Deliverable 5.2: Hydro4U Replication plan. 2nd release

WP5, Task 5.1

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Abbreviations and Acronyms

Acronym	Description
ADB	Asian Development Bank
AIIB	Asian Infrastructure Investment Bank
CA	Central Asia
CAPS	Central Asia Integrated Power System
CIF	Climate Investments Funds
DX.Y	Deliverable number Y of the X^{th} Work-Package
EU	European Union
EEAS	European External Action Service
EIB	European Investment Bank
ERBD	European Bank for Reconstruction and Development
FCPS	Francis Container Power Solution
FIT	Feed-in Tariffs
GCF	Green Climate Fund
GEF	Global Environment Facility
GIS	Geographic Information System
H2020	Horizon 2020 (8^{th} Framework Programme for Research of the EU)
HP	Hydropower
HPP	Hydropower Plant
HSPS	Hydroshaft Power Solution
IEA	International Energy Agency
IFCA	Investment Facility for Central Asia
IHA	International Hydropower Association
KAZ	Kazakhstan
KER	Key Exploitable Result
KGZ	Kyrgyzstan
PA	Planning Activities
PICTs	Pacific Island Countries and territories
RE	Renewable Energy
RES	Renewable Energy Sources
SHP	Small Hydropower
TJK	Tajikistan
TKM	Turkmenistan
UNIDO	United Nations Industrial Development Organization
UZB	Uzbekistan
WFEC	Water-Food -Energy - Climate
WP	Work Package

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1. Publishable Summary

Hydro4U Project aims to adapt hydropower European technologies to Central Asia (CA) by demonstrating their viability through design alterations for price-competitiveness and in a cross-border Water-Food-Energy-Climate (WFEC) Nexus context. Hydro4U will install and assess **two Small Hydropower (SHP) plants**, which will radically reduce planning and construction costs, without compromising efficiency. Those are:

- approx. 2 MW Francis Container Power Solution (FCPS), medium-head plant, in Shakimardan site at Koksu River in Uzbekistan (UZB),
- approx. 1.6 MW Hydroshaft Power Solution (HSPS), low-head eco-friendly run-of-river plant, in At-Bashy River in Kyrgyzstan (KGZ).

Hydro4U also addresses the development of a standardized methodology for the assessment of the unexploited and sustainable SHP potential in the region. A **replication model** will be developed in order to demonstrate EU quality standards and to create entry points in developing markets for the European SHP industry. These goals are supported by arising technical, organisational, managerial, and financial innovations which need to be exploited for an increased impact of the project.

This report corresponds to **D5.2: "Hydro4U Replication plan. 2nd release"**, which is the second deliverable from WP5: "Replication of sustainable SHP potential". D5.2 is the outcome from the work carried out so far within Task 5.1: "Hydro4U replication plan". This report, submitted by M24, updates the information reported in the D5.1: "Hydro4U Replication plan. 1st release" submitted by M12. The Hydro4U replication strategy to be developed within Task 5.1 will be reviewed and updated within further releases: D5.4 (by M36) and D5.7 (by M48).

This Deliverable D5.2 is divided into the following chapters:

Chapter 3 provides an overview of the electricity sector in the region and describes in detail the situation in all the countries.

Chapter 4 addresses the description of the SHP context in Central Asia, based on the methodology developed within WP1 for the calculation of the technical and sustainable SHP potential. Results are compared with those reported by UNIDO, which were included in D5.1.

Chapter 5 is focus on the funding options for green and sustainable projects in CA. In the previous D5.1, it was found that the financial barriers are very relevant when assessing the low SHP development in the region. This is the reason why in this D5.2, several European and

International organisations and financing institutions have been identified, together with the eligibility criteria for funding new SHP projects.

Chapter 6 is describing the lessons learnt during the installation of new SHP plants in Central Asia, based on the experience gained in the demonstration of the two SHP plants in Shakimardan site (UZB) and the At-Bashy river in Kyrgyzstan (KGZ).

Finally, Chapter 7 is describing the current the **Hydro4U replication guideline tool**, selected as one of the Key Exploitable Result of the Project (KER), and the current analysis of the target audience and market, being done within the WP6.

2. Introduction & Relation to Project Progress

2.1. Purpose of Deliverable

This deliverable aims at elaborating a comprehensive Replication plan in order to ensure that all the research activities are oriented to maximize future replicability and impact among potential project promoters in CA as well as among the EU hydropower industry.

2.2. Objectives of WP & Expected Impact

WP5 aims at facilitating the sustainable implementation of future SHP plants in CA and, potentially, other geographical contexts and to support the international leadership of the European hydropower industry beyond the project timeframe. In the core of WP5 is the specific objective 6: “Support the competitiveness and sustainable market uptake of European SHP technologies in CA and globally”. In this context, WP5 comprises **4 main objectives**, which are addressed in 4 different Tasks:

Objective 1. Development of a **comprehensive replication plan** to strengthen the position of European hydropower partners in the region by providing innovative, cost-efficient and sustainable solutions adapted to the climate changes scenarios

→ Task 5.1. Hydro4U replication plan

Objective 2. Assessment of different **hydropower development scenarios** beyond the project according to future prospective analyses from demographical, political and economic dimensions as well as including **WFEC Nexus** constraints and requirements.

→ Task 5.2. Assessment of hydropower development scenarios beyond project timeframe

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Objective 3. Development of feasibility studies in at least **3 test cases** where the implementation of Hydro4U solutions will be analyzed considering the experience, tools and methods developed in other project activities.

→Task 5.3. Feasibility studies and planning at test cases

Objective 4. Compilation of lessons learnt, general recommendations and decision support material in the form of an **interactive Replication Guideline tool**, which will be validated in 3 test cases.

→Task 5.4. Hydro4U replication guideline tool

2.3. Relation to other activities in the project

The tasks foreseen in WP5 fall on the **levels 1, 2 and 3** of the novel methodological approach proposed in Hydro4U (see Figure below), which moves away from classical planning concepts that are difficult to implement in the region towards innovative, regionally adapted solutions, as is shown in the figure below.

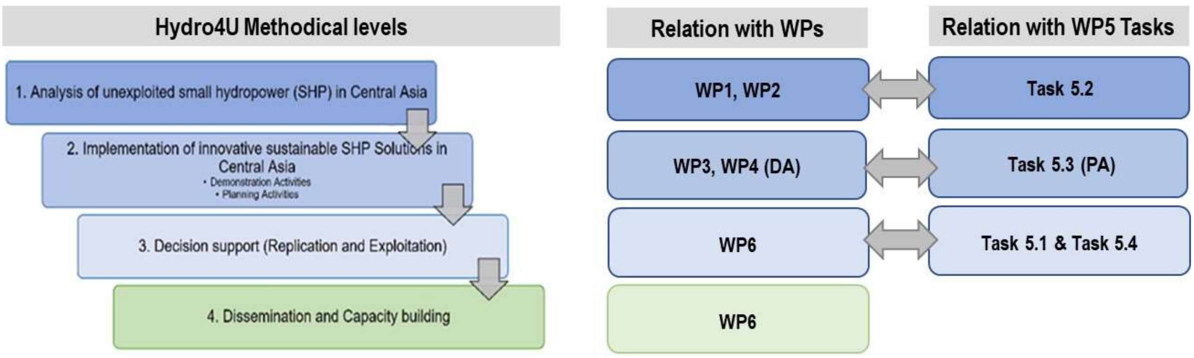

Figure 1: Alignment of WP5 with Hydro4U methodology

<u>Level 1: Analysis of unexploited SHP potential in CA</u>.

Within Hydro4U, an interdisciplinary GIS-based approach is being developed to map the sustainable, so far unexploited SHP potential in a transparent, comprehensive and freely accessible way, considering WFEC Nexus constraints (WP1 and WP2). Information from local partners and stakeholders will be prepared for a web-based geo-database, supplemented by modelling tools from the fields of i) natural, ii) engineering and iii) socio-economic sciences.

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Level 2: Implementation of innovative sustainable SHP solutions in CA: Demonstration Activities and Planning Activities

Hydro4U is not a theoretical work, as the innovative hydropower solutions are realized on site within the project lifetime (WP3 and WP4) in the two project Demonstration Activities in Shakimardan site (UZB) and the At-Bashy river (KGZ). In order to demonstrate that the solutions will also work under different conditions on other sites, virtual follow up studies are conducted in the so-called Planning Activities (PA), that are being developed in three planning sites throughout the region and which will end in **technical and bankable feasibility studies** (WP5). This work constitutes the basis and background to create overall guidelines and a comprehensive framework for a replication guideline with respect to existing EU and CA regulations, guidelines and legislatives.

Level 3: Decision support.

Hydro4U wants to show that SHP can be standardized and thus significantly increase efficiency in terms of cost and time. Level 3 is primarily about harmonizing the potential of Level 1 with the hydropower solutions and guidelines of Level 2. The target group is not just a few experts who are familiar with the specific details, but broadly-based decision makers, investors and politicians (public use). Considering the before mentioned, Hydro4U shapes the forward-looking long-term development of a region and enables growth and prosperity. Hydro4U provides this group with a decision-support tool, i.e. the **interactive Replication Guideline tool** (WP5), based on the available potential and appropriate technical solutions, considering related factors such as WFEC Nexus, climate impact and socio-economic viability.

Table 1: Relation to other activities in the project

R&D activities within WP1-WP4		Replication approach within WP5
WP1	Collection and conceptualization of the project geodatabase (Task 1.1)	Use geodatabase for the Planning Activities (Task 5.3) and incorporate them into the decision tool (Task 5.4)
WP1	Definition of the methodology to calculate SHP potential in CA and further quantification (Task 1.2)	Assessment of the impact of the estimated SHP potential in the region. Systematic stakeholder analysis.
WP1	Definition of a methodology for site assessment, GIS tool development and validation in 10 sites (Task 1.3-1.7)	Integration of the methodology in the assessment of HP scenarios (Task 5.2), use it in the Planning Activities (Task 5.3), and incorporate it into the decision tool (Task 5.4)
WP2	Quantification of shared benefits and trade-offs analysis from SHP (Task 2.1)	Incorporation of lessons learnt from the different interviews and consultation meetings that are being organized within WP2. Special attention will be paid to the drivers that support the understanding on how SHP can influence other sectors and improve socio-economic conditions of the sites. This provides additional information

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		which is important to realize SHP, to avoid (transboundary) conflicts and to indicate relevant stakeholders from the beginning.
WP2	Innovative web-based WFEC accounting system (Task 2.2): Count4D. Online nexus toolbox based on an innovative monitoring and accounting methodology	Synergies with this new online Nexus toolbox will be explored and will fit both the assessment of HP scenarios (Task 5.2) and the replication guideline tool (Task 5.4).
WP3	Analysis of the optimization potential of SHP technologies to be demonstrated HSPS and FCPS (Task 3.1)	The optimized SHP technologies will be promoted via the replication products of WP5. Additionally, a screening of other SHP technologies will be performed to include other European SHP technologies matching the conditions in CA.
WP3	Realization of the Demonstration Activities (Task 3.5)	The demonstrated SHPs of Hydro4U in Central Asia, will serve as best practice examples how to plan, finance, build and operate SHP in a sustainable way. The findings from the demonstration activities will be promoted in the Replication guidelines, having a lighthouse character.
WP4	Assessment strategy integrating environmental, financial and socio-economic sustainability (Task 4.3)	Hydro4Us sustainability assessment strategy elaborated at the demonstration sites will be integrated with international standards, such as IHA protocols and WB guidelines.
WP4	Demo-site design development and optimization (Task 4.4), Demo-site implementation (Task 4.7), Assessment of the operation (Task 4.8)	The detailed planning at the demonstration sites will be included in the replication documents as best practice examples and blueprints for future SHP projects in CA.

2.4. Contribution of Partners

In total, four partners are involved in Task 5.1: CARTIF as the task leader and the partners BOKU, TUM and KSTU contributed with different shares. See Table below for a detailed work description per partner.

Table 2: Contribution of Partners to D5.2

Partner Short name	Contributions
CARTIF	CARITF has been responsible for the description of the different funding sources for new HP projects in Central Asia (Section 5) and the replication guideline tool (Section 7).
BOKU	BOKU contributed to this report by giving an overview of the sustainable HP potential of CA (Section 4). This has been addressed within Task 1.2 and was discussed in detail in D1.4. Here, these assessment and approaches and results are placed in the context of developing a replication plan. Moreover, BOKU gives an overview of ongoing initiatives for the development of SHP in CA.
KSTU	KSTU has been responsible for the overview of the electricity sector in Central Asia (Section 3)
TUM	TUM contributed to the guidelines for technical design Section (Section 6), including the lessons learnt in the process.

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2.5. Definitions

Small Hydropower (SHP): The definition of SHP varies throughout the Central Asia region. Kazakhstan (KAZ) has the highest upper limit of installed capacity in its definition of SHP, at 35 MW, while Kyrgyzstan, Uzbekistan and Tajikistan maintain a 30 MW limit. Turkmenistan does not have an official definition, and the standard EU definition up to 10 MW is used in the present report.

Gross theoretical SHP potential: It expresses the total amount of electricity that could potentially be generated if all available water resources were devoted to this use. The gross capacity of a HP plant in a river can be calculated as:

$$P = \rho \cdot g \cdot H \cdot Q \qquad (1)$$

where P is the hydropower capacity (in W), ρ is the density of water (kg/m^3), g is the gravitational acceleration (m/s^2), H is the head (m) and Q is the discharge (m^3/s). The maximum annual energy production is reached when 100% of the annual runoff is used for hydropower production (i.e. gross potential).

Technically exploitable SHP potential: it represents the SHP capacity that is attractive and readily available with existing technology.

Economically feasible SHP potential: it is the amount of SHP generating capacity that could be built at current prices and with a positive outcome after conducting a feasibility study for each site. Technical and economic feasibility is strongly dependent on local conditions and therefore requires in-depth studies at each potential site, which is why we focus on gross theoretical potential.

Remaining sustainable SHP potential: it represents the SHP capacity based on the method developed by Hydro4U (D1.4: "First technical report", De Keyser *et al.*, 2023). The SHP potential was computed using a multistage procedure that progressively breaks down theoretical line potential based on the hydrological conditions to remaining sustainable potential based on environmental parameters, ecological and geomorphological constraints and climate change considerations.

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3. Overview of the electricity sector in Central Asia

From the 1970s until 1990, the Central Asia Integrated Power System (CAIPS) was a centralized body which provided electricity to all the CA region regardless of national borders. CAIPS was also in charge of resolving energy and water related problems and generated 30% of electricity from hydropower and 70% from thermal power. After the disintegration of the Soviet Union, the CAIPS collapsed and national electricity systems were separated. As the resources are non-uniformly spread across the countries, supplies of water and power in the region became imbalanced and electricity consumption dropped severely.

The countries of the region can be divided in terms of water resources. Most hydropower resources are concentrated in Kyrgyzstan and Tajikistan, with mountainous territories, e.g., within the Pamir and Tian Shan Mountain ranges and which are considered “upstream” countries (see Figure 2). On the other hand, Kazakhstan, Turkmenistan and Uzbekistan have an abundance of thermal resources such as fossil fuels and can be considered “downstream” countries (Hamidov *et. al*, 2016). This imbalance drove the countries to undertake measures and agree on maintaining parallel operations within the separately functioning power systems (World Bank, 2017a).

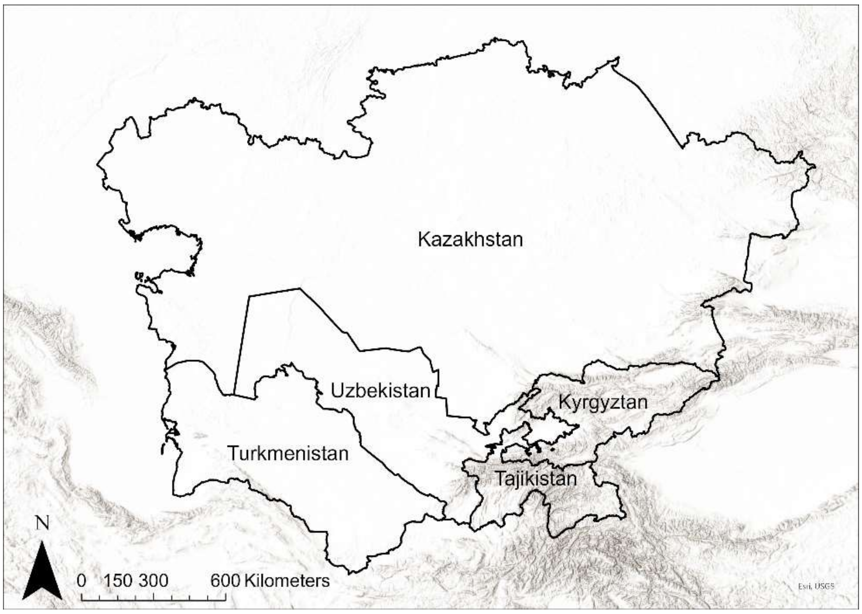

Figure 2: Overview of the Central Asian countries and their topography. (Data source: hattps://gadm.org/index.html; Basemap: Esri, 2021)

Economic development and urbanization combined with energy independence have been an impetus for the expansion of the national energy sectors, in particular, electric generation. Electrification rates in the region have been steadily increasing, having reached 100% in all countries, except Tajikistan with 99.3% (World Bank, n.d.).

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Tajikistan and the Kyrgyz Republic are considered the most energy insecure countries in the region. Both nations have the potential to provide major exports of HP in the summer and are therefore important partners in the energy sector. In addition, changes in weather patterns and extreme conditions negatively affect energy supply and power distribution. Severe landslides could permanently affect SHP Plants, as well as other Renewable Energy facilities.

All countries of the region, except Turkmenistan, have adopted primary legislation on renewable energy and energy efficiency. The legislation framework includes introducing incentives such as grid-access, tax exemptions and feed-in tariffs (FITs). FITs have been introduced in Kazakhstan, Kyrgyzstan and Tajikistan. However, starting from 2018, Kazakhstan switched from the FIT system to an auction system (Liu *et al*., 2019).

This second version of the Hydro4U Replication Plan includes a description of the electricity sectors of the five countries in CA. The level of detail of the overview varies between the more complete for Kazakhstan and Kyrgyz Republic and a less detailed version for Tajikistan, Turkmenistan and Uzbekistan, which will be extended in the D2.4: "Hydro4U Replication plan. 3rd release" to be submitted by M36.

3.1. Electricity sector in Kazakhstan

The country is the largest in the region. About 90% of Kazakhstan has an arid or semi-arid climate. Over 70% of the country consists of desert or steppe. Apart from the mountainous region in the south and southeast of the country, little precipitation falls in Kazakhstan. The country generates around 90% of its energy from coal and gas. The remaining 10% is mainly covered by HP.

The production of electrical energy in Kazakhstan is carried out by **158 power plants** of various forms of ownership. The annual maximum load in the Unified Electricity System of Kazakhstan for the last WZP was recorded on November 26, 2019 and amounted to 15,182 MW. As of January 1, 2020, the total installed capacity of power plants in Kazakhstan amounted to 22,936.6 MW, and the available capacity was 19,329.7 MW. Power plants are divided into national power plants, industrial power plants and regional power plants.

In 2019, the volume of electricity generation amounted to 106.0 billion kWh, or 99.3% compared to 2018 (106.8 billion kWh). Electricity consumption amounted to 105.1 billion kWh or 102% by 2018 (103.2 billion kWh), which indicates the full coverage of the country's economy's need for electricity. For 6 months of 2020, the volume of electricity generation amounted to 53.5 billion kWh, or 103% by 6 months of 2019 (51.9 billion kWh). Electricity consumption amounted to 53.1 billion kWh or 102.1% by 6 months of 2019 (52 billion kWh). By order of the Minister of Energy of the Republic of Kazakhstan dated January 15, 2020, No.

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15, the Forecast balance of electric energy and capacity for 2020-2026 was approved. According to it, the volume of generation and consumption of electrical energy should be:

Table 3: Forecast balance of electric energy and capacity for 2020-2026

Year	Production (billion kWh)	Consumption(billion kWh)
2020	113.8	108.8
2021	113.5	110.7
2022	116.1	112.7
2023	120.9	114.5
2024	123.5	118.0
2025	128.1	120.8
2026	128.5	124.1

Electricity transmission sector

The electric networks of the Republic of Kazakhstan are a set of substations, switchgears and power transmission lines connecting them with a voltage of 0.4–1150 kV, intended for the transmission and (or) distribution of electrical energy.

The role of the backbone network in the UES of the Republic of Kazakhstan is performed by the national electric grid (NEG), which provides electrical connections between the regions of the republic and the energy systems of neighbouring states (the Russian Federation, the Kyrgyz Republic and the Republic of Uzbekistan), as well as the issuance of electrical energy by power stations and its transmission to wholesale consumers. Substations, switchgears, interregional and (or) interstate power lines and power lines that supply electric power to power plants with a voltage of 220 kV and above, which are part of the NPG, are on the balance sheet of KEGOC JSC.

Electric networks of the regional level provide electrical connections within the regions, as well as the transmission of electrical energy to retail consumers. Electric networks of the regional level are on the balance and operation of 19 regional electric grid companies (REC), including the transmission of electric energy is carried out by smaller energy transmission organizations in the amount of 130 pieces.

Power transmission organizations (EPO) carry out, on the basis of contracts, the transmission of electric energy through their own or used (rent, leasing, trust management and other types of use) electric networks to consumers of the wholesale and retail market or energy supply organizations.

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Renewable energy policy: Action plan for 2050

In 2012, the Kazak government defined the "**Kazakhstan 2050 strategy**" (IEA Energy Sector Review, 2022). According to the national plan for transitioning to a green economy, the share of alternative and renewable energy sources should be 3% by 2020, 30% by 2030, and 50% by 2050 (Liu *et al.*, 2019). The plan pledges to reduce the country's greenhouse gas emissions and introduce a pilot emissions trading system. There is considerable interest from investors to develop SHP in Kazakhstan, with many new prospective projects. In the course of the action plan for 2050, 106 facilities with a total capacity of 3,055 MW are planned (IEA Energy Sector review, 2022): (i) 41 SHP plants (totaling 539 MW), (ii) 34 wind farms (totaling 1,787 MW), (iii) 28 solar parks (totaling 714 MW) and (iv) 3 biofuel plants (totaling 15 MW).

There are several funding sources aiming to support the sustainability of the electricity sector. One example could be the DAMU FUND, which has already promoted more than a hundred green projects in Kazakhstan. DAMU FUND is administered by *Baiterek National Management Holding Joint-Stock Company*, a public-private co-funding entity. The instruments used for this purpose are guarantees, subsidies and different types of loan programs. For example, in order to decrease the investments risks for renewable energy projects, this fund will provide working capital up to 25% of the initial investment (see Section 5 for more detailed information of available funding sources in Central Asia).

3.2. Electricity sector in Kyrgyzstan

The Kyrgyz Republic has fairly good energy resources. This is especially true for hydropower resources, the potential of which is estimated at 142 billion kWh, of which about **10% have been developed to date**. More than 10,000 km of high-voltage transmission lines with a voltage of 35-500 kV, more than 70,000 km of distribution networks of 10-0.4 kV, 518 units of substations of 35 kV and above are in operation. The maximum potential for annual electricity generation exceeds **15 billion kWh**.

The history of the development of electrical networks in Kyrgyzstan is closely connected with the overall development of the energy sector of the republic. With the growth of the capacities of power plants, their combination for parallel operation, the centralization of power supply, the voltage classes of power transmission lines and their length grew. In 1934, the Bureau of the Kyrobkom of the All-Union Communist Party of Bolsheviks adopted a resolution on the transfer of the Frunze city networks to a voltage of 6 kV, the creation of a dispatch service and the approval of the organizational and structural body for managing the Frunze energy system - the FOGES trust. Since the adoption of this document, the history of the development of the energy system of Kyrgyzstan has begun.

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The high availability of energy resources created favorable conditions for the rapid development of the energy complex of the republic, which since the beginning of the 80s has become a major producer of hydropower in the Central Asian region, and supplied up to 50% of the generated cheap and environmentally friendly electricity to the IPS of Central Asia. The energy system operates **18 power plants** with an installed capacity of 3,666 MW, **including 16 hydroelectric power plants** and **2 thermal power plants**, more than 10 thousand km of high-voltage power lines with a voltage of 35-500 kV, more than 70,000 km of distribution networks of 10-0.4 kV, 518 units of substations 35 kV and above. The maximum possibility of annual electricity generation reaches 15 billion kWh. The energy system of Kyrgyzstan fully provides the sectors of the economy and the population of the republic with electric energy and ensures export to other countries. It has a connection with the states of Central Asia via 220-500 kV main networks and operates in a single energy mode. Through the backbone networks of Kazakhstan, there is access to the energy system of the Russian Federation. Kyrgyzstan is a stable exporter of electricity to Kazakhstan, Uzbekistan and China. The volume of exports is 2-2.5 billion kWh per year, which can be increased to 3.0 billion kWh.

The electricity sector in the Kyrgyz Republic faces challenges that have accumulated and worsened over the years. The country has an energy deficit driven by insufficient generation, especially in the winter when demand is 2.5-3 times higher than in summer. The total losses in the sector are about 20% of net generation, more than twice as high as commercial and technical losses in high- and some middle-income countries. About half of generation capacity and up to 70% of distribution assets are beyond their useful lives, leading to frequent supply disruptions due to equipment failures and overloading across the country. Moreover, the Kyrgyz Republic has one of the lowest electricity tariff rates in the world. The sector is heavily indebted, with cumulative debt of above KGS 130 billion (equivalent to about $1.5 billion) or around 20 percent of the GDP, placing a heavy fiscal burden on the country.

Management structure of the energy sector of the Kyrgyz Republic

State management in the electric power industry is carried out by the Government of the Kyrgyz Republic through the State Fund for State Property Management and the Ministry of Energy of the Kyrgyz Republic.

The electrification rate in the Kyrgyz Republic is 100% (World Bank, 2017b). Regulation of the energy sector is implemented by four public bodies in Kyrgyzstan (Figure 3):

(1) Ministry of Energy of the Kyrgyz Republic, develops forecasts, analyzes and evaluates the energy development of the Kyrgyz Republic. Provides and implements state policy in the fuel and energy complex.

(2) State Agency for Regulation of the Fuel and Energy Complex, licensing of subjects of the energy sector, tariff policy.

(3) State Inspectorate for Environmental and Technical Safety, implementation of control and supervision over ensuring the reliability, security and uninterrupted power supply in the production, transmission, distribution and consumption of energy and natural gas.

(4) National Energy Holding Company, management of energy joint-stock companies - subjects of natural monopolies.

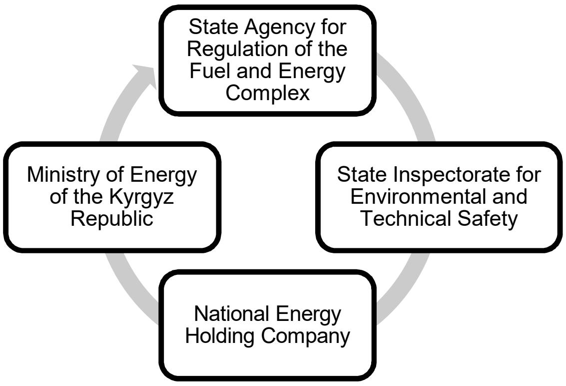

Figure 3: Management structure of the energy sector of the Kyrgyz Republic

Then, Figure 4 shows the structure of the electric power industry of the Kyrgyz Republic, with several generating, transmission and distribution companies:

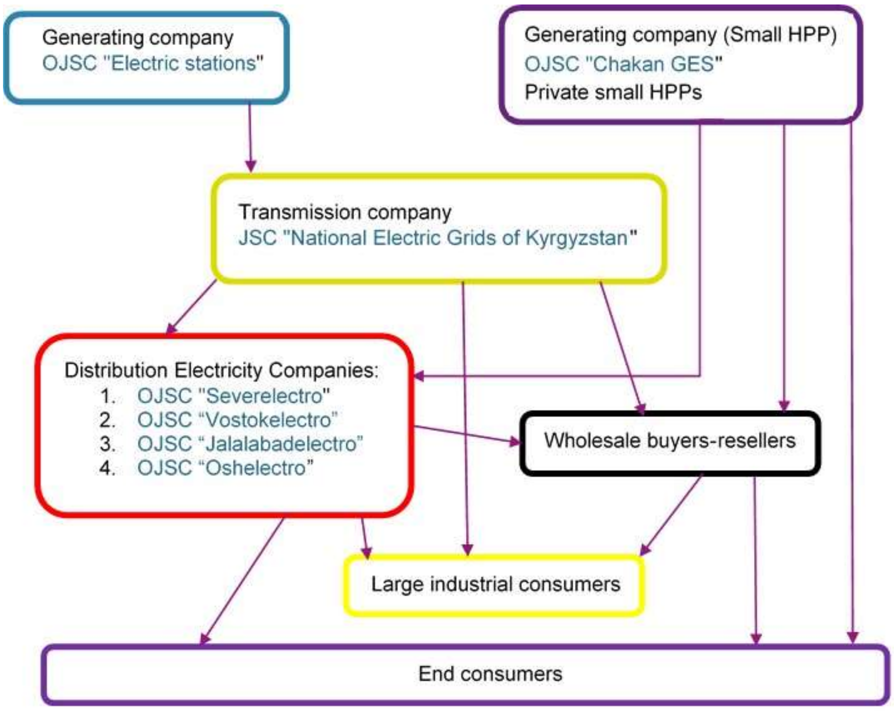

Figure 4: Structure of the electric power industry of the Kyrgyz Republic

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Generating companies:

OJSC "Electric stations", is the basis of the Kyrgyz electric power industry. The generating company generates 98% of all electricity in Kyrgyzstan, provides domestic and foreign consumers with it, regulates the frequency in the Central Asian Unified Energy System. The company includes 7 HPPs and 2 CHPs. These are HPPs: Toktogulskaya, Kurpsaiskaya, Shamaldysayskaya, Tash- Kumyrskaya, Uch-Kurganskaya, Kambarata-2 and At-Bashinskaya. Of these, Toktogul HPP produces 30% of all electricity in the country

JSC "Chakan GES", the main activities are the generation, transmission and sale of electricity. The company includes 9 small HPPs with a total capacity of 38.5 MW.

Transmission company:

JSC "National Electric Grids of Kyrgyzstan", is an energy company that transports electricity generated by power plants through high-voltage networks throughout the Kyrgyz Republic to distribution companies and large industrial consumers. Also, JSC "National Electric Grid of Kyrgyzstan" is a system operator that carries out centralized operational and dispatch control of the national energy system of Kyrgyzstan. The company has high-voltage electrical networks, including:

- overhead transmission lines of 110 kV, 220 kV and 500 kV with a total length of 7641 km;
- 119 substations with a voltage of 110 - 500 kV, divided in: 181 substations of 110 kV, 14 substations of 220 kV and 4 substations of 500 kV.

Distribution Electricity Companies (OJSC "Severelectro", OJSC “Vostokelectro”, OJSC “Jalalabadelectro”, OJSC “Oshelectro”), carry out the purchase, transportation, distribution and sale of electricity generated in the republic for the domestic market, as well as repair, maintenance and operational maintenance of distribution electrical networks with a voltage of 35-10-6-0.4 kV throughout the country.

Finally, private companies ("NK GROUP" LLC, "Ak-Terek HPP" LLC, "Kochkor HPP" LLC, "Koisuu HPP" LLC, "Tegirmentinsky HPP" LLC), carry out electrical installation work, construction and electricity generation by hydroelectric power plants.

There are also 16 wholesale buyers and resellers of electricity, 21 private companies which operate portions of the distribution network in certain areas of Bishkek and one district heating company (JSC Bishkekteploset). The Kyrgyz Government owns nearly 95% of the shares of the energy sector companies (World Bank, 2017c).

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In order to ensure effective management of the energy industry, reliable energy supply to consumers, and improve the quality of energy services, on February 8, 2022, the Concept for Restructuring the Energy Management System of the Kyrgyz Republic No. 51-r was approved. According to which, the reorganization was carried out in three key areas:

1) association of distribution energy companies (OJSC "Severelectro", OJSC "Vostokelektro", OJSC "Oshelectro" and OJSC "Jalalabatelectro");

2) association of energy companies (OJSC "Electric Stations" and OJSC "Bishkekteploset");

3) consolidation of the assets of JSC "National Electric Grids of Kyrgyzstan" and the united RECs with the allocation of the function of selling electric energy.

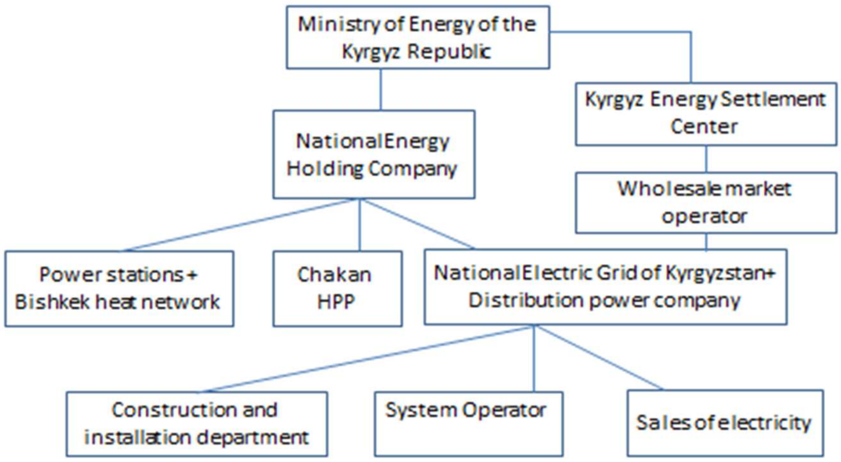

Figure 5: Management structure of the energy sector of the Kyrgyz Republic after the restructuring

Renewable energy policy

The development of SHP and other RES has been of high importance for many years in Kyrgyzstan, but so far hardly any national plans have been consistently fulfilled. The main laws of primary energy sector legislation affecting the electricity sub-sector and RES are:

Law of the Kyrgyz Republic "On Energy". adopted on 30 October 1996, No. 56, since then amended three times, the most recent being on May 16, 2008. It contains a delegation of norms which allows the Government and the Authorized Government Body in the Energy Sector to exercise significant powers.

Law of the Kyrgyz Republic "On Renewable Energy Sources", as of 31 December 2008, No. 283, supports RE development and includes main RE definitions. Amendments were made in terms of tariff surcharges for each type of RE source.

Additional laws are:

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- Law of the Kyrgyz Republic "On Electric Power Industry".
- Law of the Kyrgyz Republic "On Energy Saving".
- Law of the Kyrgyz Republic "On energy efficiency of buildings".

Finally, there are several State programs, plans, strategies and other government documents on sustainable development in the energy sector. Their potential influence on the exploitation on SHP will be elaborated in further version of the replication plan.

Issues and problems of energy security are becoming more acute and relevant every year. To date, the entire produced electrical energy in the amount of about 15 billion kWh has been consumed by the Kyrgyz Republic exclusively for its own needs and has moved from the category of export-oriented countries to the category of import-oriented ones. In addition, it is necessary to note the annual growth of domestic consumption of electrical energy. Dependence on external supplies of electricity reduces the energy security of the country and supports the economy of exporting countries instead of the economy of the Kyrgyz Republic. Therefore, the problem of commissioning new capacities is acute today. In the context of a shortage of large generating capacities, the use of renewable energy opportunities should be an important direction for ensuring energy security, solving problems of local energy supply and ensuring sustainable development of the country's remote areas.

The Kyrgyz Republic has set a target to reduce greenhouse gas emissions by 44% by 2030 and achieve carbon neutrality by 2050. Kyrgyzstan recognizes that renewable energy sources, primarily hydropower, will be the driving force behind zero-carbon policies given their huge potential in the country. The issue of increasing the share of renewable energy sources is a strategic direction today. Is clear the importance of national policies and strategies to increase the use of new and renewable energy sources and carbon reduction technologies, including cleaner fossil fuel technologies.

On October 30, 2020, The Government of the Kyrgyz Republic approved the "Regulation on the conditions and procedure for the implementation of activities for the generation and supply of electrical energy using renewable energy sources" No. 525.

On June 16, 2022 was adopted the New Law of the Kyrgyz Republic Parliament "On Renewable Energy Sources".

This is a big step towards the real introduction of renewable energy in the Kyrgyz Republic.

A lot of work is being done to financially rehabilitate the energy sector, create a competitive environment and attract investment. The Kyrgyz Republic announced an ambitious "**Electricity Sector Modernization and Sustainability Project**" during the Bishkek

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International Energy Forum in April 2022. The World Bank's Board of Executive Directors has approved a $50 million project to support the Government of the Kyrgyz Republic in improving the financial performance and operational reliability of the electricity sector in the country. The financing for this Project is provided on highly concessional terms through the International Development Association (IDA). Half of the funding is allocated in the form of a grant, which requires no repayment, while the other half is a credit with a 0.75% administrative fee, the repayments of which are spread out over 38 years, with a six-year grace period. The project is also co-financed by the Swiss State Secretariat for Economic Affairs that will provide additional $8 million in grant funding. The "Electricity Sector Modernization and Sustainability Project" aims to put the electricity sector on a sustainable path and to transform it into a driver for economic growth, job creation, and improvement of the welfare of all citizens. The Project will help improve the financial performance, ensure a reliable electricity supply for the people and businesses, and create a supportive social protection mechanism to the vulnerable groups. Finally, the project will finance soft and hard investments that are urgently needed to improve performance of the energy sector in four main areas:

1. Rehabilitation and Upgrade of Distribution Networks
2. Digitalization of Distribution Network
3. Strengthening Social Protection Systems
4. Institutional Development

3.3. Electricity sector in Tajikistan

Regulation of the energy sector is implemented by means of three public bodies:

(1) The Ministry of Energy and Water Resources is responsible for licensing, approval of investment plans and technical and safety standards.

(2) The Antimonopoly Service (AMS) is responsible for the regulation of the energy sector, tariff methodology and tariff level proposals. Final approval and amendment of tariffs for the end-users is within the competency of the President.

(3) Barki Tojik is a vertically integrated state-owned national power utility. Electricity prices are raised on an annual basis and the tariffs vary by customer type. Due to a high poverty rate in the country, current electricity tariffs are still below the supply costs and are among the lowest in the world. Because of this, the company is continuously running at a loss. There is no sufficient funding to fully cover the operation and maintenance costs of the power plants, so Barki Tojik is using external funding from the international landers for this purpose.

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3.4. Electricity sector in Turkmenistan

Turkmenistan has a continental and very dry climate. The Kara Kum Desert covers more than 80% of Turkmenistan's territory. Turkmenistan has one of the largest proved natural gas reserves in the world, so the country generates 99.8% of its electricity from natural gas and only 0.02% from HP (Liu *et al*., 2019).

The electricity market is managed by the state-owned company Turkmenenergo, maintaining and operating the main electric grid. There is a new development strategy for Turkmenistan electricity sector *Concept of the energy industry development for 2013-2020*. This plan includes the future objectives for increasing the installed capacity and exports; in order to do so, it has been planned to upgrade the high-voltage transmission lines, to renovate old plants and install new gas-powered stations

3.5. Electricity sector in Uzbekistan

Topographically, Uzbekistan can be divided into different areas: 60% of the country is characterized by dry steppe and desert, while the rest is formed by the valleys of the Syr Darya and Amu Darya Rivers, as well as some mountainous areas.

Uzbekistan is the largest electricity producer in Central Asia and a net exporter of electricity. Around 87% of its electricity demand is generated by gas, and the remaining 13% is produced by hydropower (IEA, 2022).

All hydropower stations of Uzbekistan are owned by JSC Uzbekgidroenergo, co-coordinating body responsible to implement the *Programme for the Hydropower Development in Uzbekistan in 2017–2021*. Most of the power generation, transmission and distribution assets used to be owned and operated by JSC Uzbekgidroenergo. In 2017 after the World Bank recommendations, it was then splitted into different state-owned bodies:

- JSC Thermal Power Plants,
- JSC Uzbekistan National Electric Power Networks,
- JSC Regional Electric Power Networks and
- Uzbekgidroenergo

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4. Framing the development of the Small Hydropower sector in Central Asia

Natural resources are non-uniformly spread across Central Asian countries, which are, therefore, strongly interdependent. While upstream countries have abundant water resources, downstream countries are characterized by natural water scarcity but are major producers of crops and fossil fuel energies (Hamidov *et. al*, 2016).

Within the last year of the project, the sustainable HP potential in Central Asia had been assessed by the lead of BOKU in Task 1.2: "GIS- and model-based determination of the SHP potential in CA". The hydropower potential was computed using a multistage procedure (Dhaubanjar *et al*., 2021). In this procedure, the theoretical line potential, based on the hydrological conditions, is gradually broken down towards a sustainable potential based on environmental parameters and constraints (see Figure 6). This procedure allowed it to incorporate all kinds of sectors relevant to a sustainable perspective.

The following steps were performed to calculate the sustainable hydropower potential: In a first step, (1) the line potential was computed. Following, (2) technical aspects of hydropower plants, such as certain efficiency factors were considered. Furthermore, (3) already existing and operating plants were identified and subtracted from the technical potential. Since Hydro4U addresses only small HP, (4) an additional condition was introduced, limiting the installed capacity of SHP to 10 MW per river segment. Less suitable locations from an environmental point of view were considered by taking (5) ecological as well as (6) geomorphological constraints into account (Figure 6).

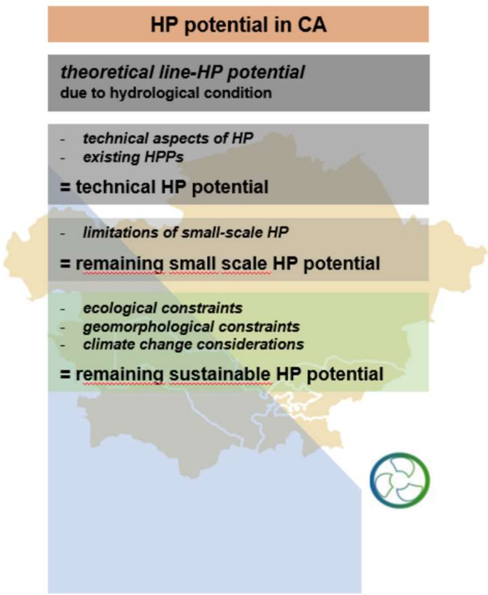

Figure 6: Schematic workflow of the multi-step procedure when computing the sustainable HP potential.

This transparent methodology of computing the sustainable potential of the different countries is described in more detail in D1.4: "First technical report" (De Keyser *et al*., 2023), including also forward-looking climate change modelling approaches to examine the availability of the determined potential in the future (Figure 6).

Such an analysis with this holistic approach to determine the hydropower potential has not been performed previously in this region. By highlighting the remaining sustainable hydropower potential and its distribution, this study contributes to enhancing the development

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of small hydropower in Central Asia, thereby constituting a basis for the replication of SHP construction in the project area.

4.1. Technical and sustainable Small Hydropower potential

Hydropower already accounts for almost 25% of the installed energy generation capacity in CA. The actual share highly depends on the country. For example, according to the UNIDO 2019 World SHP Development Report, while Tajikistan generates the majority all of its needed electricity from HP, the contribution to the energy sector in Turkmenistan is negligible (Liu *et al.*, 2019). The reason for this non-uniformly distribution of the HP potential lies in Central Asia's diverse topography, with mountains and runoff formation situated in the upper reaches of the Aral Sea basin (see Figure 2 in Section 3). Therefore, countries like Kyrgyzstan and Tajikistan are predestined for hydropower generation while other areas like Turkmenistan or many parts of Kazakhstan are characterized by an arid climate and a plain topography.

A key step within our multi-step approach was to identify already existing and operating plants in order to calculate the remaining technical potential. To this aim, we consolidated various hydropower and dam data sources (e.g., ICOLD World Register of Dams, GOODD (Mulligan *et al.*, 2020), GRanD (Lehner *et al.*, 2011), GeoDAR (Wang *et al.*, 2022) in a unified Hydro4U database, excluding possible double entries. We determined the location and output power of each hydropower plant identified. We cross-checked the final database status by comparing the sum of installed hydropower capacity per country to the values presented by UNIDO (Liu *et al.*, 2019). The data shows a good accordance regarding the overall installed hydropower capacity (Table 4). Regarding only SHP, we observe a larger deviation between the Hydro4U and the UNIDO figures (Liu *et al.*, 2019).

Table 4: Existing hydropower capacities* in Central Asia

Country	Overall installed hydropower (MW)		Installed SHP (MW)	
	UNIDO[1]	Hydro4U[2]	UNIDO[1]	Hydro4U[2]
Kazakhstan	2,699	2,702	116	8
Kyrgyzstan	3,077	3,097	4	47
Tajikistan	5,039	5,101	28	11
Turkmenistan	1	1	1	1
Uzbekistan	1,879	1,849	76	55
Total	**12,695**	**12,748**	**226**	**121**

*[1]Source: UNIDO Report (Liu et al., 2019). [2]Source: Deliverable 1.4 (De Keyser et al., 2023). *The values presented are rounded for better readability.*

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Table 5 shows the remaining sustainable hydropower potential expressed as SHP capacity. A significant discrepancy can be seen between the figures presented by UNIDO (Liu *et al.*, 2019) and those calculated in Hydro4U. The fact that the values of some countries are relatively good aligned while others differ by more than an order of magnitude shows that it is unlikely that a standardized methodology has been applied by UNIDO. According to a statement made by UNIDO (Liu *et al.*, 2019) got data from different independent local experts. Even though the UNIDO values are widely cited in the literature (e.g., Laldjebaev *et al.*, 2021), their significance may, therefore, be limited when comparing the potential of different countries. This underlines the importance of using a standardized method to assess Central Asia's hydropower potential within Hydro4U.

Table 5: Remaining technical Hydropower potential in Central Asia

Country	Overall SHP potential (MW)[1]	Overall technical HP potential (MW)[2]	Remaining technical SHP potential[2] (MW)	Remaining sustainable SHP potential (MW)[2]
Kazakhstan	2,707	22,499	18,842	6,470
Kyrgyzstan	275	24,905	22,716	13,294
Tajikistan	30,000	24,671	19,160	5,017
Turkmenistan	1,300	2,933	1,117	282
Uzbekistan	76*	11,171	8,446	3,617
Total (MW)	**34,358**	**86,179**	**70,281**	**28,680**

*[1]Source: UNIDO Report (Liu et al. 2019). [2]Source: Deliverable 1.4 (De Keyser et al., 2023). * This estimate is based on the installed capacity as no data on potential capacity is available.*

Considering also ecological and geomorphological criteria (De Keyser *et al.*, 2023), the remaining technical potential is reduced to the sustainable potential (Table 5). Especially in terms of replication (e.g., advocating hydropower development), it is key to include sustainability aspects to avoid overexploitation, particularly in sensitive areas. In summary, these results show that only a small fraction of the existing sustainable HP potential has been used so far in CA. In the following section, we describe the status of **installed capacity** and **potential** on a country-per-country basis:

Kazakhstan. The country has significant hydro resources, being the Irtysh, Ili and Syr Darya, the main rivers of the country. The overall installed HP according to Hydro4U (De Keyser *et al., 2023*) is 2,702 MW (table 4). Theoretically, the capacity of all hydro resources is 170 billion kWh per year, which provide **10% of the country's needs**. 65% of its current hydropower generation is located in the east (mountainous Altai) and in the south of the country. The largest HP Plants are Shulbinskaya (720 MW), Bukhtarminskaya (675 MW), Kapchagaiskaya (on the

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Ili River, 364 MW) and Ust-Kamenogorskaya (on the Irtysh River, 331 MW). In December 2011, the Moinak HPP (300 MW) was put into operation together with the Bulak HPP (80 MW) and the Kerbulak HPP (50 MW).

Kazakhstan's overall hydropower potential was estimated to be around 22,500 MW, while only 6,400 MW of the remaining small-scale potential is sustainable (Table 5). The potential has to be set in relation to its large size compared to much smaller countries like Kyrgyzstan or Tajikistan.

Kyrgyzstan. The country has a comparable mountainous topography as Tajikistan. The Tian Shan Mountain Range makes up 95% of the country. One of the two major streams of the CA region, the Syr Darya River, originates in those mountains. **To date, 90% of the annual electricity is produced by hydropower (IHA, 2018)**, with an overall installed HP of 3,097 MW (De Keyser *et al., 2023*) as shown in the Table 4.

The country has a similar overall technical hydropower potential as Tajikistan with 24,905 MW (Table 5). Of this, 13,294 MW are considered sustainable SHP potential. Keeping in mind that the installed small-scale capacity is 47 MW, it can be concluded that only 0.35% of the sustainable SHP potential is utilized. According to UNIDO (Liu *et al*., 2019), the country's potential is only 275 MW. This low number can only be explained by an assessment error or this value is based on single case studies, where feasibility studies have already been carried out.

Tajikistan. The country is located in the southeast of CA in the upper reach of the Aral Sea basin. Ranging between 300 and 7,495 meters above sea level, its topography is predestined for hydropower development. 60% of CA's total runoff is generated in this area (IHA, 2018). Tajikistan already produces almost **90% of its electric energy from hydropower** (Ministry of Energy and Water Resources of the Republic of Tajikistan). We identified an overall generation capacity of around 5,100 MW, whereas only a negligible share of 11MW is currently generated by SHP (Table 4).

According to the methodology developed within Hydro4U (De Keyser *et. al*, 2023), the overall hydropower potential in Tajikistan is 24,671 MW (Table 5). When only considering the remaining sustainable, the SHP potential drastically reduces to 5,017 MW.

Turkmenistan. According to our dataset, only one SHP plant operates within Turkmenistan, with a capacity of 1.2 MW (Table 4), which covers 0.02% of the country's energy needs.

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The country's overall hydropower potential is estimated to be almost 3000 MW (Table 5), one third of which is the remaining SHP potential of 1,100 MW. Of this, 282 MW are classified as sustainable. UNIDO proposes a potential in a similar order of magnitude with 1,300 MW. It is clear that due to the country's topography and water scarcity, it is not best suited for strong SHP development when compared to its neighboring countries.

Uzbekistan. The overall installed HP according to Hydro4U (De Keyser *et al., 2023*) is 1,849 MW (table 4) and provides **13% of the country's energy needs**.

The country's remaining sustainable small-scale potential was estimated to be 3,617 MW (Table 5). Considering that only around 55 MW have been exploited so far (Table 4), it can be concluded that much SHP development is still feasible in Uzbekistan – even in this largely rather arid country. However, it should be noted that irrigated crops are grown in many parts of the country, resulting in high water demand. In such irrigated areas, there are high uncertainties regarding the discharge in the natural river system, entailing uncertainties in estimating the HP potential. Therefore, the study might overestimate the potential within the natural stream network.

4.2. Description of on-going initiatives for the development of Small Hydropower

In Europe, the majority of the hydropower potential has already been exploited over the last century, having limited unused profitable potential available (Xu *et al*., 2023). Therefore, activities have been more and more shifting from commissioning new sites to technological and operational optimization of existing plants (Wagner *et al*., 2021). Central Asia is a fast-developing region with increasing energy demand. As shown previously in Chapter 3.1 the majority of the potential has not been exploited so far. Various initiatives are investing in HP technologies and the construction new hydropower facilities in order to encore energy security and increase sustainable energy generation to tackle climate change. Overall, the hydropower capacity is planned to be increased by 40.950 MW by 2050 leading to an expected surplus in the region of 1 to 2 billion kWh per year (Green action task force, 2020). With those gains in energy generation seasonal peaks are planned to be balanced and the excess electric energy can be exported.

The following paragraphs describe current as well as planned initiatives on a country-per-country basis to deliver an overview of the development of hydropower in Central Asia.

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Kazakhstan. There is considerable interest from investors to develop SHP in Kazakhstan, with many new prospective projects. In the course of the action plan for 2050, 41 SHP plants with a total capacity of 539 MW are planned (IEA Energy Sector review, 2022). In 2018, a further 82 MW of SHP capacity was already approved for development through tenders for renewable energy projects (Liu *et al*., 2019).

Kyrgyzstan. By today, hydropower is the most important energy source in Kyrgyzstan. Especially the development of small-scale hydropower is a major goal to increase national production, making the country less dependent on energy imports, especially during the cold winter (IEA, Kyrgyz Republic Energy Profile, 2021). Hydropower investments target the modernization of the Naryn cascade (IHA, 2018).

In 2022 the Kyrgyz authorities announced that in the upcoming years, hundreds of new small hydroelectric power stations should be put into operation (Big Asia, 2022). The State Committee for Industry, Energy, and Subsoil Use plans to **build and rehabilitate 136 SHP plants** (<30 MW) by 2025 with a total capacity of 278 MW. Among them, 22 promising sites have been identified for SHPPs in the Naryn region which have also been approved by the government. The design work of these 22 potential SHPPs are finished and construction has started. Currently, the construction of the Kulanak HPP cascade on the Naryn River is underway

Tajikistan. Tajikistan plans to increase total generating capacity to 10 GW by 2030, therefore, doubling its hydropower output compared to today (IHA Sustainability Ltd, n.d.). Nevertheless, SHP plays a minor role since Tajikistan's energy production relies on major hydropower plants. Currently, Tajikistan aims to complete the Rogun dam which is under construction and planned to have a power output of 3,600 MW (IHA, 2018). While other new hydropower plants have already been commissioned, this plant is scheduled to achieve full operational capacity by 2028 (NS Energy, n.d., Rogun HP project). Further hydropower investments include the modernization and rehabilitation of the Nurek and Qairokkum power plants (IHA, 2018). The modernization of the Qairokkum plant started in 2019 and is planning to upgrade the plant from 126 MW to 174 MW (NS Energy, n.d., Qairokkum Hydropower Rehabilitation Project). The Nurek Hydropower plant is currently with 3 GW the biggest facility of its kind in Central Asia. The rehabilitation of the plant is supposed to lead to an increase of 300 MW and is expected to be completed by 2028 (NS Energy, n.d., Nurek Hydropower Plant Rehabilitation Project). In parallel, several restoration initiatives in the SHP sector are underway together with an action

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plan for investment in SHP, which focuses on the commercialization of SHP, feed-in tariffs, and grid access systems, SHP tax regime, and accessible investment procedures.

In addition to national efforts, it is also recognized that energy security at the national level requires transnational solutions. The Central Asia-South Asia power project (CASA-1000) is an energy infrastructure project, connecting Kyrgyzstan and Tajikistan as electricity exporters with Afghanistan and Pakistan as electricity importers via a 1,200 km long 500 kV line. The project was approved by the respective countries in 2012 and the construction began in 2019. Tajikistan completed the construction in 2022 (IEA, Tajikistan 2022 Energy sector review, 2022) and Kyrgyzstan is expected to complete the activities in 2023 (IEA, Kyrgyz Republic - Energy Profile, 2021).

Turkmenistan. The country is located on large natural gas and oil sources, contributing to 99.8% of its energy production. According to Liu *et al*. (2019), renewable energy sources will even by 2030 contribute less than 1% of the country's energy mix. Therefore, no current plans linked to the exploitation of hydropower are known in Turkmenistan.

Uzbekistan. HP potential in Uzbekistan derived from the Amu Darya and Syr Darya Rivers has not been widely developed due to the built canals, which altered the river flows and have affected the Aral Sea, The Uzbek government added a hydropower capacity of 260 MW in recent years. In 2023, it announced plans to continue constructing a series of large- and small-scale hydropower projects, **17 projects** with a total capacity of 197 MW scheduled to be commissioned this year alone (HydroReview, 2023a). Compared to 2018, the country plans to increase hydropower generation by 1.50 GW by 2030 (IEA, 2022, Uzbekistan - Energy Policy Review). Uzbekistan also partners with neighboring countries in bilateral projects, such as the Zarafshan project in Tajikistan, with a planned capacity of 150 MW (HydroReview, 2023b).

Outlook. Many Central Asian countries have ambitious goals, including expanding sustainable small hydropower. Therefore, the technologies developed and demonstrated within the Hydro4U project will likely increase the attention of potential investors and other stakeholders.

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5. Financing green and sustainable energy Projects in Central Asia

Hydro4U replication strategy aims to bring European HP solutions to CA to maximize the impact among potential project promoters and increase the percentage of SHP development.

The causes behind the low SHP development in CA were analysed in the Deliverable 5.1 (López *et al*. 2022). A varied number of barriers were identified and classified considering the different Political, Economic, Social, Technological, Legal and Environmental implications. Among them, there were common issues in the region such as market barriers, regulatory barriers or technical barriers. The **financial barriers** due to the lack of funding from the private sector were also found very relevant. Because of this, this D5.2 includes the description of European and International financing organisations able to fund green and sustainable projects in CA. Then, in the next deliverable D.5.4 (to be submitted by M36), local entities and Sovereign Wealth Funds will be studied in more detail for each country. The eligibility criteria of these organisations and can be summarised as projects which are:

- Located within eligible countries
- Aligned with the EU objectives: focused on environmental and social sustainability, rather than economic benefits and having a clear positive impact on the overall environment, e.g. renewable energy, energy efficiency, carbon capture…
- Improving the energy infrastructure and security of supply at a regional, or even cross-border level.

As it can be seen, the eligibility criteria are rather generic and specific technical requirements such as minimum/maximum installed capacity or environmental measures as fish-passes are not defined in much detail.

There are plenty of financing mechanisms offered by these institutions, the most common, defined by the EU (EU funding, grants and subsidies) are:

- Grants: Direct funding for specific projects awarded to sustainable projects aligned with the EU policies through "calls", which are public announcements. A grant can cover partially the initial investment.
- Subsidies: Indirect funding managed by national and regional authorities. Subsidies are applied at national level.
- Loans, guarantees and equity investment options, closer to a commercial bank.

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- Other type of funding by the EU is with prizes, e.g. Horizon 2020 contests.

This funding schemes can be granted to researchers, farmers and rural businesses, SMEs, public entities and non-profit organisations among others.

Each organisations and financing institutions has its own Application Process, but has a common application procedure as pictured in the **Figure 7**, these steps can be summarised as:

1. For applying to a loan, some documents must be prepared to warrant that the loan specific requirements will be fulfilled.
2. There must be an appraisal on the financial, economic, social, environmental and technical fields; in order to obtain the Board of Directors approval.
3. After the procurement, there will be monitoring of the activities to keep aligned to their requirements.

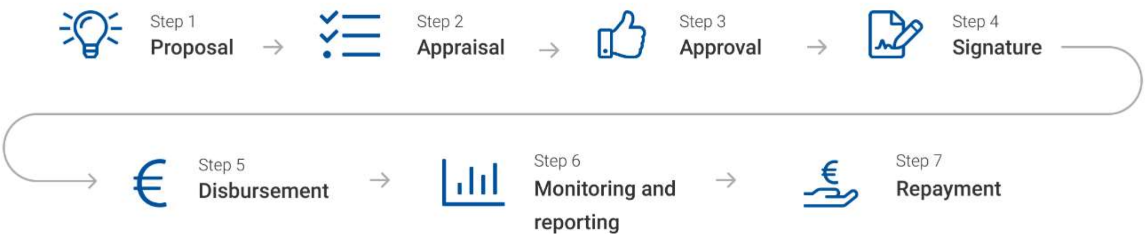

Figure 7. European Investment Bank (EIB) Project cycle.

As described above, the projects need the approval of the Board of Directors during the application process and for this, the projects have to be aligned with the EU sustainability objectives. However, it has not been possible to identify the specific requirements in the consulted documentation or websites. In the next deliverable D5.4 to be submitted by M36, local partners as IWMI or KSTU will be consulted in order to clarify this specific requisites.

5.1. EU-affiliated entities

In this section some of the identified EU-affiliated entities that collaborates within the CA countries has been described, including examples of case studies that are available.

The European External Action Service (EEAS):

Promotes cooperation through projects and grants. Some programs with CA are “Sustainable Energy Connectivity in Central Asia (SECCA)” promoting sustainable energy generation mix;

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the Central Asia Water and Energy Program (CAWEP) promoting water and energy security, or the Central Asia Water, Environment and Climate Change Cooperation (WECOOP).

Investment Facility for Central Asia (IFCA):

This facility is part of the Development Cooperation Instrument (DCI) and supports the EU Strategy for CA, with the grant resources obtained from multilateral and bilateral European Finance Institutions (e.g. EBRD, EIB or KfW), Regional Development Banks (e.g. ADB) as well as the World Bank, alongside with partner countries and beneficiary institutions in CA. IFCA instruments are: Investment grants, Technical assistance, Risk capital and other risk sharing instruments.

European Investment Bank (EIB):

The EIB is the European Union’s bank and can be defined as a (non-profit, long-term lending banking institution). The EIB can be considered as the world’s largest multilateral borrower and lender, the bank borrows money on capital markets and lends it on favourable terms to sustainable green projects aligned with EU objectives. Provides financing for both public and private sector the different instruments such as: loans, guarantees, microfinance, equity investment; and also blended financing and administrative advisory.

European Bank for Reconstruction and Development (EBRD):

The EBRD can be considered as both multilateral developmental investment bank and international financial institution, with both public and private shareholders. The EBRD supports mainly private projects. One of its funding channels for CA projects is the aforementioned **IFCA.**

Some projects are related to the modernisation of the electrical infrastructure as this actions for "Kazakhstan Electricity Grid Operating Company” (“KEGOC”) under Kazakhstan national Sustainable Energy Action Plan (SEAP).

Big projects can obtain direct financing from M€ 5 to M€ 200, as loans or equity investments; but smaller projects require indirect financing, so it needs intermediaries (local banks) or special programmes, e.g. Green Climate Funds (GCF).

KfW Development Bank (KfW):

This is a German government-owned development bank, aimed to support governments and public entities and banks in microfinance for developing countries; and also, indirect support for SMEs via efficient financial institutions, in the form of budget fund and loans.

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French Development Agency (AFD, Agence Française de Développement):

AFD is a bilateral French public financial institution that mainly provides financial support to foreign countries as Loans, guarantees and bond issues for company projects and grants for specific actions aimed at social, rural and urban sustainable development.

There are also other financial sources for sustainable development projects obtained through government-owned agencies, this is the case of Finland, Austria, Germany and France.

5.2. Non EU-affiliated entities

World Bank Group (WB):

Constituted by the International Bank for Reconstruction and Development (IBRD), and the International Development Association (IDA). It provides low-interest loans, zero to low-interest credits, and grants, also blended financing with governments and banks.

SMEs financing options are indirectly given by the WB, as direct investment and guarantees are provided by MIGA and IFC.

Some financed projects under the WB group are for example the restoration of the *Nurek Hydropower Plant* in Tajikistan, or the construction of the country's first large-scale solar power plant in Uzbekistan.

Asian Development Bank (ADB):

The ADB is an international development finance institution, aimed at reducing poverty in Asia and the Pacific supporting the ADB member governments, which are also its shareholders through loans, grants, research and technical assistance. But the ADB also supports private projects located in developing member countries through equity investments and loans, with a limited participation.

Its grant resources come mainly from ordinary capital resources, which will be then offered at near-market terms or at very low interest rates for low-income countries

Asian Infrastructure Investment Bank (AIIB):

The AIIB is a multilateral financial institution focused on supporting the building of infrastructure in the Asia-Pacific region. This entity offers sovereign and non-sovereign financing and loans for sustainable projects; and there is also the "Project Preparation Special Fund (PPSF)" defined for projects located within eligible countries.

Global Environment Facility (GEF):

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The GEF is constituted by an international partnership of 183 countries, international institutions, civil society organizations and the private sector. This facility mainly provides funding to support government projects and sustainable development programs.

Some of these programs are:

- Energy Efficiency and Renewable Energy for Sustainable Water Management in Turkmenistan;
- Technology Transfer and Market Development for Small-Hydropower in Tajikistan;
- Small Hydro Power Development in Kyrgyzstan or
- De-risking Renewable Energy Investment to promote private investment in Kazakhstan and achieve their national goal in renewable energy for 2030.

Green Climate Fund (GCF):

This fund is a financial mechanism (Funding channel) under the United Nations Framework Convention on Climate Change (UNFCCC). Aimed for both public and private sector, it also has a specific Private Sector Facility (PSF). The GCF uses different instruments like grants, concessional loans, subordinated debt, equity, and guarantees.

Climate Investments Funds (CIF):

It is a multilateral climate finance partnership that channels concessional finance through six multilateral development banks (MDBs) like the World Bank Group, as grants, highly concessional loans, and risk mitigation instruments.

The CIF fund comprises the Clean Technology Fund (CTF) and the Strategic Climate Fund (SCF).

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Table 6. European and international Financing institutions

Entity	Eligible countries	Funding Channel	Instruments
European financing institutions			
EEAS	CA	Builds alliances with different EU delegations and member states.	EU-funded projects, public contracts, grants, budget support.
IFCA	CA	Resources from multilateral and bilateral European Finance Institutions, regional development banks, partner countries and beneficiary institutions in CA.	Investment grants, technical assistance, risk capital and other risk sharing instruments.
EIB	KAZ, KGZ, TJK, UZB	The EU bank, which borrows money on capital markets, lend it on favourable terms to projects aligned with EU objectives.	Loans, guarantees, microfinance, equity investment, blended solutions and even project management.
EBRD	CA	Its main funding channel on CA is the *Investment Facility for Central Asia (IFCA).*	Big projects: Loans, equity investments or guarantees [from M€ 5 to M€ 200], Small projects: direct investments through local intermediaries or programmes [less than M€ 5].
KfW	KGZ, TJK, UZB	Indirect support is provided through financial institutions for SMEs.	Grants, Budget funds and loans.
AFD	CA	Bilateral public financial institution	Loans, guarantees and bond issues for company projects. Grants for sustainable development actions.
International financing institutions			
World Bank	CA	The world bank raises funds from the capital markets at low interest rates, allowing to finance developing countries at lower rates.	Indirect for governments: IBRD Loan, IDA credit/grant, and guarantees. For infrastructure and policy development, Direct: Program-for-results, Trust funds and grants in critical situations. Private sector: IFC and MIGA direct investment and guarantees.
ADB	CA	ADB's lending comes mainly from ordinary capital resources at near-market terms and at very low interest rates for lower income countries to help reduce poverty.	Loans, technical assistance, grants, and equity investments. Private sector: Direct and limited financial assistance, Co-financing: Results-Based Lending (RBL) for programs, and Trade finance program (TFP) for banks.
AIIB	CA	AIIB works with MDBs in co-financing, e.g. World Bank, ADB or even receives funding from the Global Innovation Fund (GIF).	Sovereign and non-sovereign loans mainly, but also grants and funds (Trust-funds and other Special-Funds). For SMEs: vaccine financing and liquidity support, and also the Project Preparation Special Fund (PPSF).

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GEF	CA	Funding by GEF is contributed by donor countries, international institutions, civil society organizations and the private sector; for Government projects and programmes.	Full-sized Project (FSP): > M€ 2 US dollars. Medium-sized Project (MSP): ≤M€ 2 US dollars. Enabling activities and programs.
GCF	CA	GCF is the financial mechanism under the UNFCCC	Blended finance through grants, concessional loans, subordinated debt, equity, and guarantees.
CIF	CA	Funding channel of the World bank, that disburse the economic resources through MDBs.	Grants, highly concessional loans, and risk mitigation instruments.

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6. Guidelines for technical design

Both the optimization of technical hydropower equipment and the elaboration of innovative workflows and planning methods are at the core of the Hydro4U project. Both the technologies and the planning methods are designed with the goal of high replicability in CA – and beyond. In this chapter the approaches how to reach a high replication potential regarding the technical design and construction process are described.

6.1. Optimization of innovative Small Hydropower equipment

The two core technologies of the Hydro4U project are the Hydroshaft Power Solution (HSPS) for low heads and small to medium flows, and the Francis Container Power Solution (FCPS) for medium heads and small flows. Both technical concepts have been tested and implemented before Hydro4U, but their implementation has been characterised by complexity, customisation and on-site construction, resulting in long construction periods and high costs. Therefore, both technologies are being further developed and optimized into modular and standardized systems, with the goal of maintaining their proven advantages while decreasing complexity, construction time and project costs. The aim is to ensure that the final optimized products can be implemented in as many locations as possible without placing high demands on logistical, economic and infrastructure-related framework conditions and thus offer the highest possible replication potential.

To reach this objective, the first step was to collect and summarize the optimization potential for both the FCPS and the HSPS, which was elaborated by reviewing and analysing the state of the art of both technologies, based on projects that were realized with these concepts. This potential is described in detail within Deliverable 3.1. The result is a list of measures that is currently being used to improve the technologies in the design phase during Task 3.2. A short overview, on how the planned developments will help to increase the replicative ability of the small hydropower equipment is given for each technology in the following two subchapters:

6.1.1. Hydroshaft Power Solution

The main lever to reach higher replicative ability of this system lies in reducing on-site complexity, meaning that construction works have to be reduced to simple and easy-to build structures and the installation of the technical equipment must follow a modular logic with standardised components without the need to adapt them on site. Further, it is necessary to enable access to the technical equipment for service and revision works without great effort.

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The first step of implementation will always remain the site-specific design and establishment of a construction pit including dewatering, in which the highly simplified structure consisting of a ground plate and two side walls (per HSPS unit) is constructed. Once this structure is completed, the modular steel-rig is erected and statically linked as the load-bearing unit of the HSPS system between the side walls and on the ground plate. The main functional components of the HSPS-Systems are finally mounted onto the steel-rig. The following main components are placed in the rig: turbine-generator unit with lifting system, flow gate incl. electrical drive system, trash rack with cleaning mechanism. Electrical plant controls are placed in a small building or container next to the river. The system is being designed in a way, that the structural work can always be held as simple as described above, therefore enabling replication of such projects also at remote sites with only simple construction methods and low infrastructure and logistic requirements. However, the technically complex components are all housed in the factory-prefabricated and pre-assembled components of the modular HSPS system. Thus, these components can be quickly and efficiently assembled on site to complete the power plant.

The design of this system has been elaborated within WP3 and presented in detail in Deliverable 3.2.

In brief, the main features of the optimized system are as follows:

- Simplified constructional setup with approach channel
- Hydraulically optimized intake dimensions for one-sided approach flow
- Modular Straflo-type Turbine-Generator Unit “KaplanEVO”
- Turbine module frame for easy installation and revision
- Electrically driven sliding gate system
- Modular and tiltable electrically operated trash-rack units
- Standardization of electrical components

During the demonstration site design development within WP4 the above-mentioned modular design framework built the technical basis for the site-specific planning work. It is important to note here, that this modular system still needs a certain amount of adaption to the site. This is mainly because of varying site parameters such as available head, flow and given boundary conditions (such as the geometry of an existing structure).

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In case of the At-Bashy demonstration site for example, the project includes the refurbishment of the existing structures, the addition of a new fish pass and the change of the operating water levels. Therefore, the HSPS-modules only make up a part of the project, with the rest being related activities. Overall it proved very helpful and effort-minimizing, that the technical parameters of the system were all available on very short notice as it was needed for the site-specific design, which is one of the big advantages of the modular and standardized design framework.

6.1.2. Francis Container Power Solution

The optimization of the FCPS follows a similar logic, thus reduction of on-site complexity, the simplest possible construction process and pre-assembly of all technically complex components in the factory.

The main technical optimisations include the reduction of construction site material, the optimization and minimization, or where possible, omission of hydro-mechanical elements (such as pressure relief pipes, shaft sleeve, slotted levers, bypass line etc.). Additionally, the applicable turbine runner types are simplified and the number of possible types is reduced to the necessary minimum, that both ensures a wide operating range of the system, but at the same time enables a modular planning and fabrication procedure without much variation.

The replicable potential of the FCPS system is given by the fact, that all technically complex components are placed in a standard container with standardised connection possibilities to the on-site infrastructure. With further measures, such as the development of a real-time suspended sediment monitoring, the constructional requirements can also be reduced, as this may eliminate the need for a costly sand trap at the inlet structure. With this method, the components of the power plant setup that need to be constructed on site are a simple inlet structure, a pressure pipe and the foundation of the powerhouse. The powerhouse itself, with all its components pre-assembled, comes in form of the container mentioned before, that is simply placed on the foundation and connected to the pressure pipe on site.

Same as for the HSPS, also the optimized design of the FCPS has been elaborated within WP3 and was presented in Deliverable 3.2.

The main features of the optimized design include:

- A newly developed turbine dimensioning tool
- The use of additive manufacturing

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- The development of a generic base frame that can be used for various turbine sizes
- Standardization of electrical components

Also, for the FCPS it has to mentioned, that site-specific adaption cannot be completely avoided in hydropower development. But this system - due to the arrangement of all technical equipment within the container – needs even less site-specific adaption compared to the HSPS. Some relevant boundary conditions that generally need to be taken into account regarding adaption are the connection of the containers to the penstock, the operation scheme of the plant (e.g. island or grid-connected operation, or both), connection of the tailwater levels to the river.

6.2. Technical planning, sustainability and assessment

The development and implementation of SHP in CA provides the possibility to gain the relevant experience and formulate precise statements about which steps, measures and information are necessary in order to successfully and sustainably develop, build and operate SHP facilities in CA. The gathered information and all lessons learnt regarding the technical planning are summarized here to provide guidance for future planning and implementation of additional hydropower projects in the study area.

6.2.1. Planning process

This subchapter aims to represent a rather general overview on the overall planning process from site selection to the start of construction. The final aim of this description is to present a process that is as generally applicable as possible, from which potential project developers in the region can calculate the necessary steps, challenges, costs and timelines and thus maximise replication ability. Figure 5 shows the technical planning process over time and with increasing level of detail.

- Potential Analysis: The first step is the **identification of potential sites**. This can be done using contacts to local partners who have good knowledge of the local river systems and also other water uses. As the Hydro4U project progresses, the hydropower potential tool of WP1, which will be incorporated in the guideline tool of WP5 (see also Chapter 5) will also help users to find potentially suitable small hydropower sites.
- Site Selection: **Information exchange** with local partners as well as **field visits** will then provide more detailed information on the potential sites and also the SHP type to be

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installed (site and technology selection). Hydrological data and first rough hydrological models will additionally produce information on available discharge as basis for the dimensioning of the SHP capacity. As part of this site selection, local stakeholders need to be identified and contacted in order to obtained as much information as possible regarding additional water uses, to avoid conflicts in the planning process and to maximize the effectiveness and acceptance of the SHP later on. In CA, irrigation is one major water user and is of high importance for food production and the economic situation in general. Local partners or investors help to identify local stakeholders such as authorities, NGOs, local communities and other potential water users and establish ways of communication. Information exchange between stakeholders is necessary to balance different interests and to define suitable and sustainable water uses. At both demonstration sites and also for the potential planning sites (see D4.1) this balancing and optimization of different water uses will be of high importance. Hydro4U's Nexus work, allocated in WP2, supports this process as relevant stakeholders were mapped, and involved in the project progress. In addition, Hydro4U will present in the final replication guideline a country specific analysis of the energy sectors mapping different institutions and explain different laws and national energy programs to consider (see section 3.3).

- **Pre-feasibility study**: This study contains a roughly estimated technical, economic, environmental and social assessment of the future SHP and its effects including a first estimation of construction and equipment costs. Especially, the annual energy output needs to be assessed and considered in relation to capital and operation expenditures in order to design an economically sustainable solution.
- Feasibility Study: Including more and more details in the planning process allows the preparation of a **bankable feasibility study** including a **detailed environmental impact assessment**. Here, additional data obtained during field visits, results of hydrological, hydro-morphological and hydraulic calculations and simulations as well as economic optimizations are elaborated and supplemented by information from stakeholders. This information is used to design and compare different design alternatives for the SHP and finally make a fact-based decision for the best variant overall. This variant needs to be presented in the applicable way to the approval authorities according to locally relevant licensing requirements, with presentation, scope and language varying by country.
- Detailed Design: The **detailed construction design** is finally elaborated based on the approved design from the feasibility study. This step includes now the detailed design of all civil works and structural elements as well as the detailed production design of the

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technical equipment and a precise cost calculation building the basis for the equity and debt financing of a project.

Hydro4U advances more sustainable hydropower solutions. This means all steps within the planning process include an assessment of all relevant environmental, social and economic aspects. A close contact with local stakeholders provides the possibility to identify optimized solution addressing all three aspects. In addition, Hydro4U pays particular attention to minimizing the ecological impact of the hydropower production. The entire process of technical planning is supplemented by environmental and ecological assessments (e.g. fish sampling, habitat modelling and fish telemetry studies). Furthermore, the WFEC Nexus approach complements the sustainable approach of Hydro4U.

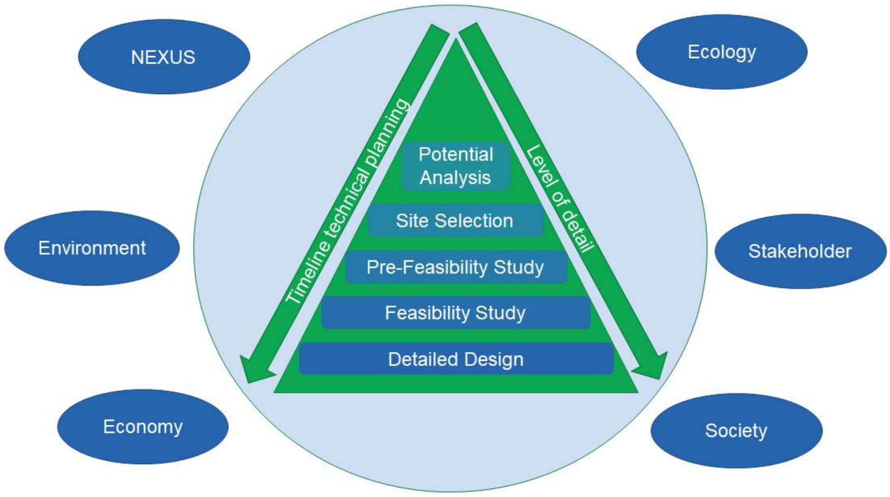

Figure 8: Steps of the technical planning process for small-scale hydropower in CA including all relevant aspects to obtain sustainable HPP solutions

Based on the experience gained in the Hydro4U project, the individual procedures are revised and expanded with increasing detail and with reference to and examples from the two demonstration projects and the three planning sites within the upcoming revisions of the Hydro4U replication plan. The following sections show the current status of the technical planning for the demonstration and as well as for the planning sites and describe lessons learnt so far.

6.2.2. Current state of planning within the Hydro4U project

Within the Hydro4U project, small-scale hydropower technologies are being optimized and installed at two sites (demonstration activities). Parallel to the product development in WP3

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(Task 3.1 and 3.2) the sites are developed step by step in planning terms. For these two sites, first a preliminary layout, then a feasibility study and finally the detailed construction design will be prepared. The authority approval process is also part of these demonstration activities, that is based on the design and assessments of the feasibility study phase. Additionally, at least three further bankable feasibility studies in cooperation with potential investors are elaborated, which are called planning activities in the Hydro4U nomenclature and will be elaborated within Task 5.3. These planning activities aim to develop additional small hydropower projects from Hydro4U in order to increase the replicability and reach of the project, but with financial resources raised elsewhere in an economically sustainable way for their implementation.

At the current state of the project, potential hydropower sites have been investigated. In autumn 2021, Hydro4U visited a number of potential sites in Kyrgyzstan, Uzbekistan and Kazakhstan and identified several potentially suitable sites for small-scale hydropower (see D4.1). In the beginning of 2022, it was decided to select the site Shakimardan at Koksu River in Uzbekistan for a demonstration site for the FCPS and At-Bashy River in Kyrgyzstan for demonstrating the HSPS. The main criterion for the selection of the demonstration sites was the availability of a motivated, committed and creditworthy local investor for the implementation, due to the special situation that the demonstration facilities are to be implemented within a time-limited funding project. Especially within international projects, local experts and qualified partners are important in order to be successful, as they provide detailed knowledge of the specific sites, establish the possibility to exchange information with local authorities and stakeholders and guarantee an efficient and long-term operation of the HPPs.

Within the first assessment phase the head, flow and therefore power potential is estimated. Based on this it is already possible to decide, whether it makes sense to follow up with more detailed assessments and also on which hydropower technologies come into question.

The next phase comprised the detailed assessment of the condition/usability of existing civil structures, infrastructure and accessibility to the site, connection to the electricity grid and most importantly, the hydrological situation in order to narrow down the size of the power plant and estimate the possible annual energy production, which in turn is necessary to define the financial cost framework. Therefore, discharge data was collected from authorities and hydrological models were developed to obtain hydrographs and flow duration curves. In addition, models were set up to simulate potential effects of different climate-change scenarios in order to estimate their impact on the power plant design. Parallel to this, the ecological situation at both sites was assessed and measures for the preservation and – where possible – improvement of the ecological condition were developed. This includes aspects like

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upstream and downstream fish migration possibilities, fish protection, habitat-based environmental flow assessment and hydromorphological equilibrium.

All these assessments showed that both sites are well suitable for the further consideration and fit well to each Hydro4U SHP technology options.

The Hydro4U experts created the draft design of both demonstration sites presented in Deliverable 4.2. Within the next steps, the detailed feasibility / authority approval designs (Deliverable 4.4) and sustainability reports (Deliverable 4.3) have been developed. In Shakimardan, the construction works have already started, while in At-Bashy, currently, the authority approvals are pending and expected to be granted by August 2023. In parallel, the detailed construction design for the At-Bashy HSPS is being developed by the H4U team. (In Shakimardan this was done through the design institute of the state utility Uzbekgidroenergo)

In addition to the demonstration activities, in June 2022, Badam Reservoir in Kazakhstan was selected to be the location of the first planning activity. Originally handled as a demonstration site for HSPS, Badam reservoir was identified to be more suitable for the FCPS technology due to the available head provided by the reservoir. So far, discharge data has been selected and analysed and a hydrological model has been set up. Furthermore, a preliminary variant study has been submitted to the investor, describing and comparing different locations for the turbines and different turbine types. The study also included a description on the ecological measures required.

Two further planning sites are going to be selected within Task 5.3 of the project.

6.2.3. Lessons learnt in the technical design process

Within the realisation of the technical planning process at the demonstration sites and the first planning activity as described above, several difficulties emerged which had to be managed by the Hydro4U consortium. These aspects are complementary to the main barriers and drivers to SHP described in Deliverable 5.1, but are focus on the technical planning process. The following table summarizes the identified difficulties and the associated lessons learnt which emerged in the specific planning stage so far.

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Table 7. Lessons learnt in the technical design process in Hydro4U Project

Planning Step	Difficulty	Lessons Learnt
Potential Analysis / Site Selection	Low spatial and temporal resolution of hydrological data	Use of state-of the art climate models and hydrological models
	Missing information and limited knowledge on existing water uses and channel system: Definition of available water resources is difficult	- Close contact to local stakeholders and experts as well as local authorities is needed to enable a good information exchange - Field visits by hydrology and hydropower experts to understand availability and use of local water resources - Use of aerial images as well as topographic tools and hydrological models to detect river and channel systems as well as water quantities - Importance of the in WP1 developed potential analysis tool to facilitate this process in future
Pre-feasibility and Feasibility studies	Limited knowledge of expected material and construction costs / Limited knowledge on expected Feed-in Tariffs (FITs)	Information exchange with local investors as well as local construction companies to estimate local cost ranges
	Missing or limited information and drawings on existing civil structures	- Close contact to local experts and investors providing contact to authorities in order to find old documents - Use of innovative and modern survey methods such as structure from motion to obtain high resolution terrain data and dimensions of civil structures
	Limited knowledge of local investors on innovative and sustainable hydropower solutions	- Meetings between local investors and hydropower experts at sites to understand the local conditions and to elaborate a sustainable hydropower option together - Invitations of local investors to visit the manufactures as well as existing sustainable hydropower plants - Use of several information platforms in English and Russian to inform the international community about the project goals and sustainable SHP in general (website, social media, conferences, publications, flyers …)
	Low social awareness of the importance of ecosystems integrity and the need of ecological mitigation measures	- Meetings between local investors and hydropower experts to discuss ecological impacts of hydropower and to highlight social importance of ecosystems integrity - Designing mitigation measures which are easily implemented and maintained to increase social acceptance - Motivation of investors / operators to implement ecological measures by making it part of material transfer and funding agreements
	Limited knowledge about geotechnical site conditions	Exact definition of scope and methods for geotechnical surveys that are adapted to technical possibilities of the locally available equipment and workforce

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7. Hydro4U replication guideline tool

In Central Asia allocation **conflicts** between **large-scale hydropower in the upstream and irrigation in the downstream** occur regularly and mostly across complex international borders, especially during water scarce years and low storage conditions. With an increasing attention on climate-neutral hydropower solutions (such SHP), the Water – Food – Energy– Climate (WFEC) Nexus is now under renewed focus in the region. In line with these developments, new Nexus trade-offs are emerging that need to be recognized and quantified, including in a changing climate.

Taking into account this context, replicability in Hydro4U will be addressed by means of a **replication guideline tool**, to support decision-making for new SHP projects considering WFEC Nexus constrains, sustainability of resources, climate change impacts and socio-economic scenarios. The replication guideline tool will make possible the identification of **replication areas** together with feasible policies to build sustainable hydropower scenarios in Central Asia at basin or sub-basin scale.

7.1. The importance of including transboundary WFEC Nexus considerations in the decision making for new SHP projects

Following the global trend, **water demand in Central Asia is increasing** due to the growing agricultural production and changes from rainfed to irrigation systems, the demographic growth or the increased evaporation due to the average temperature rise. However, water resources are non-uniformly spread across Central Asian countries. While upstream countries have abundant water resources, downstream countries are characterized by natural water scarcity. Freshwater shortage already causes 70% of the region's developmental problems, with increasing tensions related to water supply (Severskiy, *et. al*. 2004). Climate change will exacerbate water scarcity and therefore, will increase these local tensions (Sorg, *et. al*. 2014).

Furthermore, CA countries can be divided in terms of **the share of hydropower stations in the energy supply**. Currently, 90% of electricity in Tajikistan and Kyrgyzstan comes from hydropower, compared with around 10% in Uzbekistan and Kazakhstan. The two "upstream countries" are interested in generating and exporting more electricity through the construction of hydroelectric dams and reservoirs in the main transboundary tributaries of Amu Darya and Syr Darya. This aspect is creating serious problems for agricultural water supply in other countries in the region and has been the main root of conflict between CA countries for many years.

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The stability of the region is also threatened by the increased desire for unilateral and non-coordinated management of water resources of transboundary rivers or the growing tendency to commercialize water and treat it as a commodity. Considering the effect of one country's decisions on its neighbours, the WFEC Nexus in Central Asia must not only integrate cross-sectoral considerations but also requires cross-border integration from a geographical as well as political point of view (Liu, *et. al.*, 2019).

CA countries need to coordinate and revise their strategies in order to preserve the common ecosystem and reduce the economic losses associated to loss of resources and ecosystem services. In order to support this process, the Hydro4U replication guideline tool has been conceived as an easy-to-use and user-friendly application and will be based on the following considerations:

- Target audience of the tool: river basin authorities, river basin irrigation administrations, policy-makers, private and public energy stakeholders as technology providers or energy planners, investors and project promoters, citizens, etc.
- Potential role of the tool: support decision-making for new SHP projects considering WFEC Nexus constrains, sustainability of resources, climate change impacts and socio-economic constraints and scenarios.
- The tool will use the sustainable hydropower potential methodology and the results from WP1 in order to obtain geo-located values at river basin/sub-basin scale for the maximum capacity to expand hydropower in each basin.

7.2. Tool definition

The tool will be designed including information to solve the following questions:

- What are the main characteristics of each river basin/sub-basin?
- How is the river network and their length at basin/sub-basin scale?
- What is the hydropower generation potential?
- What is the land use and the corresponding water demands?
- What is the water demand by households and industries?
- How climate change will affect in the future water availability?
- How will be the change in future population? How they will impact in the demands?

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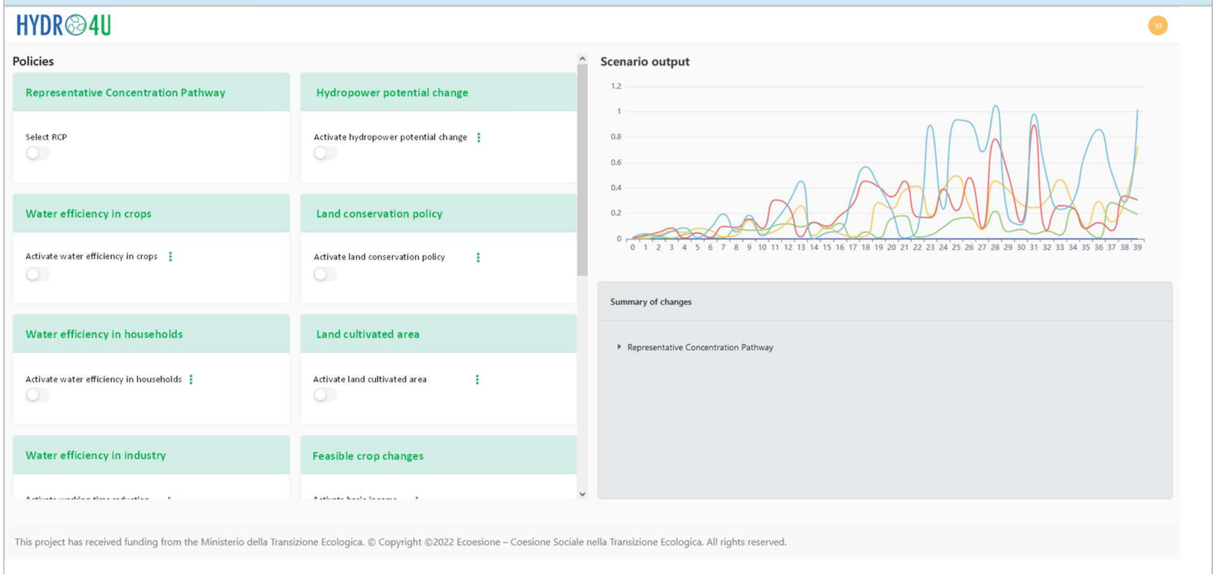
- What is the impact of a hydropower solution before implementation (ex-ante evaluation)?
- How can the different policies at basin-region impact the feasibility of a solution implementation?

The tool will be based on a computational model integrating GIS information, statistical data to complete a database for model implementation and other findings of Hydro4U such as the hydropower potential calculations from WP1 and the Nexus constraints identified in WP2. It will be able to provide a simulation environment that will help to identify the main areas for the Hydro4U hydropower technologies replication considering also the potential improvements and the associated impacts as a consequence of the implementation of policies and measures related to WFEC Nexus and associated systems. The main idea of the tool is summarized in the Figure 9, including the interlinkages between the different components of the tool:

Simulation of hydropower scenarios at river basin level

Policies selection and WFEC Nexus system modelling. To simulate different scenarios of Hydropower potential, considering the impacts on the nexus.



→ The user will be able to decide Hydropower generation scenarios by (1) selecting the additional HP to be installed or (2) selecting the locations according to the remaining potential.
→ The user will be able to make water demand decisions.

→ The tool will simulate scenarios of HP generation and demand decisions and will provide the correspondent outputs in terms of power generation, water demand and consumption, GHG emissions, etc.

Figure 9: Concept idea of the replication guideline tool.

As it was explained before, the replication tool will be based on a computational model, starting from the main components of the hydrological cycle and integrating GIS data for the basin and

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sub-basin selection. To this end, a database with relevant information to evaluate the water cycle will be developed integrating all the necessary data for the model implementation including the current hydropower installed capacity, the projected installations and the technical and sustainable hydropower potential calculated within the methodology developed in WP1.

It is also necessary to reflect that the main interlinkages with other sectors will be included considering the drivers that are affecting in the water availability as demand (consumption by population, industry, energy production) and supply (effects of climate change in temperature, precipitation and evapotranspiration). The **high-level conceptual model** is presented in Figure 10, including the interlinkages between the main WEF Nexus components and the socio-economic, climate and land drivers, affecting the availability of water for hydropower generation at basin level. Finally, it is necessary to reflect the role of technology (e.g. efficiency, required flow, etc.) as a main driver to quantify the final potential of hydropower in an area ensuring river flow levels that help to maintain the ecosystem services.

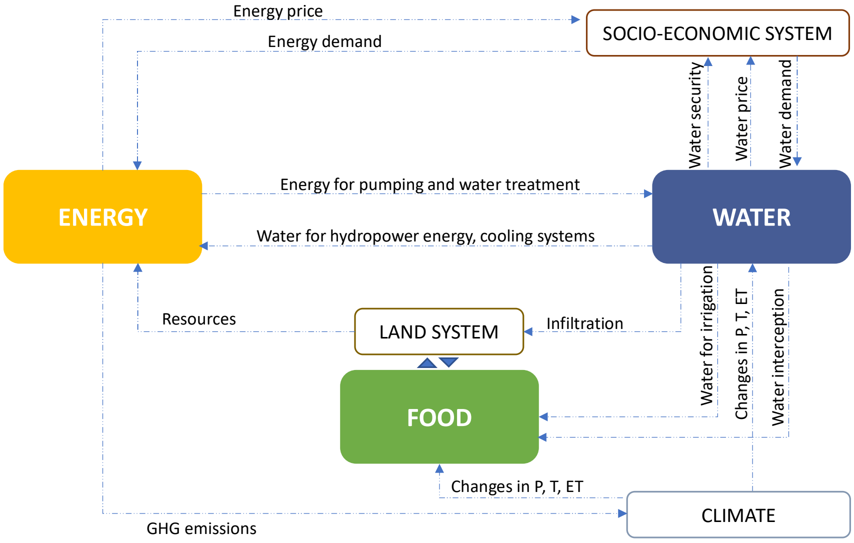

Figure 10: High level conceptual model of the Nexus approach for the replication tool development.

Different **tool architectures** will be evaluated for model integration starting from a client-server architecture with a pre-calculated database for the implementation of simulations with the model selecting the initialization data by means of a selection of the basin boundaries in the tool interface. Different alternatives (e.g. emulation, server licensed, real time, etc.) for model integration will be analysed. These alternatives will consider as key, the real time implementation of simulations using the tool. To this end, a Python version of the model or a translation into WebAssembly (WASM) will be analysed to understand the effects of the water

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demand decisions taken by the user. The main idea of the replication tool architecture is summarized in the Figure 11, including the interlinkages between the different components of the tool and the database.

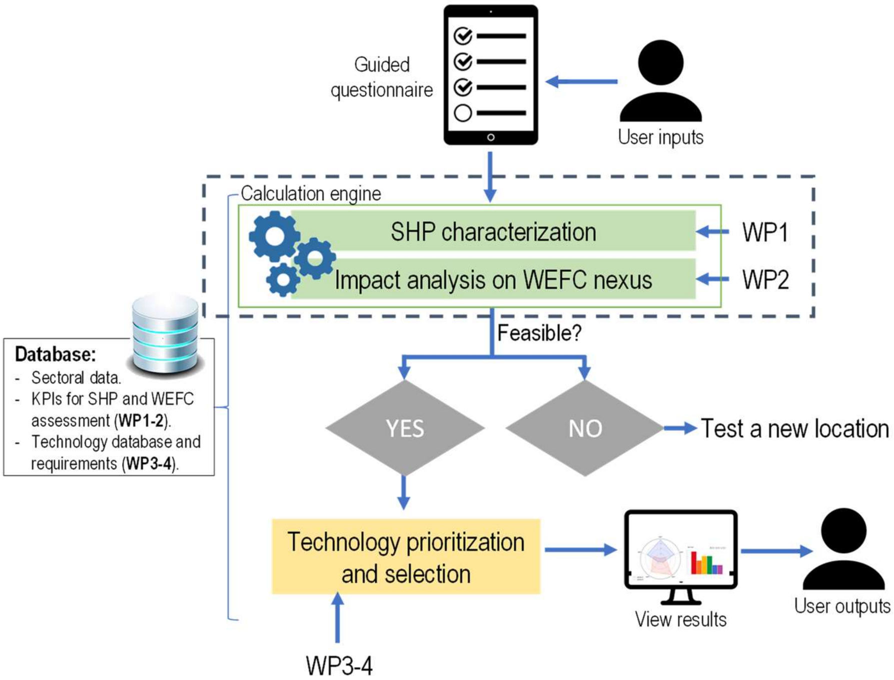

Figure 11: Initial architecture design for the replication tool.

8. Conclusions

Central Asia region has one of the **largest hydropower potential capacity of the world**. Within Hydro4U, a new methodology has been developed to standardize the calculation of the remaining sustainable SHP potential, which considers environmental, ecological, geo-morphological and climate change constraints. According to our procedure, the total **remaining sustainable SHP potential in the region is 28,680 MW**, which is distributed heterogeneously between countries with a high potential (KGZ, KAZ or TJK) and others where this capacity is lower (UZB) or residual (TKM). Despite this high potential, small-scale hydropower is not well developed, **with only 121 MW installed** in the region.

The growth of the sector is favoured by the political and economic reforms being implemented in CA countries. All countries of the region, except Turkmenistan, have adopted **primary legislation on renewable energy and energy efficiency**. They have set ambitious goals including expanding sustainable large and small-scale hydropower. For example, it can be cited the Kazakhstan 2050 strategy (with 41 SHP plants to be built), the Electricity Sector

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Modernization and Sustainability Project in Kyrgyzstan (with 136 SHP to be built or rehabilitated) or the Programme for the Hydropower Development in Uzbekistan 2017–2021 (with 17 HP plants). This political context will favour the development of new SHP projects in the region.

European and international financing organisations are also supporting the development of a broad range of **renewable energy and sustainable projects in CA**, including the promotion of new SHP plants. Such projects have assisted the Governments to attract investments through enabling legal and regulatory frameworks, capacity building and developing sustainable delivery models. They are expected to eventually aid in decreasing the use of conventional biomass and fossil fuels for electricity generation and other energy needs. As a barrier, it should be noted that the specific technical and environmental requisites to access to these economic resources are not always easy to be identified.

In addition to this favorable political and financial context, Hydro4U consortium as gained an ample experience during the realization of the technical planning process at the two demonstration sites (in UZB and KGZ) and the first planning activity (in KAZ). The **lessons learnt** within the site selection phase or the next pre-feasibility and feasibility studies will be vital for the execution of the two pending planning activities (Task 5.3) and future SHP projects.

Central Asia region has a number of geographical characteristics that make it necessary to consider the WFEC Nexus when planning and designing new SHP plants. The two upstream countries (TJK and KGZ) have a large SHP potential and the current installed HP already provides 90% of the country's electricity needs. The two of them are interested in generating and exporting more electricity through the construction of hydroelectric dams and reservoirs in the main transboundary tributaries of Amu Darya and Syr Darya. This aspect is creating serious problems for agricultural water supply in other countries in the region and has been the main root of conflict between CA countries for many years. The **Hydro4U replication guideline tool** is being developed to support decision-making for new SHP projects and will consider WFEC Nexus constrains, sustainability of resources, climate change impacts and socio-economic scenarios. The tool will be based on a computational model integrating GIS information and statistical data.

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