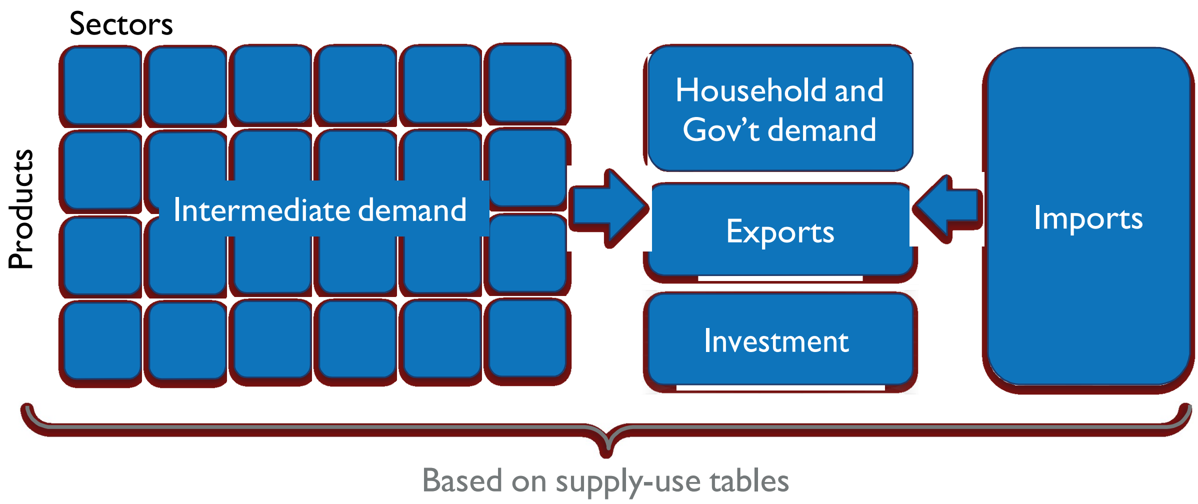


Figure 8: ***Structure of the underlying accounts in the Macro model***

Some further features of Macro that can be helpful when interpreting results include:

- Imports adjust to meet demand, but some goods are "non-tradeable". For those goods:
  - Investment demand is always met by sufficient supply (or the model reports that it cannot find a solution);
  - Export supply and supply to households and government might fall short of desired demands;
- Wages tend to rise with inflation, but they rise even faster when labor demand grows faster than the working-age population (and slower in the opposite case);
- Investment demand depends on the utilization rate of installed capital, the profitability of the sector, and a bank lending rate (which depends on inflation and the growth rate);
- Domestic prices are set based on costs, while foreign prices are specified externally: differences between domestic and foreign prices impact on exports and imports.

3. THE ACTIVITY'S APPROACH TO MODELING: COMBINING THE MODELS

Individually, both LEAP and WEAP can address basic aspects of water and energy planning. For example, LEAP can be used to model hydropower, but this system does not account for water scarcity or dry years as a possible challenge. WEAP, meanwhile, can calculate how hydropower potential might change under different water supply scenarios, but does not allow for the study of how hydropower fits into the overall energy system.

The modeling approach from the Activity side is to combine the water planning and management model (system) built with the WEAP modeling platform with the energy planning model (system) built with LEAP and NEMO, and the macroeconomic Macro model that is designed to work with LEAP. The LEAP/NEMO, WEAP, and Macro models are run iteratively until the results converge.

Thus, SEI has integrated these models so that they can complement each other. WEAP and LEAP can now exchange key modeling parameters and results, such as hydropower generation or water requirements for unit cooling, etc. Together, they can represent changes in conditions in both water and energy systems and allow for a more comprehensive water-energy model that considers different sectors of the economy simultaneously.

The iteration process was implemented in a custom Python script written by SEI. The script accepts a configuration file (provided in Annex 1 of this report) and reports progress in a log file (a sample is shown in Annex 4). Results are available for examination in the LEAP and WEAP platforms and, for Macro, in text files. The script follows these steps:

1. The script runs the Macro model, generating values for economic drivers (value added and GDP), which are passed to LEAP;
2. LEAP passes those drivers, with population, to WEAP (without calculating);
3. WEAP runs, generating results for water demand and supply:
    a. Hydropower availability, based on hydrology, is passed to LEAP;
    b. Crop production and industrial water availability is passed to Macro;
4. LEAP runs, generating results for the energy sector:
    a. Hydropower generation is passed to WEAP;

b. Power sector investment, as well as coal and crude oil production, are passed to Macro;

5. Macro runs, and the cycle continues from Step 1 until convergence: key results (particularly hydropower production) are compared from one run to the next, and if all are within a specified tolerance (assumed as 10%), then the process halts.

Overall, the integrated LEAP-Macro-WEAP model captures synergies between different sectors of the economy, both direct and indirect, as shown in Figure 9 below.

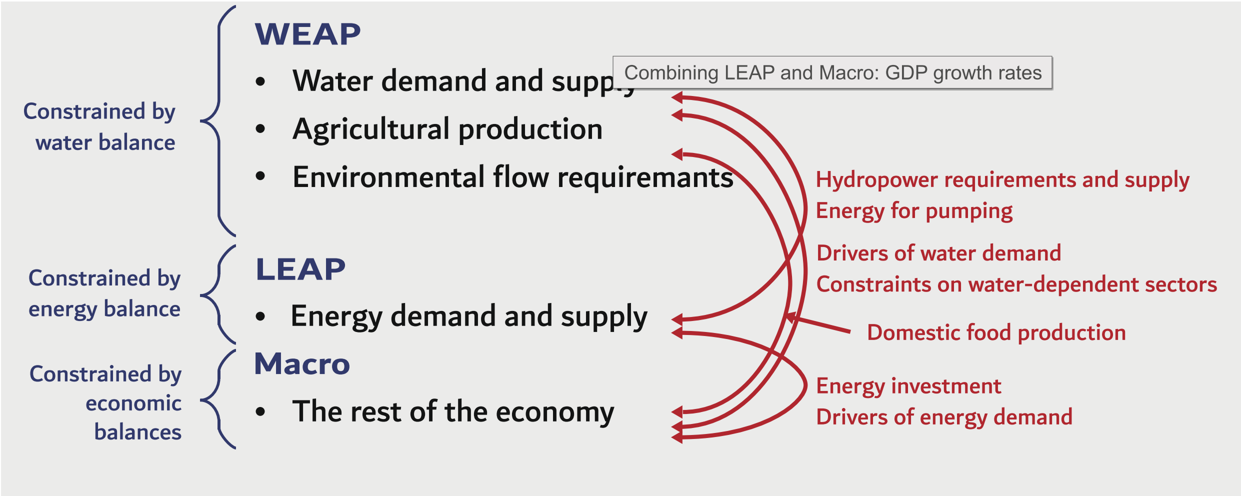


Figure 9. ***Interrelationships between sectors***

Using both systems together, decision-makers can now examine how individual water and/or energy management choices might affect other sectors of the economy. This allows the assessment of potential future scenarios and outcomes against current policies, goals, and objectives. If one approach leads to unacceptable outcomes, alternative scenarios, strategies and measures can be explored.

4. REGIONAL SCENARIOS IN WEAP AND LEAP MODELS

The RDS process starts prior to the modeling analysis,with a series of national and regional consultations with theWEFE-related ministries and agencies (water, energy, agriculture, environment, as well as foreign affairs and economy) and strategic and scientific-research institutes of the Syr Darya basin countries – Kazakhstan, Kyrgyz Republic, Tajikistan, and Uzbekistan.The main goal of those consultations was to identify key parameters, goals, data sources and, most importantly, to develop the regional scenarios (with the inclusion of national interests and priorities and different climate projections) for further analysis through the models. Further application of the siloed approach in modeling (separately WEAP or LEAP) and an integrated approach (WEAP-LEAP-Macro) demonstrated different results proving that an integrated understanding to planning brings more holistic and comprehensive results and should be used for overall sustainable development.

The regional consultations resulted in the development of six narratives for further modeling, presented below in Figure 10.

All six narratives were explored with the WEAP and LEAP models for the Syr Darya River Basin.These included a baseline narrative, representing current conditions and rules surrounding the management of water and energy resources within the basin, and five narratives that considered how resource management might change in the future. Following the baseline, we find three narratives (2, 3, and 4) that considered the national plans around water, agriculture, and energy while maintaining the status quo in how resources are shared between the basin countries. The final two narratives (numbered 5 and 6) considered how each country's targets relating to water, agriculture, and energy may change if resources are shared more readily between countries. The starting point of each narrative uses the narrative that precedes it, such that narrative 2 includes all of the modeling assumptions made in narrative 1, narrative 3 includes all of the modeling assumptions made in narrative 2, and so on.

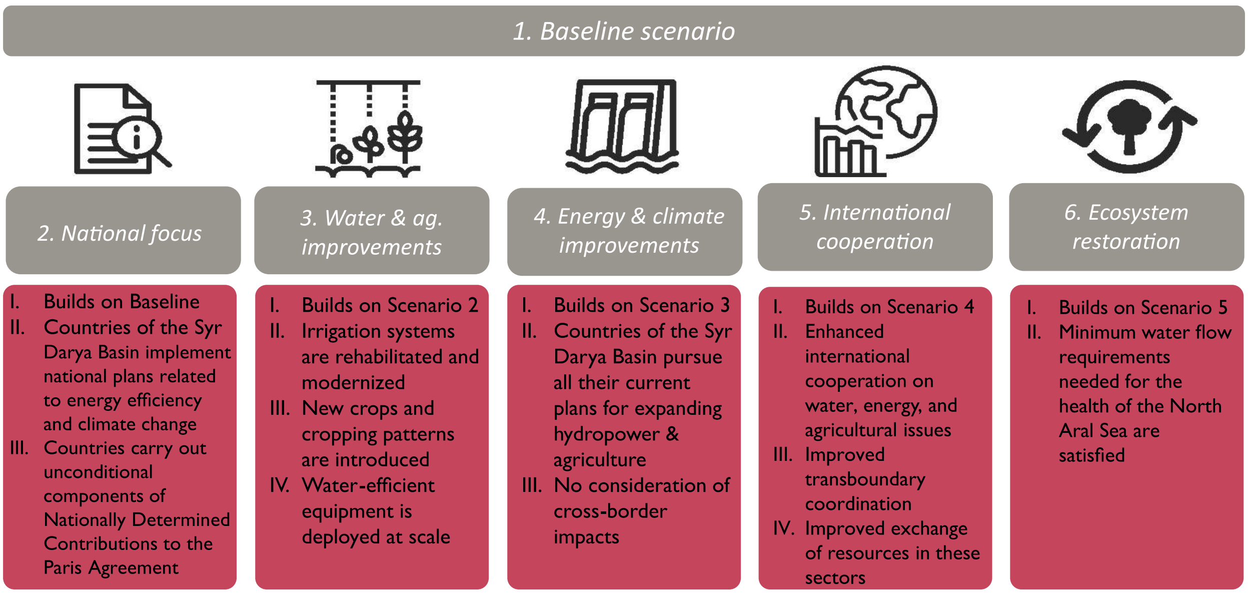


Figure 10. ***Regional narratives for the Syr Darya model***

The narratives include existing WEFE-related policies, strategies and plans of each country, as well as potential activities that are now under discussion and not put in force yet. Thus, the results of this modeling exercise cannot be used for actual decision making and promotion. The main goal of the modeling was to demonstrate the benefits of applying the complex WEFE approach towards decision-making and prove that complex results can bring to different actions in comparison with siloed approach.

2.4. WEAP-narratives implementation

The implementations of the six narratives in WEAP are summarized in Table 2. As shown in the table, some features were preserved from one narrative to the next. For example, ecosystems are given the lowest priority in narratives S1-S5, and only given the highest priority in narrative S6.

*Table 2: **Summary WEAP implementation of narratives***

Narrative	Hydropower	Agriculture	Water Allocation	Ecosystems
S1: Baseline	Expanded capacity for 4 hydropower plants	Crop areas fixed at 2020 levels. Yields follow past trends	Set in accordance with national priorities	Lowest priority
S2: National Interest	Baseline plus 4 new hydropower plants	Baseline plus shift to higher value crops in KAZ and UZB	Set in accordance with national priorities	Lowest priority
S3: Agriculture	Baseline plus 4 new hydropower plants	Narrative 2 plus a range of investments to improve water use and yield	Set in accordance with national priorities	Lowest priority
S4: Energy & Climate	*Informed by LEAP model*	Narrative 2 plus a range of investments to improve water use and yield	Set in accordance with national priorities	Lowest priority
S5: Regional cooperation	*Informed by LEAP model*	Narrative 2 plus a range of investments to improve water use and yield	Dams in upper basin release to meet all downstream demands	Lowest priority
S6: Ecosystem restoration	*Informed by LEAP model*	Narrative 2 plus a range of investments to improve water use and yield	Dams in upper basin release to meet all downstream demands	Highest priority

Details for the WEAP implementation in each narrative are provided below.

Narrative S1: Baseline

This narrative represents business-as-usual. Most features of the WEAP model are fixed. However, domestic demands continue to change with increasing population as projected by the UN Department of Economic and Social Affairs (2019) and industrial demands grow with expected growth in GDP consistent with the assumptions of the Macroeconomic model. In this narrative the WEAP model also considers:

- Hydropower: Toktogul expands from 1228 to 1440 MW between 2023 and 2025; Uch Kurgansk expands from 180 to 216 MW in 2025; Kairakkum expands from 126 to 174 MW in 2023; At Bashi expands from 40 to 44 MW in 2022
- Agriculture: Total irrigated area is fixed at 2020 levels; Cropping patterns are unchanged; Potential yields continue increasing at same rate as historical trends (1990-2020).

- Water Allocation:Allocation priorities range from 1 to 99, with 1 the highest priority and 99 the lowest; demand priorities must be greater than storage priority to withdraw water from storage. For the Syr Darya basin, a two-tier system was followed, with allocations shown in Table 3:
  - Tier 1: Position within watershed
  - Tier 2: Water use

Table 3: ***Priorities by location in watershed (Tier 1) and water use (Tier 2)***

Type of demand	KGZ	UZB Upper	TJK	UZB Lower	KAZ Upper	KAZ Lower
Domestic	1	11	21	31	41	41
Hydropower	2	12	22	32	42	42
Irrigation	3	13	23	33	43	43
Industrial	3	13	23	33	43	43
Thermal Cool-ing	4	14	24	34	44	44
Ecosystems	99	99	99	99	99	99
Storage	10	20	30	40	50	50

Narrative S2: National Interest

This narrative inherited and expanded upon Narrative 1. It considered that each basin country will pursue its own agendas concerning the development of water, agriculture, and energy resources.This includes:

- Hydropower: the expansion of hydropower in Kyrgyzstan with the construction of Kambarata 1 (1860 MW), Upper Naryn Cascade (237.7 MW), Kokomeren Cascade (1305 MW), and Kazarman Cascade (1160 MW); Expansion of Kambarata 2 from 120 to 360 MW in 2030
- Agriculture: considered the stated objectives of both Uzbekistan and Kazakhstan to increase the share of agriculture in their GDP.Within the WEAP model, this intention represented a shift away from wheat as the primary crop to a higher-valued crop, fruit orchards (apples). The modeling assumption was to transition 50 percent of the existing land grown for wheat to orchards by the year 2050 in both countries
- Water Allocation: Remains the same as in narrative 1.

Narrative S3:Agriculture –

This narrative assumes that the countries of the Syr Darya basin focus on improvements in agricultural practices that lead to more efficient use of water resources. Irrigation systems are rehabilitated and modernized, new crops and cropping patterns are introduced, and water-efficient equipment is deployed at scale. This was informed by national development plans from each country.

- Hydropower: Remains the same as in Narrative 2
- Agriculture: Focus on improving water use and agricultural practices throughout the basin via:
  - Increasing irrigation efficiencies achieved through the application of water-saving technologies in each basin country;
  - Reducing conveyance losses in each basin country;
  - Improving yields in Kazakhstan, Tajikistan, and Uzbekistan (Kyrgyzstan continues historical trend);
  - Kazakhstan aims to expand the cropped area under drip irrigation, while also increasing crop yields by at least 10 percent by 2030. Within the WEAP model, this was represented by increasing irrigation efficiencies from 55 to 80 percent for orchards, 55 to 70 percent for rice, and 65 to 80 percent for vegetables. A growth factor was applied to all crops such that the potential yields increase by 10 percent over 2020 levels by the year 2030.
  - Kyrgyzstan aims to increase the amount of land in production by four percent and add 487 million cubic meters of additional storage for irrigation by 2030. Within WEAP, the expansion of cropped areas was applied uniformly for all crops and additional storage was introduced in the year 2030.
  - Tajikistan aims to double agricultural water productivity in irrigated systems, while expanding

the cropped area by ten percent. Improved water productivity can be achieved through a combination of adopting improved irrigation technologies, loss reduction, and improved crop varieties. The WEAP model considered that by 2030 Tajikistan would increase potential crop yields by 10 percent and reduce canal losses by 25 percent, and improve overall irrigation efficiencies for orchards (from 55 to 65 percent), vegetables (from 65 to 70 percent), grains (from 55 to 60 percent), and rice (from 55 to 60 percent). Expansion in cropped areas was applied uniformly for all crops.

  - Uzbekistan aims to expand cropped area by as much as 10%, while improving agricultural water productivity using a combination of canal loss reduction, improved irrigation efficiency, shifting cropping patterns, and farming practices that increase yields. The improved productivity objective will be at least partially met by transitioning half of the area currently used to grow wheat to orchards as described under narrative 2. The additional interventions include reducing conveyance losses by 25 percent and increasing potential yield by five percent by 2030, as well as increasing irrigation efficiency for orchards (from 55 to 75 percent by 2030), vegetables (from 65 to 80 percent by 2030), grains (from 55 to 75 percent by 2030), and rice (from 55 to 75 percent by 2030).

- Water Allocation: Remains the same as in Narratives 1 and 2.

Narrative S4: Energy & Climate

This narrative focused primarily on assumptions within the LEAP model, and it includes meeting NDCs (Nationally Determined Contributions). As such, it did not require any changes in WEAP:

- Hydropower: Any changes are passed to WEAP from LEAP.
- Agriculture: Remains the same as in Narrative 3.
- Water Allocation: Remains the same as in Narratives 1, 2, and 3.

Narrative S5: Regional cooperation

This narrative adds assumptions about enhanced international cooperation on water, energy, and agricultural issues. It explores the gains that can be realized through improved transboundary coordination and exchange of resources in these sectors. This is represented within the WEAP model by altering the priority structure that was presented in Tables 2 and 3. Now, instead of using a two-tiered structure based on location within the basin and water use sector, the priorities are set based on water use sector only, such that domestic water use has the highest priority, followed by hydropower, irrigation and industry (who share the same priority), storage, and finally ecosystems.

- Hydropower: Remains the same as in Narrative 4.
- Agriculture: Remains the same as in Narratives 3 and 4.
- Water Allocation: Allocation priorities changed such that dams in upper basin release to meet water demands in downstream countries.

Narrative S6: Ecosystem restoration

The final narrative assumes that the minimum flow requirements needed to sustain the health of the North Aral Sea are satisfied. This is accomplished in WEAP by adjusting the priority structure used in narrative 5. Now, domestic water use is given the highest priority followed by ecosystems, hydropower, irrigation and industry, and finally storage. Flow requirements were set at the border between each country and were established using the Flow Duration Curve (FDC) Shift method, which takes into account the extent to which the original ecological condition of a river has been altered from its natural reference condition. This method considers five Ecological Management Classes (EMC):

- Class A = natural (unmodified) ; protected rivers and basins, reserves and national parks with minor modification of in-stream and riparian habitat, where no new dams or diversions allowed
- Class B = largely natural conditions ; slightly modified and/or ecologically important rivers where small water supply development schemes are allowed
- Class C = moderately modified, where the modifications are such that they generally have a limited impact on the ecosystem integrity, although sensitive species are impacted.
- Class D = largely modified ecosystems, where sensitive biota in particular are reduced in numbers and expanse and where community structure is substantially but acceptably changed.

- Class E = Seriously modified ecosystems, in poor condition where most of the ecosystem's functions and services are lost. This class is considered unacceptable from a management perspective as it represent ecosystems that are being used unsustainably

Flow requirements were configured using Environmental Management Class D:

- Hydropower: Same as Narratives 4 and 5.
- Agriculture: Same as Narrative 3-5.
- Water Allocation: Same as Narrative 5, except that the highest priority is assigned to ecosystems/ flow requirements.
- Ecosystems: Flow Requirements set along Syr Darya at each border crossing:
  - o Flow Requirements set based on estimated natural flows for each climate projection;
  - o FDCShift Method: Sets flow requirements based on the extent to which the basin has been modified from natural conditions, with a higher degree of modification resulting in a lower flow requirement.

Detailed report on WEAP implementation is presented in Annex 2 to this report.

2.5. LEAP narratives implementation

The implementation of Narratives S2-S6 are summarized in Table 4.

Table 4: Summary LEAP implementation of narratives

Narrative	Kazakhstan	Kyrgyz Republic	Tajikistan	Uzbekistan
Narrative 2: National Interest	Large hydropower expansion	Small hydropower expansion	Large hydropower expansion; meet electricity export target	
Narrative 3: Agriculture	Hydropower availabilities and energy demand for water pumping informed by WEAP			
Narrative 4: Energy & Climate	100% high efficiency water pumps by 2023; other changes in line with national plans	100% high efficiency water pumps by 2023; other changes in line with national plans	100% penetration of high efficiency water pumps by 2023	100% high efficiency water pumps by 2023; other changes in line with national plans
Narrative 5: Regional cooperation	Hydropower availabilities and energy demand for water pumping informed by WEAP			
Narrative 6: Ecosystem restoration	Hydropower availabilities and energy demand for water pumping informed by WEAP			

Details for the LEAP implementation in each narrative are provided below.

Narrative S2: National Interest

- Kazakhstan: Construction of Upper Naryn, Suusamyr-Kokomeren, Kazarman, and Kambarata I hydropower plants, expansion of Kambarata II hydropower plant.
- Kyrgyz Republic: Installation of 300-400 MW of small hydropower capacity.
- Tajikistan:
  - o Construction of Rogun, Shurob, Sanobodskaya, Sebzor, Zeravshan, Kairokkum, Nurek, and Sarband hydropower plants;
  - o Meet electricity export target of 5 billion kWh by 2025.
- Uzbekistan: Same as S1: Baseline.

Narrative S3: Agriculture

• Keep energy assumptions the same as in Narrative S4, but take hydropower availabilities and energy demand for water pumping from WEAP.

Narrative S4: Energy & Climate

In all countries: 100% high efficiency water pumps by 2023. In addition:

- Kazakhstan:
    - 10% increase in energy intensity of metal and chemical production, 15% decrease in residential energy consumption, decrease in heat transmission and distribution losses to 10%, increase in heat production efficiency to 90%;
    - Renewable energy generation targets by 2030: 30% alternative electricity; 25% natural gas; 10% wind and solar;
    - 12 MTOE of energy efficiency savings by 2030.
- Kyrgyz Republic:
    - 50% road electrified by 2050;
    - 10% renewable energy in total primary energy supply by 2040
    - 60% electrification in rail;
    - ~12% reduction in transmission and distribution losses by 2023.
- Uzbekistan:
    - 25% renewable energy in electricity mix by 2026;
    - 60% of rail electrified by 2026;
    - 50% of road transport via electric vehicles by 2050;
    - Sectoral efficiency targets:
        - Industry: 20%;
        - Agriculture: 25%;
        - Commercial sector: 25%;
        - Non road transport: 25%;
    - 5 GW new solar, 3 GW new wind, and 1.9 GW of new hydroelectricity capacity.

Narratives S5: Regional cooperation and S6: Ecosystem restoration

- Keep energy assumptions the same as in Narrative S4, but take hydropower availabilities and energy demand for water pumping from WEAP.

Detailed report on LEAP implementation is presented in Annex 3 to this report.

2.6. Climate projections

In addition to the six thematic modeling narratives described above, four climate projections (climate models) were used. As shown in Figure 11, model results from the 6th Climate Model Intercomparison Project (CMIP6) can be clustered into "dry", "average", and "wet" groupings. Therefore, for the Models, in addition to the historical climate projection, three representative climate model runs (projections) were chosen:

- Historical: This projection assumes no further climate change.
- Dry: Paralleling the Wet projection, this projection anticipates significant climate change that results in hotter and drier conditions in the Syr Darya Basin. Model CM5 of the Institute for Numerical Mathematics (INM), simulating an 8.5 W/m^2 climate forcing under Shared Socioeconomic Pathway SSP5: High Mitigation Challenges (INM-CM5-0-ssp585);
- Average: This projection is for a moderate level of climate change, causing temperatures to increase but precipitation to stay about the same in the Syr Darya Basin. Model ESM1 of the Max Planck Institute (MPI), simulating a 4.5 W/m^2 climate forcing under Shared Socioeconomic Pathway SSP2: Intermediate Challenges (MPI-ESM1-2-HR-ssp245);
- Wet: This is a projection for significant climate change that makes the Syr Darya region both hotter and wetter. Model CM4 of the Geophysical Fluid Dynamics Laboratory (GFDL), simulating an 8.5 W/m^2 climate forcing under Shared Socioeconomic Pathway SSP5: High Mitigation Challenges (GFDL-CM4-ssp585).

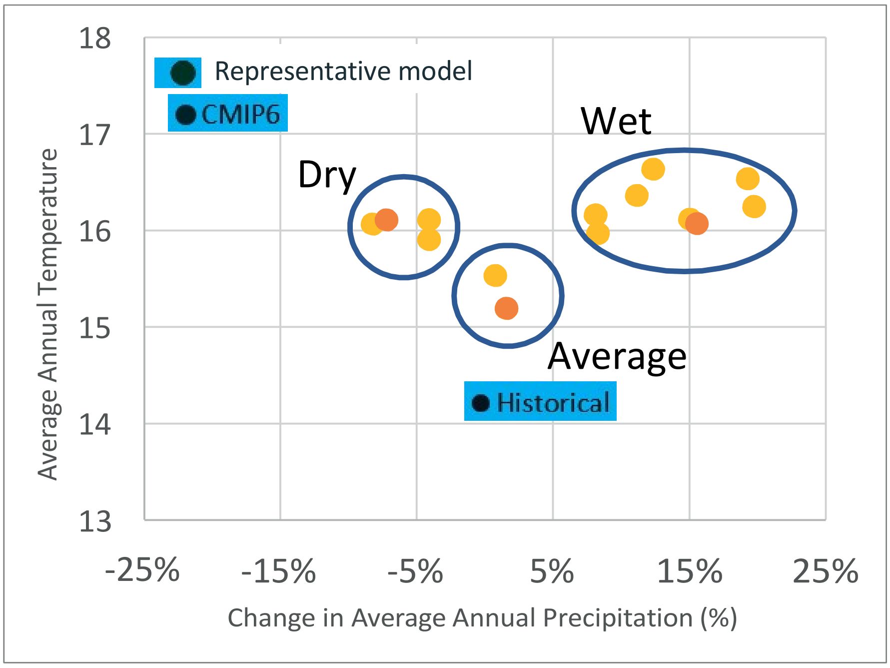


Figure 11: ***Four climate projections: Historical, Dry (INM-CM5-0-ssp585), Average (MPI-ESM1-2-HR-ssp245), and Wet (GFDL-CM4-ssp585)***

The scenario runs were then defined by a combination of four climate projections (historical, dry, average, or wet) and the six thematic narratives. This resulted in a total of 24 scenarios implemented in both LEAP and WEAP. Climate models suggest that the basin is likely to get hotter, but differ over whether it will get somewhat drier or wetter. Detailed results of all scenarios are presented in Annexes 2 and 3 to this report.

5. ANALYSIS RESULTS

For analytical purposes, only a subset of the narratives were run using full integration between WEAP, LEAP/NEMO, and Macro: S1, S2, S4, and S5 for wet and dry climates, for a total of eight. Of those, six were selected for particular study: S2, S4, and S5 wet and dry. Each narrative builds on the other; the incremental differences between the narratives are schematically in Figure 12.

The analysis suggested that pursuing national policies tends to increase the amount of unmet water demand, in particular for irrigation, under both dry and wet climate projections (see the red lines in Figure 12). Once water and energy efficiency policies, as well as increased regional cooperation, were introduced, the amount of unmet water requirements fell substantially (by roughly 30%) under both climate projections. The benefits persisted through the end of the run in 2050.

The right hand side of Figure 13 shows six scenario combinations on a graph of the percent of time that a particular level of unmet demand is exceeded. In such a graph, a drop in high exceedance values means less likelihood of high unmet demand. Thus, dotted lines (dry climate) lie below solid lines (wet climate) in the left-hand portion of the graph. Similarly, passing from S2: National focus to S4: Water, agriculture, and energy efficiency, reduce the severity of unmet demand, while cooperation reduces it even further.

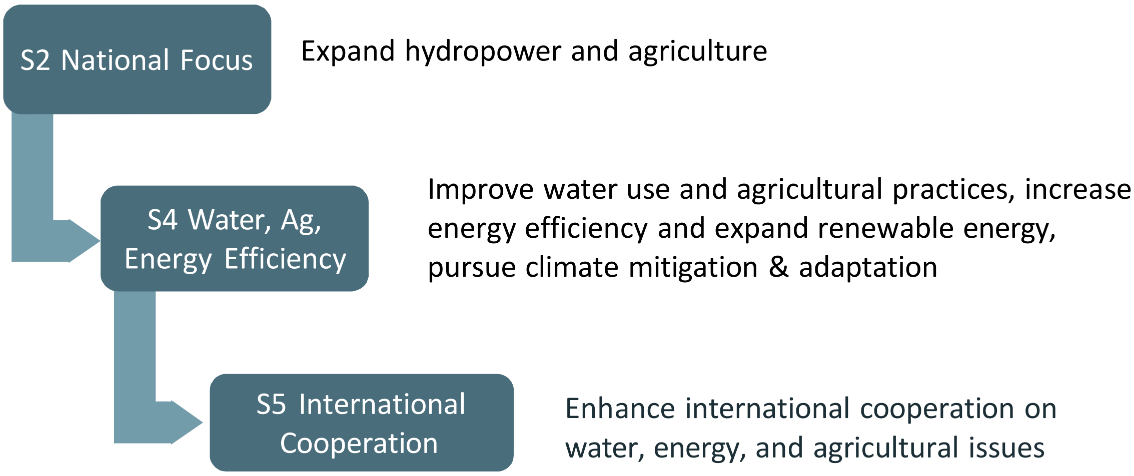


Figure 12: ***Selected narratives for analysis***

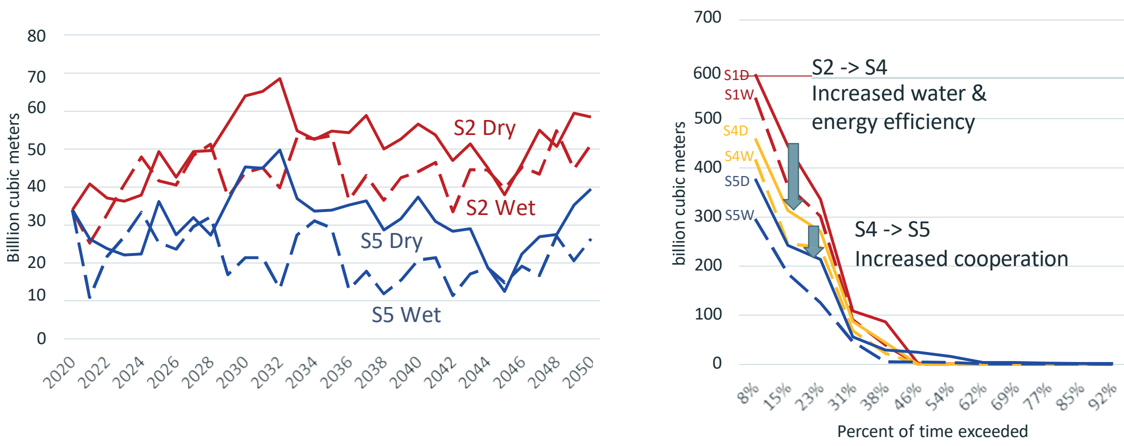


Figure 13: ***Unmet demand for irrigation in different scenarios: absolute and as exceedance time***

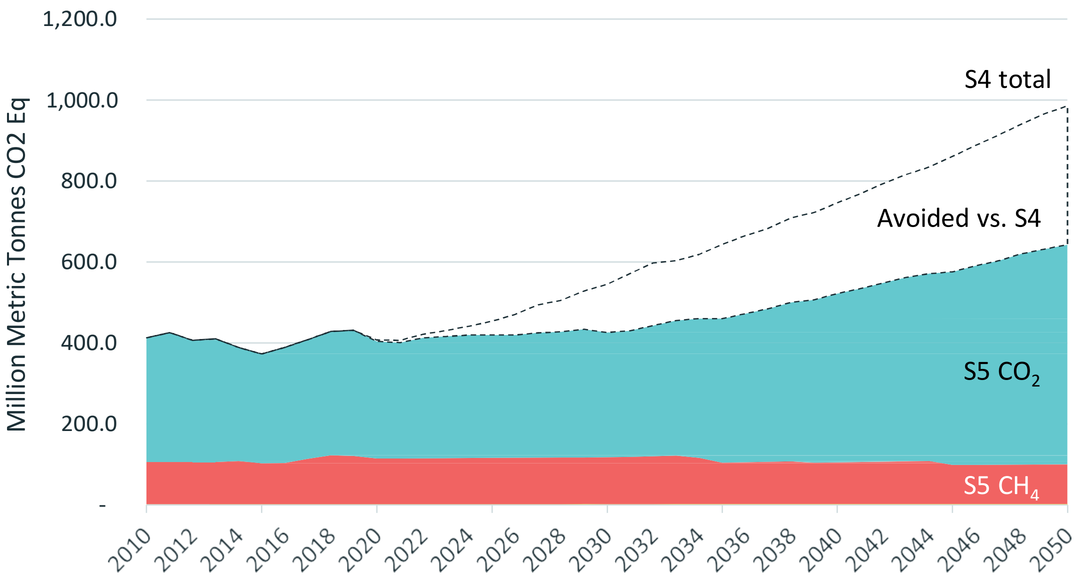


Figure 14: ***Greenhouse gas emissions from the Syr Darya riparian countries in scenarios S4 and S5***

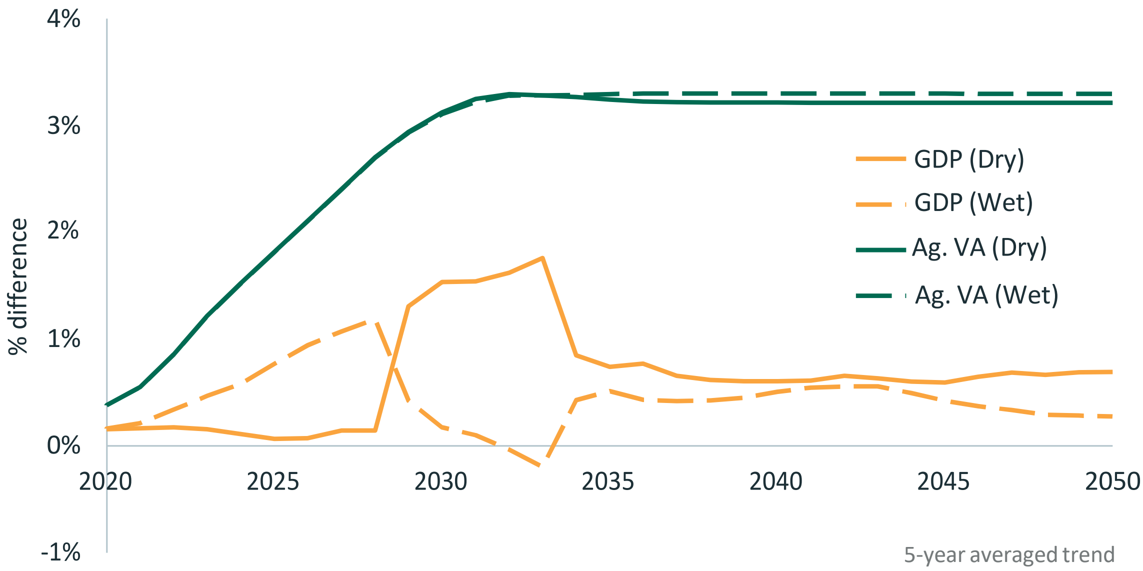


Figure 15: ***Percent differences in key economic indicators between the S5 and S2 scenarios (5-year average trend)***

Cooperation also leads to reduced greenhouse gas emissions relative to nationally-focused energy and water efficiency measures. As shown in Figure 14, by 2050, about 20% of cumulative GHG emissions could be avoided between Uzbekistan, Kazakhstan, Kyrgyz Republic and Tajikistan as a result of such measures.

As an illustration of simulated economic impacts, Figure 15 shows results for Kyrgyz Republic, which has a large fraction of the national territory in the Syr Darya Basin. In the simulations, national plans for increasing agricultural production, together with increased availability of water, resulted in an increase of annual agricultural value added of over 3% in both dry and wet climate projections.The dry climate results are slightly below those of the wet climate projection. Increased investment expenditure, together with increased agricultural output, translated into a 0.5% increase in GDP overall.

Results from the study suggest that pursuing national interests will in fact increase water stress in the region compared to the present day. In contrast, the simulation results suggest that water and energy efficiency policies and regional cooperation in Syr Darya Basin can decrease unmet water requirements for irrigation and other uses, and reduce greenhouse gas emissions. Moreover, they can have not only a positive impact on agricultural value added and GDP, but one that persists over time, after the initial period of investment.

An additional study was made on another sub-set of three of the six narratives using LEAP-WEAP-Macro, projecting results to 2050:

1. (S1) Business as usual (BAU): based on existing policies and plans by the four countries, as well as a future pursuit of national interest in hydropower and agriculture expansion in the Syr Darya basin
2. (S3) Efficiency: improved water use and agricultural practices through efficiency, increased energy efficiency and expanded renewable energy, the pursuit of climate mitigation and adaptation
3. (S5) Cooperation: Efficiency narrative and enhanced international cooperation on water, energy and agricultural issues through joint planning

These scenarios were modeled with and without integration across the LEAP,WEAP and Macro models, to explore the degree to which integrated food-energy-water nexus models can produce more realistic results and used to analyze the impact of cooperation across the countries of the Syr Darya.

The timing of hydropower production and irrigation is critical to determining water availability from hydro dams to meet different demands. Yet, water models typically treat hydropower simplistically, missing the use of hydropower for the purpose of addressing peak demands in the energy sector, like heating in the winter season. Similarly, energy models over-simplify the availability of hydropower, typically using historical streamflow records that do not incorporate climate change and year-to-year variability. Integrated water and energy models can provide more realistic results, and hence support better planning decisions as is evident when comparing the energy and water results of scenarios from WEAP and LEAP with and without the integration of WEAP-LEAP-MACRO.

In the integrated model, WEAP provides key inputs on an annual and sub-annual variation of hydropower production, as well as the impacts of climate change and water scarcity to the energy model LEAP. Using the example of the Kyrgyz Republic and narrative S5 on cooperation, this results in significantly higher water availability for hydropower generation – increasing hydropower generation by up to 21 percent by 2050, as shown in Figure 16 compared to LEAP alone.

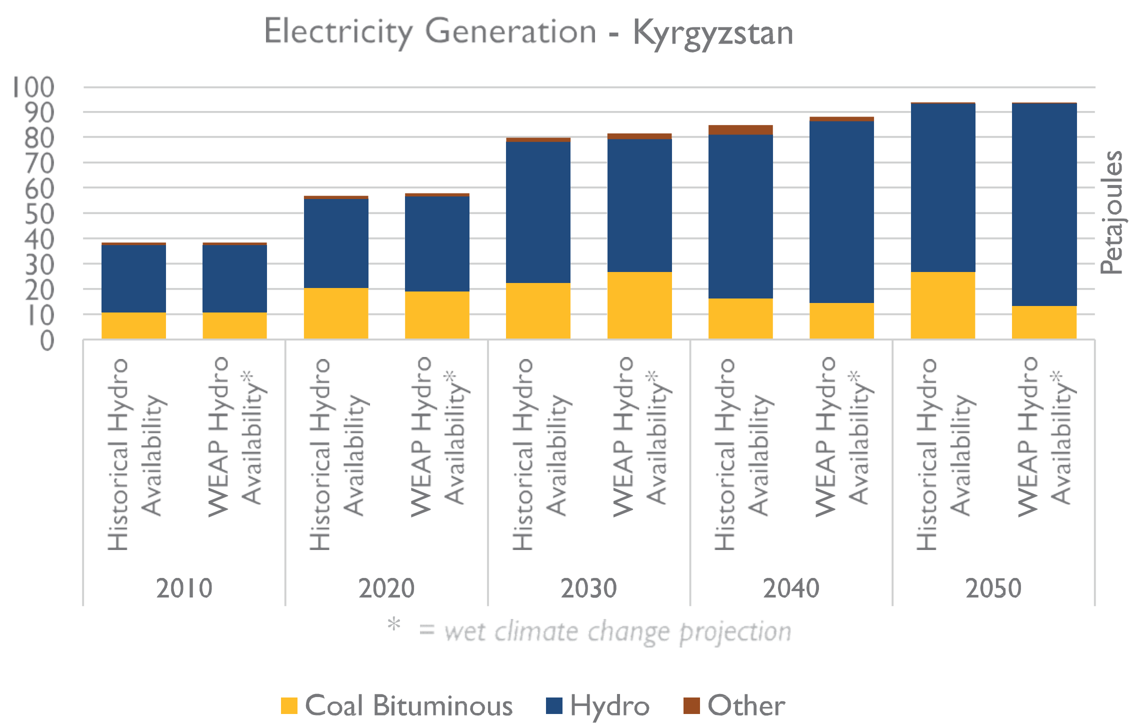


Figure 16. ***Comparison of electricity generation for Kyrgyzstan with and without integration of LEAP and WEAP and Macro for Regional cooperation***

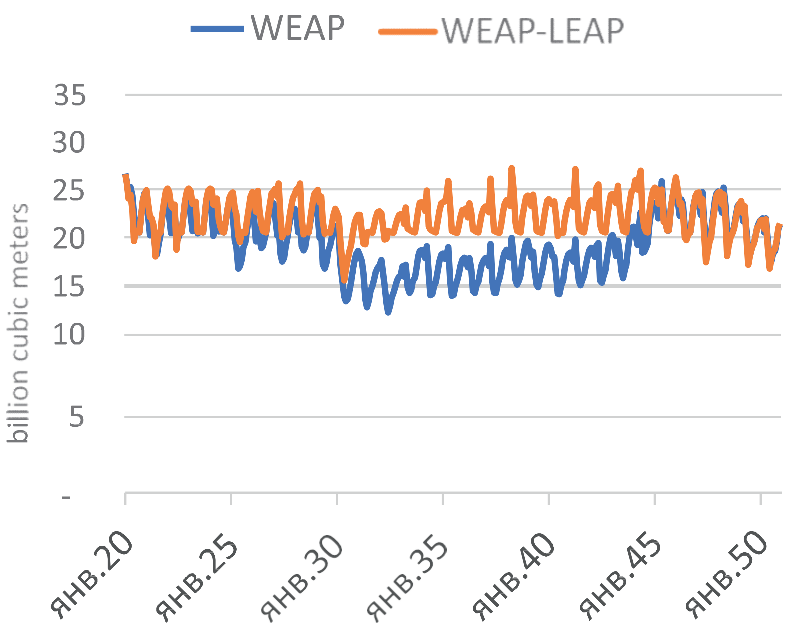


Figure 17. ***Comparison of water storage in billion cubic meters, with and without integration of models***

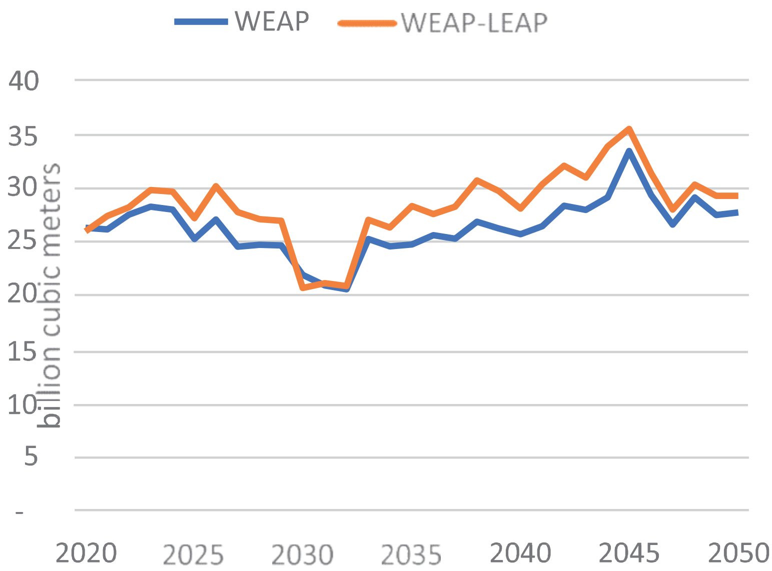


Figure 18. ***Comparison of water delivered with and without integrated modelling in billion cubic meters***

Similarly, when comparing the results of integrating WEAP-LEAP-Macro to using the WEAP model alone, we see a substantial difference both in storage and water availability to meet demands, particularly for irrigation. Figure 17 shows a comparison of running the WEAP model alone versus the integrated models (WEAP-LEAP-Macro) for water storage across the Syr Darya. The integrated model shows significantly higher levels of storage, due to the more nuanced dispatch of hydropower using LEAP, in effect creating a 20% increase in water availability.

The integrated model shows, that in fact fewer demands remain unmet than would be integrated by the separate models, as illustrated in Figure 18, which shows a significant increase in water delivered year-on-year.

This integrated modeling system opens new possibilities when examining the potential gains from cooperation.

The policies introduced in the regional cooperation narrative impact on economic outcomes through multiple and sometimes conflicting channels. One clear and positive benefit from regional cooperation (S5) is that agricultural output receives a boost compared to the baseline scenario (S1). It rises by over 3% in the Kyrgyz Republic, and that increase persists. The boost is less in Kazakhstan, but reaches about 1% before slowly declining. The impact on GDP depends on interactions between sectors, and is more muted, with a slight rise in Kyrgyz Republic and a decline in Kazakhstan.

6. CONCLUSIONS

Integrated analyses are difficult, so they should be carried out only when the integrated model gives better insights than the separate models. This analysis shows that this *is* the case for the Syr Darya basin, notably the following:

- Linking LEAP and WEAP changes the results for hydropower
- Linking LEAP and Macro gives more complex GDP trajectories
- Linking WEAP and Macro captures how water availability affects the economy
- Linking LEAP, WEAP and Macro combines these feedbacks

From a policy perspective, the results strongly suggest that pursuing national interests in isolation (S1) will likely increase water stress in the region. Because the countries share a common basin, increased stress has ripple effects across the region. To counter those stresses, implementing water and energy measures together with regional cooperation – planning for the basin as a whole – increases water availability for agriculture and other uses while strengthening climate mitigation. What is more, these policies can boost agricultural value added and GDP.

Beyond this Activity, the results demonstrate that a nexus analysis linking water, food, energy, environment and economy can provide useful policy insights. Such analyses are demanding, drawing on expertise from different disciplines. Yet, the insights they provide could not have emerged from isolated analyses within each of these areas. Crucially, one of the research findings is that hydropower in the region is best studied in a linked energy-water-agriculture model that encompasses competing water demands and alternative energy supplies. Integrated modeling also demonstrates the economic consequences of climate-related constraints on agricultural production. The economic analysis moreover expanded the scope of water and energy planning from a conventional cost-effectiveness assessment to encompass the whole economy, including the stimulus effect of using resources more efficiently.

The study and the process of facilitating different sectors of national governments demonstrated that resource planning with a Nexus approach can bring more sustainable results. These results are analyzed through different perspectives, that consider the demands and requirements of different sectors, and bring benefits to all of them. Therefore, the integrated tools are beneficial for decision-makers, charting the way toward better economic outcomes with the potential to positively influence the region's overall development.

ANNEX 1:

CONFIGURATION FILE

```
###############################################################
#           WAVE integration config file
# Defines variable parameters required to run integration
# Needs to be kept up-to-date by user
###############################################################
WEAP:
   Area: 'WAVE-SyrDarya 2022_09_19_MABIA'
  Branches:
    Population_KAZ:
      path: Key\Demographic\KAZ\National population
      variable: Annual Activity Level
      unit: cap
      leap_branch: Population
      leap_region: Kazakhstan
    Population_KGZ:
      path: Key\Demographic\KAZ\National population
      variable: Annual Activity Level
      unit: cap
      leap_branch: Population
      leap_region: Kyrgyzstan
    Population_TJK:
      path: Key\Demographic\KAZ\National population
      variable: Annual Activity Level
      unit: cap
      leap_branch: Population
      leap_region: Tajikistan
    Population_UZB:
      path: Key\Demographic\KAZ\National population
      variable: Annual Activity Level
      unit: cap
      leap_branch: Population
      leap_region: Uzbekistan
    GDP_KAZ:
      path: Key\Macroeconomic\KAZ\GDP
      variable: Annual Activity Level
      unit: Billion 2020 USD
      leap_branch: GDP
      leap_region: Kazakhstan
    GDP_KGZ:
      path: Key\Macroeconomic\KGZ\GDP
      variable: Annual Activity Level
      unit: Billion 2020 USD
      leap_branch: GDP
      leap_region: Kyrgyzstan
    GDP_TJK:
      path: Key\Macroeconomic\TJK\GDP
      variable: Annual Activity Level
      unit: Billion 2020 USD
      leap_branch: GDP
      leap_region: Tajikistan
    GDP_UZB:
      path: Key\Macroeconomic\UZB\GDP
      variable: Annual Activity Level
      unit: Billion 2020 USD
      leap_branch: GDP
      leap_region: Uzbekistan
    Industrial_VA_KAZ:
      path: Key\Macroeconomic\KAZ\Industrial value added
      variable: Annual Activity Level
      unit: '% share'
      leap_branch: GDP
      leap_branch: Industrial_VA_fraction
      leap_region: Kazakhstan
    Industrial_VA_KGZ:
      path: Key\Macroeconomic\KGZ\Industrial value added
      variable: Annual Activity Level
      unit: '% share'
      leap_branch: Industrial_VA_fraction
      leap_region: Kyrgyzstan
    Industrial_VA_TJK:
      path: Key\Macroeconomic\TJK\Industrial value added
      variable: Annual Activity Level
      unit: '% share'
      leap_branch: Industrial_VA_fraction
```

```
    leap_region: Tajikistan
  Industrial_VA_UZB:
    path: Key\Macroeconomic\UZB\Industrial value added
    variable: Annual Activity Level
    unit: '% share'
    leap_branch: Industrial_VA_fraction
    leap_region: Uzbekistan


Hydropower_plants:
  Toktogul:
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Toktogul reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [TOKTOGUL]
  Kambarata_I:
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Kambarata_I
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [KAMBARATA_1]
  Kambarata_II:
    weap_path : Supply and Resources\River\Syr Darya River\Run of River Hydro\Kambarata II
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [KAMBARATA_2]
  Kayrakkum :
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Kayrakkum reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [KAIRAKKUM]
  Shardara :
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Shardara reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [SHARDARINSKYA]
  Kurpsaiskaja:
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Kurpsaiskaja
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [KURPSAI]
  Taschkumyrskaja :
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Taschkumyrskaja_cascade
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [TASH_KUMYR, SHAMALDYSAI,UCH_KURGANSK]
  Farkhad :
    weap_path : Supply and Resources\River\Syr Darya River\Reservoirs\Farkhad reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [FARKHAD]
  Akhangaran :
    weap_path : Supply and Resources\River\Ahangaran\Reservoirs\Akhangaran reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps: [AKHANGARAN]
  Charvak:
    weap_path : Supply and Resources\River\Circik River\Reservoirs\Charvak reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [CHARVAK, GAZLKENT, KHODZHIKENT]
  Chirchik:
    weap_path : Supply and Resources\River\Circik River\Reservoirs\Chirchik_cascade
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [AKKAVAK_1, CHIRCHIK_1, CHIRCHIK_2, TAVAK]
  Andijan :
    weap_path : Supply and Resources\River\Andijan River\Reservoirs\Andijan Reservoir
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [ANDIJAN_1, ANDIJAN_2]
  At-Bashi :
    weap_path : Supply and Resources\River\Syr Darya River\Run of River Hydro\At Bashi RoR
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [AT_BASHIN]
  Kokomeren :
    weap_path : Supply and Resources\River\Kokomeren River\Run of River Hydro\Kokomeren RoR
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [KOKOMEREN]
  Upper Naryn :
    weap_path : Supply and Resources\River\Syr Darya River\Run of River Hydro\Upper Naryn RoR
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [UPPER NARYN]
  Kazarman :
    weap_path : Supply and Resources\River\Syr Darya River\Run of River Hydro\Kazarman RoR
    weap_variable: :Hydropower Generation[GWH]
    leap_hpps : [KAZARMAN]
```

```yaml
Agricultural regions: # these are used for water pumping
  Kazakhstan:
    Kyzlorda:
      weap_path : Demand Sites and Catchments\Agriculture_KAZ_Kyzylorda
      leap_region: Kazakhstan
      variable: Supply Requirement
      unit: m^3
    Shmykent:
      weap_path: Demand Sites and Catchments\Agriculture_KAZ_Turkestan_Shymkent
      leap_region: Kazakhstan
      variable: Supply Requirement
      unit: m^3
  Kyrgyzstan:
    JalalAbat:
      weap_path: Demand Sites and Catchments\Agriculture_KGZ_Naryn_JalalAbat_Osh_Batken
      leap_region: Kyrgyzstan
      variable: Supply Requirement
      unit: m^3
  Tajikistan:
    Sogd:
      weap_path: Demand Sites and Catchments\Agriculture_TJK_Sogd
      leap_region: Tajikistan
      variable: Supply Requirement
      unit: m^3
  Uzbekistan:
    Andijan:
      weap_path: Demand Sites and Catchments\Agriculture_UZB_Andijan_Namangan_Fergana
      leap_region: Uzbekistan
      variable: Supply Requirement
      unit: m^3
    SyrDarya:
      weap_path: Demand Sites and Catchments\Agriculture_UZB_SyrDarya_Tashkent_Jizzakh
      leap_region: Uzbekistan
      variable: Supply Requirement
      unit: 'm^3'

Industrial and domestic regions: # these are used for water pumping
  Kazakhstan:
    Kyzlorda_Ind:
      weap_path : Demand Sites and Catchments\Industrial_KAZ_Kyzylorda
      leap_region: Kazakhstan
      variable: Supply Requirement
      unit: m^3
    Shmykent_Ind:
      weap_path: Demand Sites and Catchments\Industrial_KAZ_Turkestan_Shymkent
      leap_region: Kazakhstan
      variable: Supply Requirement
      unit: m^3
    Kyzlorda_Dom:
      weap_path : Demand Sites and Catchments\Domestic_KAZ_Kyzylorda
      leap_region: Kazakhstan
      variable: Supply Requirement
      unit: m^3
    Shmykent_Dom:
      weap_path: Demand Sites and Catchments\Domestic_KAZ_Turkestan_Shymkent
      leap_region: Kazakhstan
      variable: Supply Requirement
      unit: m^3
  Kyrgyzstan:
    JalalAba_Ind:
      weap_path: Demand Sites and Catchments\Industrial_KGZ_Naryn_JalalAbat_Osh_Batken
      leap_region: Kyrgyzstan
      variable: Supply Requirement
      unit: m^3
    JalalAbat_Dom:
      weap_path: Demand Sites and Catchments\Domestic_KGZ_Naryn_JalalAbat_Osh_Batken
      leap_region: Kyrgyzstan
      variable: Supply Requirement
      unit: m^3
  Tajikistan:
    Sogd_Ind:
      weap_path: Demand Sites and Catchments\Industrial_TJK_Sogd
      leap_region: Tajikistan
```

```yaml
        variable: Supply Requirement
        unit: m^3
      Sogd_Dom:
        weap_path: Demand Sites and Catchments\Domestic_TJK_Sogd
        leap_region: Tajikistan
        variable: Supply Requirement
        unit: m^3
    Uzbekistan:
      Andijan_Ind:
        weap_path: Demand Sites and Catchments\Industrial_UZB_Andijan_Namangan_Fergana
        leap_region: Uzbekistan
        variable: Supply Requirement
        unit: m^3
      SyrDarya_Ind:
        weap_path: Demand Sites and Catchments\Industrial_UZB_SyrDarya_Tashkent_Jizzakh
        leap_region: Uzbekistan
        variable: Supply Requirement
        unit: m^3
      Andijan_Dom:
        weap_path: Demand Sites and Catchments\Domestic_UZB_Andijan_Namangan_Fergana
        leap_region: Uzbekistan
        variable: Supply Requirement
        unit: m^3
      SyrDarya_Dom:
        weap_path: Demand Sites and Catchments\Domestic_UZB_SyrDarya_Tashkent_Jizzakh
        leap_region: Uzbekistan
        variable: Supply Requirement
        unit: m^3


LEAP:
  Area: 'wave central asia v43'
  Regions: ["Kazakhstan", "Kyrgyzstan", "Tajikistan", "Uzbekistan"]
  # Folder for storing Excel files with WEAP outputs for hydropower plants used by LEAP as inputs
  # Should be at the same level as the "LEAP Areas" folder -- it will be discovered by starting
with the LEAP Areas folder
  Folder: WAVE_Hydro
  # These are month names as specified in time slices; they should start with January and go
through December
  Months: [January, February, March, April, May, June, July, August, September, October,
November, December]
  Branches:
    GDP:
      path: Key\Macroeconomic\Gross Domestic Product
      variable: Activity Level
      unit: 2020 USD
    Population:
      path: Key\Demographic\Population
      variable: Activity Level
      unit: people
    Industrial_VA_fraction:
      path: Key\Macroeconomic\Industrial\Industry_Value Added Fraction
      variable: Activity Level
      unit: Fraction
    Industrial VA:
      path: Key\Macroeconomic\Industrial_Value Added
      variable: Activity Level
      unit: 2020 USD
    Commercial VA:
      path: Key\Macroeconomic\Commercial_Value Added
      variable: Activity Level
      unit: 2020 USD
     Agricultural VA:
      path: Key\Macroeconomic\Agriculture_Value Added
      variable: Activity Level
      unit: 2020 USD
    Ag_water_demand:
      path: Demand\Agriculture\Syr Darya\Water demand
      variable: Activity Level
      unit: Cubic Meter/No Data
    Ind_water_demand:
      path: Demand\Industry\Other\Syr Darya Water Pumping
      variable: Activity Level
      unit: Cubic Meter/No Data
```

```yaml
Hydropower_plants: # LEAP results to be checked for convergence
  AKHANGARAN:
    leap_path: Transformation\Electricity Production\Processes\AKHANGARAN RESERVOIR
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  ANDIJAN_1:
    leap_path: Transformation\Electricity Production\Processes\ANDIJAN_1
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  AKKAVAK_1:
    leap_path: Transformation\Electricity Production\Processes\AKKAVAK_1
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  ANDIJAN_2:
    leap_path: Transformation\Electricity Production\Processes\ANDIJAN_2
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  AT_BASHIN:
    leap_path: Transformation\Electricity Production\Processes\AT_BASHIN
    leap_region: Kyrgyzstan
    leap_variable: Energy Generation
    leap_unit: GWh
  CHARVAK:
    leap_path: Transformation\Electricity Production\Processes\CHARVAK
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  CHIRCHIK_1:
    leap_path: Transformation\Electricity Production\Processes\CHIRCHIK_1
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  CHIRCHIK_2:
    leap_path: Transformation\Electricity Production\Processes\CHIRCHIK_2
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  FARKHAD:
    leap_path : Transformation\Electricity Production\Processes\FARKHAD
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  GAZLKENT:
    leap_path: Transformation\Electricity Production\Processes\GAZALKENT
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  KAIRAKKUM:
    leap_path: Transformation\Electricity Production\Processes\KAIRAKKUM
    leap_region: Tajikistan
    leap_variable: Energy Generation
    leap_unit: GWh
  KAMBARATA_1:
    leap_path: Transformation\Electricity Production\Processes\KAMBARATA_1
    leap_region: Kyrgyzstan
    leap_variable: Energy Generation
    leap_unit: GWh
  KAMBARATA_2:
    leap_path: Transformation\Electricity Production\Processes\KAMBARATA_2
    leap_region: Kyrgyzstan
    leap_variable: Energy Generation
    leap_unit: GWh
  KHODZHIKENT:
    leap_path: Transformation\Electricity Production\Processes\KHODZHIKENT
    leap_region: Uzbekistan
    leap_variable: Energy Generation
    leap_unit: GWh
  KURPSAI:
    leap_path: Transformation\Electricity Production\Processes\KURPSAI
```

```yaml
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    SHAMALDYSAI:
      leap_path: Transformation\Electricity Production\Processes\SHAMALDYSAI
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    SHARDARINSKYA:
      leap_path:  Transformation\Electricity  Production\Processes\SHARDARINSKYA
      leap_region: Kazakhstan
      leap_variable: Energy Generation
      leap_unit: GWh
    TASH_KUMYR:
      leap_path: Transformation\Electricity Production\Processes\TASH_KUMYR
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    TAVAK:
      leap_path: Transformation\Electricity Production\Processes\TAVAK
      leap_region: Uzbekistan
      leap_variable: Energy Generation
      leap_unit: GWh
    TOKTOGUL:
      leap_path: Transformation\Electricity Production\Processes\TOKTOGUL
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    UCH_KURGANSK:
      leap_path:  Transformation\Electricity  Production\Processes\UCH_KURGANSK
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    KOKOMEREN:
      leap_path: Transformation\Electricity Production\Processes\SUUSAMYR_KOKOMEREN CASCADE
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    UPPER NARYN:
      leap_path: Transformation\Electricity Production\Processes\UPPER NARYN CASCADE
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh
    KAZARMAN:
      leap_path: Transformation\Electricity Production\Processes\KAZARMAN CASCADE
      leap_region: Kyrgyzstan
      leap_variable: Energy Generation
      leap_unit: GWh

 LEAP-Macro: # Removing this will stop wave-integration from running with leap-macro
  # Main folder for Macro models: Should be at the same level as the "LEAP Areas" folder -- it
will be discovered by starting with the LEAP Areas folder
  folder: WAVE_Macro
  # Target variables are the same for each region: must match branches in LEAP config above
  LEAP:
    target_variables : ['GDP', 'Industrial VA', 'Commercial VA', 'Agricultural VA']
  WEAP:
    cov_to_util_exponent: 0.2
    sectorlist: ["Agriculture_", "Industrial_", "Domestic_"]
    croplist: ["Seasonal crops", "Perennial crops"]
  regions:
      Kazakhstan:  directory_name:
        KAZ_Macro  script:
        runleapmacro.jl
        weap_region: ['KAZ']
        weap_coverage_mapping:
          'Agriculture_':  ['S_agfor']
          'Industrial_': ['S_food', 'S_paperpulp', 'S_otherind']
          'Domestic_':  ['S_hotelrestaurant',  'S_otherserv']
        weap_crop_production_value_mapping:
          'Agriculture_':  ['S_agfor']
        weap_real_output_index_mapping:
          'Agriculture_':
             'All crops': ['S_agfor']
```

```
      weap_price_index_mapping:
        'Agriculture_':
          'Seasonal crops': ['P_agforseasonal']
          'Perennial crops': ['P_agforperennial']
    Kyrgyzstan:  directory_name:
      KGZ_Macro  script:
      runleapmacro.jl
      weap_region: ['KGZ']
      weap_coverage_mapping:
        'Agriculture_': ['S_agfor']
        'Industrial_': ['S_food', 'S_woodpaper', 'S_otherind']
        'Domestic_': ['S_hotelrestaurant', 'S_otherserv']
      weap_crop_production_value_mapping:
        'Agriculture_': ['S_agfor']
      weap_real_output_index_mapping:
        'Agriculture_':
          'All crops': ['S_agfor']
      weap_price_index_mapping:
        'Agriculture_':
          'All crops': ['P_agfor']
crop_categories:
    WEAP_to_Macro:
        'Apples': 'Perennial crops'
        'Barley': 'Seasonal crops'
        'Corn': 'Seasonal crops'
        'Cotton': 'Seasonal crops'
        'Grapes': 'Perennial crops'
        'Oil seeds and pulses': 'Seasonal crops'
        'Other crops': 'Seasonal crops'
        'Other grains': 'Seasonal crops'
        'Other orchards': 'Perennial crops'
        'Potatoes': 'Seasonal crops'
        'Rice': 'Seasonal crops'
        'Sugar beet': 'Seasonal crops'
        'Vegetables': 'Seasonal crops'
        'Watermelons and squash': 'Seasonal crops'
        'Wheat': 'Seasonal crops'
    Macro_to_WEAP:
        'Perennial crops':
            - 'Apples'
            - 'Grapes'
            - 'Other orchards'
        'Seasonal crops':
            - 'Barley'
            - 'Corn'
            - 'Cotton'
            - 'Oil seeds and pulses'
            - 'Other crops'
            - 'Other grains'
            - 'Potatoes'
            - 'Rice'
            - 'Sugar beet'
            - 'Vegetables'
            - 'Watermelons and squash'
            - 'Wheat'
```

ANNEX 2:

WEAP MODEL FOR THE SYR DARYA RIVER BASIN

1 The WEAP Model for the Syr Darya River Basin

In line with previous analysis in Syr Darya, this assessment used the WEAP platform to review the supply and demand of water in Syr Darya to identify potential scarcity and conflict between different users. The WEAP software has been under development by Stockholm Environment Institute (SEI) for nearly 20 years. The software provides a comprehensive suite of tools for simulating water resources systems including rainfall-runoff hydrology, water resources infrastructure, agricultural, urban, and environmental demands, and the ability to apply complex operating rules and constraints to the water allocation problem. The water allocation problem is solved using linear programming (LP) defined by user-specified demand priorities and water supply preferences. The software is well-documented and has a well-developed training tutorial provided on the WEAP21 website. Comprehensive information on the software and download links are available at www.weap21.org. The data sources for this application are given in Annex 2.A.

1.1 Spatial Disaggregation

WEAP allows for a fairly high level of disaggregation to describe water supplies and demands. In practice the data structure of the model is determined by the research or policy questions that are being addressed. This commonly starts with questions pertaining to how best to allocate water to competing users, which may include different water use sectors (i.e., domestic, municipal, industrial, agricultural, hydropower, environmental, etc.) as well as water users in different parts of the basin. Thus, the first level of data disaggregation is determining which water use sectors should be included in the model. The next level of data disaggregation is to determine how each of these water use sectors should be spatially disaggregated. The spatial disaggregation is generally determined by water sources. For example, agricultural areas that divert water from the mainstem of a river may be considered separately from agricultural areas that divert water from a tributary flowing into the main river. Similarly, we may separate domestic demands that each take water from the same river, where downstream users are affected by the level of upstream abstraction.

These considerations are reflected in the data structure used to develop the national WEAP model for Syr Darya. For this model, we considered the following water use sectors and associated demand drivers:

- **Domestic:** population, per capita water use
- **Irrigated agriculture**: crop types, cropped area
- **Industry**: production units, water use per unit
- **Hydropower**: electricity demands
- **Ecosystems:** based on ecosystem needs

These demands were defined for six demand regions within the Syr Darya. An example of how these demands is represented in WEAP for each demand region is shown in Figure 1 below, where red circles represent water demands, green circles represent sub-catchments, green squares represent groundwater, blue dotted lines represent rainfall runoff and groundwater recharge, blue solid lines represent rivers and streams, orange lines represent canals, green lines represent surface water diversions and/or groundwater pumping, and red lines represent return flows.

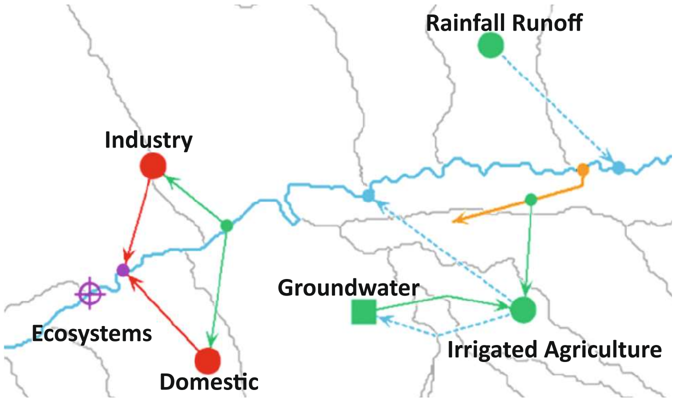


Figure 1. ***Representation of water demands in WEAP (screenshot of the WEAP model interface)***

The spatial disaggregation of the basin into sub-catchments for the purpose of modeling basin hydrology followed a similar approach. For this, we first identified the key locations for which we need to estimate river flows. These was primarily determined by existing and planned infrastructure, including dams and river abstraction locations, as well as the inflow locations of the main tributaries. This resulted in dividing the Syr Darya basin into fifteen sub-catchment area, which are presented below in Figure 2.

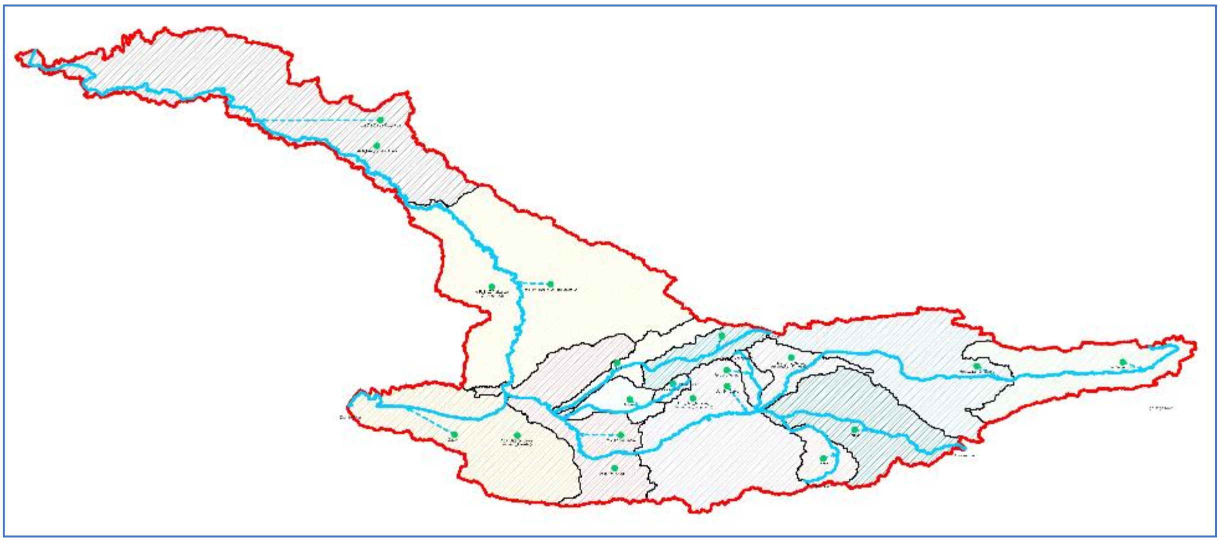


Figure 2. ***Spatial disaggregation of Syr Darya River basin into sub-catchments (screenshot of the WEAP model interface)***

1.2 Measures of Success

The resilience of a systems is expressed through performance metrics that are of the most interest for stakeholders. Metrics that are derived from WEAP or the associated macroeconomic model include:

- Coverage of demands by sector (percent of demand met)
- Unmet demands by sector (m3/year)
- Hydropower production (tJ/year)
- agricultural production (millions of kg)

- Industrial outputs (varies by sector)
- Impacts on the macro-economy (percent change in GDP)

Additional metrics can be added based on stakeholder inputs.

1.3 Critical Uncertainty: Climate Change

Syr Darya will need to develop strategic water plans that consider the deep uncertainty around climate change. For this study, we compiled projections of future climate from the Coupled Model Intercomparison Project Phase 6 (aka CMIP6), which represents the latest climate projections from a large number of Global Climate Models (GCM's) and is a substantial expansion over previous phases in terms of the number of experiments conducted.

These data show that for the period 2030 to 2050 the average annual temperature is expected to increase 1 to 2.5 degrees Celsius over the historical average of 14.1 degrees Celsius. The data also suggest that there is a range of possible outcomes concerning annual precipitation, with the majority of climate projections indicating more rainfall. However, some projections suggest that precipitation could decrease by as much as 10 percent, which indicates a need to prepare for both wet and dry years.

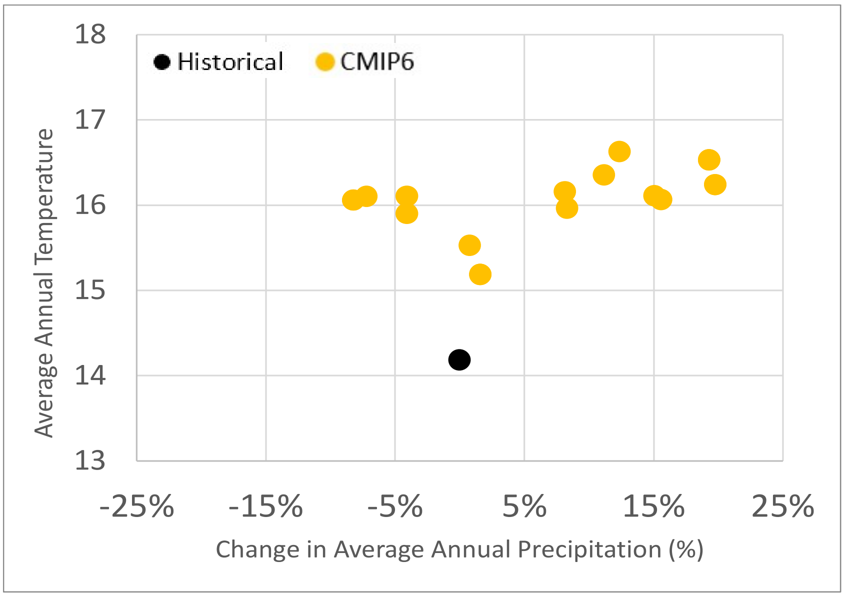


Figure 3. ***Historical rainfall and temperature relative to selected CMIP6 projections (2030-2050)***

1.4 Water Demands

WEAP is a demand-driven model and, as such, provides a lot of flexibility in how data can be structured to characterize water use. This can range from highly disaggregated end-use oriented data structures to highly aggregate analyses. Typically, the data will be organized around water use sectors, including households, industry, and agriculture, each of which might be broken down into different subsectors, end-uses and water-using devices. You can adapt the structure of the data to your purposes, based on the availability of data, the types of analyses you want to conduct, and your unit preferences. WEAP also allows for the creation of different levels of disaggregation in each demand site and sector.

There are 19 water demand sites in the WEAP model. These water demand sites are disaggregated by sectors (domestic, industry, and agriculture) and countries (Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan). Since key data on agriculture, population and industry is typically reported at the national and province levels, demand sites in WEAP were represented to closely resemble province boundaries. In some cases, data for different provinces was aggregated into one demand site in WEAP. This approach was also used by (Hunink, Lutz, and Droogers 2014) on a previous WEAP model for the region. The allocation of provinces to basins and WEAP demand sites was done based on the geographical location and information from CAWater-info.net, which reports water related statistics by country, province and basin. Water demand sites in WEAP are shown in Figure 4 and Table 1 below.

Table 1. ***Water demand sites***

Water demand	Kazakhstan (KAZ)	Uzbekistan (UZB)	Kyrgyz Republic (KGZ)	Tajikistan (TJK)
Domestic (DOM)	▪ DOM_KAZ_Kyzylorda ▪ DOM_KAZ_Turkestan_Shymkent	▪ DOM_UZB_Andijan_Namangan_Fergana ▪ DOM_UZB_SyrDarya_Tashkent_Jizzakh	▪ DOM_KGZ_Naryn_JalalAbat_Osh_Batken	▪ DOM_TJK_Sogd
Industry (IND)	▪ IND_KAZ_Kyzylorda ▪ IND_KAZ_Turkestan_Shymkent	▪ IND_UZB_Andijan_Namangan_Fergana ▪ IND_UZB_SyrDarya_Tashkent_Jizzakh	▪ IND_KGZ_Naryn_JalalAbat_Osh_Batken	▪ IND_TJK_Sogd
Agriculture (AGR)	▪ AGR_KAZ_Kyzylorda ▪ AGR_KAZ_Turkestan_Shymkent	▪ AGR_UZB_Andijan_Namangan_Fergana ▪ AGR_UZB_SyrDarya_Tashkent_Jizzakh	▪ AGR_KGZ_Naryn_JalalAbat_Osh_Batken	▪ AGR_TJK_Sogd

All of the demand data sources are given in Appendix 2.A.

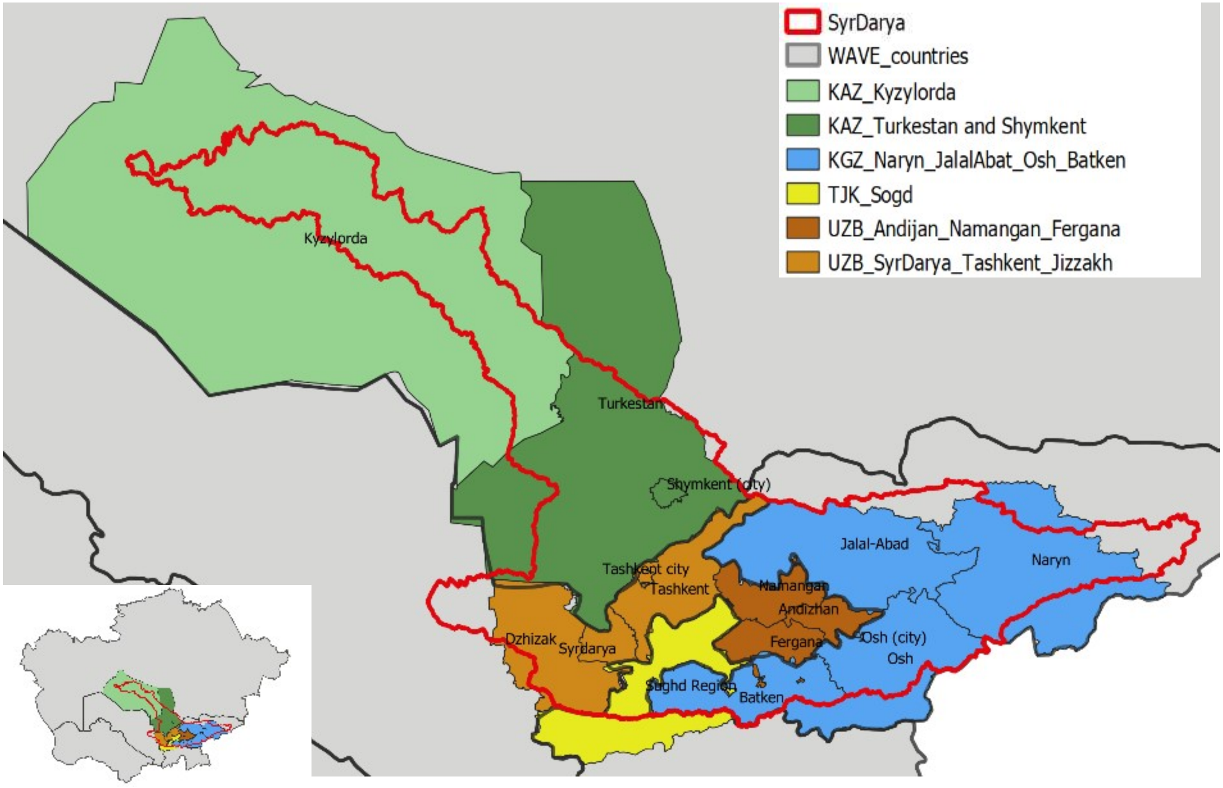


Figure 4. ***Division of provinces over WEAP demand sites (screenshot of interface in ArcGIS)***

1.4.1 Allocation to Water Users

WEAP uses a system of priorities to determine allocations from supplies to demand sites and catchments, for instream flow requirements, filling reservoirs, and generating hydropower. For the Syr Darya model, we used a two-tier priority structure in which the first tier was determined by water users' position within the watershed and the second tier was based on water use sectors. In this configuration, water users in the upper part of the basin were given the highest priority (assuming that they would choose to use available supplies before releasing water downstream) and within a demand region domestic demands have the highest priority, followed by hydropower, agriculture, industry, water storage, and ecosystem. The demand priority structure is described in Table 2.

Table 2 ***Demand priority structure in WEAP***

	Kyrgyz Republic	Uzbekistan Upper (Andijan-Namangan-Fergana)	Tajikistan	Uzbekistan Lower (SyrDarya-Tashkent-Jizzakh)	Kazakhstan Upper (Tuekestan-Shymkent)	Kazakhstan Lower (Kyzylorda)
Domestic	1	11	21	31	41	51
Hydropower	2	12	22	32	42	52
Irrigation	3	13	23	33	43	53
Industrial	3	13	23	33	43	53
Ecosystems	99	99	99	99	99	99
Storage	6	16	26	36	46	56

1.4.2 Domestic

Domestic water demands are estimated based on an activity level (population) and a water intensity (annual water use per capita). Demographic drivers are aligned between WEAP and LEAP models.

Historical population (1970-2021) by province was taken from National Statistics Agencies. Population in each WEAP demand site was estimated by aggregating corresponding provinces. National population projections based on UN World Population Prospects (2019). For each country, the same growth rates were applied to each province.

Annual water use rates were obtained by residential water use per capita from OECD (2020) (see Table 3). Based on (Hunink, Lutz, and Droogers 2014), the effective domestic consumption is estimated in 10%, which means that 90% of the water is returned to the system and available downstream (see Figure 5).

Table 3. *Annual domestic water use rate*

Country	Annual domestic water consumption per capita (m^3/capita)
Kazakhstan	48.6
Kyrgyzstan	32.6
Tajikistan	83.3
Uzbekistan	86.3

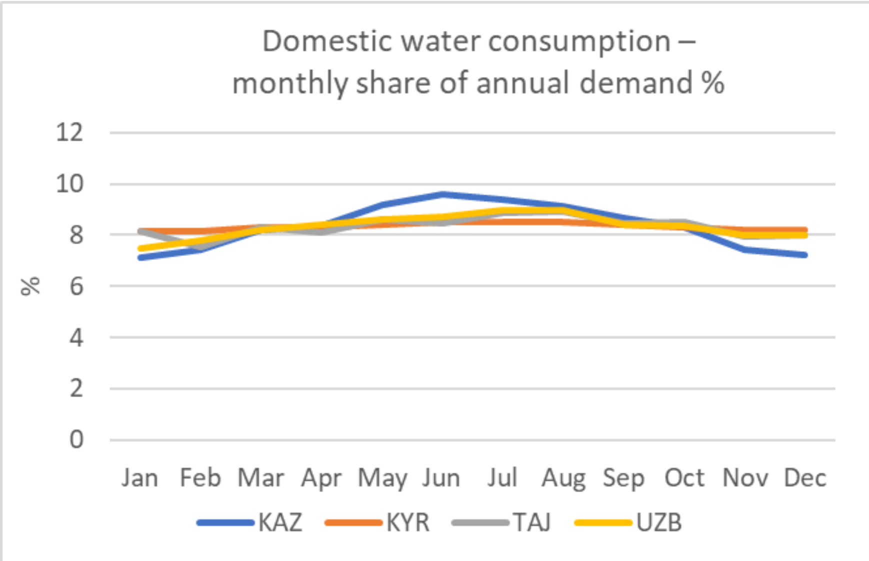


Figure 5. ***Monthly share of annual demand for domestic water consumption***

Historical water demands in the WEAP model are lower than the reported water demands in CAWater-Info.net, particularly for Uzbekistan (see Figure 6). WEAP results reflect historical population and water use rates from (OECD, 2020). For Uzbekistan, the annual domestic water consumption per capita calculated from CAWater (1980-1995) is in the range of 207-180 m3/cap, compared to 86.3 m3/cap reported by (OECD, 2020).

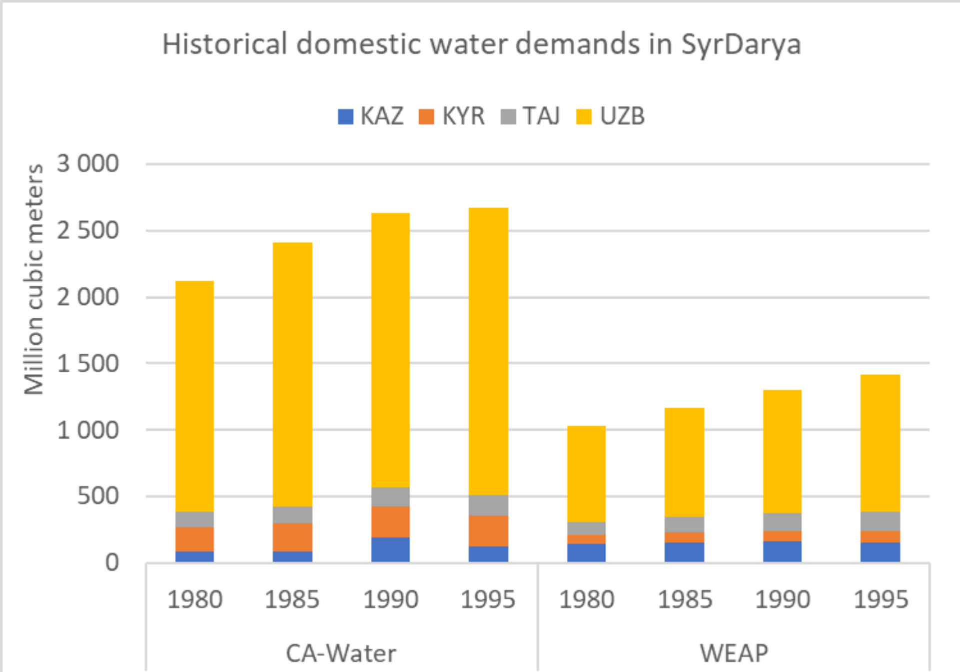


Figure 6. ***Historical domestic water demands in Syr Darya***

1.4.3 Industry

Industrial water demands are estimated based on an activity level (industrial value added) and a water intensity (annual water use per unit of industrial value added). Water withdrawals for power plant cooling are included within the industrial water demands (i.e., at the moment, individual thermal power plants are not represented separately). Macroeconomic drivers are aligned between WEAP and LEAP models.

Historical GDP (2020 USD) and industrial value added (%) for each country were obtained from National Statistics Agencies, and the World Bank. GDP and sectoral value added are projected based on World Economic Outlook (2021) and an extrapolation of historical trends. Contribution of each province to the national industrial value added was estimated based on gross regional product by type of economic activity reported in National Statistics Agencies and other international sources. Industrial value added in each WEAP demand site was estimated by aggregating corresponding provinces.

Annual water use per unit of industrial value added (m3/$) was estimated based on Aquastat (2022) industrial water withdrawals (see Table 4). Based on Aquastat (2022), the effective consumption is estimated in 5% (see Figure 7).

Table 4. ***Annual industrial water use rate***

Country	Annual industrial water consumption per unit of industrial value added (m^3/USD)
Kazakhstan	0.097
Kyrgyzstan	0.166
Tajikistan	0.795
Uzbekistan	0.158

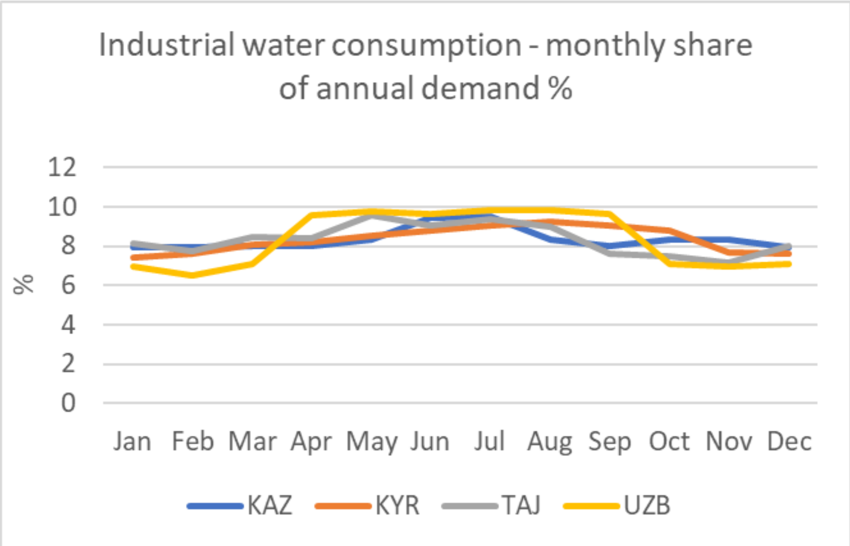


Figure 7. ***Monthly share of annual demand for industrial water consumption***

Historical water demands in the WEAP model are lower than the reported water demands in CAWater-Info.net, particularly for Uzbekistan (see Figure 8). WEAP results reflect historical GDP and industrial value added, as well as water use rates from (AQUASTAT, 2022). For Uzbekistan, the annual industrial water consumption per unit of industrial value added calculated from CAWater (1980-1995) is in the range of 1.1-1.4 m3/USD, compared to 0.158 m3/USD based on (AQUASTAT, 2022).

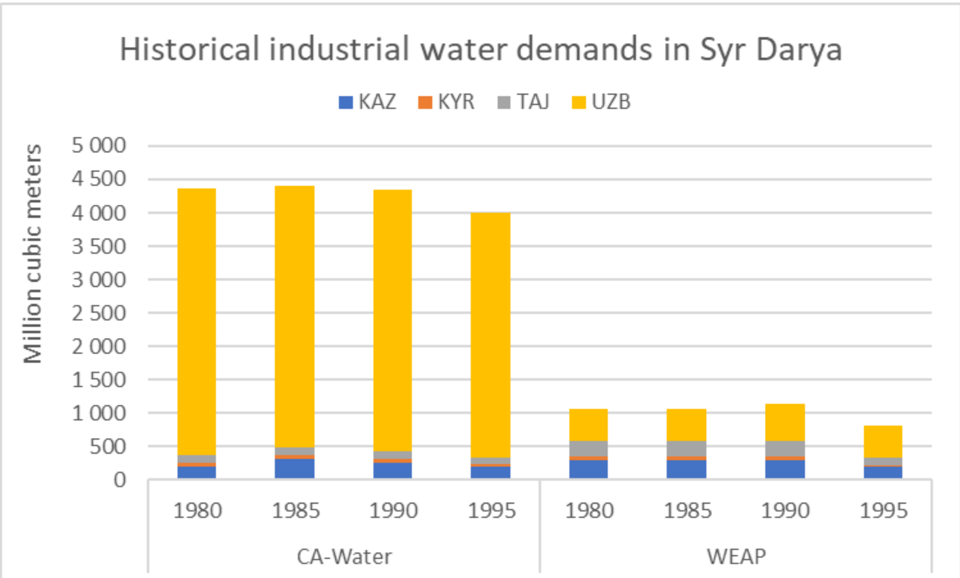


Figure 8. ***Historical industrial water demands in the Syr Darya River Basin***

1.4.4 Agriculture

1.4.4.1 MABIA

To better represent the agriculture sector in the model, the MABIA method of determining crop demands was utilized. The MABIA-WEAP package allows for daily simulation of evapotranspiration, irrigation needs, and other climatic and crop-specific variables. The method estimates reference evapotranspiration (ET_{ref}) and soil water capacity. One of the main improvements with introducing MABIA is the utilization of the dual crop coefficient (K_c) method. K_c is divided into two components; the basal crop coefficient, K_{cb} and evaporation representation factor, K_e. This separation of transpiration and evaporation allows for representing actual ET conditions under dry surface with sufficient root zone moisture.

Crop coefficients were estimated for each crop and month, based on the typical planting dates and growing stages of the crop (see Figure 9). Main sources include FAO Irrigation and Drainage Paper 56 (Allen et al. 1998), a regional study for Central Asia (Liu, Luo, and Wang 2020), and the Irrigated Crop Calendars Database from FAO (AQUASTAT, 2022). For crop categories that group multiple crops, a representative crop was selected based on the total area harvested by individual crops in the category (see Table 5).

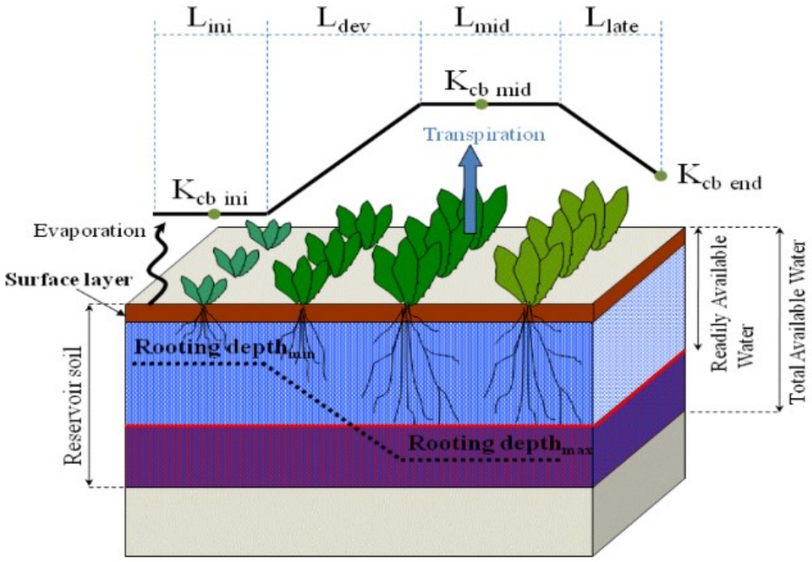


Figure 9. ***Conceptual illustration of MABIA showing root growth and variation of crop coefficients (Kcb) during the growing season***

The details of the WEAP-MABIA model validation are presented in Appendix 2.D

Table 5. ***Crop coefficients (Kc) and crop calendars***

Crop category in WEAR	Kc									Planting date	Representative crop
	Ke ini	Kc rapid growth period	Kc mid	Kc end	Initial	Development	Mid-season	late	Total		
Apples	0.75	0.95	1.15	0.8	20	70	120	60	270	15-Mar	Apples, Cherries, Pears (active ground cover, no frosts) (Low latitudes)
Barley	0.35	0.75	1.15	0.45	15	24	45	24	108	15-Apr	Spring wheat/Barley/Oats
Corn	0.4	0.80	1.15	0.7	19	34	40	30	123	1-Jun	Maize
Cotton	0.45	0.75	1.15	0.75	30	50	55	45	180	10-Apr	Cotton
Grapes	0.15	0.48	0.8	0.4	20	50	75	60	205	15-Mar	Grapes (Table) (Calif., USA)
Oil seeds and pulses	0.15	0.63	1.1	0.25	25	35	45	25	130	1-May	Sunflower (Medit.; California)
Other crops	0.15	0.63	1.1	0.25	15	25	35	20	95	15-Jun	Beans (dry) (Pakistan, Calif.)
Other grains	0.35	0.75	1.15	0.45	15	24	45	24	108	15-Apr	Spring wheat/Barley/Oats
Other orchards	0.75	0.93	1 1	0.8	20	70	120	60	270	15-Mar	Apricots, Peaches, Stone Fruit (active ground cover, no frosts) (Low latitudes)
Potatoes	0.15	0.63	1.1	0.65	25	30	45	30	130	15-May	Potato (Continenta Climate)
Rice	1.05	1.10	1.2	0.8	30	30	61	29	150	10-May	Rice
Sugar beet	0.15	0.65	1.15	0.5	35	60	70	40	205	1-Nov	Sugarbeet (Arid regions)
Vegetables	0.15	0.55	0.95	0.95	20	35	110	45	210	1-Oct	Onion (dry) (Arid Region; Calif.)
Watermelons and squash	0.15	0.55	0.95	0.7	10	20	20	30	80	15-May	Watermelons (Near East (desert))
Wheat (spring)	0.35	0.75	1.15	0.45	15	24	45	24	108	15-Apr	Spring wheat/Barley/Oats
Wheat (winter)	0.35	0.75	1.15	0.45	170	30	54	30	284	1-Oct	Winter wheat

1.4.4.2 *Crop categories*

The 15 crop categories listed above in Table 5 reflect the most important crops in each country, while also reconciling crop categories reported by National Statistics Agencies, and by international data sources like FAO and CAWater-info.net.

Additional information about crop categories can be found in Appendix C.

1.4.4.3 *Harvested areas*

For each country, areas harvested by crop type and by year (1995-2020) were obtained from FAOSTAT (2022). Agricultural land by crop was allocated to each WEAP demand site based on statistics at the province level, reported by the National Statistics Agencies and CAWater-info.net

The total irrigated area within the Syr Darya River Basin over the historical period from 1995 to 2020 is shown for each of the six demand regions below in Figure 10. As of 2020, the total irrigated area within the basin was approximately 3.314 million hectares. Uzbekistan, at 42 percent, held the greatest share of irrigated area, followed by Kazakhstan (36 percent), Kyrgyzstan (12 percent), and Tajikistan (10 percent).

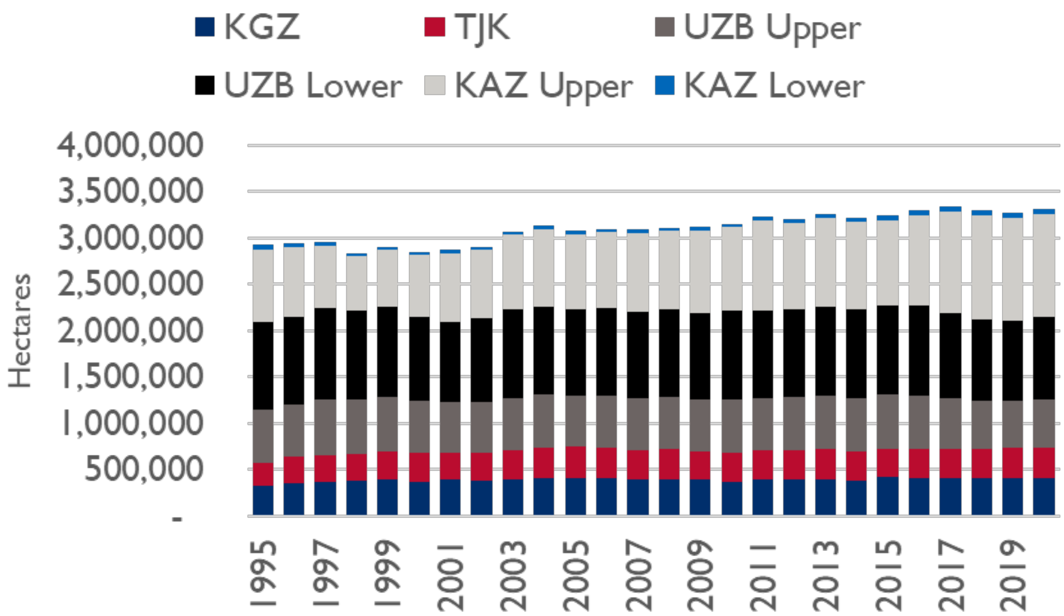


*Figure 10. **Total cropped area within the Syr Darya Basin by demand region***

These same data are presented in Figure 11 by crop type. These data indicate that wheat represents the greatest share of area at 31 percent, followed by cotton (22 percent), oil seeds and pulses (10 percent), barley (7 percent), vegetables (6 percent), and all others having four percent or less of the shared area.

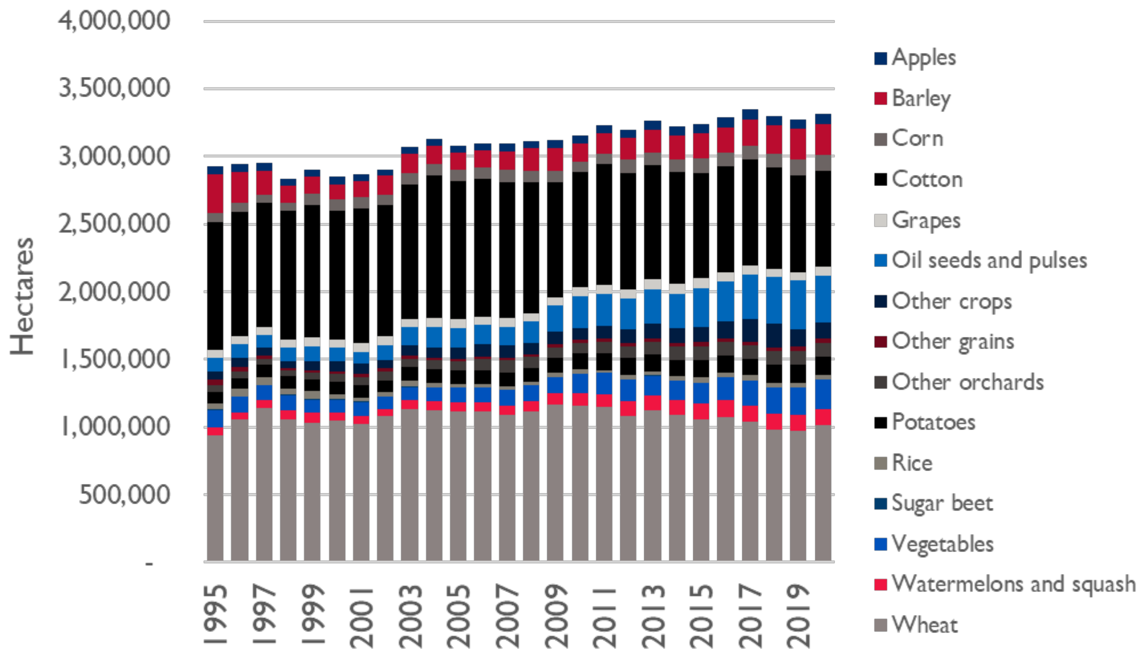


Figure 11. ***Total cropped area within the Syr Darya basin by crop***

1.4.4.4 Potential evapotranspiration

Reference evapotranspiration is an estimation of ET from a reference surface that is hypothetical assuming specific crop and surface characteristics (Allen et al., 1998). MABIA estimates ET_{ref} using the FAO Penman-Monteith equation. This approach requires daily climatic data that represent the region of study. These data were obtained from the Terrestrial Hydrology Research Group at Princeton University, which provides a gridded dataset of bias-corrected, downscaled data constructed from a suite of global observation-based datasets (Sheffield et al., 2006)

1.4.5 Other main assumptions

Model assumes all cultivated land is irrigated from surface water sources. Prospective narratives assume no change in the harvested areas. No multi cropping is considered.

1.5 Water Supplies

1.5.1 Climate

The Syr Darya WEAP model was developed and calibrated using a reconstruction of the historical climate data, 1948-2008, developed by the Terrestrial Hydrology Research Group at Princeton University (Sheffield et al., 2006). These data include climate sequences of daily temperature and precipitation, spatially averaged for each hydrologically connected catchment. These data were aggregated to monthly values for the purpose of calculating basin hydrology and they also served as a baseline climate for the scenario analysis, in which they are referred to as the *Historical* climate condition.

1.5.2 Glaciers

The WEAP model includes an optional glacier module that can account for the accumulation and melt of ice on the land surface. This module was used to track changes in the depth and volume of ice in the upper regions of the Syr Darya River Basin.

Randolph Glacier Inventory 6.0 (2017) was used to set initial conditions for glaciers. Extent of glaciers was derived from Snow and Ice data within ESA land cover dataset. Depth of ice increases or decrease as old snow transforms into ice or existing ice melts. Snow which has not melted transforms into ice. Ice only melts if there is no snow covering it and the temperature is above a threshold. Glaciers were estimated by Depth, Volume, Melt and Accumulation.

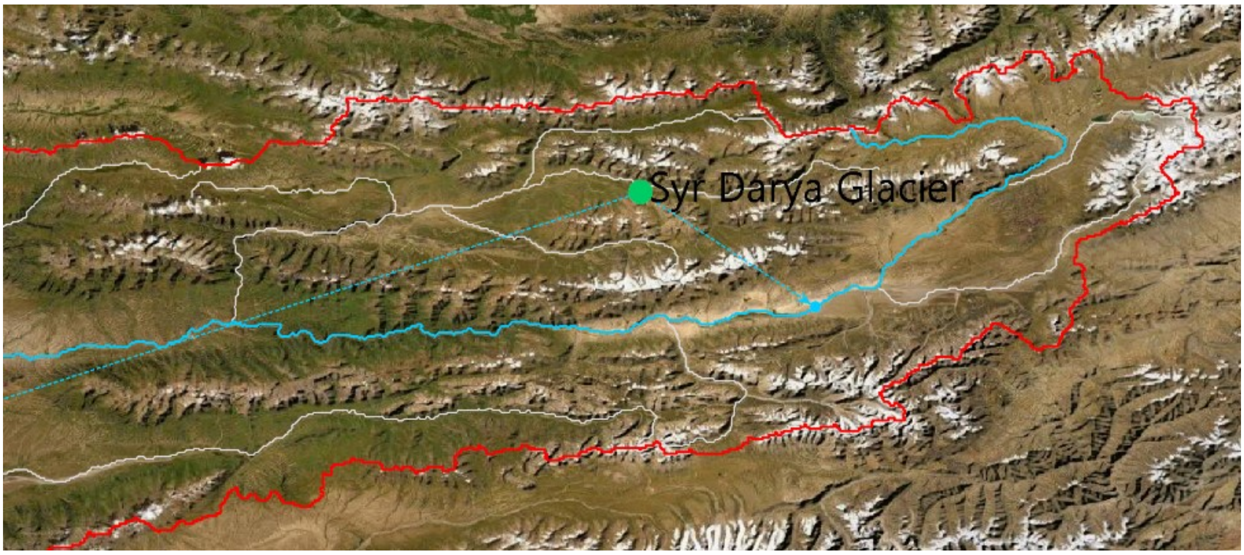


Figure 12. ***Representing Syr Darya Glacier in WEAP (screenshot of the WEAP model interface)***

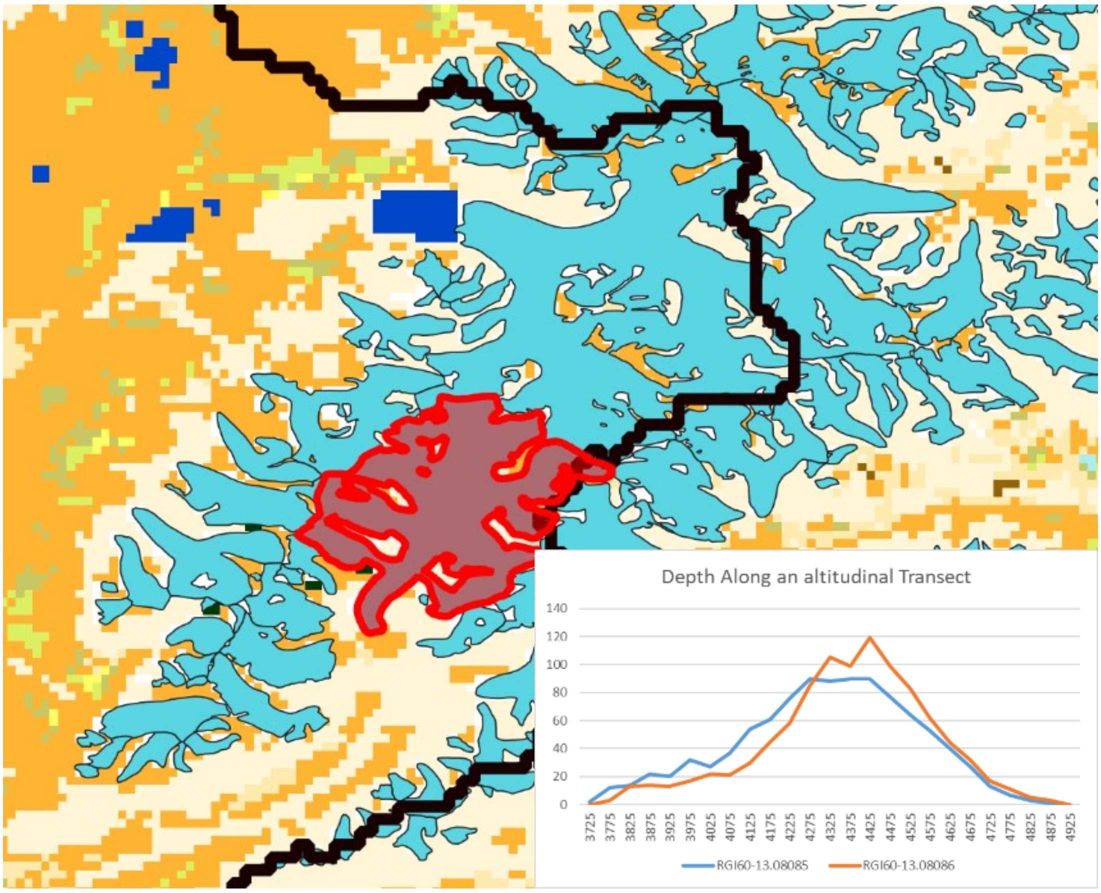


Figure 13. ***Syr Darya Glacier Depth along an altitudinal Transect (screenshot of interface in ArcGIS)***

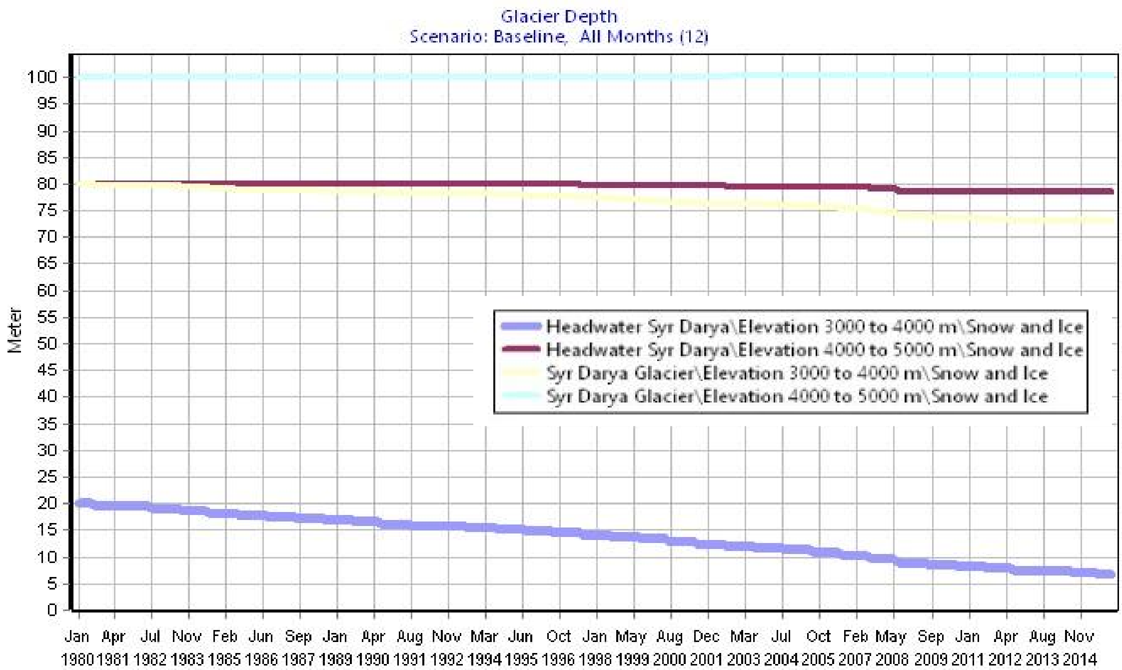


Figure 14. ***Syr Darya Glacier Depth in the baseline during 1980 - 2014 (screenshot of the WEAP model interface)***

Ice melting point (see Figure 15) and radiation coefficient were adjusted to calibrate the glacier melt to observed streamflow. Figure 16 shows observed and simulated Toktogul inflows by WEAP with and without glaciers. We find that WEAP with glaciers improves the model performance in simulating stream flows, especially the falling limb of hydrograph (see Figure 16).

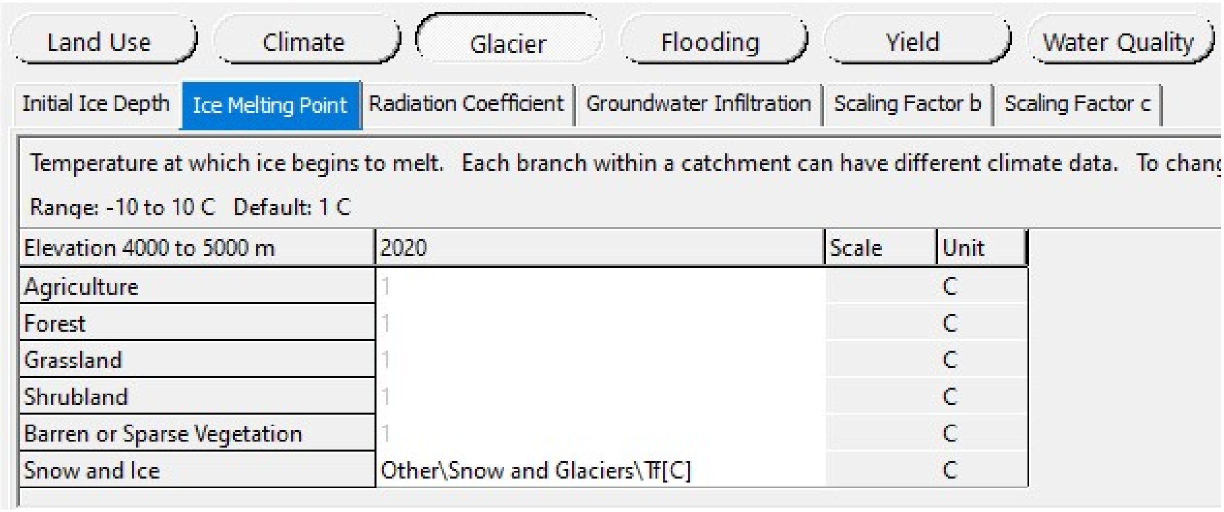


Figure 15. ***Ice melting point in WEAP model (screenshot of the WEAP model interface)***

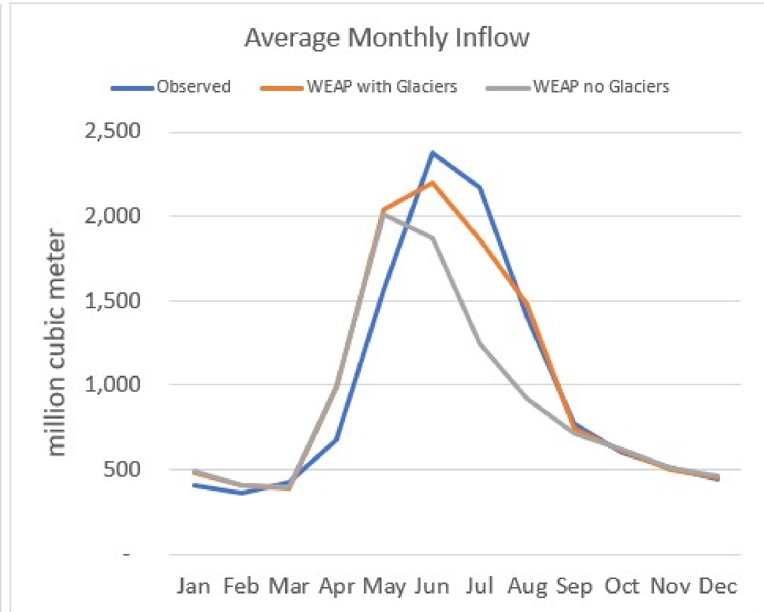


Figure 16. ***Comparison of WEAP with and without glaciers for simulating the Toktogul inflow***

1.5.3 Rainfall-Runoff

For the Syr Darya WEAP model, 15 sub-catchments were created that represent the spatial extent of the main tributaries and reaches of the Syr Darya River. These were subdivided into a unique set of independent land use/land cover classes based on land cover maps (European Space Agency, 2017).

The land cover map indicates that irrigated agriculture is the predominant land cover at lower elevations (zero to 2000 m), accounting for approximately 75 percent of the surface area between zero and 1000 meters and 43 percent of the area between 1000 and 2000 meters (see Figure 17 below). Forests and grasslands become more predominant as elevation increases up to about 5000 meters. Above 5000 meters, the main land classes are grasslands (47 percent), barren (46 percent), and snow and ice (7 percent). These data suggest that the hydrological response is controlled by different land covers throughout the basin, which is factored into the calibration. The details of the calibration of the hydrological model are presented in Appendix 2.E.

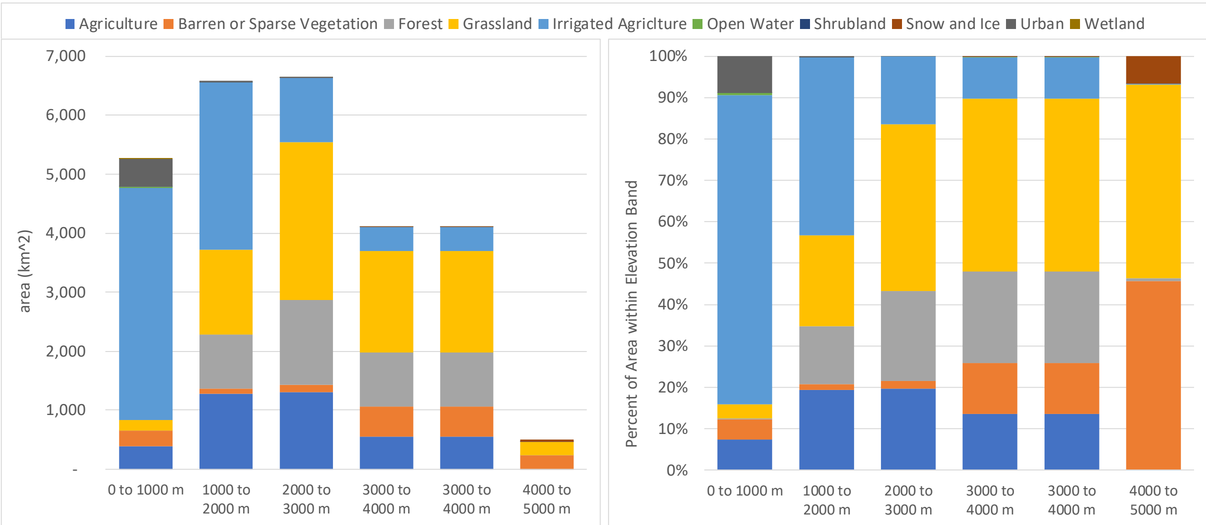


Figure 17. ***Land cover within each elevation band (Km2 and % of total)***

1.6 Hydropower

The WEAP model can be used to evaluate hydropower generation within a basin, considering both plants with fixed heads (i.e. run-of-river) and variables heads (i.e. generated as releases from a reservoir). Hydropower generation is computed from the flow passing through the turbine, based on the reservoir release or run-of-river streamflow, and constrained by the turbine's maximum flow capacity. The amount of energy produced is a function of the mass of water through the turbines multiplied by the drop in elevation (i.e. head), as well as the generating efficiency and plant factor (percent of time in operation), which are entered as data.

The WEAP model for the Syr Darya River Basin includes the following existing and planned facilities:

Hydropower facility	Installed Capacity (MW)	
	202	203
Akhangaran reservoir	21	21
Andijan Reservoir	190	190
At Bashi RoR	40	44
Charvak cascade	905	905
Chirchik_cascade	191	191
Farkhad reservoir	126	126
Kambarata II	120	360
Kambarata_I	0	1860
Kayrakkum reservoir	126	174
Kazarman RoR	0	1160
Kokomeren RoR	0	1305
Kurpsaiskaja	824	824
Papan reservoir	24	24
Shardara reservoir	126	126
Taschkumyrskaja_casca	870	906
Toktogul reservoir	1228	1440
Upper Naryn RoR	0	238
Sum	**4,791**	**9,893**

2 Entering Narratives in WEAP

Six narratives were explored with the WEAP model of the Syr Darya. These included a baseline narrative, representing current conditions and rules surrounding the management of water and energy resources within the basin, and five narratives that considered how resources management might change in the future. Following the baseline, there were three narratives (numbered 2, 3, and 4) that considered the national plans around water, agriculture, and energy while maintaining the status quo in how resources are shared between the basin countries. The final two narratives (numbered 5 and 6) considered how each country's targets relating to water, agriculture, and energy may change if resources are shared more readily between countries. The starting point of each narrative uses the narrative that precedes it, such that narrative 2 includes all of the modeling assumptions made in narrative 1, narrative 3 includes all of the modeling assumptions made in narrative 2, and so on. The implementation of these narrative is summarized in Table 6 below and described in the sections below.

Table 6. ***Summary of implemented narratives***

Narrative	Hydropower	Agriculture	Water Allocation	Ecosystems
Narrative 1: Baseline	Expanded capacity for 4 hydropower plants	Crop areas fixed at 2020 levels. Yields follow past trends	Set in accordance with national priorities	Lowest priority
Narrative 2: National Interest	Baseline plus 4 new hydropower plants	Baseline plus shift to higher value crops in KAZ and UZB	Same as above	Same as above
Narrative 3: Water&Agriculture improvements	Same as above	Narrative 2 plus a range of investments to improve water use and yield	Same as above	Same as above
Narrative 4: Energy & Climate improvements	*Informed by LEAP model*	Same as above	Same as above	Same as above
Narrative 5: Cooperation	Same as above	Same as above	Dams in upper basin release to meet all downstream demands	Same as above
Narrative 6: Ecosystems	Same as above	Same as above	Same as above	Highest priority

2.1 Narrative 1: Baseline

This narrative represents business-as-usual. Most features of the WEAP model are fixed. However, domestic demands continue to change with increasing population as projected by the UN Department of Economic and Social Affairs (2019) and industrial demands grow with expected growth in GDP consistent with the assumptions of the MacroEconomic model. The WEAP model also considers expansion of hydropower at Toktogul (from 1228 to 1436 MW), Tashkumyr (from 870 906 MW), At Bashi (40 to 44 MW), and Kambarata II (from 120 to 159 MW).

2.2 Narrative 2: National Interests

This narrative expanded upon narrative 1. It considered that each basin country will pursue its own agendas concerning the development of water, agriculture, and energy resources. This included the expansion of hydropower in Kyrgyzstan with the development of Kambarata I (1860 MW), the Kazarman cascade (1160 MW), the Kokomeren cascade (1305 MW), and the Upper Naryn cascase (238), which are each introduced into the model in the year 20230. This narrative also considered the stated objectives of both Uzbekistan and Kazakhstan to increase the share of agriculture to their GDP. Within the WEAP model, this was represented as a shift away from wheat as the primary crop to a higher valued crop, fruit orchards. The modeling assumption was to transition 50 percent of the existing land grown for wheat to orchards by the year 2050 in both countries.

2.3 Narrative 3: Water and Agriculture Improvements

This narrative assumes that the countries of the Syr Darya basin focus on improvements in agricultural practices that lead to more efficient use of water resources. Irrigation systems are rehabilitated and modernized, new crops and cropping patterns are introduced, and water-efficient equipment is deployed at scale. This was informed by national development plans from each country.

Kazakhstan aims to expand the cropped area under drip irrigation, while also increasing crop yields by at least 10 percent by 2030. Within the WEAP model, this was represented by increasing irrigation efficiencies from 55 to 80 percent for orchards, 55 to 70 percent for rice, and 65 to 80 percent for vegetables. A growth factor was applied to all crops such that the potential yields increase by 10 percent over 2020 levels by the year 2030.

Kyrgyzstan aims to increase the amount of land in production by four percent and add 487 million cubic meters of additional storage for irrigation by 2030. Within WEAP, the expansion of cropped areas was applied uniformly for all crops and additional storage was introduced in the year 2030.

Tajikistan aims to double agricultural water productivity in irrigated systems, while expanding the cropped area by ten percent. Improved water productivity can be achieved through a combination of adopting improved irrigation technologies, loss reduction, and improved crop varieties. The WEAP model considered that by 2030 Tajikistan would increase potential crop yields by 10 percent and reduce canal losses by 25 percent, and improve overall irrigation efficiencies for orchards (from 55 to 65 percent), vegetables (from 65 to 70 percent), grains (from 55 to 60 percent), and rice (from 55 to 60 percent). Expansion in cropped areas was applied uniformly for all crops.

Uzbekistan aims to expand cropped area by as much as ten percent, while improving agricultural water productivity using a combination of canal loss reduction, improved irrigation efficiency, shifting cropping patterns, and farming practices that increase yields. The improved productivity objective will be at least partially met by transitioning half of the area currently used to grow wheat to orchards as described under narrative 2. The additional interventions include reducing conveyance losses by 25 percent and increasing potential yield by five percent by 2030, as well as increasing irrigation efficiency for orchards (from 55 to 75 percent by 2030), vegetables (from 65 to 80 percent by 2030), grains (from 55 to 75 percent by 2030), and rice (from 55 to 75 percent by 2030).

2.4 Narrative 4: Energy and Climate Improvements

This narrative focused primarily on assumptions within the LEAP model. As such, it did not require any changes in WEAP.

2.5 Narrative 5: International (regional) Cooperation

This narrative adds assumptions about enhanced international cooperation on water, energy, and agricultural issues. It explores the gains that can be realized through improved transboundary coordination and exchange of resources in these sectors. This is represented within the WEAP model by altering the priority structure that was presented in Table 6. Now, instead of using a two-tiered structure based on location within the basin and water use sector, the priorities are set based on water use sector only, such that domestic water use has the highest priority, followed by hydropower, irrigation and industry (who share the same priority), storage, and finally ecosystems.

2.6 Narrative 6: Ecosystem Restoration

The final narrative assumes that the minimum flow requirements needed to sustain the health of the North Aral Sea are satisfied. This is accomplished in WEAP by adjusting the priority structure used in narrative 5. Now, domestic water use is given the highest priority followed by ecosystems, hydropower, irrigation and industry, and finally storage. Flow requirements were set at the border between each country and were established using the Flow Duration Curve (FDC) Shift method, which takes into account the extent to which the original ecological condition of a river has been altered from its natural reference condition. This method considers five Ecological Management Classes (EMC):

- Class A = natural (unmodified) ; protected rivers and basins, reserves and national parks with minor modification of in-stream and riparian habitat, where no new dams or diversions allowed
- Class B = largely natural conditions ; slightly modified and/or ecologically important rivers where small water supply development schemes are allowed
- Class C = moderately modified, where the modifications are such that they generally have a limited impact on the ecosystem integrity, although sensitive species are impacted.
- Class D = largely modified ecosystems, where sensitive biota in particular are reduced in numbers and expanse and where community structure is substantially but acceptably changed.
- Class E = Seriously modified ecosystems, in poor condition where most of the ecosystem's functions and services are lost. This class is considered unacceptable from a management perspective as it represent ecosystems that are being used unsustainably

Flow requirements were configured using Environmental Management Class D.

Annex 2.A: Data Sources

Data sources for water demand

- **National Statistics Agencies:**
  - Historical data on population, GDP, value added, gross regional product, agricultural lands by crop and province
  - Agency for Strategic Planning and Reforms of the Republic of Kazakhstan Bureau of National Statistics (2021); National Statistical Committee of the Kyrgyz Republic (2021); Agency on Statistics under President of the Republic of Tajikistan (2021); Republic of Uzbekistan State Statistical Committee (2022)
- **CAWater-info.net**
  - Historical (1980-1995) monthly water intakes by sector and province
  - Historical gross regional product by type of economic activity
  - Historical agricultural land by crop and province
- **Demographic and macroeconomic drivers:**
  - *Population:* UN World Population Prospects (2019)
  - *Historical GDP:* World Bank GDP Current US$ (2020)
  - *GDP projections:* IMF World Economic Outlook (2021)
- **Water intensities and consumption fractions**
  - Aquastat (2022), *Domestic:* OECD. 2020. *Overview of the Use and Management of Water Resources in Central Asia: A Discussion Document.*
  - Hunink, J. E., A. Lutz, and P. Droogers. 2014. Regional Risk Assessment for Water Availability and Water-Related Energy Sector Impacts in Central Asia. FutureWater Report: 196.
- **Agriculture**
  - Harvested areas by crop: FAOSTAT (2022)
  - Crop coefficients and calendars:
    - Allen, Richard G., Luis S. Pereira, Dirk Raes, and Martin Smith. 1998. Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements - FAO Irrigation and Drainage Paper 56. Rome, Italy: Food and Agriculture Organization of the United Nations
    - Liu, Shuang, Geping Luo, and Hao Wang. 2020. "Temporal and Spatial Changes in Crop Water Use Efficiency in Central Asia from 1960 to 2016." Sustainability 12(2):572.

- FAO. 2022. “GIEWS - Global Information and Early Warning System - Country Briefs.”

- FAO. 2022. “AQUASTAT - Irrigated Crop Calendars Database.”

– Irrigation efficiency: Dukhovny and Schutter (2011). *Water in Central Asia*

– Crop water use rates *(m3/ha)*: Dukhovny and Schutter (2011). *Water in Central Asia*

- **Climate data**

Terrestrial Hydrology Research Group. Princeton University. High-resolution global climate dataset

Annex 2.B: WEAP

System Capabilities

WEAP is an integrated water resources planning tool that is used to represent current water conditions in a given area and to explore a wide range of demand and supply options for balancing environment and development objectives. WEAP is widely used to support collaborative water resources planning by providing a common analytical and data management framework to engage stakeholders and decision-makers in an open planning process. Within this setting, WEAP is used to develop and assess a variety of narratives that explore physical changes to the system, such as new reservoirs or pipelines, as well as social changes, such as policies affecting population growth or the patterns of water use. Finally, the implications of these various policies can be evaluated with WEAP's graphical display of results.

WEAP is a widely used modelling platform for water security studies. It takes into consideration supplies and demands, with many built-in models around hydrology, water quality, groundwater and climate. WEAP can links to external models as well. But WEAP is not designed to address hydraulic models of pipelines, for example, nor is it an optimization tool, unless linked to an external platform, such as GAMS or Excel.

Modelling Approach

The development of all WEAP applications follows a standard approach, as illustrated in Figure 18. The first step in this approach is the *Study Definition*, wherein the spatial extent and system components of the area of interest are defined and the time horizon of the analysis is set. The user subsequently defines system components (e.g., rivers, agricultural and urban demands) and the network configuration connecting these components. Following the study definition, the *Current Accounts* are defined, which is a baseline representation of the system – including existing operating rules to manage both supplies and demands. The current accounts serve as the point of departure for developing *Narratives*, which characterize alternative sets of future assumptions pertaining to regulations, infrastructure, water demands, and water supplies. Finally, the scenarios are *Evaluated* regarding water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables. In this context, scenarios represent evaluations of water management alternatives under uncertain future conditions. The steps in the analytical sequence are described in greater detail in the following sections.

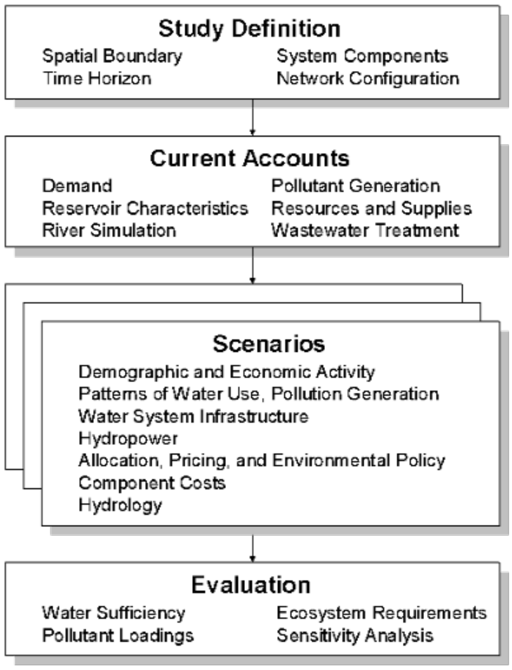


Figure 18. ***Steps in Developing and Applying a WEAP model***

One of the main strengths of WEAP is its flexibility in the way in which it can be adapted to the needs of a particular water system. Starting with the *Study Definition*, WEAP can be set up to consider a range of spatial and temporal scales. It has been used to evaluate daily water usage patterns at the municipal scale in Bangalore, India as well as to evaluate the impact of long-term climate change and the implications on trans-boundary water sharing agreements in the Nile River basin.

This flexibility carries through to the data types that are used to define the *Current Accounts*. This step typically begins with defining water supplies, which can be entered into the model in a variety of ways, including constant inflows, reading in historical streamflow values from files, or using climate inputs to simulate watershed hydrology (i.e. rainfall-runoff, infiltration, groundwater recharge, stream-aquifer interactions, etc.). Similarly, WEAP demand nodes can be set up to consider a range of water users, including domestic, industrial, agriculture, livestock, inter=basin transfers, etc. Additionally, each water use type can be disaggregated to best represent water use dynamics. For example, domestic demands are often defined based on population and per capita water use rates. However, in situations where it is important to consider the drivers of household water use, it is possible to disaggregate demands such that these drivers (e.g. toilets, showers, washing machines, outdoor watering, etc.) are explicitly considered. This is also common for agricultural demands, where agricultural areas can be divided between different crop types, and crop types may be further refined to reflect different irrigation practices.

Another way in which WEAP offers flexibility is through its ability to link to external models. This linkage can be either a 'soft' linkage, in which the models are run independently and then outputs are shared such that they become inputs to the other, or a 'dynamic' linkage, in which the models are run concurrently, and data is passed between models at regular intervals during simulation.

Model Setup

WEAP models are constructed using a collection of model objects (Figure 19) to represent the water system. Each object is programmable, allowing users to specify rules that control patterns of water supply and usage.

Figure 19. ***Model objects in WEAP (screenshot of the WEAP model interface)***

WEAP Calculation

At each time step, WEAP first computes the hydrologic flux, which it passes to each river. The water allocation is then made for the given time step, where constraints related to the characteristics of reservoirs and the distribution network, environmental regulations, and the priorities and preferences assigned to points of demands are used to condition a linear programming optimization routine that maximizes the demand "satisfaction" to the greatest extent possible. All flows are assumed to occur instantaneously; thus a demand site can withdraw water from the river, consume some, and optionally return the remainder to a receiving water body in the same time step. As constrained by the network topology, the model can also allocate water to meet any specific demand in the system, without regard to travel time. Thus, the model time step should be at least as long as the residence time of the study area. For this reason, a monthly time step was adopted for this HEA study.

Water Allocation

WEAP is a demand-driven model, which uses a hierarchical priority structure to determine the order in which water supplies are allocated to different water users. Two user-defined priority systems are used to determine allocations of water supplies to meet demands (modelled as demand sites and as catchment objects for irrigation), instream flow requirements, and for filling (or draining) reservoirs. These are: (1) demand priorities, and (2) supply preferences.

A demand priority is attached to a demand site, catchment, reservoir, or flow requirement, and may range from 1 to 99, with 1 being the highest priority and 99 the lowest. Demand sites can share the same priority, which is useful in representing a system of water rights, where water users are defined by their water entitlement and/or seniority. In cases of water shortage, higher priority users are satisfied as fully as possible before lower priority users are considered. If priorities are the same, shortage will be shared equally (as a percentage of their water demands).

When demand sites or catchments are connected to more than one supply source, supply preferences determine the order of withdrawal. Like demand priorities, supply preferences are assigned a value between 1 and 99, with lower numbers indicating preferred water sources. The assignment of these preferences usually reflects economic, environmental, historical, legal, and/or political realities. Several water sources may be available when a preferred water source is insufficient to satisfy all of an area's water demands. WEAP treats additional sources as supplemental supplies and will draw from these sources only after it encounters a capacity constraint (expressed as either a maximum flow volume or a maximum percent of demand) associated with a preferred water source.

WEAP's allocation routine uses demand priorities and supply preferences to balance water supplies and demands. To do this, WEAP must assess the available water supplies each time step. While total supplies may be sufficient to meet all the demands within the system, it is often the case that operational considerations prevent the release of water to do so. These rules are usually intended to preserve water in times of shortage so that long-term delivery reliability is maximized for the highest priority water users (often indoor urban demands). WEAP can represent this controlled release of stored water using its built-in reservoir routines.

WEAP uses generic reservoir objects, which divide storage into four zones, or pools, as illustrated in Figure 20. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone, and inactive zone. The conservation and buffer pools together constitute a reservoir's active storage. WEAP always evacuates the flood-control zone, so that the volume of water in a reservoir cannot exceed the top of the conservation pool. The size of each of these pools can change throughout the year per regulatory requirements, such as flood control rule curves.

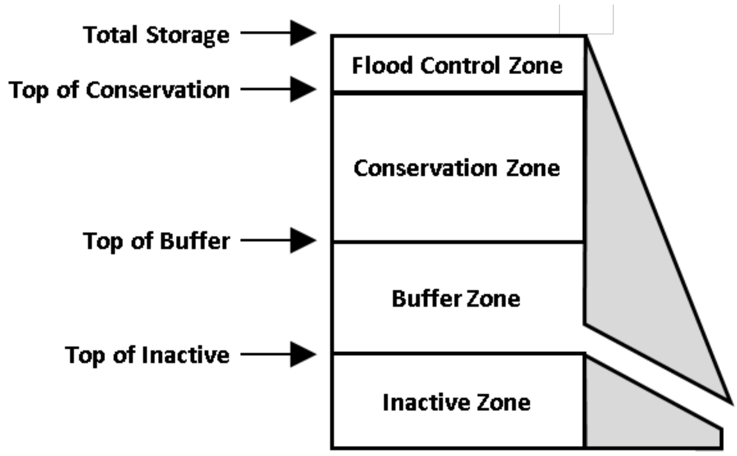


*Figure 20. **WEAP Reservoir Zones***

WEAP allows reservoirs to freely release water from the conservation pool to fully meet downstream requirements. Once the reservoir storage level drops into the buffer pool, the release is restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. The buffer coefficient is the fraction of the water in the buffer zone available each month for release. Thus, a coefficient close to 1.1 will cause demands to be met more fully, while rapidly emptying the buffer zone. A coefficient close to zero will leave demands unmet while preserving the storage in the buffer zone. Alternatively, the conservation zone and buffer zone may be assigned different priorities to represent changing priorities as storage reserves dwindle. Water in the inactive pool is not available for allocation, although under extreme conditions evaporation may draw the reservoir below the top of the inactive pool.

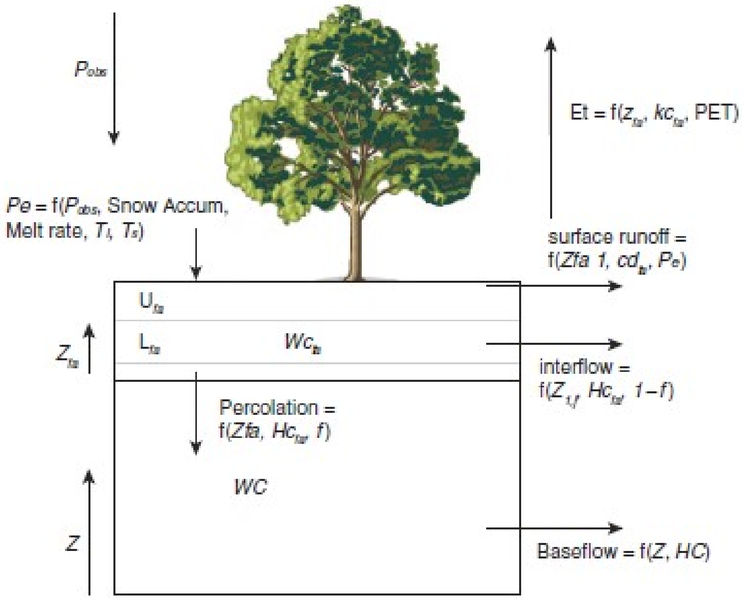
Rainfall-Runoff

WEAP's Soil Moisture module is used to simulate basin hydrology. This module configures a basin as a contiguous set of sub-catchments that cover the entire extent of the river basin. This conceptual model for each sub-catchment is show below in Figure 21. This continuous representation of the river basin is overlaid with a water management network topology of rivers, canals, reservoirs, demand centers, aquifers and other features. A unique climate-forcing dataset of precipitation, temperature, relative humidity, and wind speed is uniformly prescribed across each sub-catchment.

A one-dimensional, quasi-physical water balance model depicts the hydrologic response of each fractional area within a SC and partitions water into surface runoff, infiltration, evapotranspiration, interflow, percolation, and baseflow components (see Equation 1 and Figure 21). Values from each fractional area within the SC are then summed to represent the lumped hydrologic response, with the surface runoff, interflow and baseflow being linked to a river element and evapotranspiration being lost from the system.

Equation 1.

$$Rd_j \frac{dz_{1,j}}{dt} = P_e(t) - PET(t)k_{c,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t)z_{1,j}^{RRF_j} - f_j k_{s,j} z_{1,j}^2 - (1-f_j)k_{s,j} z_{1,j}^2$$



Source: Yates et al. 2005a.

Figure 21. ***Diagram of WEAP's Soil Moisture Hydrology Model***

Annex 2.C: Crop Categories

Table 7. ***Grouping crops into categories***

WEAP categories	FAO crop categories
Corn	Maize
	Maize, green
Cotton	Seed cotton
Watermelons and squash	Pumpkin, squash, grounds
	Cucumbers and gherkins
	Watermelons
	Melona, other (inc. cantaloupes)
Wheat	Wheat
Barley	Barley
Other grains	Oats
	Rye
	Sorghum
	Grain (mixed)
	Cereals nes
	Triticale
	Soybeans
	Millet
Potatoes	Potatoes
Rice	Rice, paddy
Sugar beet	Sugar beet

Grapes	Grapes
Apples	Apples
Other orchards	Fruit, stone nes
	Pears
	Peaches and nectarines
	Apricots
	Plums and sloes
	Cherries
	Cherries, sour
	Kiwi fruit
	Fruit, pome nes
	Fruit, citrus nes
	Fruit, fresh nes
	Figs
	Oranges
	Lemons and limes
	Tangerines, mandarins, clementines, satsumas
	Grapefruit (inc. pomelos)
	Hazelnuts
	Walnuts, with shell
	Persimmons
	Pistachios
	Hazelnuts, with shell
	Quinces
	Olives
	Almonds, with shell
Vegetables	Artichokes
	Carrots and turnips
	Cauliflowers and broccoli
	Chillies and peppers, dry
	Chillies and peppers, green
	Eggplants (aubergines)
	Leeks, other alliaceous vegetables
	Pepper (piper spp.)
	Lettuce and chicory
	Onions, dry
	Onions, shallots, green
	Vegetables, fresh nes
	Vegetables, leguminous nes
	Peas, green
	Peas, dry
Oil seeds and pulses	Oilseeds nes
	Safflower seed
	Sesame seed
	Jute

	Sunflower seed
	Rapeseed
	Pulses nes
	Linseed
	Pulses
Other crops	Tobacco, unmanufactured
	Raspberries
	Spices nes
	Berries nes
	Buckwheat
	Lentils
	Blueberries
	Chick peas
	Nuts nes
	Currants
	Strawberries
	Gooseberries
	Chicory roots
	Groundnuts, with shell
	Mustard seed
	Cabbage and other brassicas
	Beans, dry
	Beans, green
	Garlic
	Tomatoes
	Broad beans, horse beans, dry

Annex 2.D: WEAP-MABIA Model Validation

The WEAP-MABIA model performance was evaluated using three separate metrics over a historical period 1995-2020. These metrics included annual applied water for each of the 15 crop types, crop yields, and average annual water withdrawals from surface water sources. Each are presented in the sections below.

It should be noted that a traditional calibration of the model was not possible due to a lack of adequate local data with which we could calculate standard measures of performance. This was particularly true for crop yields, for which only national level data was available for the simulation period. Several years of water withdrawal data were available, but covered an earlier period (1980-1995) than the simulation period. Fortunately, in this case the values did not diverge significantly from the average withdrawal, which we used as a basis of comparison. More data were available for applied water, but varied widely depending upon data sources.

Applied Water

Reported crop water use rates were obtained from Dukhovny and Schutter (2011), the water use and farm management survey of the Syr Darya (1997), and from the Kyrgyzstan NPE. These data varied widely across the basin for common crops. As such, average values were used as the basis for comparison.

Table 8. ***Comparison of observed and simulated average annual applied water (m3/ha/year)***

	KAZ_Lower	KAZ_Upper	KGZ	TJK	UZB_Lower	UZB_Upper	Observed
Apples	10,517	7,871	13,575	12,550	11,476	7,873	9,470
Barley	4,866	2,783	6,789	6,034	4,710	2,704	
Corn	8,546	5,575	5,674	5,385	9,171	5,225	7,500
Cotton		8,321	8,303	7,380	10,732	7,592	9,340
Grapes	4,730	4,265	7,359	6,971	5,331	5,058	7,636
Oil seeds and pulses	6,314	4,054	5,278	9,166	7,053	4,050	
Other crops	4,332	2,789	4,969	4,206	5,912	3,591	
Other grains	6,515	3,915	5,868	5,253	7,348	5,192	
Other orchards	8,840	5,475	8,137	6,691	9,671	7,463	
Potatoes	5,913	4,671	6,448	8,136	6,373	3,112	4,600
Rice	12,142	9,091	12,414	10,414	13,825	10,002	8,400
Sugar beet		3,164	6,797		6,312	5,011	
Vegetables	5,066	3,109	9,849	9,120	5,912	4,114	10,000
Watermelons and squash	5,187	3,146	5,719	5,805	5,232	2,503	
Wheat	5,014	3,511	4,903	5,048	5,039	3,365	4,000

River Withdrawals

Total annual river withdrawals were obtained from the CAWater database for the period 1980-1995. These data are shown in Figure 22 below and indicate that, except for Uzbekistan, total withdrawals were steady over this period. Withdrawals in Uzbekistan decreased significantly 1980 and 1990, but maintained about an average of 19,300 million m^3/year over the final five years. The average of the years 1991-1995 were then used as the basis of comparison, because no more recent data were available. The comparison of the simulated withdrawals over the period 1995-2020 to the CAWater data are presented in Figure 23.

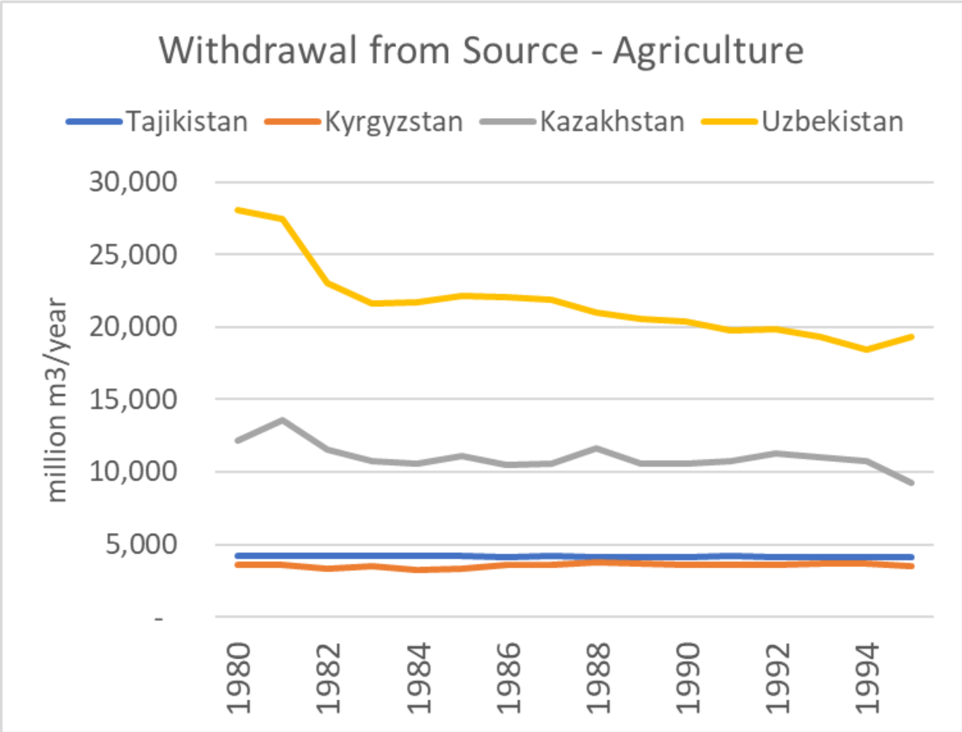


*Figure 22. **Total annual river withdrawals for agriculture, 1980-1995***

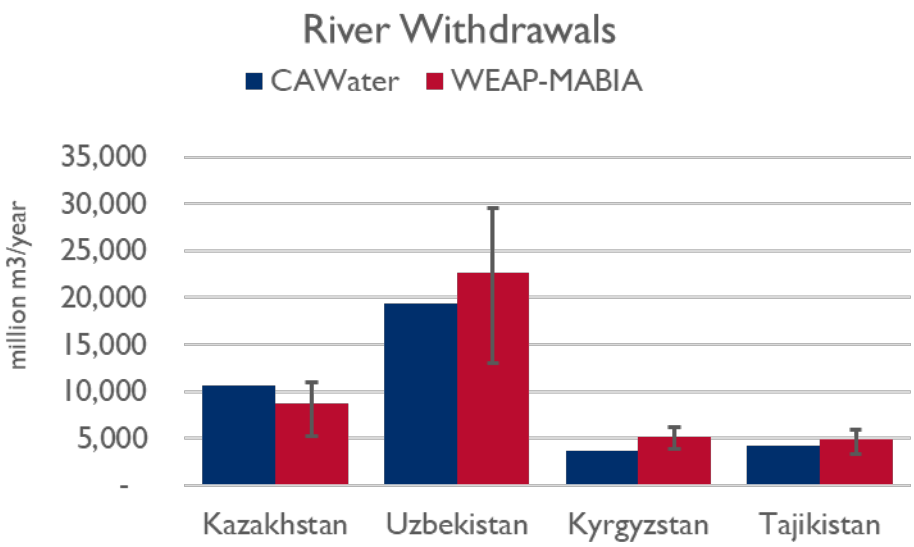


Figure 23. ***Comparison of simulated river withdrawals to average observed data.***

Crop Yields

Crop yields vary considerably between countries of the Syr Darya basin. For example, FAO reports that the average annual yields for wheat for the years 2011 to 2020 were 4,605 kg/ha for Uzbekistan, 2,960 kg/ha for Tajikistan, 2,260 kg/ha for Kyrgyzstan, and 1,170 kg/ha for Kazakhstan. Thus, it is important to consider these differences within the WEAP model. Unfortunately, as previously noted, only national level data were available for the purpose of model validation, which means that the model assumes yields within the Syr Darya basin mirror those of the national average.

The graphs below show comparisons of observed and simulated yields for three crops that comprise 60 percent of the total irrigated area within the basin. These comparisons demonstrated how the model generally captures the variability in yields between countries, the increasing trends in crop yields, and the inter-annual variability due to climate and other factors.

Wheat

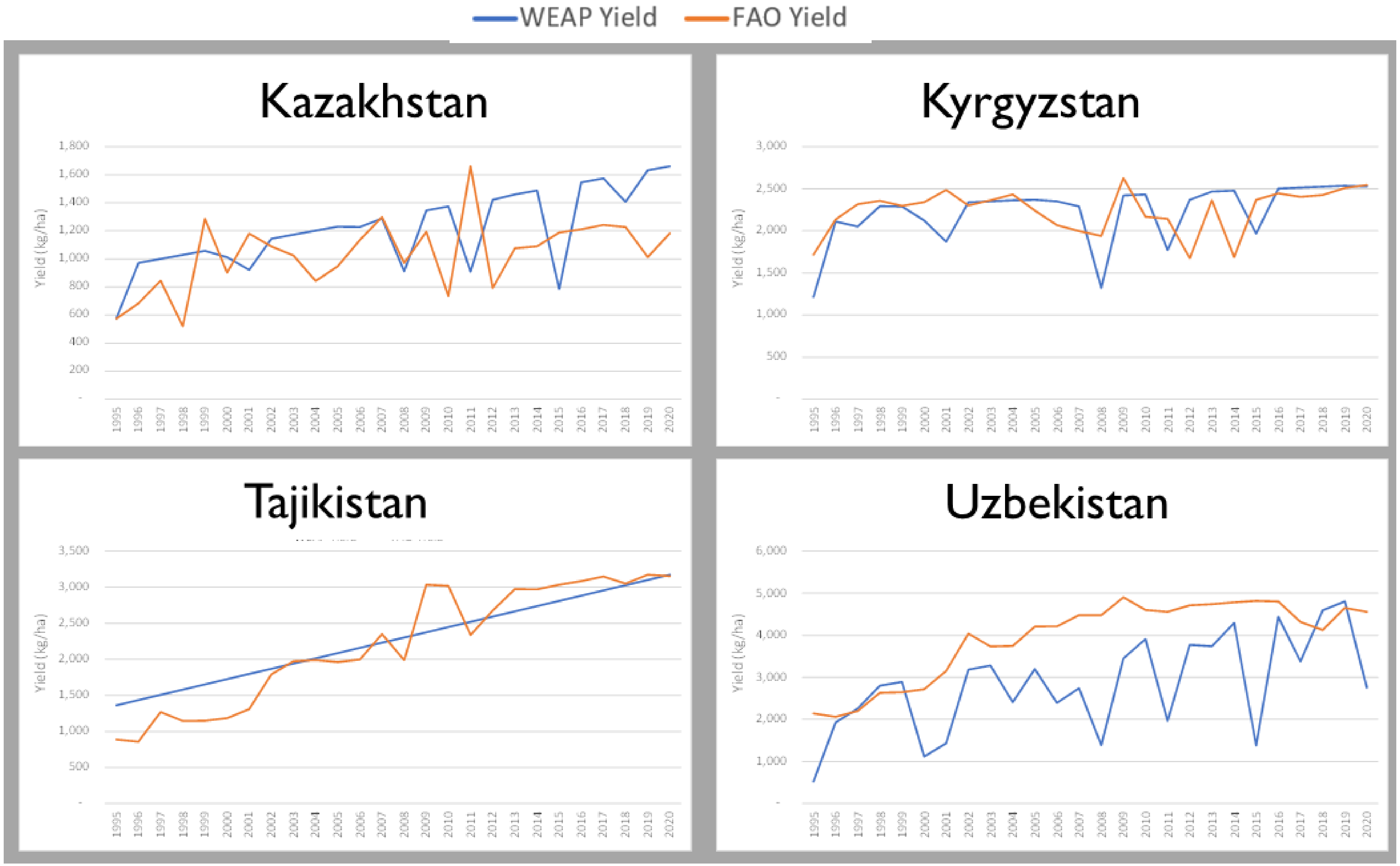


Figure 24. ***Comparison of observed and simulated yields (kg/ha) for wheat in each country, 1995-2020.***

Cotton

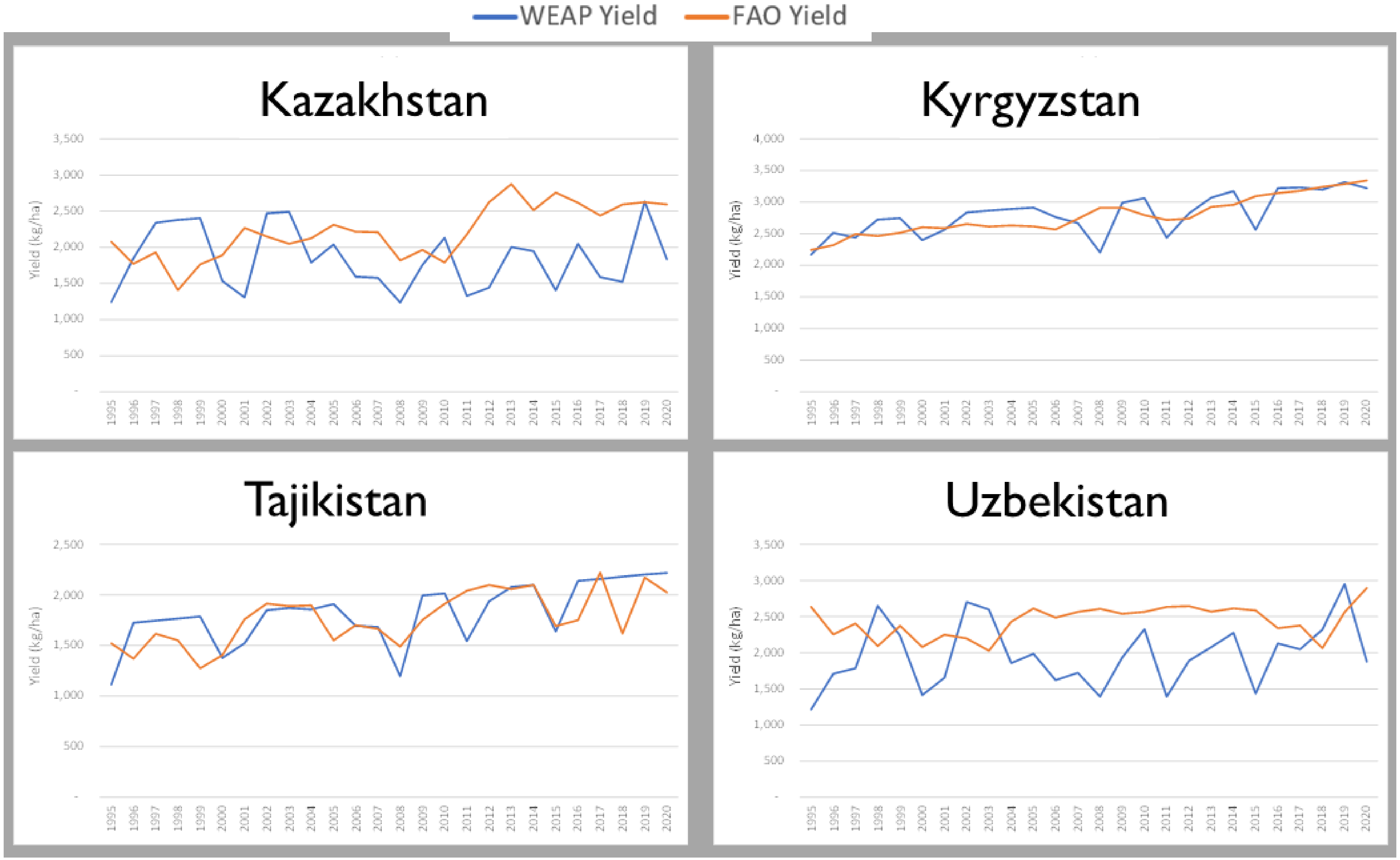


Figure 25. ***Comparison of observed and simulated yields (kg/ha) for cotton in each country, 1995-2020.***

Barley

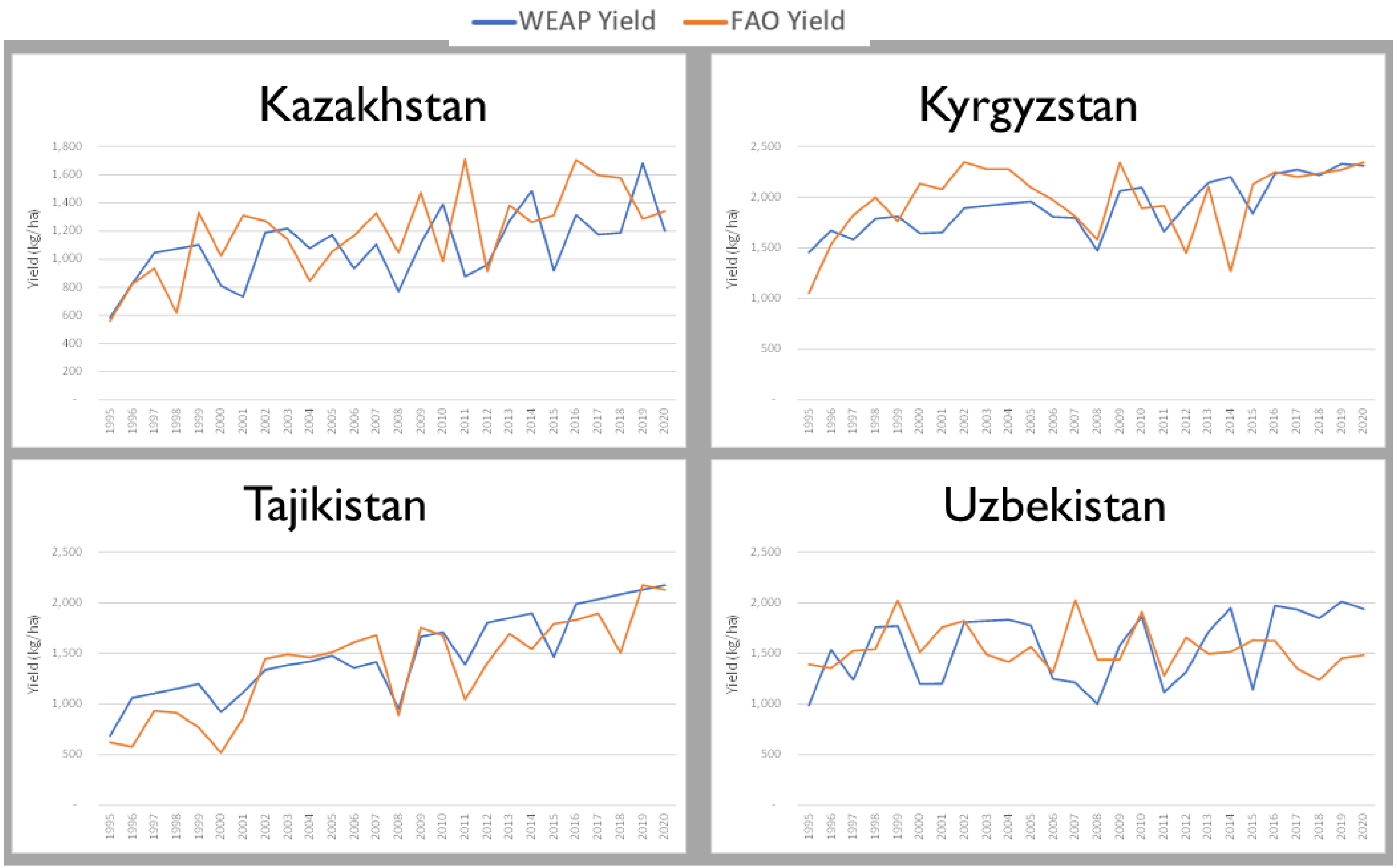


Figure 26. ***Comparison of observed and simulated yields (kg/ha) for barley in each country, 1995-2020.***

Annex 2.E: WEAP Hydrology Calibration

Before using the model to evaluate the performance of water supply reliability within the Syr Darya River basin, it was necessary to first calibrate the hydrological routines to ensure that it can adequately estimate flows in rivers.

The first step in calibrating any model is to select a historical period of record that includes concurrent input and observation data that cover a period long enough to capture the range of conditions (wet and dry) within a basin. In this case, the main input data for the WEAP model include climate data and the observation data are gaged streamflow. We selected the sixteen-year period from 1980 to 1995, during which there were multiple stream gauges containing several years of flow data. These included the following locations:

- Syr Darya River at Toktogul
- Andijan River above Andijan Dam
- Akhangaran River above Akhangaran Dam
- Circik River above Charvak Cascade
- Papan River above Papan Dam

The WEAP model was calibrated to historical streamflows at each of these locations using a combination of manual methods and computer algorithms, such as the PEST software (Doherty, 2002). Five land use parameters were adjusted to achieve calibration to streamflow at various locations. The parameters are the evapotranspiration coefficient (Kc), soil water capacity (SWC), runoff resistance factor (RRF), root zone conductivity (RZC), and the preferred flow direction (PFD). Model simulations are most sensitive to SWC, RZC, and RRF. Thus, initial calibration focused on these three parameters. Further refinement to the shape and timing of the resulting hydrographs was accomplished by adjusting Kc and PFD.

Calibration Metric	Value
Nash-Suttcliffe Efficiency (NSE)	0.62
Percent Bias (PBIAS)	7.1%
Ratio of Standard Deviations (SDR)	0.95

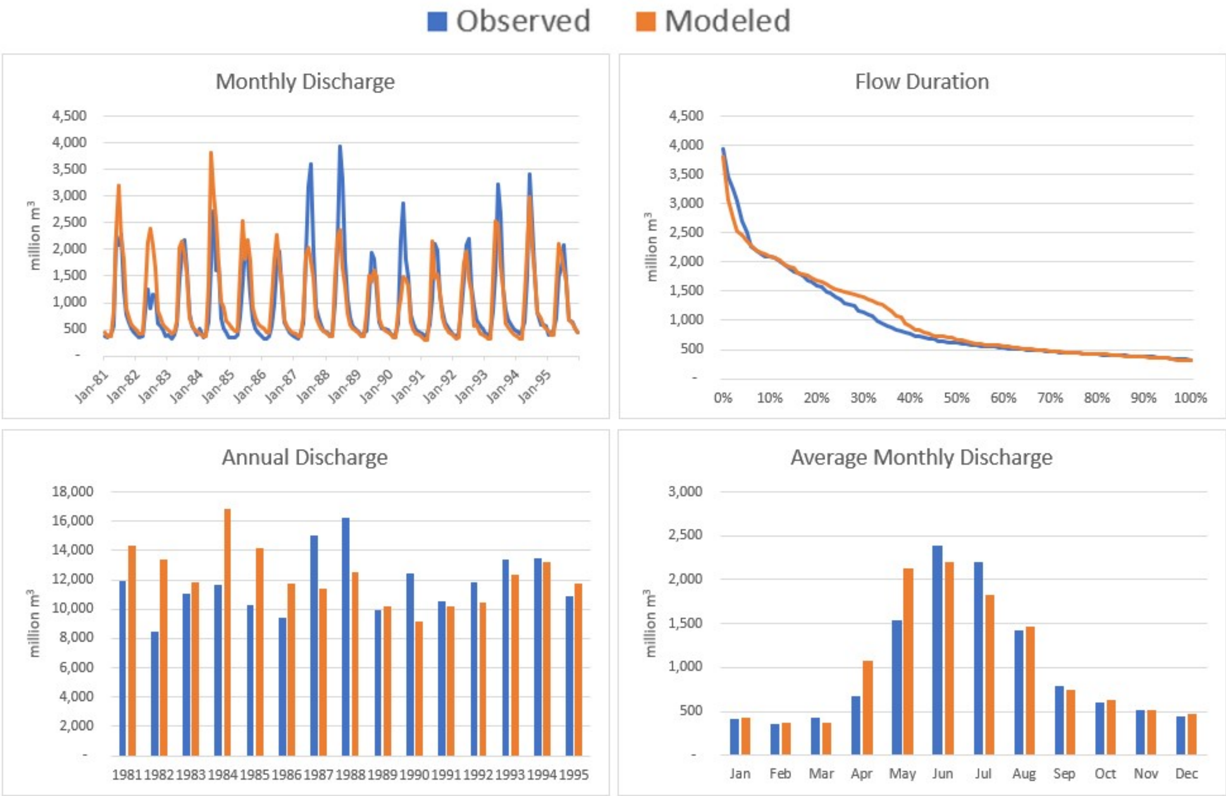


Figure 27. ***Comparison of observed and simulated Syr Darya River flows at Toktogul***

Calibration Metric	Value
Nash-Suttcliffe Efficiency (NSE)	0.72
Percent Bias (PBIAS)	12%
Ratio of Standard Deviations (SDR)	0.91

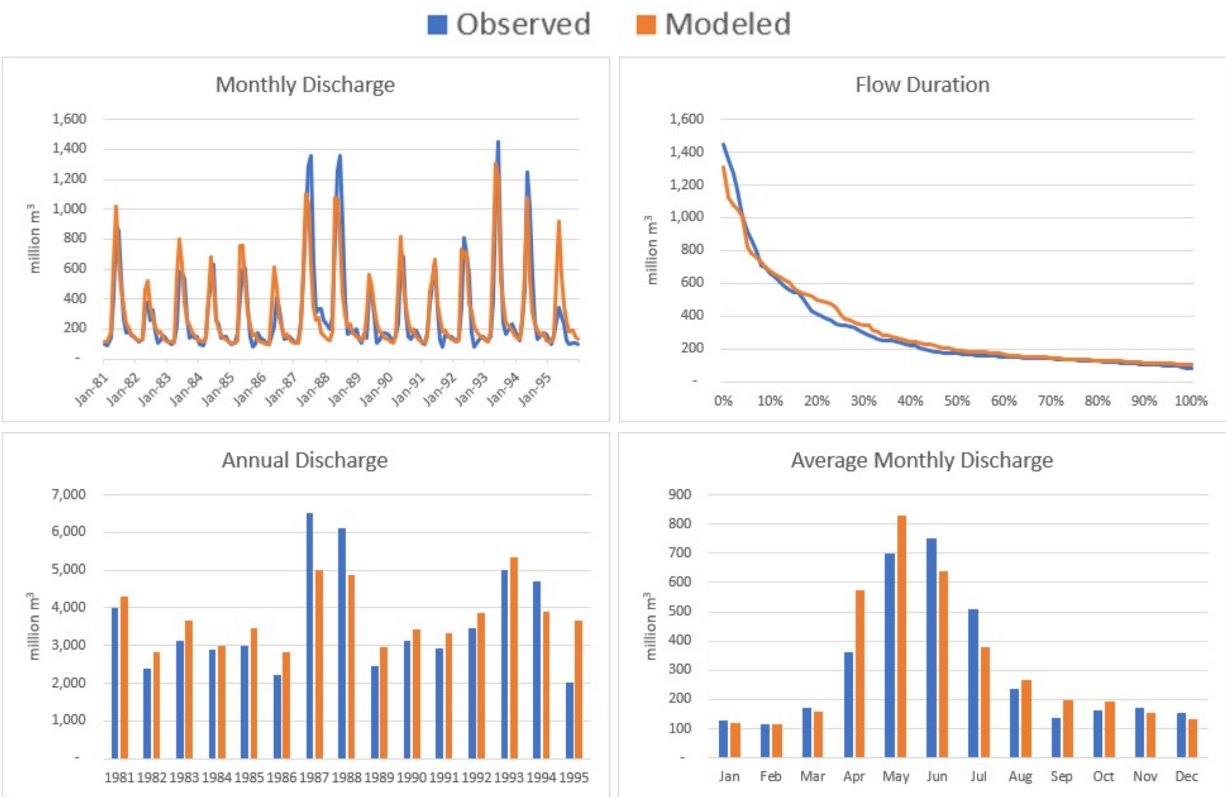


Figure 28. ***Comparison of observed and simulated Andijan River flows above Andijan Dam***

Calibration Metric	Value
Nash-Suttcliffe Efficiency (NSE)	0.72
Percent Bias (PBIAS)	-1%
Ratio of Standard Deviations (SDR)	0.97

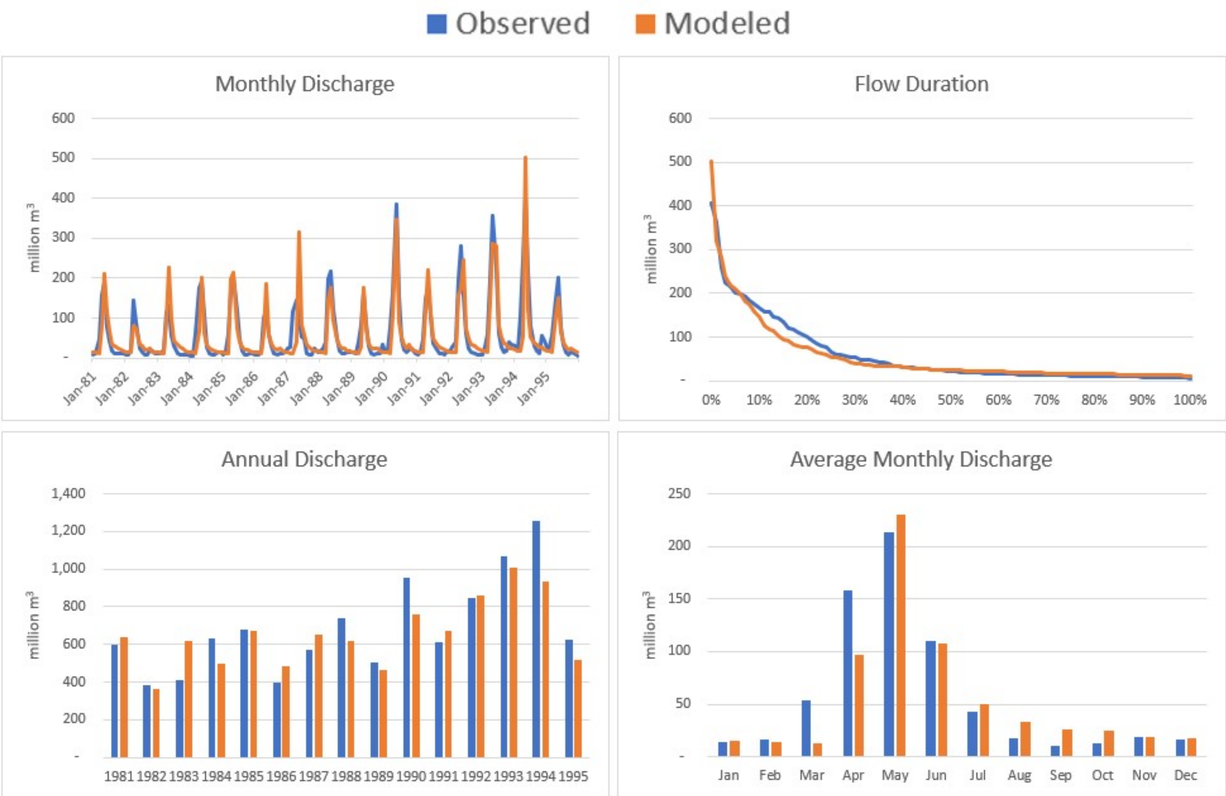


Figure 29. ***Comparison of observed and simulated Akhangaran River flows above Akhangaran Dam***

Calibration Metric	Value
Nash-Suttcliffe Efficiency (NSE)	0.32
Percent Bias (PBIAS)	-5%
Ratio of Standard Deviations (SDR)	1.49

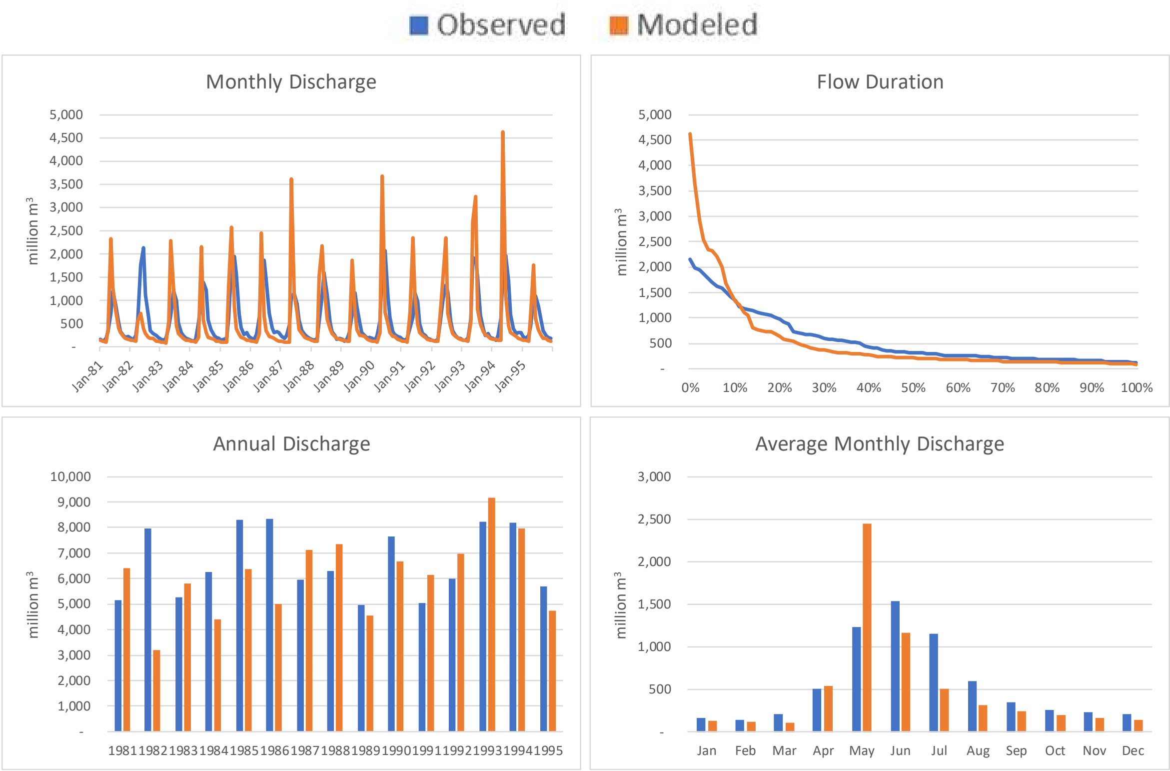


Figure 30. ***Comparison of observed and simulated Cirkik River flows above Charvak Cascade***

Calibration Metric	Value
Nash-Suttcliffe Efficiency (NSE)	0.52
Percent Bias (PBIAS)	15%
Ratio of Standard Deviations (SDR)	1.3

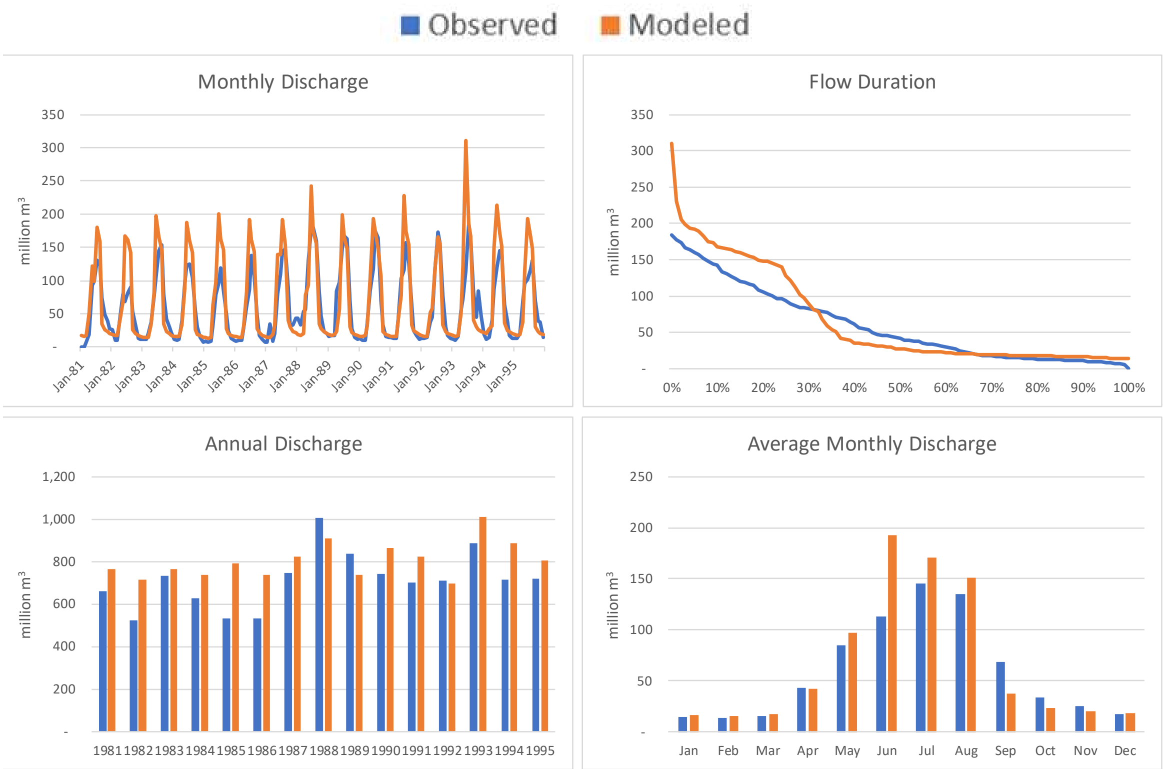


Figure 31. ***Comparison of observed and simulated Papan River flows above Papan Dam***

ANNEX 3:

LEAP MODEL FOR THE SYR DARYA BASIN

Introduction

This report documents the design of an energy system model that the Stockholm Environment Institute (SEI) developed for the USAID Regional Water and Vulnerable Environment Activity's (WAVE's) robust decision support (RDS) initiative in the Syr Darya River Basin ("the model"). Built in 2022 with inputs from a range of stakeholders, the model was connected to water resources and macroeconomic models to perform integrated analyses of the water-energy- food-environment nexus in the Basin. These analyses explored impacts of policy and planning options under critical uncertainties, and derived insights on strategies to improve resource security.

This report describes the model's software platform, scope and structure, simulation methods, inputs, and outputs. It also outlines different narratives represented in the model. Results from these narratives are provided in other reports and presentations that SEI has delivered to WAVE. Further information on the model's design and implementation can be obtained by inspecting the model itself (Annex 3.A:).

Modeling platform

The model is built on the **Low Emissions Analysis Platform (LEAP)**, a software tool for modeling energy systems, pollutant emissions, sustainable development goals, and related externalities. LEAP is developed by SEI and is one of the most widely used energy system modeling tools in the world. The LEAP community of practice includes nearly 60,000 members[1], and dozens of countries rely on LEAP to produce energy strategies, climate change mitigation plans, low emission development plans, and similar policies. For example, 61 countries have used LEAP to prepare their Nationally Determined Contributions (NDCs) to the Paris Agreement.

LEAP is the most important element of the model's software platform. The model uses LEAP to simulate final energy demands, pollutant emissions, and most sources of energy supply. For electricity supply, however, an additional piece of software is involved: the **Next Energy Modeling system for Optimization (NEMO)**. NEMO is a high performance, open source energy system modeling tool also produced by SEI. It is designed to integrate with LEAP as a graphical user interface. The model uses NEMO to simulate electricity supply by least cost optimization. It is configured so users do not need to interact with NEMO directly; instead, LEAP runs NEMO when the model is calculated, and outputs from NEMO are shown in LEAP's results interface.

NEMO formulates an optimization problem for electricity supply that it then solves with a third-party solver program. NEMO is compatible with a variety of solvers, including open source and commercial/proprietary options. For the Syr Darya analysis, the SEI team used two solvers at different times – **Gurobi** and **HiGHS**. Gurobi is a commercial solver and generally requires a paid license, while HiGHS is open source and freely available. The team

[1] https://leap.sei.org/default.asp?action=stats.

used HiGHS primarily when running the model in capacity building workshops with stakeholders. Gurobi was utilized when conducting integrated runs with the water and macroeconomic models, as its superior performance was an advantage in this context.

Each part of the model's software platform – LEAP, NEMO, and the solvers – has documentation online that describes its operation in detail. These resources are available at the following links:

- LEAP–https://leap.sei.org/
- NEMO– https://sei-international.github.io/NemoMod.jl/stable/
- Gurobi–https://www.gurobi.com/
- HiGHS–https://highs.dev/

Model scope and structure

The model is a full energy system model for the countries of the Syr Darya Basin: Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan. It simulates the production, consumption, and exchange of all energy carriers (fuels) in these countries, including final energy demands[2], energy transformation activities and intermediate energy demands, primary energy extraction, and energy imports and exports. Each of the four Syr Darya countries is represented as a separate region in the model, and most energy demand and supply sources/activities are geographically aggregated at this level. An additional geographic distinction is used for agricultural energy demand, demand for water pumping, and hydropower, however. In these cases, the model distinguishes between demand or supply inside the Syr Darya Basin and outside the Basin.

The model covers years between 2010 and 2050. In general (but depending on the variable), results for 2010-2019 are based on historical data, and results in other years are projections. The default time step in the model is annual, and most energy demand, energy supply, and other results are calculated on an annual basis. Electricity is an exception: electricity demand and supply are modeled using 288 time slices per year, representing a typical 24-hour day in each month.

In addition to geography, the modeling of final energy demands is broken down by sector, subsector, and fuel. The following sectors are represented:

- Agriculture
- Commercial
- Industry
- Residential
- Transport

[2] Demands by energy end-users (i.e., users that are not energy producers).

The demand modeling also covers demand for international bunkers, energy inputs to non-energy processes (e.g., petrochemical feedstocks), statistical differences in energy balances, and other unclassified final energy demands.

Within each country, the supply side of the model is organized by energy-producing sector or industry, technology, and fuel. The main sectors are the following:

- Biomass production
- Blast furnaces
- Brown coal briquettes production
- Charcoal production
- Coal anthracite mines
- Coal bituminous mines
- Coal lignite mines
- Coke ovens
- Electricity production
- Hard coal briquettes production
- Heat production
- Natural gas production
- Oil production
- Oil refineries

The supply model also represents changes in energy stocks or inventories; transfers of energy between supply sectors; own use by energy-producing industries; and losses of energy in transmission, distribution, and transport.

SEI paid particular attention to electricity supply when constructing the model due to this sector's importance in the Syr Darya Basin. Each existing, planned, or potential large hydropower facility in the Basin is separately represented in the model (24 in total). Other power production facilities are aggregated by technology; 33 such technologies are represented, including fossil fuel, nuclear, solar, wind, and biogas technologies. Figure 1, which is a screenshot from LEAP, shows the internal structure of the electricity production sector in the model. The figure provides a full list of all power production facilities and technologies in the model, although it should be noted that LEAP hides facilities and technologies in regions where they are not used/do not exist.

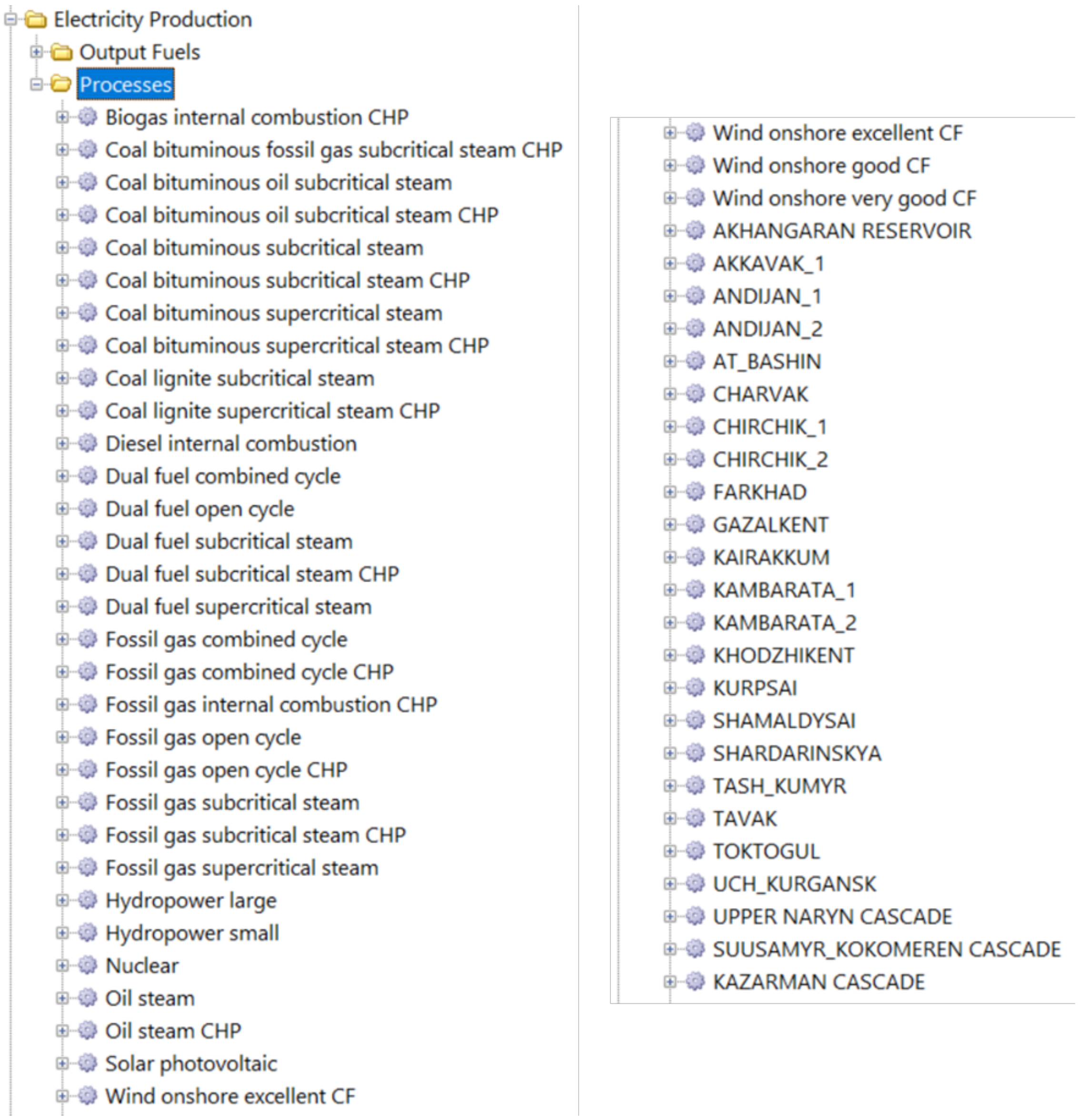


Figure 1: ***Structure of electricity production sector***

The model tracks endowments of primary energy resources (both renewable and non-renewable) as well as energy imports and exports by fuel. As described further in the next section, LEAP uses this information when calculating energy balances in each modeled year.

In addition to energy consumption and production, the model quantifies emissions of major greenhouse gases from the energy system. These include carbon dioxide, methane, and nitrous oxide.

Modeling methods, input data, and assumptions

As explained in depth in LEAP's documentation[3], energy system simulations in LEAP are demand-driven. Calculations are performed for each modeled year and start with a simulation of final energy demands. LEAP then mobilizes the supply side of the model to meet the final demand for each fuel. Modeled supply sectors or industries are used to produce the required fuels subject to limits on production capacity and primary energy resources. The supply sectors are linked in LEAP to specify their interactions and dependencies – e.g., outputs from electricity production enter the electricity transmission and distribution grid; crude oil production provides inputs to oil refineries. As supply sectors operate to fulfill final demands, they may generate intermediate energy demands that must also be met by the supply system. Ultimately, demands that cannot be met by production in the modeled area are satisfied by imports or reported as unmet (depending on how the model is configured).

In the WAVE model, this sequence is carried out for each modeled region. Imports are allowed as a last resort for all fuels, and any surplus energy production is assumed to be exported. Although energy imports and exports are simulated, the model does not distinguish the source of imports or the destination of exports for each region. SEI wished to provide this capability – including explicit modeling of power flow through electricity transmission connections between the regions – but the required input data were not available.

The model simulates final energy demands using activity analysis. This method calculates demand as the product of an activity level and an energy intensity. For historical years, the activity levels and energy intensities are derived from historical data. These quantities are then projected in forward-looking narratives. Table 1 provides an overview of the activity levels and drivers of future changes in energy intensity used in the model.

Table 1: Activity analysis modeling of final energy demands

Sector / category	Activity level	Drivers of changes in energy
Agriculture – Syr Darya water pumping	Volume of water pumped (from WAVE water	None – intensities held constant
Agriculture – other	Agricultural value added	None – intensities held constant
Commercial	Commercial value added	Personal income, heating degree days, fuel prices
Industry – water pumping for industrial and domestic purposes	Volume of water pumped (from WAVE water resources model)	None – intensities held constant
Industry – other	Industrial value added	Fuel prices
Residential	Households	Personal income, heating and cooling degree days, fuel
Transport – road	Vehicle-kilometers	None – intensities held constant
Transport – rail, aviation, and navigation	Tonne-kilometers	Fuel prices
Transport – other	Gross domestic product	None – intensities held constant
International bunkers, non-energy, other final demands	GDP	None – intensities held constant

[3] https://leap.sei.org/help/leap.htm.

To determine the drivers of changes in energy intensity, SEI conducted a statistical analysis of the relationship between historical intensities, personal income, heating and cooling degree days, and fuel prices (in each region). Relationships that were found to be statistically significant were included in the model.

As noted in Table 1, the model is designed to take projections of certain activity levels – volumes of water pumped – from the WAVE water resources model. It is also designed to take projections of GDP and value added from the WAVE macroeconomic models. In regions not covered by the macroeconomic models, GDP and value added are projected based on trends and targets in national policies. The projection of households depends on historic household sizes and projected population from UN Department of Economic and Social Affairs (2019). Vehicle and tonne-kilometers are generally projected using their statistical relationship with GDP, unless national policies state a different future target or there is no statistically significant relationship with GDP (in which case the last observed historical value is held constant).

Future values of the drivers of changes in energy intensity are projected using complementary techniques. Personal income is calculated from projected population and GDP, while future fuel prices are based on prices and growth rates in International Energy Agency (2021d) and National Renewable Energy Laboratory (2021). Heating and cooling degree days are taken from climate model runs performed for the 6th Climate Model Intercomparison Project (CMIP6). The specific runs used for the Syr Darya analysis are documented in SEI's final report on the analysis, submitted separately to WAVE.

With respect to energy supply, the model is configured to reproduce historical records, notably International Energy Agency (2021c). Future energy supply is then projected with several simulation methods. Future electricity production is calculated via least cost optimization in NEMO. Subject to technical limits and accounting for cost and performance characteristics of power production options, the model finds the least costly way to supply electricity in every year and time slice. The optimization is conducted with perfect foresight and discounts all costs to the first simulation year (2020) at a 5% real discount rate. It covers both capacity expansion and dispatch – choosing what new production capacity to build and how to utilize the capacity that exists at each time step. There are some limits on the technologies the model can choose to build. Wind and solar capacity is limited by the potential of these resources; hydropower and biogas additions are restricted to replacing retiring facilities[4]; and fossil and nuclear capacity is unlimited.

SEI calibrated the electricity optimization routine to historical energy balance data for 2010-2019. Calibration factors introduced in the model ensure that its short-term results align with the historical record in the Syr Darya countries' power systems. This design accounts for the

[4] By default – certain scenarios explore the construction of planned hydropower plants as noted below.

fact that these systems may not be cost-optimizing today. Over time, the calibration factors are removed, simulating a progression toward more open and competitive power markets.

For future supply from other energy-producing sectors, the model performs a simple simulation in which the technologies and input fuels that have historically satisfied energy demands are assumed to continue doing so. Production capacity is not modeled, but the production of non-renewable primary energy (coal, oil, and gas) is limited by each country's reserves.

Losses in the transmission, distribution, and transport of energy are calculated using fuel-specific loss factors. For the most part, these are based on historical data, though in some countries future rates are modified by policy targets (e.g., a policy to reduce electricity transmission and distribution losses). As indicated earlier, electricity transmission and distribution capacity is not modeled due to a lack of necessary input data.

The discussion in the first part of this section described how the model allows imports to cover for energy supply shortages, and exports to absorb energy surpluses. In addition to this mechanism, the model assumes that historically observed energy imports and exports continue in the future. These imports and exports occur regardless of shortages or surpluses in the supply system.

Key input data used in the model include the following.

- Historical energy balances: International Energy Agency (2021c)
- Population: Bureau of National Statistics of Kazakhstan (2021b); Agency of Statistics, Republic of Tajikistan (2018); UN Department of Economic and Social Affairs(2019)
- GDP: Bureau of National Statistics of Kazakhstan (2021b); World Bank (2022); Agency of Statistics, Republic of Tajikistan (2018)
- Value added: Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics (2022b; 2022a), National Statistical Committee of the Kyrgyz Republic (n.d.; 2021), Agency on Statistics under President of the Republic of Tajikistan (n.d.; n.d.), Bureau of National Statistics of Kazakhstan (2019; 2021a), Republic of Uzbekistan State Statistical Committee (2022a; 2022b; 2022c)
- Electricity production capacity: Platts (2021)
- Historical fuel prices: International Monetary Fund (2015; 2021)
- Reserves of non-renewable primary energy: BP (2021), International Energy Agency (2021b; 2021a; 2022)
- Solar and wind potentials: Eshchanov et al. (2019), Eshchanov et al. (2019)

Further information on the model's inputs and methods is available in the model itself (Annex A:). Input data are documented in the model using LEAP's Notes feature[5], which allows explanatory text and citations to be included in the model file (Figure 2).

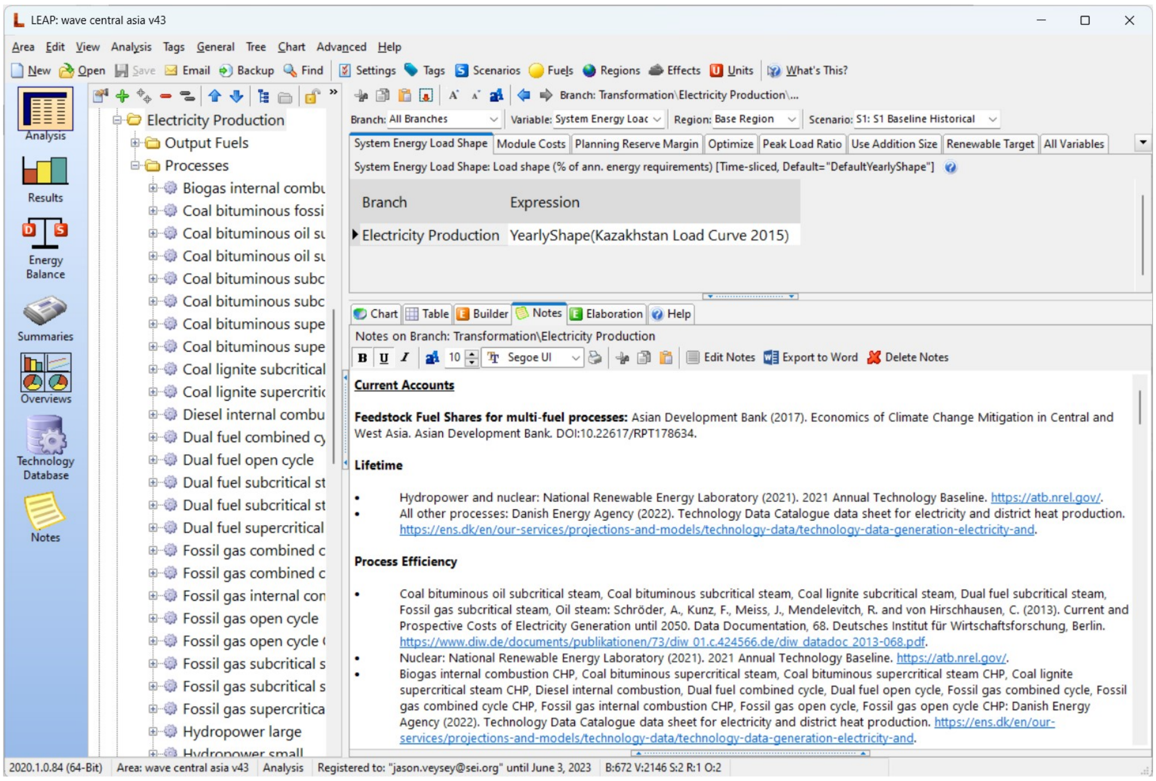


Figure 2: ***View of LEAP inputs including Notes feature***

Model outputs

The model can generate a wide variety of outputs related to the Syr Darya countries' energy systems. These include energy demands by sector and fuel, total primary energy supply, domestic production of different energy carriers, energy imports and exports, non-renewable energy resource depletion, unmet energy requirements, and greenhouse gas emissions from energy production and consumption. In the power sector, generation, hourly dispatch, capacity additions and retirements, peak load, capacity factors, reserve margins, curtailment of renewables, and production costs can be reported. All of these results can be segmented by region, year, and other dimensions.

A key output for the Syr Darya analysis is dispatch of hydropower plants in the Syr Darya Basin. When the model is run in an integrated fashion with the WAVE water resources model, the water model determines the availability of water for hydropower, and the LEAP/NEMO

[5] https://leap.sei.org/help/leap.htm#t=Screen_Layout%2FNotes.htm.

model calculates how much water is actually used for hydropower. The two models iterate to seek convergent solution.

In addition to the above-mentioned results, LEAP and NEMO can provide various other outputs as described in their respective documentation (see Modeling platform). Users can also add custom output variables to the model using LEAP's Indicators feature.[6]

Modeled narratives

The model contains 24 scenarios. These are the product of six narratives (thematically linked sets of planning decisions) and four climate projections.

Narratives

1) **Baseline:** The Baseline pathway models a business-as-usual future. National economic development plans are largely realized and population growth trends continue, but there are no significant changes in water and resource management practices or the structure of agricultural and energy systems. Some existing hydropower facilities are rehabilitated, but no major new sources of hydropower are developed.
2) **National Interests:** The National Focus pathway assumes the countries of the Syr Darya Basin pursue all of their current plans for expanding hydropower and agriculture, without regard to cross-border impacts. In other respects, including water and resource management practices, the pathway adopts the same assumptions as the Baseline pathway.
3) **Water and Agricultural Improvements:** This pathway builds on the National Focus pathway by adding an assumption that the countries of the Syr Darya Basin improve water use and agricultural practices. Irrigation systems are rehabilitated and modernized, new crops and cropping patterns are introduced, and water-efficient equipment is deployed at scale.
4) **Energy and Climate Improvements:** This pathway extends the prior pathway by assuming that the countries of the Syr Darya Basin implement national plans and policies related to energy efficiency, renewable energy, and climate change. On the climate side, the countries carry out the unconditional components of their NDCs as well as national climate change adaptation plans.
5) **International (regional) Cooperation:** The International Cooperation pathway starts with the Energy and Climate Improvements pathway and adds assumptions about enhanced international cooperation on water, energy, and agricultural issues. It explores gains that can be realized through improved transboundary coordination and exchange of resources in these sectors.

[6] https://leap.sei.org/help/leap.htm#t=Indicators%252FIndicators.htm.

6) **Ecosystem Restoration:** This pathway builds on the International Cooperation pathway by introducing an assumption that the minimum water flow requirements needed for the health of the North Aral Sea are satisfied.

Climate projections

1) **Historical:** This projection assumes no further climate change.
2) **Wet:** This is a projection for significant climate change that makes the Syr Darya region both hotter and wetter.
3) **Dry:** Paralleling the Wet projection, this projection anticipates significant climate change that results in hotter and drier conditions in the Syr Darya Basin.
4) **Average:** This projection is for a moderate level of climate change, causing temperatures to increase but precipitation to stay about the same in the Syr Darya Basin.

Detailed assumptions about plans, policies, and targets in the scenarios are provided in Annex B: Detailed assumptions about plans, policies, and targets in scenarios.

Annex 3.A: Model file

The model can be downloaded at this link:
https://www.riverbp.net/eng/community_of_practice/hub/weap_leap/. It is compatible with version 2020.1.0.84 of LEAP and version 1.9 of NEMO.

Annex B: Detailed assumptions about plans, policies, and targets in scenarios

Baseline

Kazakhstan

- 80.8% growth in real manufacturing value added 2018-2025 (Government of the Republic of Kazakhstan 2019)
- Decrease in electricity system reserve margin to 2030 (Government of the Republic of Kazakhstan 2014)

Kyrgyzstan

- Real GDP growth rate 5% during 2023-2026, 2.5% during 2030-2050 (Government of the Kyrgyz Republic 2021a; Government of the Kyrgyz Republic 2021b)
- Per capita income reaches 1500 2021 USD in 2026 (Government of the Kyrgyz Republic 2021a)
- Reconstruction of At-Bashi, Uch-Kurgan, and Toktogul hydropower facilities (Government of the Kyrgyz Republic 2018)
- At least 30% growth in air traffic 2018-2023 (Government of the Kyrgyz Republic 2018)

Tajikistan

- 6% annual growth in real GDP through 2030 (Republic of Tajikistan 2021)
- GDP shares by 2025: industry 25%, agriculture 19%, services 33% (Government of the Republic of Tajikistan 2021)
- 400-450 MW new coal combined heat & power by 2025 (Government of the Republic of Tajikistan 2021)
- Electricity transmission and distribution losses reduced to 12% by 2025 (Government of the Republic of Tajikistan 2021)
- Reconstruction of Kairokkum, Nurek, and Sarband (Golovnaya) hydroelectric plants (Government of the Republic of Tajikistan 2021)

Uzbekistan

- Per capita income reaches $4k 2021 USD by 2030 (President of the Republic of Uzbekistan 2022)
- 1.4x growth in industrial value added 2021-2026 (President of the Republic of Uzbekistan 2022)
- Chemical and petrochemical value added attains $2B 2021 USD by 2026 (President of the Republic of Uzbekistan 2022)
- 2.8x growth in wood and wood products value added 2021-2026 (President of the Republic of Uzbekistan 2022)
- Doubling of textile and leather value added 2021-2026 (President of the Republic of Uzbekistan 2022)
- 1.4x growth in transport equipment value added 2021-2026 (President of the Republic of Uzbekistan 2022)
- Electricity generation grows 30 billion kWh 2021-2026 (President of the Republic of Uzbekistan 2022)

National Focus

Kazakhstan

- Substantial growth in agricultural value added by 2050 (target: 5x 2013-2050) (President of the Republic of Kazakhstan 2012)

Kyrgyzstan

- Expansion of Kambarata 2 (Government of the Kyrgyz Republic 2018)
- Construction of Kambarata 1, Upper Naryn HPP Cascade, Suusamyr-Kokomeren HPP Cascade, Kazarman HPP Cascade (Government of the Kyrgyz Republic 2018; Government of the Kyrgyz Republic 2021a)
- 300-400 MW of new small hydropower by 2026 (Government of the Kyrgyz Republic 2021a)

Tajikistan

- Construction of following hydropower plants: Rogun, Shurob, Sanobodskaya, Sebzor, Zeravshan river basin (Government of the Republic of Tajikistan 2021)

- Electricity exports reach 5 billion kWh by 2025 (Government of the Republic of Tajikistan 2021)

Uzbekistan

- Agricultural value added grows 5% annually during 2021-2026 (President of the Republic of Uzbekistan 2022)

Water and Agricultural Improvements

No changes in model-specific inputs compared to prior pathway

Energy and Climate Improvements

- All water pumping in Syr Darya Basin (for agricultural, industrial, and domestic uses) switched to high efficiency pumps by 2030 (assumption developed with WAVE stakeholders)

Kazakhstan

- 10% decrease in electricity intensity of production of non-ferrous metals, ferrous metals, and chemicals 2021-2025 (Republic of Kazakhstan 2021)
- 15% decrease in energy consumption in residential sector 2021-2025 (Republic of Kazakhstan 2021)
- 50% of conventional road transport switched to electricity by 2050 (assumption developed with WAVE stakeholders)
- Heat production efficiency increases to 90% by 2030 (President of the Republic of Kazakhstan 2013)
- Heat transmission and distribution losses reduced to 10% by 2030 (President of the Republic of Kazakhstan 2013)
- Solar, wind, hydro, nuclear, and gas electricity generation: 55% of national total by 2030, 100% by 2050 (President of the Republic of Kazakhstan 2013)
- 12 MTOE of energy efficiency savings realized by 2030 (Government of the Republic of Kazakhstan 2014)
- Reduction of energy intensity of GDP (2008 baseline) – 30% by 2030, 50% by 2050 (President of the Republic of Kazakhstan 2013)
- Reduction of CO2 emissions from power generation (2012 baseline) – 15% by 2030, 40% by 2050 (President of the Republic of Kazakhstan 2013)
- 15% reduction in economy-wide GHG emissions by 2030 (1990 baseline) (Republic of Kazakhstan 2016)

Kyrgyzstan

- 60% electrification of rail transport by 2040 (Government of the Kyrgyz Republic 2018)
- 11.6% reduction in electricity transmission and distribution losses 2018-2023 (Government of the Kyrgyz Republic 2018)
- 10% renewables in total primary energy supply by 2040 (Government of the Kyrgyz Republic 2018)

- Other climate change mitigation measures from NDC (Government of the Kyrgyz Republic 2021b)
    - Reducing coal consumption through gasification of households
    - Improving Traffic Management and Cycling Infrastructure Development
    - Replacement of buses with diesel/gasoline fuel engines by buses with gas-powered engines in Bishkek
    - Construction of new buildings according to energy efficient CSR

Tajikistan

- Energy sector GHG emissions decrease to between 12.8 and 15.0 $MtCO_2e$ by 2030 (Republic of Tajikistan 2021)
- 10% decrease in commercial and residential electricity intensity by 2024 (Gauss International Consulting S.L. 2020)
- Commercial and residential coal demand switched to electricity by 2030 (Gauss International Consulting S.L. 2020)
- 10% improvement in industrial energy efficiency by 2030 (SEI assumption informed by NDC)
- 65% of gasoline and diesel road transport switched to gas by 2026 (Gauss International Consulting S.L. 2020)
- 50% of conventional road transport switched to electricity by 2050 (SEI assumption informed by NDC)
- 15% decrease in energy intensities of international bunkers, non-energy uses of energy, and other miscellaneous energy uses by 2030 (SEI assumption informed by NDC)
- 83% renewable electricity by 2030 (SEI assumption informed by NDC)

Uzbekistan

- 50% of conventional road transport switched to electricity by 2050 (President of the Republic of Uzbekistan 2022)
- 60% of rail transport electrified by 2026 (President of the Republic of Uzbekistan 2022)
- 20% improvement in industrial energy efficiency 2019-2030 (President of the Republic of Uzbekistan 2019)
- 25% of electricity generation from renewables by 2026 (President of the Republic of Uzbekistan 2022)
- 5 GW new solar, 3 GW new wind, and 1.9 GW of new hydro electricity generating capacity 2022-2030 (Republic of Uzbekistan 2021)
- 50% decrease in energy intensity of GDP 2010-2030 (Republic of Uzbekistan 2021)
- 35% reduction in GHG intensity of GDP 2010-2030 (Republic of Uzbekistan 2021)

International Cooperation

No changes in model-specific inputs compared to prior pathway

Ecosystem Restoration

No changes in model-specific inputs compared to prior pathway

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ANNEX 4:

SAMPLE LOG FILE

```
[2022-10-02 08:44:49.072]INFO:Validating branches in WEAP and LEAP
[2022-10-02 08:44:50.006]INFO:Running the model for regions:
[2022-10-02  08:44:50.006]INFO:          Kazakhstan
[2022-10-02  08:44:50.035]INFO:          Kyrgyzstan
[2022-10-02  08:44:50.054]INFO:          Tajikistan
[2022-10-02  08:44:50.072]INFO:          Uzbekistan
[2022-10-02 08:44:50.094]INFO:Including LEAP hydropower plants:
[2022-10-02  08:44:50.094]INFO:          AKHANGARAN
[2022-10-02  08:44:50.141]INFO:          ANDIJAN_1
[2022-10-02  08:44:50.184]INFO:          AKKAVAK_1
[2022-10-02  08:44:50.263]INFO:          ANDIJAN_2
[2022-10-02  08:44:50.339]INFO:          AT_BASHIN
[2022-10-02  08:44:50.385]INFO:          CHARVAK
[2022-10-02  08:44:50.438]INFO:          CHIRCHIK_1
[2022-10-02  08:44:50.500]INFO:          CHIRCHIK_2
[2022-10-02  08:44:50.549]INFO:          FARKHAD
[2022-10-02  08:44:50.605]INFO:          GAZLKENT
[2022-10-02  08:44:50.652]INFO:          KAIRAKKUM
[2022-10-02  08:44:50.720]INFO:          KAMBARATA_1
[2022-10-02  08:44:50.770]INFO:          KAMBARATA_2
[2022-10-02  08:44:50.815]INFO:          KHODZHIKENT
[2022-10-02  08:44:50.883]INFO:          KURPSAI
[2022-10-02  08:44:50.937]INFO:          SHAMALDYSAI
[2022-10-02  08:44:50.992]INFO:          SHARDARINSKYA
[2022-10-02  08:44:51.087]INFO:          TASH_KUMYR
[2022-10-02  08:44:51.178]INFO:          TAVAK
[2022-10-02  08:44:51.273]INFO:          TOKTOGUL
[2022-10-02  08:44:51.368]INFO:          UCH_KURGANSK
[2022-10-02  08:44:51.630]INFO:          KOKOMEREN
[2022-10-02  08:44:51.788]INFO:          UPPER NARYN
[2022-10-02  08:44:51.889]INFO:          KAZARMAN
[2022-10-02 08:44:51.971]INFO:Including WEAP hydropower reservoirs:
[2022-10-02  08:44:51.971]INFO:          Toktogul
[2022-10-02  08:44:52.007]INFO:          Kambarata_I
[2022-10-02  08:44:52.015]INFO:          Kambarata_II
[2022-10-02  08:44:52.049]INFO:          Kayrakkum
[2022-10-02  08:44:52.061]INFO:          Shardara
[2022-10-02  08:44:52.074]INFO:          Kurpsaiskaja
[2022-10-02  08:44:52.089]INFO:          Taschkumyrskaja
[2022-10-02  08:44:52.103]INFO:          Farkhad
[2022-10-02  08:44:52.114]INFO:          Akhangaran
[2022-10-02  08:44:52.123]INFO:          Charvak
[2022-10-02  08:44:52.133]INFO:          Chirchik
[2022-10-02  08:44:52.146]INFO:          Andijan
[2022-10-02  08:44:52.156]INFO:          At-Bashi
[2022-10-02  08:44:52.171]INFO:          Kokomeren
[2022-10-02  08:44:52.178]INFO:          Upper Naryn
[2022-10-02  08:44:52.187]INFO:          Kazarman
[2022-10-02 08:44:57.915]INFO:Calculating the following scenarios:
[2022-10-02  08:44:57.915]INFO:          S1 Baseline Historical (LEAP) ⟷ S1 Historical (WEAP)
[2022-10-02 08:44:58.348]INFO:Clearing hydropower reservoir energy demand from WEAP scenarios to avoid forcing model with results from past integration runs.
[2022-10-02 08:45:04.946]INFO:Running LEAP-Macro for scenario: S1 Baseline Historical
[2022-10-02  08:45:04.946]INFO:          Region: Kazakhstan
[2022-10-02  08:45:04.946]INFO:          Executing: C:\Users\EricKemp-Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe        "C:\Users\EricKemp-Benedict\Documents\WAVE_Macro\KAZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -v -y 2050
[2022-10-02  08:46:08.694]INFO:          Region: Kyrgyzstan
[2022-10-02  08:46:08.694]INFO:          Executing: C:\Users\EricKemp-Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe        "C:\Users\EricKemp-Benedict\Documents\WAVE_Macro\KGZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -v -y 2050
[2022-10-02 08:47:11.194]INFO:Pushing demographic and macroeconomic drivers from LEAP to WEAP
[2022-10-02  08:47:11.194]INFO:          Population_KAZ
[2022-10-02  08:47:20.456]INFO:          Population_KGZ
[2022-10-02  08:47:29.844]INFO:          Population_TJK
[2022-10-02  08:47:39.700]INFO:          Population_UZB
[2022-10-02  08:47:49.527]INFO:          GDP_KAZ
[2022-10-02  08:47:59.479]INFO:          GDP_KGZ
[2022-10-02  08:48:10.162]INFO:          GDP_TJK
```

```
[2022-10-02 08:48:20.396]INFO:         GDP_UZB
[2022-10-02 08:48:30.428]INFO:         Industrial_VA_KAZ
[2022-10-02 08:48:40.544]INFO:         Industrial_VA_KGZ
[2022-10-02 08:48:50.431]INFO:         Industrial_VA_TJK
[2022-10-02 08:49:00.630]INFO:         Industrial_VA_UZB
[2022-10-02 08:49:10.716]INFO:Pushed 12 variable(s) to WEAP
[2022-10-02 08:49:10.721]INFO:Calculating WEAP (iteration 1)
[2022-10-02 08:51:50.672]INFO:Finished calculating WEAP. Moving hydropower maximum availabilities
from WEAP to LEAP....
[2022-10-02 08:51:53.666]INFO:WEAP scenario: S1 Historical
[2022-10-02 08:51:53.666]INFO:         WEAP hydropower reservoir: Toktogul
[2022-10-02 08:51:57.001]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch88_lscenario2.xlsx"
[2022-10-02 08:51:59.889]INFO:                 Assigning to LEAP hydropower plant: TOKTOGUL
[2022-10-02 08:52:03.103]INFO:         WEAP hydropower reservoir: Kambarata_I
[2022-10-02 08:52:07.167]INFO:         WEAP hydropower reservoir: Kambarata_II
[2022-10-02 08:52:11.376]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5677_lscenario2.xlsx"
[2022-10-02 08:52:11.742]INFO:                 Assigning to LEAP hydropower plant: KAMBARATA_2
[2022-10-02 08:52:15.063]INFO:         WEAP hydropower reservoir: Kayrakkum
[2022-10-02 08:52:19.273]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch106_lscenario2.xlsx"
[2022-10-02 08:52:19.592]INFO:                 Assigning to LEAP hydropower plant: KAIRAKKUM
[2022-10-02 08:52:23.083]INFO:         WEAP hydropower reservoir: Shardara
[2022-10-02 08:52:27.308]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch108_lscenario2.xlsx"
[2022-10-02 08:52:27.619]INFO:                 Assigning to LEAP hydropower plant: SHARDARINSKYA
[2022-10-02 08:52:31.378]INFO:         WEAP hydropower reservoir: Kurpsaiskaja
[2022-10-02 08:52:35.564]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1364_lscenario2.xlsx"
[2022-10-02 08:52:35.872]INFO:                 Assigning to LEAP hydropower plant: KURPSAI
[2022-10-02 08:52:39.267]INFO:         WEAP hydropower reservoir: Taschkumyrskaja
[2022-10-02 08:52:50.999]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1366_lscenario2.xlsx"
[2022-10-02 08:52:51.411]INFO:                 Assigning to LEAP hydropower plant: TASH_KUMYR
[2022-10-02 08:52:54.798]INFO:                 Assigning to LEAP hydropower plant: SHAMALDYSAI
[2022-10-02 08:52:57.492]INFO:                 Assigning to LEAP hydropower plant: UCH_KURGANSK
[2022-10-02 08:53:00.270]INFO:         WEAP hydropower reservoir: Farkhad
[2022-10-02 08:53:04.564]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1371_lscenario2.xlsx"
[2022-10-02 08:53:04.850]INFO:                 Assigning to LEAP hydropower plant: FARKHAD
[2022-10-02 08:53:08.500]INFO:         WEAP hydropower reservoir: Akhangaran
[2022-10-02 08:53:12.734]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch637_lscenario2.xlsx"
[2022-10-02 08:53:13.037]INFO:                 Assigning to LEAP hydropower plant: AKHANGARAN
[2022-10-02 08:53:16.599]INFO:         WEAP hydropower reservoir: Charvak
[2022-10-02 08:53:28.160]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch103_lscenario2.xlsx"
[2022-10-02 08:53:28.467]INFO:                 Assigning to LEAP hydropower plant: CHARVAK
[2022-10-02 08:53:32.085]INFO:                 Assigning to LEAP hydropower plant: GAZLKENT
[2022-10-02 08:53:34.772]INFO:                 Assigning to LEAP hydropower plant: KHODZHIKENT
[2022-10-02 08:53:37.430]INFO:         WEAP hydropower reservoir: Chirchik
[2022-10-02 08:53:52.621]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1369_lscenario2.xlsx"
[2022-10-02 08:53:52.919]INFO:                 Assigning to LEAP hydropower plant: AKKAVAK_1
[2022-10-02 08:53:56.559]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_1
[2022-10-02 08:53:59.264]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_2
[2022-10-02 08:54:01.953]INFO:                 Assigning to LEAP hydropower plant: TAVAK
[2022-10-02 08:54:04.663]INFO:         WEAP hydropower reservoir: Andijan
[2022-10-02 08:54:12.529]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch226_lscenario2.xlsx"
[2022-10-02 08:54:12.836]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_1
[2022-10-02 08:54:16.326]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_2
[2022-10-02 08:54:18.983]INFO:         WEAP hydropower reservoir: At-Bashi
[2022-10-02 08:54:23.159]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5675_lscenario2.xlsx"
[2022-10-02 08:54:23.489]INFO:                 Assigning to LEAP hydropower plant: AT_BASHIN
[2022-10-02 08:54:26.627]INFO:         WEAP hydropower reservoir: Kokomeren
[2022-10-02 08:54:30.703]INFO:         WEAP hydropower reservoir: Upper Naryn
[2022-10-02 08:54:34.754]INFO:         WEAP hydropower reservoir: Kazarman
[2022-10-02 08:54:38.857]INFO:Moving water pumping information from WEAP to LEAP
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[2022-10-02 08:54:38.857]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 08:54:39.570]INFO:                 Region: Kazakhstan
[2022-10-02 08:54:40.228]INFO:                 Region: Kyrgyzstan
[2022-10-02 08:54:40.762]INFO:                 Region: Tajikistan
[2022-10-02 08:54:41.438]INFO:                 Region: Uzbekistan
[2022-10-02 08:54:41.607]INFO:Moving industrial water requirements from WEAP to LEAP
[2022-10-02 08:54:41.614]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 08:54:42.294]INFO:                 Region: Kazakhstan
[2022-10-02 08:54:43.000]INFO:                 Region: Kyrgyzstan
[2022-10-02 08:54:43.574]INFO:                 Region: Tajikistan
[2022-10-02 08:54:44.258]INFO:                 Region: Uzbekistan
[2022-10-02 08:54:44.432]INFO:Calculating LEAP area (iteration 1)
[2022-10-02 09:08:54.509]INFO:Saving LEAP and WEAP areas
[2022-10-02 09:09:11.963]INFO:Saving versions for iteration 1
[2022-10-02 09:09:45.175]INFO:Checking LEAP results...
[2022-10-02 09:10:08.418]INFO:Checking Macro results...
[2022-10-02 09:10:09.141]INFO:Checking WEAP results...
[2022-10-02 09:10:09.467]INFO:Pushing WEAP results to Macro...
[2022-10-02 09:10:30.481]INFO:Processing for WEAP scenario: S1 Historical
[2022-10-02 09:10:31.048]INFO:Running LEAP-Macro for scenario: S1 Baseline Historical
[2022-10-02 09:10:31.048]INFO:         Region: Kazakhstan
[2022-10-02 09:10:31.048]INFO:         Executing: C:\Users\EricKemp-
Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe        "C:\Users\EricKemp-
Benedict\Documents\WAVE_Macro\KAZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -w -v -y
2050 -u 38 -r 1 --load-leap-first
[2022-10-02 09:46:46.980]INFO:         Region: Kyrgyzstan
[2022-10-02 09:46:46.981]INFO:         Executing: C:\Users\EricKemp-
Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe        "C:\Users\EricKemp-
Benedict\Documents\WAVE_Macro\KGZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -w -v -y
2050 -u 38 -r 1 --load-leap-first
[2022-10-02 09:48:53.046]INFO:Pushing demographic and macroeconomic drivers from LEAP to WEAP
[2022-10-02 09:48:53.046]INFO:         Population_KAZ
[2022-10-02 09:49:02.133]INFO:         Population_KGZ
[2022-10-02 09:49:09.840]INFO:         Population_TJK
[2022-10-02 09:49:18.071]INFO:         Population_UZB
[2022-10-02 09:49:25.827]INFO:         GDP_KAZ
[2022-10-02 09:49:33.858]INFO:         GDP_KGZ
[2022-10-02 09:49:41.649]INFO:         GDP_TJK
[2022-10-02 09:49:48.914]INFO:         GDP_UZB
[2022-10-02 09:49:56.034]INFO:         Industrial_VA_KAZ
[2022-10-02 09:50:03.643]INFO:         Industrial_VA_KGZ
[2022-10-02 09:50:11.474]INFO:         Industrial_VA_TJK
[2022-10-02 09:50:18.773]INFO:         Industrial_VA_UZB
[2022-10-02 09:50:25.769]INFO:Pushed 12 variable(s) to WEAP
[2022-10-02 09:50:25.781]INFO:Calculating WEAP (iteration 2)
[2022-10-02 09:53:03.669]INFO:Finished calculating WEAP. Moving hydropower maximum availabilities
from WEAP to LEAP....
[2022-10-02 09:53:04.293]INFO:WEAP scenario: S1 Historical
[2022-10-02 09:53:04.293]INFO:         WEAP hydropower reservoir: Toktogul
[2022-10-02 09:53:06.722]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch88_lscenario2.xlsx"
[2022-10-02 09:53:09.706]INFO:                 Assigning to LEAP hydropower plant: TOKTOGUL
[2022-10-02 09:53:13.203]INFO:         WEAP hydropower reservoir: Kambarata_I
[2022-10-02 09:53:17.199]INFO:         WEAP hydropower reservoir: Kambarata_II
[2022-10-02 09:53:21.390]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5677_lscenario2.xlsx"
[2022-10-02 09:53:21.737]INFO:                 Assigning to LEAP hydropower plant: KAMBARATA_2
[2022-10-02 09:53:25.554]INFO:         WEAP hydropower reservoir: Kayrakkum
[2022-10-02 09:53:29.696]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch106_lscenario2.xlsx"
[2022-10-02 09:53:30.004]INFO:                 Assigning to LEAP hydropower plant: KAIRAKKUM
[2022-10-02 09:53:33.837]INFO:         WEAP hydropower reservoir: Shardara
[2022-10-02 09:53:38.283]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch108_lscenario2.xlsx"
[2022-10-02 09:53:38.636]INFO:                 Assigning to LEAP hydropower plant: SHARDARINSKYA
[2022-10-02 09:53:42.528]INFO:         WEAP hydropower reservoir: Kurpsaiskaja
[2022-10-02 09:53:46.688]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1364_lscenario2.xlsx"
[2022-10-02 09:53:47.004]INFO:                 Assigning to LEAP hydropower plant: KURPSAI
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[2022-10-02 09:53:50.813]INFO:         WEAP hydropower reservoir: Taschkumyrskaja
[2022-10-02 09:54:02.612]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1366_lscenario2.xlsx"
[2022-10-02 09:54:02.947]INFO:                 Assigning to LEAP hydropower plant: TASH_KUMYR
[2022-10-02 09:54:06.676]INFO:                 Assigning to LEAP hydropower plant: SHAMALDYSAI
[2022-10-02 09:54:09.673]INFO:                 Assigning to LEAP hydropower plant: UCH_KURGANSK
[2022-10-02 09:54:12.719]INFO:         WEAP hydropower reservoir: Farkhad
[2022-10-02 09:54:16.896]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1371_lscenario2.xlsx"
[2022-10-02 09:54:17.182]INFO:                 Assigning to LEAP hydropower plant: FARKHAD
[2022-10-02 09:54:20.922]INFO:         WEAP hydropower reservoir: Akhangaran
[2022-10-02 09:54:25.114]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch637_lscenario2.xlsx"
[2022-10-02 09:54:25.495]INFO:                 Assigning to LEAP hydropower plant: AKHANGARAN
[2022-10-02 09:54:29.608]INFO:         WEAP hydropower reservoir: Charvak
[2022-10-02 09:54:41.457]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch103_lscenario2.xlsx"
[2022-10-02 09:54:41.772]INFO:                 Assigning to LEAP hydropower plant: CHARVAK
[2022-10-02 09:54:45.599]INFO:                 Assigning to LEAP hydropower plant: GAZLKENT
[2022-10-02 09:54:48.710]INFO:                 Assigning to LEAP hydropower plant: KHODZHIKENT
[2022-10-02 09:54:51.660]INFO:         WEAP hydropower reservoir: Chirchik
[2022-10-02 09:55:06.984]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1369_lscenario2.xlsx"
[2022-10-02 09:55:07.323]INFO:                 Assigning to LEAP hydropower plant: AKKAVAK_1
[2022-10-02 09:55:11.293]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_1
[2022-10-02 09:55:14.403]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_2
[2022-10-02 09:55:17.573]INFO:                 Assigning to LEAP hydropower plant: TAVAK
[2022-10-02 09:55:20.582]INFO:         WEAP hydropower reservoir: Andijan
[2022-10-02 09:55:28.343]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch226_lscenario2.xlsx"
[2022-10-02 09:55:28.669]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_1
[2022-10-02 09:55:32.450]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_2
[2022-10-02 09:55:36.344]INFO:        WEAP hydropower reservoir: At-Bashi
[2022-10-02 09:55:40.788]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5675_lscenario2.xlsx"
[2022-10-02 09:55:41.154]INFO:                 Assigning to LEAP hydropower plant: AT_BASHIN
[2022-10-02 09:55:44.958]INFO:         WEAP hydropower reservoir: Kokomeren
[2022-10-02 09:55:49.103]INFO:         WEAP hydropower reservoir: Upper Naryn
[2022-10-02 09:55:53.166]INFO:         WEAP hydropower reservoir: Kazarman
[2022-10-02 09:55:57.207]INFO:Moving water pumping information from WEAP to LEAP
[2022-10-02 09:55:57.207]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 09:55:58.272]INFO:                 Region: Kazakhstan
[2022-10-02 09:55:59.320]INFO:                 Region: Kyrgyzstan
[2022-10-02 09:56:00.271]INFO:                 Region: Tajikistan
[2022-10-02 09:56:01.359]INFO:                 Region: Uzbekistan
[2022-10-02 09:56:01.459]INFO:Moving industrial water requirements from WEAP to LEAP
[2022-10-02 09:56:01.490]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 09:56:02.736]INFO:                 Region: Kazakhstan
[2022-10-02 09:56:03.898]INFO:                 Region: Kyrgyzstan
[2022-10-02 09:56:04.859]INFO:                 Region: Tajikistan
[2022-10-02 09:56:05.946]INFO:                 Region: Uzbekistan
[2022-10-02 09:56:06.046]INFO:Calculating LEAP area (iteration 2)
[2022-10-02 10:11:35.508]INFO:Saving LEAP and WEAP areas
[2022-10-02 10:11:58.331]INFO:Saving versions for iteration 2
[2022-10-02 10:12:32.763]INFO:Checking LEAP results...
[2022-10-02 10:12:56.445]INFO:Checking Macro results...
[2022-10-02 10:12:57.198]INFO:Checking WEAP results...
[2022-10-02 10:12:57.516]INFO:Checking whether calculations converged...
[2022-10-02 10:12:57.523]INFO:Difference exceeded tolerance for LEAP result "KURPSAI" in year
2036 of scenario "S1 Baseline Historical": previous value = 2023.6231399330525, current value =
1798.9459385139971
[2022-10-02 10:12:57.523]INFO:Results did not converge. Iterating...
[2022-10-02 10:12:57.524]INFO:Pushing WEAP results to Macro...
[2022-10-02 10:13:19.114]INFO:Processing for WEAP scenario: S1 Historical
[2022-10-02 10:13:19.706]INFO:Running LEAP-Macro for scenario: S1 Baseline Historical
[2022-10-02 10:13:19.706]INFO:         Region: Kazakhstan
[2022-10-02 10:13:19.706]INFO:         Executing: C:\Users\EricKemp-
Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe        "C:\Users\EricKemp-
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Benedict\Documents\WAVE_Macro\KAZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -w -v -y
2050 -u 41 -r 2 --load-leap-first
[2022-10-02 10:15:42.497]INFO:          Region: Kyrgyzstan
[2022-10-02 10:15:42.497]INFO:          Executing: C:\Users\EricKemp-
Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe        "C:\Users\EricKemp-
Benedict\Documents\WAVE_Macro\KGZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -w -v -y
2050 -u 41 -r 2 --load-leap-first
[2022-10-02 10:17:59.540]INFO:Pushing demographic and macroeconomic drivers from LEAP to WEAP
[2022-10-02 10:17:59.540]INFO:          Population_KAZ
[2022-10-02 10:18:06.930]INFO:          Population_KGZ
[2022-10-02 10:18:14.355]INFO:          Population_TJK
[2022-10-02 10:18:21.924]INFO:          Population_UZB
[2022-10-02 10:18:29.375]INFO:          GDP_KAZ
[2022-10-02 10:18:36.994]INFO:          GDP_KGZ
[2022-10-02 10:18:44.521]INFO:          GDP_TJK
[2022-10-02 10:18:52.175]INFO:          GDP_UZB
[2022-10-02 10:18:59.127]INFO:          Industrial_VA_KAZ
[2022-10-02 10:19:06.025]INFO:          Industrial_VA_KGZ
[2022-10-02 10:19:12.651]INFO:          Industrial_VA_TJK
[2022-10-02 10:19:19.443]INFO:          Industrial_VA_UZB
[2022-10-02 10:19:26.367]INFO:Pushed 12 variable(s) to WEAP
[2022-10-02 10:19:26.378]INFO:Calculating WEAP (iteration 3)
[2022-10-02 10:22:08.994]INFO:Finished calculating WEAP. Moving hydropower maximum availabilities
from WEAP to LEAP....
[2022-10-02 10:22:09.689]INFO:WEAP scenario: S1 Historical
[2022-10-02 10:22:09.689]INFO:          WEAP hydropower reservoir: Toktogul
[2022-10-02 10:22:13.493]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch88_lscenario2.xlsx"
[2022-10-02 10:22:16.407]INFO:                  Assigning to LEAP hydropower plant: TOKTOGUL
[2022-10-02 10:22:20.159]INFO:          WEAP hydropower reservoir: Kambarata_I
[2022-10-02 10:22:24.387]INFO:          WEAP hydropower reservoir: Kambarata_II
[2022-10-02 10:22:28.844]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch5677_lscenario2.xlsx"
[2022-10-02 10:22:29.374]INFO:                  Assigning to LEAP hydropower plant: KAMBARATA_2
[2022-10-02 10:22:33.321]INFO:          WEAP hydropower reservoir: Kayrakkum
[2022-10-02 10:22:38.844]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch106_lscenario2.xlsx"
[2022-10-02 10:22:39.398]INFO:                  Assigning to LEAP hydropower plant: KAIRAKKUM
[2022-10-02 10:22:43.662]INFO:          WEAP hydropower reservoir: Shardara
[2022-10-02 10:22:49.074]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch108_lscenario2.xlsx"
[2022-10-02 10:22:49.464]INFO:                  Assigning to LEAP hydropower plant: SHARDARINSKYA
[2022-10-02 10:22:53.776]INFO:          WEAP hydropower reservoir: Kurpsaiskaja
[2022-10-02 10:22:59.907]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch1364_lscenario2.xlsx"
[2022-10-02 10:23:00.276]INFO:                  Assigning to LEAP hydropower plant: KURPSAI
[2022-10-02 10:23:04.754]INFO:          WEAP hydropower reservoir: Taschkumyrskaja
[2022-10-02 10:23:17.263]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch1366_lscenario2.xlsx"
[2022-10-02 10:23:17.569]INFO:                  Assigning to LEAP hydropower plant: TASH_KUMYR
[2022-10-02 10:23:21.835]INFO:                  Assigning to LEAP hydropower plant: SHAMALDYSAI
[2022-10-02 10:23:25.016]INFO:                  Assigning to LEAP hydropower plant: UCH_KURGANSK
[2022-10-02 10:23:28.340]INFO:          WEAP hydropower reservoir: Farkhad
[2022-10-02 10:23:32.539]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch1371_lscenario2.xlsx"
[2022-10-02 10:23:32.847]INFO:                  Assigning to LEAP hydropower plant: FARKHAD
[2022-10-02 10:23:36.855]INFO:          WEAP hydropower reservoir: Akhangaran
[2022-10-02 10:23:41.132]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch637_lscenario2.xlsx"
[2022-10-02 10:23:41.461]INFO:                  Assigning to LEAP hydropower plant: AKHANGARAN
[2022-10-02 10:23:45.217]INFO:          WEAP hydropower reservoir: Charvak
[2022-10-02 10:23:57.584]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch103_lscenario2.xlsx"
[2022-10-02 10:23:57.934]INFO:                  Assigning to LEAP hydropower plant: CHARVAK
[2022-10-02 10:24:01.428]INFO:                  Assigning to LEAP hydropower plant: GAZLKENT
[2022-10-02 10:24:04.519]INFO:                  Assigning to LEAP hydropower plant: KHODZHIKENT
[2022-10-02 10:24:07.581]INFO:          WEAP hydropower reservoir: Chirchik
[2022-10-02 10:24:23.634]INFO:                  Saving as Excel with filename
"hydro_availability_wbranch1369_lscenario2.xlsx"
[2022-10-02 10:24:23.951]INFO:                  Assigning to LEAP hydropower plant: AKKAVAK_1
[2022-10-02 10:24:27.769]INFO:                  Assigning to LEAP hydropower plant: CHIRCHIK_1
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[2022-10-02 10:24:30.788]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_2
[2022-10-02 10:24:33.937]INFO:                 Assigning to LEAP hydropower plant: TAVAK
[2022-10-02 10:24:37.202]INFO:         WEAP hydropower reservoir: Andijan
[2022-10-02 10:24:45.313]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch226_lscenario2.xlsx"
[2022-10-02 10:24:45.647]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_1
[2022-10-02 10:24:49.979]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_2
[2022-10-02 10:24:54.023]INFO:       WEAP hydropower reservoir: At-Bashi
[2022-10-02 10:24:58.625]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5675_lscenario2.xlsx"
[2022-10-02 10:24:58.973]INFO:                 Assigning to LEAP hydropower plant: AT_BASHIN
[2022-10-02 10:25:03.267]INFO:         WEAP hydropower reservoir: Kokomeren
[2022-10-02 10:25:07.335]INFO:         WEAP hydropower reservoir: Upper Naryn
[2022-10-02 10:25:12.691]INFO:         WEAP hydropower reservoir: Kazarman
[2022-10-02 10:25:17.405]INFO:Moving water pumping information from WEAP to LEAP
[2022-10-02 10:25:17.405]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 10:25:18.536]INFO:                 Region: Kazakhstan
[2022-10-02 10:25:19.619]INFO:                 Region: Kyrgyzstan
[2022-10-02 10:25:20.526]INFO:                 Region: Tajikistan
[2022-10-02 10:25:21.701]INFO:                 Region: Uzbekistan
[2022-10-02 10:25:21.830]INFO:Moving industrial water requirements from WEAP to LEAP
[2022-10-02 10:25:21.857]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 10:25:23.174]INFO:                 Region: Kazakhstan
[2022-10-02 10:25:24.264]INFO:                 Region: Kyrgyzstan
[2022-10-02 10:25:25.212]INFO:                 Region: Tajikistan
[2022-10-02 10:25:26.294]INFO:                 Region: Uzbekistan
[2022-10-02 10:25:26.404]INFO:Calculating LEAP area (iteration 3)
[2022-10-02 10:41:11.702]INFO:Saving LEAP and WEAP areas
[2022-10-02 10:41:34.040]INFO:Saving versions for iteration 3
[2022-10-02 10:42:09.646]INFO:Checking LEAP results...
[2022-10-02 10:42:34.901]INFO:Checking Macro results...
[2022-10-02 10:42:35.679]INFO:Checking WEAP results...
[2022-10-02 10:42:36.102]INFO:Checking whether calculations converged...
[2022-10-02 10:42:36.141]INFO:Difference exceeded tolerance for LEAP result "KURPSAI" in year
2037 of scenario "S1 Baseline Historical": previous value = 1644.7050494994025, current value =
1467.1263496518939
[2022-10-02 10:42:36.141]INFO:Results did not converge. Iterating...
[2022-10-02 10:42:36.141]INFO:Pushing WEAP results to Macro...
[2022-10-02 10:43:00.413]INFO:Processing for WEAP scenario: S1 Historical
[2022-10-02 10:43:01.031]INFO:Running LEAP-Macro for scenario: S1 Baseline Historical
[2022-10-02 10:43:01.031]INFO:         Region: Kazakhstan
[2022-10-02 10:43:01.031]INFO:         Executing: C:\Users\EricKemp-
Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe       "C:\Users\EricKemp-
Benedict\Documents\WAVE_Macro\KAZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -w -v -y
2050 -u 44 -r 3 --load-leap-first
[2022-10-02 10:47:14.919]INFO:         Region: Kyrgyzstan
[2022-10-02 10:47:14.919]INFO:         Executing: C:\Users\EricKemp-
Benedict\AppData\Local\Programs\Julia-1.6.3\bin\julia.exe       "C:\Users\EricKemp-
Benedict\Documents\WAVE_Macro\KGZ_Macro\runleapmacro.jl" "S1 Baseline Historical" -c -p -w -v -y
2050 -u 44 -r 3 --load-leap-first
[2022-10-02 10:49:21.955]INFO:Pushing demographic and macroeconomic drivers from LEAP to WEAP
[2022-10-02 10:49:21.955]INFO:         Population_KAZ
[2022-10-02 10:49:29.207]INFO:         Population_KGZ
[2022-10-02 10:49:38.063]INFO:         Population_TJK
[2022-10-02 10:49:54.009]INFO:         Population_UZB
[2022-10-02 10:50:08.564]INFO:         GDP_KAZ
[2022-10-02 10:50:19.853]INFO:         GDP_KGZ
[2022-10-02 10:50:30.484]INFO:         GDP_TJK
[2022-10-02 10:50:43.932]INFO:         GDP_UZB
[2022-10-02 10:50:53.274]INFO:         Industrial_VA_KAZ
[2022-10-02 10:51:01.552]INFO:         Industrial_VA_KGZ
[2022-10-02 10:51:09.855]INFO:         Industrial_VA_TJK
[2022-10-02 10:51:18.587]INFO:         Industrial_VA_UZB
[2022-10-02 10:51:26.020]INFO:Pushed 12 variable(s) to WEAP
[2022-10-02 10:51:26.031]INFO:Calculating WEAP (iteration 4)
[2022-10-02 10:54:08.709]INFO:Finished calculating WEAP. Moving hydropower maximum availabilities
from WEAP to LEAP....
[2022-10-02 10:54:09.376]INFO:WEAP scenario: S1 Historical
[2022-10-02 10:54:09.376]INFO:         WEAP hydropower reservoir: Toktogul
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[2022-10-02 10:54:11.849]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch88_lscenario2.xlsx"
[2022-10-02 10:54:14.743]INFO:                 Assigning to LEAP hydropower plant: TOKTOGUL
[2022-10-02 10:54:18.383]INFO:         WEAP hydropower reservoir: Kambarata_I
[2022-10-02 10:54:22.458]INFO:         WEAP hydropower reservoir: Kambarata_II
[2022-10-02 10:54:26.606]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5677_lscenario2.xlsx"
[2022-10-02 10:54:26.944]INFO:                 Assigning to LEAP hydropower plant: KAMBARATA_2
[2022-10-02 10:54:30.699]INFO:         WEAP hydropower reservoir: Kayrakkum
[2022-10-02 10:54:34.903]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch106_lscenario2.xlsx"
[2022-10-02 10:54:35.256]INFO:                 Assigning to LEAP hydropower plant: KAIRAKKUM
[2022-10-02 10:54:39.022]INFO:         WEAP hydropower reservoir: Shardara
[2022-10-02 10:54:43.234]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch108_lscenario2.xlsx"
[2022-10-02 10:54:43.742]INFO:                 Assigning to LEAP hydropower plant: SHARDARINSKYA
[2022-10-02 10:54:47.568]INFO:         WEAP hydropower reservoir: Kurpsaiskaja
[2022-10-02 10:54:51.790]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1364_lscenario2.xlsx"
[2022-10-02 10:54:52.124]INFO:                 Assigning to LEAP hydropower plant: KURPSAI
[2022-10-02 10:54:55.839]INFO:         WEAP hydropower reservoir: Taschkumyrskaja
[2022-10-02 10:55:07.334]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1366_lscenario2.xlsx"
[2022-10-02 10:55:07.669]INFO:                 Assigning to LEAP hydropower plant: TASH_KUMYR
[2022-10-02 10:55:11.394]INFO:                 Assigning to LEAP hydropower plant: SHAMALDYSAI
[2022-10-02 10:55:14.423]INFO:                 Assigning to LEAP hydropower plant: UCH_KURGANSK
[2022-10-02 10:55:17.478]INFO:         WEAP hydropower reservoir: Farkhad
[2022-10-02 10:55:21.633]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1371_lscenario2.xlsx"
[2022-10-02 10:55:21.930]INFO:                 Assigning to LEAP hydropower plant: FARKHAD
[2022-10-02 10:55:25.803]INFO:         WEAP hydropower reservoir: Akhangaran
[2022-10-02 10:55:30.058]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch637_lscenario2.xlsx"
[2022-10-02 10:55:30.423]INFO:                 Assigning to LEAP hydropower plant: AKHANGARAN
[2022-10-02 10:55:35.455]INFO:         WEAP hydropower reservoir: Charvak
[2022-10-02 10:55:47.296]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch103_lscenario2.xlsx"
[2022-10-02 10:55:47.606]INFO:                 Assigning to LEAP hydropower plant: CHARVAK
[2022-10-02 10:55:51.497]INFO:                 Assigning to LEAP hydropower plant: GAZLKENT
[2022-10-02 10:55:54.506]INFO:                 Assigning to LEAP hydropower plant: KHODZHIKENT
[2022-10-02 10:55:57.592]INFO:         WEAP hydropower reservoir: Chirchik
[2022-10-02 10:56:12.621]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch1369_lscenario2.xlsx"
[2022-10-02 10:56:12.958]INFO:                 Assigning to LEAP hydropower plant: AKKAVAK_1
[2022-10-02 10:56:16.564]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_1
[2022-10-02 10:56:19.575]INFO:                 Assigning to LEAP hydropower plant: CHIRCHIK_2
[2022-10-02 10:56:22.501]INFO:                 Assigning to LEAP hydropower plant: TAVAK
[2022-10-02 10:56:25.459]INFO:         WEAP hydropower reservoir: Andijan
[2022-10-02 10:56:33.228]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch226_lscenario2.xlsx"
[2022-10-02 10:56:33.560]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_1
[2022-10-02 10:56:37.380]INFO:                 Assigning to LEAP hydropower plant: ANDIJAN_2
[2022-10-02 10:56:40.348]INFO:       WEAP hydropower reservoir: At-Bashi
[2022-10-02 10:56:44.414]INFO:                 Saving as Excel with filename
"hydro_availability_wbranch5675_lscenario2.xlsx"
[2022-10-02 10:56:44.710]INFO:                 Assigning to LEAP hydropower plant: AT_BASHIN
[2022-10-02 10:56:48.526]INFO:         WEAP hydropower reservoir: Kokomeren
[2022-10-02 10:56:52.581]INFO:         WEAP hydropower reservoir: Upper Naryn
[2022-10-02 10:56:56.639]INFO:         WEAP hydropower reservoir: Kazarman
[2022-10-02 10:57:00.698]INFO:Moving water pumping information from WEAP to LEAP
[2022-10-02 10:57:00.698]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 10:57:01.742]INFO:                 Region: Kazakhstan
[2022-10-02 10:57:02.749]INFO:                 Region: Kyrgyzstan
[2022-10-02 10:57:03.618]INFO:                 Region: Tajikistan
[2022-10-02 10:57:04.771]INFO:                 Region: Uzbekistan
[2022-10-02 10:57:04.855]INFO:Moving industrial water requirements from WEAP to LEAP
[2022-10-02 10:57:04.860]INFO:         Scenario: S1 Historical (WEAP)/S1 Baseline Historical
(LEAP)
[2022-10-02 10:57:05.880]INFO:                 Region: Kazakhstan
[2022-10-02 10:57:06.920]INFO:                 Region: Kyrgyzstan
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[2022-10-02  10:57:07.775]INFO:                 Region: Tajikistan
[2022-10-02  10:57:08.833]INFO:                 Region: Uzbekistan
[2022-10-02 10:57:09.012]INFO:Calculating LEAP area (iteration 4)
[2022-10-02 11:11:22.840]INFO:Saving LEAP and WEAP areas
[2022-10-02 11:11:44.599]INFO:Saving versions for iteration 4
[2022-10-02 11:12:17.429]INFO:Checking LEAP results...
[2022-10-02 11:12:40.724]INFO:Checking Macro results...
[2022-10-02 11:12:41.482]INFO:Checking WEAP results...
[2022-10-02 11:12:41.834]INFO:Checking whether calculations converged...
[2022-10-02 11:12:41.846]INFO:All target WEAP and LEAP results converged to within the specified
tolerance (10.0%). No additional iterations of WEAP and LEAP calculations are needed.
[2022-10-02 11:12:41.867]INFO:Completed WEAP-LEAP integration procedure
[2022-10-02 11:12:41.895]INFO:Total elapsed time: 02:28:02
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