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Deliverable 5.1: Hydro4U Replication plan. 1st release

WP5, Task 5.1

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Abbreviations and Acronyms

Acronym	Description
CA	Central Asia
CAPS	Central Asia Integrated Power System
DX.Y	Deliverable number Y of the Xth Work-Package
EU	European Union
FCPS	Francis Container Power Solution
FIT	Feed-in Tariffs
GIS	Geographic Information System
H2020	Horizon 2020 (8th Framework Programme for Research of the EU)
HP	Hydropower
HPP	Hydropower Plant
HSPS	Hydroshaft Power Solution
PA	Planning Activities
PICTs	Pacific Island Countries and territories
RE	Renewable Energy
RES	Renewable Energy Sources
SHP	Small Hydropower
UNIDO	United Nations Industrial Development Organization
WFEC	Water-Food-Energy-Climate
WP	Work Package

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1. Publishable Summary

The overall objective of Hydro4U is to adapt Hydropower European technologies to Central Asia (CA), demonstrating viability in a forward-looking cross-border Water-Food-Energy-Climate (WFEC) Nexus and price-competitiveness through design alterations based on a prior analysis of unexploited SHP potential in CA.

Hydro4U will install and assess **two SHP plants**, which will radically reduce planning and construction costs, without compromising efficiency. Those are:

(1) approx. 2 MW Francis Container Power Solution (FCPS), medium-head plant, in Shakimardan site at Koksu River (Uzbekistan),

(2) approx. 1.6 MW Hydroshaft Power Solution (HSPS), low-head eco-friendly run-of-river plant, in At-Bashy River (Kyrgyzstan).

Also, a **replication model** will be developed to address the sustainable SHP potential in CA. This will demonstrate EU quality standards and 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 **D5.1 Hydro4U Replication plan (1st release)**, which is the first deliverable from **WP5 Replication of sustainable SHP potential**. D5.1 is the main outcome from the work carried out so far within **Task 5.1 Hydro4U replication plan**. This deliverable D5.1 establishes the bases for the definition of the Hydro4U replication strategy, which will be reviewed and updated within further releases: D5.2 (by M24), D5.4 (by M36) and D5.7 (by M48). This Deliverable D5.1 is divided into three main chapters:

Chapter 3 addresses the description of the **SHP context in CA**, including the electricity sectors and an assessment of the main drivers and barriers for SHP development in the region.

Chapter 4 presents the **guidelines for technical design**, with the optimization of the two innovative HP solutions to be demonstrated and the technical planning and sustainability assessment.

Chapter 5 describes the **Hydro4U replication guideline tool** and presents the 2 interactive modules to (1) assess the HP potential and (2) simulate HP generation scenarios.

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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

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

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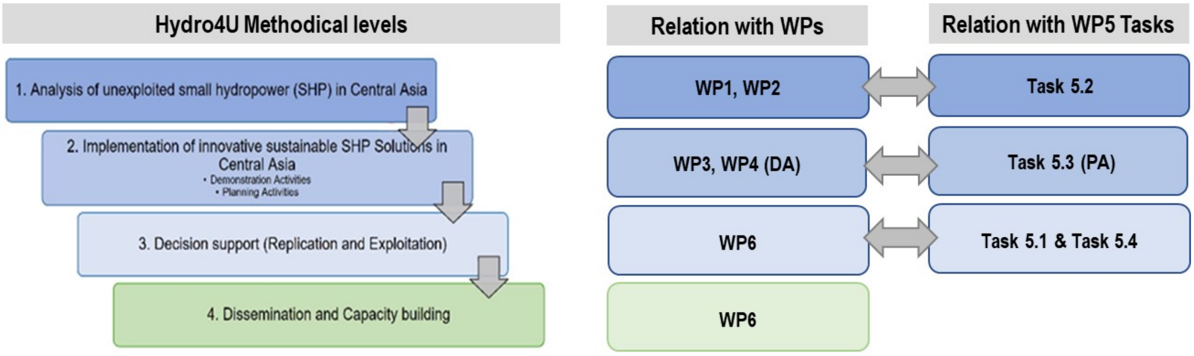
2.3. Relation to other activities in the project

Tasks foreseen in WP5 falls on the **levels 1, 2 and 3** of the novel methodical approach proposed in Hydro4U (see Figure 1) moving away from classic 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



Level 1: Analysis of unexploited SHP potential in CA.

In Hydro4U, an interdisciplinary GIS-based approach is being developed which maps the sustainable, so far unexploited SHP potential in a transparent, comprehensive and freely accessible way, considering 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 a) natural, b) engineering and c) socio-economic sciences.

Level 2: Implementation of innovative sustainable SHP solutions in CA: 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 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), which end in technical and bankable feasibility studies. 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 experiences 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**, 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)	Integration of the geodatabase into the replication guideline (Task 5.1), use them 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 geodatabase into the replication guideline (Task 5.1), use them for the Planning Activities (Task 5.3), and incorporate them 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 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.

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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. Definitions

Small Hydropower (SHP): The definition of SHP varies throughout the Central Asia region. Kazakhstan 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 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 that amount of SHP generating capacity that could be built after conducting a feasibility study on each site at current prices and producing a positive outcome. Technical and economic feasibility strongly varies depending on local conditions, and, therefore, requires in-depth studies at each potential site, which is why we focus on gross theoretical potential.

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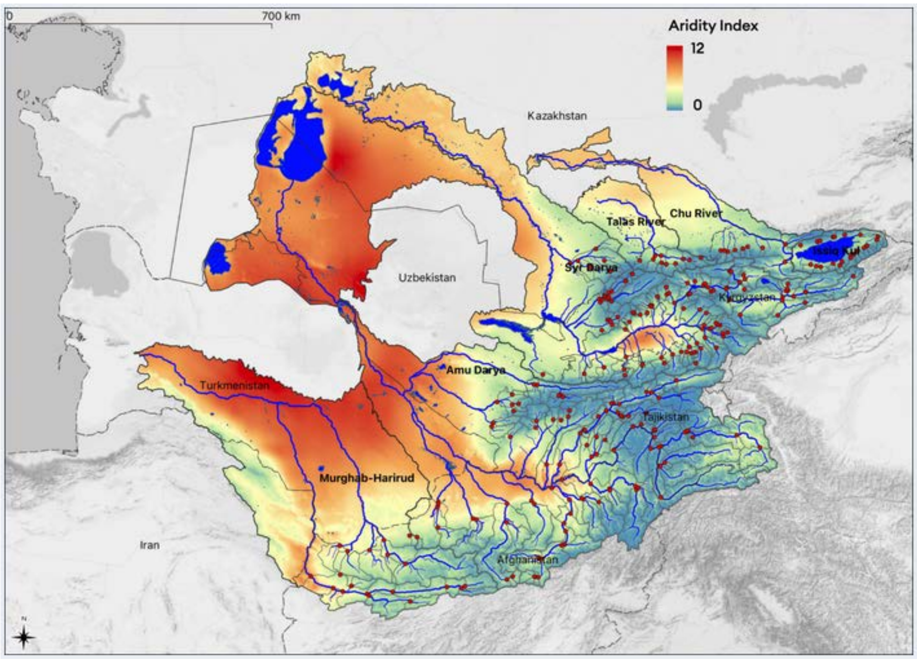
3. Understanding the context

Central Asia (CA) region includes in this context five countries: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. The topography and climate of the region vary from arid desert (Kazakhstan, Turkmenistan and Uzbekistan) to mountain ranges and grasslands (Kyrgyzstan and Tajikistan). Rainfall can be intermittent, with lows of 100-200 mm in Uzbekistan and higher averages of 2,000 mm in central Tajikistan. Most CA countries deal with extreme weather conditions; however, Tajikistan is more vulnerable and is already dealing with low agricultural productivity and high losses from natural disasters.

From a hydrological perspective, semi-arid Central Asia is a region of immense contrasts. On its south-eastern fringe are the large mountain ranges, including the Hindu Kush, the Pamir, the Gissar-Alay, and the Tien Shan. From there, the major rivers of the region emerge, including the Harirud and Murghab rivers, the Amu Darya and the Syr Darya as part of the Aral Sea basin, and finally, the Chu River and Talas River (Figure 2). These rivers are mostly snow melt-fed, with peak discharge occurring during the warm boreal summer months. During the irrigation season, much of the annually available water gets allocated for agricultural production in the downstream. This has allowed the region to prosper for millennia and led to the Aral Sea's desiccation in the second half of the 20th century after irrigation systems saw a significant expansion in the area.

Figure 2: Major river basins of south-western semi-arid Central Asia.

The red dots indicate the locations of 277 gauging stations. The colours show the aridity index where red colours indicate highly arid conditions in the downstream plains and blue hues show the zones of runoff formation in the upstream mountainous places. Source: hydrosolutions GmbH



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3.1. Framing the development of the Small Hydropower sector in Central Asia. Global overview

The need for clean and sustainable sources of energy is growing more acute in the face of climate change worldwide. As the lowest cost renewable energy technology, hydropower remains at the center of international efforts to fight climate change and **transition to a clean energy future**. SHP is an integral part of a broader strategy to promote development whilst at the same time reducing GHG emissions and promoting greater energy independence. Table 2 shows the global SHP overview (up to 10 MW) according to the UNIDO 2019 World SHP Development Report[1], including theoretical gross SHP potential, the installed capacities, % utilized and unexploited potential:

Table 2: Global Small Hydropower overview[1]

World region	Small Hydropower (< 10 MW)			
	Gross theoretical Potential (MW)	Installed (MW)	% utilized	Unexploited potential (MW)
Central Asia	34,358	266	0.8%	34,092
Eastern Asia	75,437	45,723	60.6%	29,714
Southern Asia	4,203	697	16.6%	3,506
South-Eastern Asia	16,362	850	5.2%	15,512
Western Asia	7,917	3,533	44.6%	4,384
Total Asia	**138,276**	**51,069**	**36.9%**	**87,207**
Eastern Europe	4,370	1,903	43.5%	2,467
Northern Europe	10,805	4,401	40.7%	6,404
Southern Europe	14,746	6,881	46.7%	7,865
Western Europe	7,634	6,514	85.3%	1,120
Total Europe	**37,554**	**19,699**	**52.5%**	**17,855**
Australia and New Zealand	795	327	41.1%	468
PICTs*	413	114	27.6%	299
Total Oceania	**1,208**	**441**	**36.5%**	**767**
Northern America	11,879	4,734	39.9%	7,145
South America	28,483	806	2.8%	27,677
Central America	1,202	524	43.6%	678
Caribbean	297	177	59.6%	120
Total America	**41,860**	**6,240**	**14.9%**	**35,620**
Eastern Africa	6,832	276	4.0%	6,556
Middle Africa	1,856	114	6.1%	1,742
Northern Africa	520	112	21.5%	408

[1] United Nations Industrial Development Organization. 2019 World Small Hydropower Development Report (WSHPDR)

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Southern Africa	422	50	11.8%	372
Western Africa	610	44	7.2%	566
Total Africa	**10,240**	**595**	**5.8%**	**9,645**
TOTAL WORLD	**229,138**	**78,044**	**34.1%**	**151,094**

** Pacific Island Countries and territories*

As it can be observed, Asia has the largest installed capacity (51,069 MW) and potential for SHP up to 10 MW (138,276 MW). Europe has the highest percentage of SHP development with 52.5%, with Western Europe having 85% of its potential already developed (followed by Eastern Asia with 61% developed). In the Americas, most of the SHP is concentrated in the Northern America and South America regions. In 2019, the Americas reached an SHP development rate of 15%.

When SHP data in CA is contextualized in this global set, two main conclusions can be drawn. On one hand, **CA has the second largest potential capacity of the world for SHP** (up to 10 MW) with 34,358 MW, only surpassed by Eastern Asia with 75,437 MW. However, despite this potential**, CA has the lowest percentage of SHP development with 0.8%** with only 266 MW of installed capacity.

3.2. Regional Small Hydropower overview

An individual study per country has been carried out, including not only SHP values, but also Hydropower installed capacities.[1] As it can be seen in the Table 3, SHP development is not allocated uniformly in the Region. For example, **Tajikistan** has the highest SHP potential with 30 GB but only 0.1% of this potential has been developed so far. In **Kyrgyzstan**, on the contrary, hydropower is the main direction of development of the energy industry achieving 17% of SHP development:

Table 3: Hydropower capacities in Central Asia[1]

Country	Hydropower	Small Hydropower (< 10 MW)			
	Installed (MW)	Gross theoretical Potential (MW)	Installed (MW)	% utilized	Remaining potential (MW)
Tajikistan	5,039	30,000	26.6	0.1	29,973
Kyrgyzstan	3,077	275	46.6	16.9	228
Uzbekistan	1,879	75.8*	75.8	--	--
Turkmenistan	1.2	1,300	1.2	0.1	1,299
Kazakhstan	2,699	2,707	116.0	4.3	2,591
Total (MW)	**12,695**	**34,358**	**266**	**0.8**	**34,092**

** The estimate is based on the installed capacity as no data on potential capacity is available*

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Tajikistan. Tajikistan has abundant water resources with 8,476 km^2 of glaciers, 947 rivers stretching over 28,500 km and 1,300 freshwater lakes. The country has one of the highest HP potentials in the world with 5,039 MW of total installed capacity that yield the majority of the country's electricity generation. However, SHP plays a vital role in providing electricity access to remote rural areas due to the sparse distribution of the population. SHP installed capacity is 26.6 MW, provided by **285 SHP Plants** with installed capacity of 0.005 – 4.3 MW.

SHP potential is estimated at **30 GB, coming from 6 potential sites already assessed**:

- About 4,450 MW in the River Vakhsh catchment;
- About 1,800 MW in the River Surhob catchment;
- About 1,750 MW in the River Obihingou catchment;
- About 1,450 MW in the River Kafarnigan catchment;
- About 1,260 MW in the River Zerafshan catchment; and
- About 17,900 MW in the River Pyanj catchment

In parallel, several restoration initiatives in the SHP sector are underway together with and an action 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.

Kyrgyzstan. The water resources on **Kyrgyzstan** are not allocated uniformly and are mainly concentrated in the unpopulated and economically underdeveloped areas. Hydropower is the main direction of development of the energy industry of the Kyrgyz Republic. The energy system operates 24 HP plants with a total capacity of 3,077 MW, of which the capacity of 7 large HP plants is 3030 MW and 17 SHP plants is 46.6 MW:

Table 4: Hydropower plants *of* the Kyrgyz Republic

N.	Name	Power (MW)
	Total large HP Plants (7)	**3030**
1	At-Bashi HPP	40
2	Tashkumyr HPP	450
3	Shamaldysai HPP	240
4	Uchkurgan HPP	180
5	Toktogul HPP	1200
6	Kurpsai HPP	800
7	Kambarata-2 HPP	120
	Total large Small HP Plants (17)	**46.6**

The SHP potential in the country is estimated at 275 MW, indicating that approximately 17% has been developed. Only on the river Naryn, it is possible to build 33 HP Plants with an

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installed capacity of 6,450 MW with an annual output of more than 22 billion kWh of electricity. The *State Committee for Industry, Energy and Subsoil Use* plans to build and rehabilitate **136 SHP plants** (less than 30 MW) by 2025 with a total capacity of 278 MW: (i) construction of new 90 SHP Plants with a capacity of 180 MW (average annual output of up to 1.0 billion kWh), (ii) restore 39 previously existing SHP Plants with a capacity of 23 MW (average annual output of up to 110 million kWh) and (iii) construction of 7 HPPs on irrigation reservoirs with an installed capacity of 75 MW (average annual output up to 220 million kWh).

Uzbekistan. Its ample HP potential 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. Furthermore, the country often experiences water scarcity due to a large extension of the irrigation area. In 2017, there were 15 SHP plants and a combined installed capacity of 75.8 MW. The SHP potential (up to 10 MW) has not been estimated, but for up 30 MW it is about 1,392 MW including all water resources (small rivers, canals and reservoirs). Construction of several new SHP plants with a combined capacity of 23.5 MW as well as refurbishment of the existing ones is planned by 2020.

Turkmenistan is located on the world's fourth largest natural gas reserve and has vast quantities of oil resources, which has resulted in an energy sector dominated by thermal generation. In Turkmenistan, the main rivers are located in the far south and east; the most important of which is the Amu Darya. Although HP potential is high, there is only one HP plant in operation in the country, with a capacity of 1.2 MW, commissioned in 1913. The potential development of SHP on existing irrigation dams has been studied.

Kazakhstan. Kazakhstan has one of the lowest water availability rates in Eurasia (20 m^3/km^2) despite having a high number of small and large rivers as well as lakes. The installed capacity of SHP in 2018 was about 116 MW, while the potential is estimated at 2,707 MW indicating that 4% has been developed. According to the national plan on transitioning to a green economy, the share of alternative and RES should make up 3% by 2020, 30% by 2030 and 50% by 2050. The plan pledges to reduce the country's GHG emissions as well as introduce a pilot emissions trading system. There is a considerable interest from investors to develop SHP in Kazakhstan, with many new prospective projects. In 2018, through tenders for renewable energy projects, a further 82 MW of SHP capacity was approved for development.

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3.3. Electricity sector overview

From the 1970s until 1990, the Central Asia Integrated Power System (CAPS) was a centralized body which provided electricity to all the CA region regardless of national borders. CAPS 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. Most hydropower resources are concentrated in Kyrgyzstan and Tajikistan, while Kazakhstan, Turkmenistan and Uzbekistan, on the other hand, have an abundance of thermal resources such as fossil fuels. This imbalance drove the countries to undertake measures and agree on maintaining parallel operations within the separately functioning power systems.[2]

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%.[3]

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

In this first version of Hydro4Us replication plan, two countries are briefly presented in the following sections. In future versions of the replication plan this will be completed.

3.3.1. Electricity sector in Tajikistan

Regulation of the energy sector is implemented 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.

[2] World Bank (2017). *Samoa. Population, total*. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=WS
[3] World Bank (n.d.). Access to electricity (% of population):https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?view=chart

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(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.

3.3.2. 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.

Management structure of the energy sector of the Kyrgyz Republic

The electrification rate in the Kyrgyz Republic is 100%.[4] 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.

[4] World Bank (2017). Access to electricity (% of population). https://data.worldbank.org/indicator/eg.elc.accs.zs

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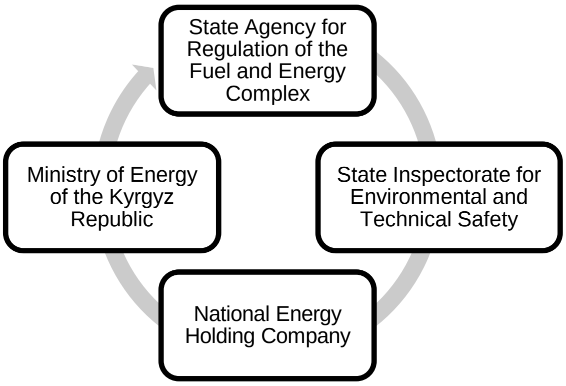
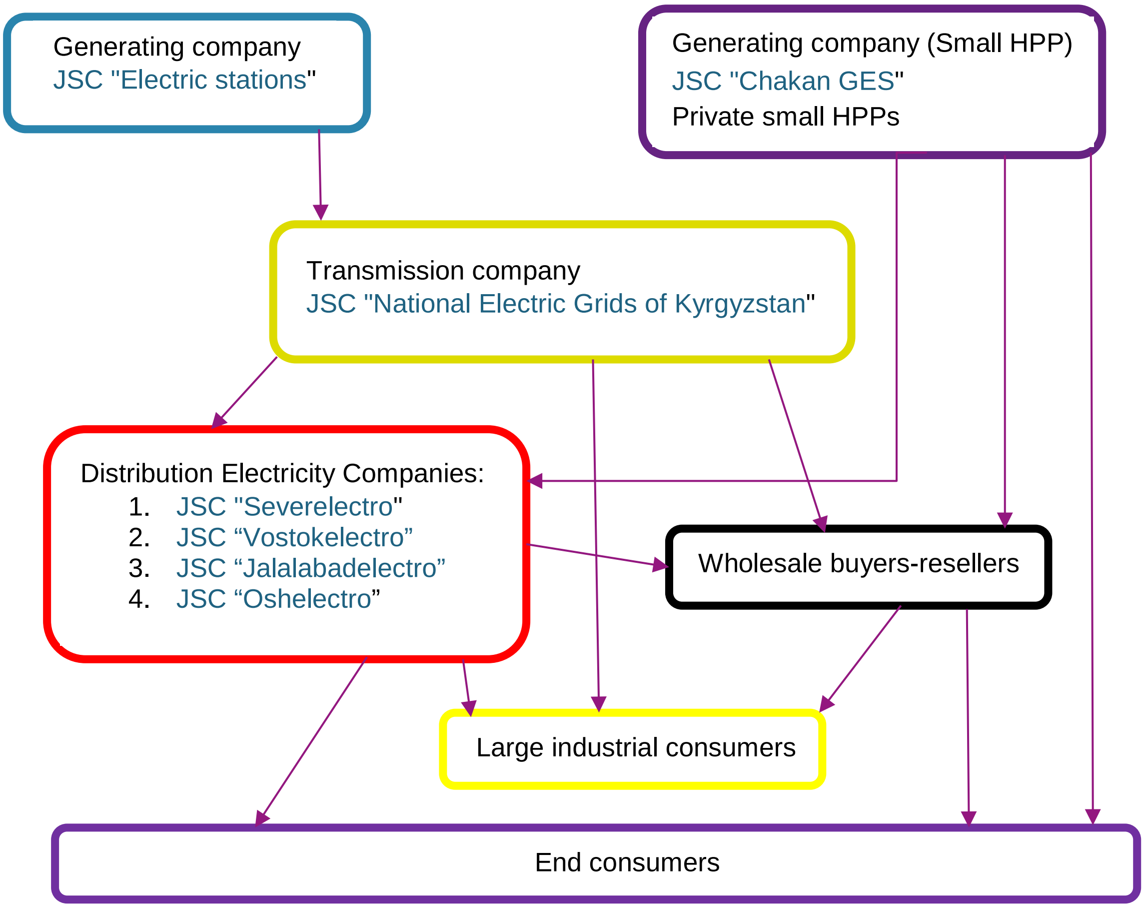
Figure 3: Management structure of the energy sector of the Kyrgyz Republic



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



JSC "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.

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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.

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; - substations with a voltage of 110 - 500 kV in the amount of 199 units, incl. 110 kV substations - 181, 220 kV substations - 14 and 500 kV substations - 4.

Distribution Electricity Companies (JSC "Severelectro", JSC “Vostokelectro”, JSC “Jalalabadelectro”, JSC “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.[5]

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 RE sources are:

Law of the Kyrgyz Republic “On Energy”. adopted on 30 October 1996, No. 56, since then amended 3 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.

[5] World Bank (2017). Analysis of the Kyrgyz Republic’s Energy Sector. Available from http://documents.worldbank.org/curated/ en/370411513356783137/pdf/122080-WP-PUBLIC-TheStateoftheKyrgyzRepublicsEnergySectorFinalMay. pdf

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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:

- 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.

3.4. Way forward for Small Hydropower

Hydro4U replication strategy aims to bring European HP solutions (described in Chapter 4) to CA to maximize the impact among potential project promoters and increase the percentage of SHP development.

The causes behind the 0.8% SHP development in CA have been analysed. A varied number of barriers have been identified and classified considering the different Political, Economic, Social, Technological, Legal and Environmental implications. As it can be seen in Table 5, there are common issues as **market barriers** due to the lack of information on SHP, **regulatory barriers**, **technical barriers** or **financial barriers** due to the lack of private sector funding. However, there are other situations that occur in specific countries as the unfavourable climate conditions in Kyrgyzstan, where streams are more likely to freeze in winter or the competence with other RES as in Turkmenistan with the high availability of thermal power sources such as natural gas and coal. In parallel, main drivers that can boost the implementation of SHP projects in CA have also been assessed.

In the next **Deliverable D5.2** to be submitted by M24 (May 2023) this table will be updated. First, this assessment will be done by country level (or river basin) in order to detect the main barriers in each case and confront them with the correspondent drivers. Lessons learnt from the different seminars, interviews and consultation meetings that are being organized within WP2, involving representatives of the water, energy, agricultural and environmental sectors as well as local authorities will be considered. 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.

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Table 5: Assessment of barriers and drivers to SHP development in CA

	Main barriers to SHP development	Main drivers to SHP development
Political	▪ Inefficient fulfilment of energy plans due to high turnover of related government positions with poor knowledge handover. ▪ Governments seem to be more likely to promote larger projects and to resolve the problem faster due to energy shortages.	▪ Incentive policies for SHP development. SHP development can be accelerated with the support of appropriate incentive policies.
Economic	▪ High upfront investment required to launch a project. ▪ Lack of private sector funding. ▪ Lack of functioning and affordable financing mechanisms (loans) available for developers of SHP projects. ▪ Lack of financial resources and low financial support from the Governments. ▪ Local banks' ability to support SHP projects is constrained by single- borrower exposure limits imposed by central banks, with their own internal guidelines being predominantly based on collateral borrowing. ▪ Low electricity prices in comparison to the generation costs. ▪ The current Feed-in Tariffs (FITs) are not sufficiently high for making the SHP projects economically viable.	▪ SHP for productive use. Reliable access to electricity through SHP allowed local enterprises to expand and create new business opportunities through greater efficiency and productivity, and reduced costs. ▪ SHP financing. Innovative mechanisms developed by some international and local banks. The Risk Sharing Framework of the European Bank for Reconstruction and Development offers local partner banks funded or unfunded risk-participation schemes.
Social	▪ Low social awareness (people, governmental agencies, organizations and institutions) about the benefits of SHP for the Region and its multiple benefits.	▪ SHP for social and community development. SHP can create conditions for communities to improve their quality of life, create employment, increase the standard of public service provision, improve overall health and education and achieve greater autonomy.

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Technological	▪ Lack of suitable sites, in particular when the most attractive potential has already been harnessed or when strict environmental or other regulations limit further development in areas with available potential. ▪ Lack of reliable SHP potential data, as well as the necessity to improve the functionality of already existent plants, ensuring less breakouts occur. ▪ Problems with data collection on the use of conventional and unconventional renewable energy and off-grid developments. This information is needed for developing energy policies and designing sustainable strategies with various energy mix options. ▪ Lack of an effective project plan and delivery. Projects tend to end up much more expensive than initially planned. ▪ The challenge of transporting RE generated electricity through the transmission system and to the consumption centres of the country. ▪ Aged electricity infrastructure due to lack of maintenance and investment, causing high losses by theft, fraud and non-payment of bills. ▪ Lack of qualified and trained local experts in the management, operation and maintenance of SHP plants and facilities.	▪ Technology, innovation and smart SHP. A range of technical solutions (as the two hydro4U solutions) can help adapt the technology to local regulations and bring it to more communities. ▪ Rehabilitation of historical sites, existing dams and waterways. Advancements in SHP technology have opened up new potential applications through the utilization of existing waterways and pipelines helping to support renewable energy targets and reduce greenhouse gas emissions.
Environmental	▪ Seasonal changes in hydropower production. In some countries (Kyrgysztan) streams are more likely (than larger rivers) to freeze in winter. As a result, facilities may be inoperable during the winter, when power and heat are greatest in demand and central grids are unable to compensate. Many communities are	▪ Mini-grid SHP solutions for remote rural areas. SHP can be deployed in various sizes of schemes that are adapted and suitable to the particular community's needs and local conditions. Off-grid SHP solutions have emerged as a mainstream option to expand access to RE in a timely and

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	connected to the grid during the summer, when power is relatively abundant; therefore, the demand for off-grid power is not high. This leads to unfavourable economic conditions for commercial SHP plants. ▪ High availability of thermal power sources such as natural gas and coal (Turkmenistan). ▪ Unregulated SHP development can result in significant ecological impacts, including river loss of water, changed river ecology, reduced river connectivity and affected migratory fish and other aquatic species.	environmentally-sustainable manner. It is necessary to disseminate reliable data that can inform policy development and energy planning, as well as guide investors entering renewable energy markets.
Legal	▪ Lack of regulation of technical specifications, particularly in regards to the power grid connection. Difficulties with obtaining permissions to join the electrical grid and approval of water usage schemes. ▪ Lack of clear framework conditions for private sector involvement and clear regulations on licensing. ▪ Lack of well-defined laws and guidelines with regards to foreign/external investment.	▪ Green SHP supported by regulations, guidelines, incentive policies and practices, to maintain the ecological safety of the sector.

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4. 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 are described.

4.1. 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 already, however their implementation was 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 used 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 summarizes 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.

4.1.1. 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.

The first step of implementation will always remain the establishment of a construction site 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 and the power plant completed.

The design of this system is currently under elaboration within WP 3 and will be presented in higher detail in Deliverable 3.2.

4.1.2. 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 HSPS 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.

The design of this system is currently under elaboration within WP 3 and will be presented in higher detail in Deliverable 3.2.

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4.2. Technical planning, sustainability and assessment

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 (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 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 and 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.

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.

At the current state of the project, **potential hydropowe**r 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 an experienced, 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 in 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. Besides this however, the assessment and subsequent selection out of the collected potential sites followed a methodical approach.

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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 comprises the rough 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 a first estimation of 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 preliminarily assessed and certain potentials for ecological improvements, mostly fish migration possibilities, were recognized.

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

Currently, the Hydro4U experts are working on the draft design of both demonstration sites, that will be presented in Deliverable 4.2. Based on these designs, the consortium will decide together with the local investors on the further procedure, in special when it comes to submission of applications for approval

Using the information and experience gained at the demonstration sites so far, the steps required to implement a successful planning process for SHPs in Central Asia are explained as follows. Figure 5 shows the technical planning process over time and with increasing level of detail.

- The first step is the **identification of potential sites** (potential analysis). 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.
- **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 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 specify analysis of the energy sectors mapping different institutions and explain different laws and national energy programs to consider (see section 3.3).

- The third step in the technical planning is a **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.
- 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.
- 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 technical equipment and a precise cost calculation building the basis for the equity and debt financing of a project.

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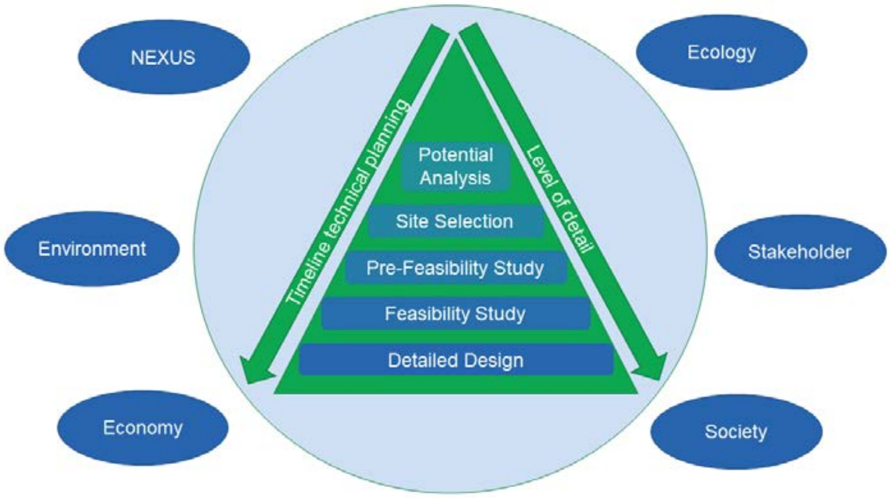
Hydro4U advances more sustainable hydropower solutions. This means all steps within the planning process include an assessment of all relevant environmental, social and economic aspects. A close contact with local stakeholders provides the possibility to identify optimized solution addressing all three aspects. In addition, in Hydro4U special attention is given to minimize 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 5: Steps of the technical planning process for small-scale hydropower in CA including all relevant aspects to obtain sustainable HPP solutions



This chapter of the first revision of the Hydro4U replication plan aims to represent a rather general overview on the overall process from site selection to the start of construction.

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 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.

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5. Hydro4U replication guideline tool

In CA, more than 90% of annually renewable water resources are consumptively utilised in irrigation and 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, including SHP, the WFEC Nexus is now under renewed focus in the region. In line with these developments, new Nexus trade-offs emerge that need to be yet acknowledged and quantified, also under the considering of 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. **Target audience** of the tool will be persons or authorities willing to exploit the so far unexploited SHP potential in CA.

At the end, the replication tool will ensure the identification of feasible policies to build **sustainable hydropower scenarios** in Central Asia at basin or sub-basin scale. As starting point, the tool will work for the basins, in which the two project Demonstration activities are located: Shakimardan in Uzbekistan and At-Bashy in Kyrgyzstan. In subsequent phases of the project, the implementation of the tool in other rivers basins will be addressed.

The tool will be based on a **computational model integrating GIS information and statistical data.** The replication tool will consider the sustainable hydropower potential calculations within the **screening tool from WP1** and the WFEC Nexus constraints identified in **WP2**. It will provide an environment to identify the main areas for replication considering also the potential improvements and the associated impacts as a consequence of the implementation of policies and measures related to WFEC Nexus.

To supports the identification of feasible areas where SHP solutions will be replicated, the tool will be designed including information to solve the following questions:

- What are the main characteristics of the river basin/sub-basin?
- How is the river network and their length at basin/sub-basin scale?
- What is the hydropower generation potential?
- What are the interlinkages in the WFEC Nexus?
- What is the land cover/land uses and their water demand?
- What is the water demand by households and industries?
- How climate change will affect in the future water availability?

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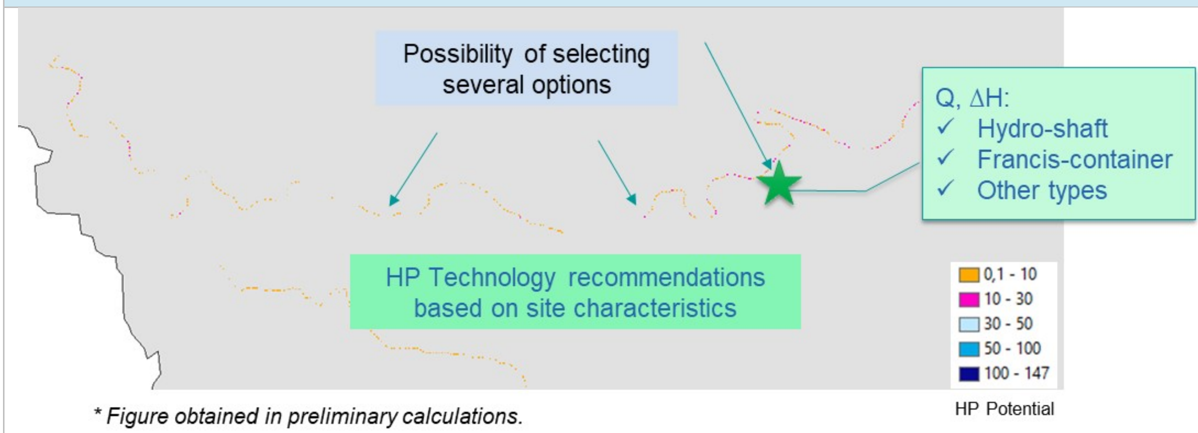
- How will be the change in future population? How they will impact in the demands?
- What is the impact of a hydropower solution before implementation (ex-ante evaluation)?
- How can the different policies at basin-region impact the feasibility of a solution implementation?

Currently it is planned that the tool will consist on **two interactive modules**, where to (1) assess the HP potential and (2) simulate HP generation scenarios. The draft user experience by means of this easy-to-use and user-friendly application is described below:

MODULE 1: Assessment of Hydropower potential at river basin level

Baseline scenario. To analyse hydropower potential at river basin level and the integrating countries, regions or sub-basins



** Figure obtained in preliminary calculations.*

→The user will be able to select the study area or a specific site.

→The tool will provide the correspondent HP potential considering sustainability and Nexus constraints

→The tool will provide HP technology recommendations based on site characteristics

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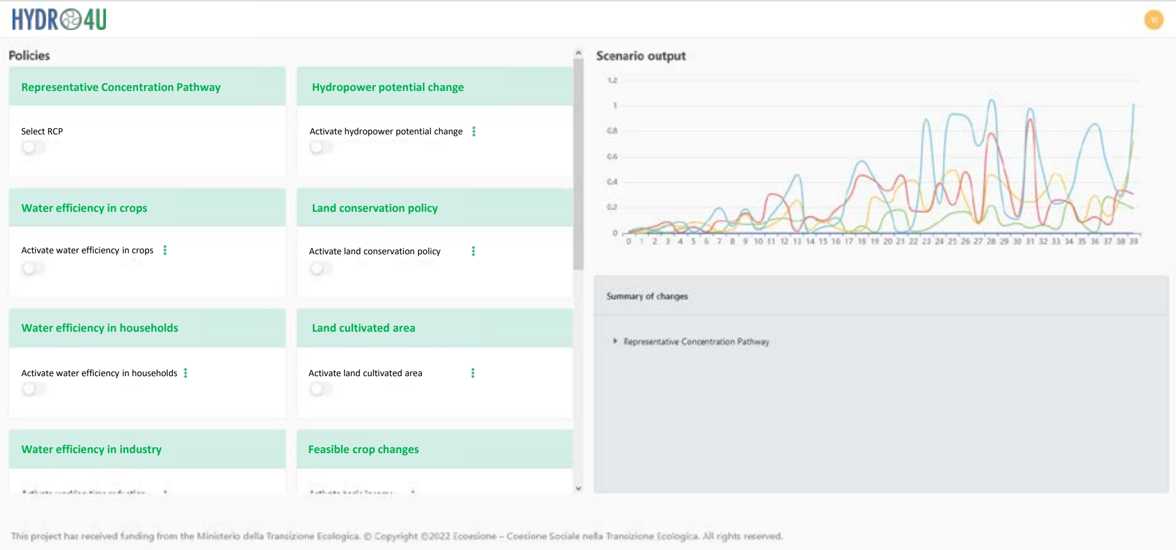
MODULE 2: Simulation of hydropower scenarios at river basin level
Policies selection and WFEC Nexus system modelling. To simulate different scenarios of Hydropower potential, considering the impacts on the Nexus.

→ The user will be able to decide **Hydropower generation scenarios** by (1) selecting the additional HP to be installed or (2) selecting the sites. → 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 consumption, GHG emissions, etc.

The design and development of this replication tool will follow three main steps which are describe in the following sub-sections:

5.1. Baseline scenario: The challenge of defining sustainable Small Hydropower potential in Central Asia

A deep analysis of the **required datasets including geo-located data will be developed**. This review included an evaluation of the data suitability for future calculation and pre-processing developments in order to adjust data covering the tool requirements.

Synergies with Hydro4U WP1: The geo-data analysis will be based on WP1 geodatabase. The baseline scenario will implement the methodology to calculate the **remaining technical and sustainable SHP potential**. This work will be carried out in collaboration with WP1, so

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that the gross theoretical SHP potential values will be refined with technically, economical, ecological and Nexus considerations.

Several studies have already made accurate hydropower potential estimations for specific areas. Different types of hydrological data and approaches can be used, such as remote sensing and hydrologic modeling, as used for poorly gauged basins.[6,7] These studies have noted that GIS-based tools combined with hydrological models or data are useful for assessing hydropower for specific areas and could be used on global scale as well. **A major challenge is hereby that in CA rivers numerous canals and diversion structures have been constructed**. These structures change the natural hydrological regime to an artificial regime, where additional information is needed such as operation schemes and the amount of extracted water.

In the following **D5.2** to be submitted by M24 (May 2023) this methodology to be developed within WP1 will be explained in more detail.

5.2. Climatic scenarios: The challenge of an uncertain future

Building upon on the baseline scenario, different climate scenarios can be simulated. It is planned to select the most representative scenarios according to IPCC AR6, which consider Representative Concentration Pathway (RCP) defined and economic/population projection using SSP scenarios. For example: SSP245 or SSP585. Combining the climate scenarios with hydrological modeling (e.g. results from WP2) the users can evaluate the electric generation of the planned hydropower plant based on the runoff now and in the future. This helps to select a sustainable layout and design of the planned solution.

Synergies with Hydro4U WP2: In WP2 hydrological modelling including climate change is performed at several sites in CA. This approach and findings will serve to determine a basis for larger scale prediction of the future flows in CA.

[6] Coskun HG, Alganci U, Eris E, Agõralioglu N, Cigizoglu HK, Yilmaz L, *et al*. (2010). Remote Sensing and GIS Innovation with Hydrologic Modelling for Hydroelectric Power Plant (HPP) in Poorly Gauged Basins. *Water Resour Manag*. 24: 3757-3772.

[7] Mosier TM, Sharp K V, Hill DF. (2016) The Hydropower Potential Assessment Tool (HPAT): Evaluation of runof-river resource potential for any global land area and application to Falls Creek, Oregon, USA. *Renew Energy*. 97: 492-503.

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5.3. Socio-economic scenarios: The challenge of a dynamic system

Apart from technical hydropower potential and climate change, the tool will allow to include possible socio-economic developments in CA at the planned SHP site to some extent. Potential scenarios to be integrated might be:

- **Water consumptive uses in agriculture**:
  - implementation of efficiency irrigation measures (decrease in water demand)
  - substitution of crops for others that consume less water (decrease in water demand)
  - improvement in the infrastructure of canals (avoid leaks) (decrease in water demand)
  - increase of the cultivated area (increase in water consumption)
- **Water consumptive uses/ water efficiency in households** and year of implementation (decrease in water demand)
- **Population growth** in the future (increase in water demand)
- **Different policies** in the energy market (higher/lower fed in tariffs)

Synergies with Hydro4U WP2: Based on the Nexus work in WP2, the different aspects in a WFEC Nexus in CA will be understood. This knowledge allows to elaborate representative and possible scenarios for CA river basins and to predict potential developments and their consequences on SHP development.

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6. Conclusions

Central Asia region has the **second largest potential capacity of the world for SHP** (up to 10 MW) with 34.358 MW but the **lowest percentage of SHP development,** with 0.8%. This SHP development is not homogeneous in the Region. For example, Tajikistan has the highest SHP potential with 30 GB due to its abundant water resources but only **0.1%** of the potential has been developed so far. In Kyrgyzstan, on the contrary, hydropower is the main direction of development of the energy industry achieving **17%** of SHP development.

The causes behind the low SHP development in the region includes several Political, Economic, Social, Technological, Legal and Environmental implications. There are common issues as the lack of information on SHP or the lack of private sector funding. Some Central Asian countries have to deal with extreme weather conditions which affect hydropower development in general for example, in high altitude regions, where streams are more likely to freeze in winter. There are other specific situations as or the competence with other energy sources such as in Turkmenistan due to the high availability of thermal power sources such as natural gas and coal.

Nevertheless, with environmentally friendly and socio-economically sustainable technical SHP solutions these barriers can be overtaken. Therefore, existing European high-quality solutions must be optimized to the demands and resources in CA. Hydro4U has the ambition to demonstrate this. At two demonstration pilot plants in CA and follow up technical feasibility studies we will show how the untapped potential could be addressed sustainably. To accelerate the exploitation in particular beyond the project lifetime a replication strategy is elaborated.

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 tool will be based on a **computational model integrating GIS information and statistical data.** During the subsequent development of the project, synergies and complementarities of this tool are generated by incorporating the **screening tool** and the methodology to sustainable hydropower potential calculations from WP1 and the WFEC Nexus constraints identified in WP2.

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