Hydropower Solutions

HYPOSO

Hydropower solutions for developing and emerging countries

D5.2
Pre-feasibilities studies for 15 case studies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857851.

Project no. 857851

Project acronym: HYPOSO

Project title: Hydropower solutions for developing and emerging countries

Call: H2020-LC-SC3-2018-2019-2020/H2020-LC-SC3-2019-RES-IA-CSA

Start date of project: 01.09.2019

Duration: 45 months

Deliverable title: D5.2 (Pre-feasibilities studies for 15 case studies)

Due date of deliverable: May 2023

Organisation name of lead contractor for this deliverable: *FN* (*05*)

Name	Organization
Nino Frosio, Bernhard Pelikan, Luigi Lorenzo Papetti, Beatrice Baratti	*Frosio Next S.r.l.*

Dissemination level		
PU	Public	X

History

Version	Date	Reason	Revised by
01	14/06/2023	Draft version	FN, WIP
02	20/06/2023	Final version for revision	FN, WIP
03	26/06/2023	Final version	WIP

DISCLAIMER REGARDING THIS PRE-FEASIBILITY STUDY

This Pre-Feasibility Study has been sponsored by European Commission and prepared for the use of the HYPOSO project (funded under Horizon2020 programme). While the information contained in this Pre-Feasibility Study has been prepared in good faith, it is not and does not purport to be comprehensive or to have been independently verified.

Neither the European Commission nor the partners of HYPOSO project or any of their officers, employees, advisers or consultants accept any liability or responsibility for the accuracy, reasonableness or completeness for any errors, omissions or misstatements contained in the Pre-Feasibility Study.

While considering the Pre-Feasibility Study, each recipient/interested party should make its own independent assessment and seek its own professional, financial, legal and tax advice.

Note to Reader: This document is based largely on existing information, and information gathered during field visits by a small team of professionals.

It is a public version of the original D5.2 documents, which are all available on request for eligible stakeholders (i.e., the 15 site owners, European hydropower stakeholders, and the European Commission). It describes the structure of a pre-feasibility study as elaborated for totally 15 sites in the five target countries. The main aim of this report is not the summary of individual data and results, but the detailed description of the steps necessary to achieve useable results and outcomes for a pre-feasibility study.

The methodological steps used in this document are comprehensible through publicly available sources, and must of course be adapted in the case of a planned replication.

In case you are interested in the original D5.2 documents, please contact:
business-cases@hyposo.eu .

Table of Contents

List of Figures

1 Introduction

HYPOSO is a multi-approach project to tackle several objectives: identification and mapping of the European hydropower industry, hydropower stakeholders in the HYPOSO target countries, education of new hydropower experts through capacity building activities and bringing together relevant actors from the EU hydropower sector with stakeholders in the target countries. Interaction with stakeholders is therefore an integral part of the activities, as workshops, capacity building activities and interviews with national/local stakeholders are envisaged in all target countries which are outside the European Union, namely workshops in Bolivia, Colombia and Ecuador in Latin America, and in Cameroon and Uganda in Africa. Additionally, capacity building courses will be carried out in Bolivia and Ecuador, and in Cameroon and Uganda.

2 Information about Deliverable

The following report is focussing on the structure of a pre-feasibility study as elaborated for totally 15 sites in the five target countries. The main aim of this report is not the summary of individual data and results but the detailed description of the steps necessary to achieve useable results and outcomes.
In such a very first chapter it is recommended to show - for example on Google Earth – the location of the site on big scale level in order to give a rough idea about the geography.

3 General regional description

The term "region" is not clearly defined generally. In the context of a pre-feasibility-study it could be seen as a part of the country with a kind of common features in terms of hydrology, geography and administrative structure. Of course, the criteria mentioned will not create a homogenous delimitation but characterises the respective area from different points of view.
The limitations are not easy to be found and need some deeper understanding of the different features. Usually a compromise has to be found. It is helpful to include a topographic and physiographic map showing the most important landscapes and big topographical units including special formations.
The interesting elements are the range of altitude, the climatic characteristic and the main structures of settlement.
Every country can be divided into main geographic regions. These regions should be described with their significant elements and illustrated with a physical map, indicating the position of the intended hydropower site.

3.1 Administration

The information about the administrative structure of the country in general and the respective site in detail is very important due to regional and local necessities in terms of contacts, cooperation, responsibilities and social aspects.
In many countries there are several levels of administrative structures like departments, provinces and municipalities. The respective structure is very individual and represents an important framework element.
It is recommended to include a map and – if available – a list of the departments including the population, the area and the density of population. On the following step a map of the provinces should be included, showing the location of the site. The example below from Nepal shows what is expected.

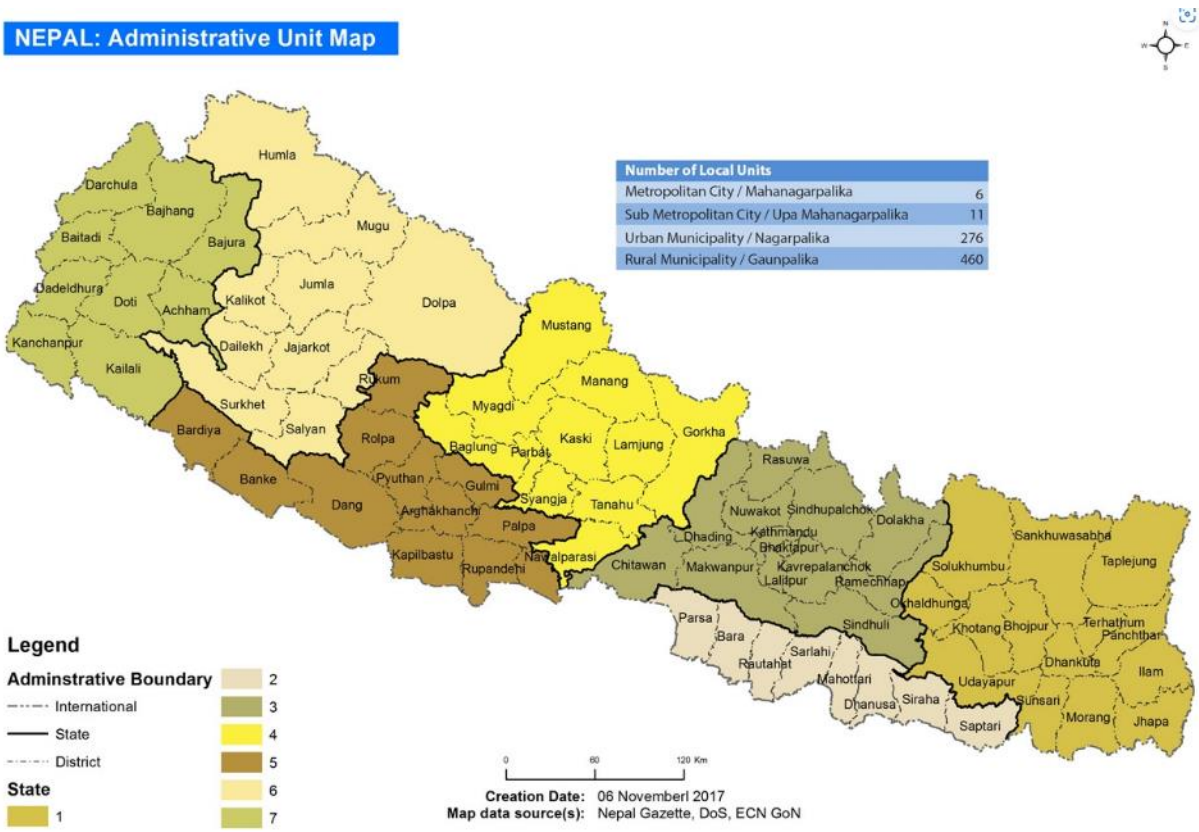

Figure 1 - Administrative unit map, example Nepal (United Nations, 2017)

In some cases, it may be necessary to mention original indigenous government, which is the self-governance of original indigenous people on the ancient territories where they live.
On the lowest local level, it could be helpful to list the names of the mayors and their contact details if already available.

3.2 Geography

The geographical environment of the site is very important for any further project development. The inclusion of a topographical map helps a lot in any description. In some cases, a national park or any other kind of protection may focus further attention. From the hydrological point of view the big relevant catchments and sub-catchments should be indicated. Most welcome would be a map showing the catchments and sub-catchments.

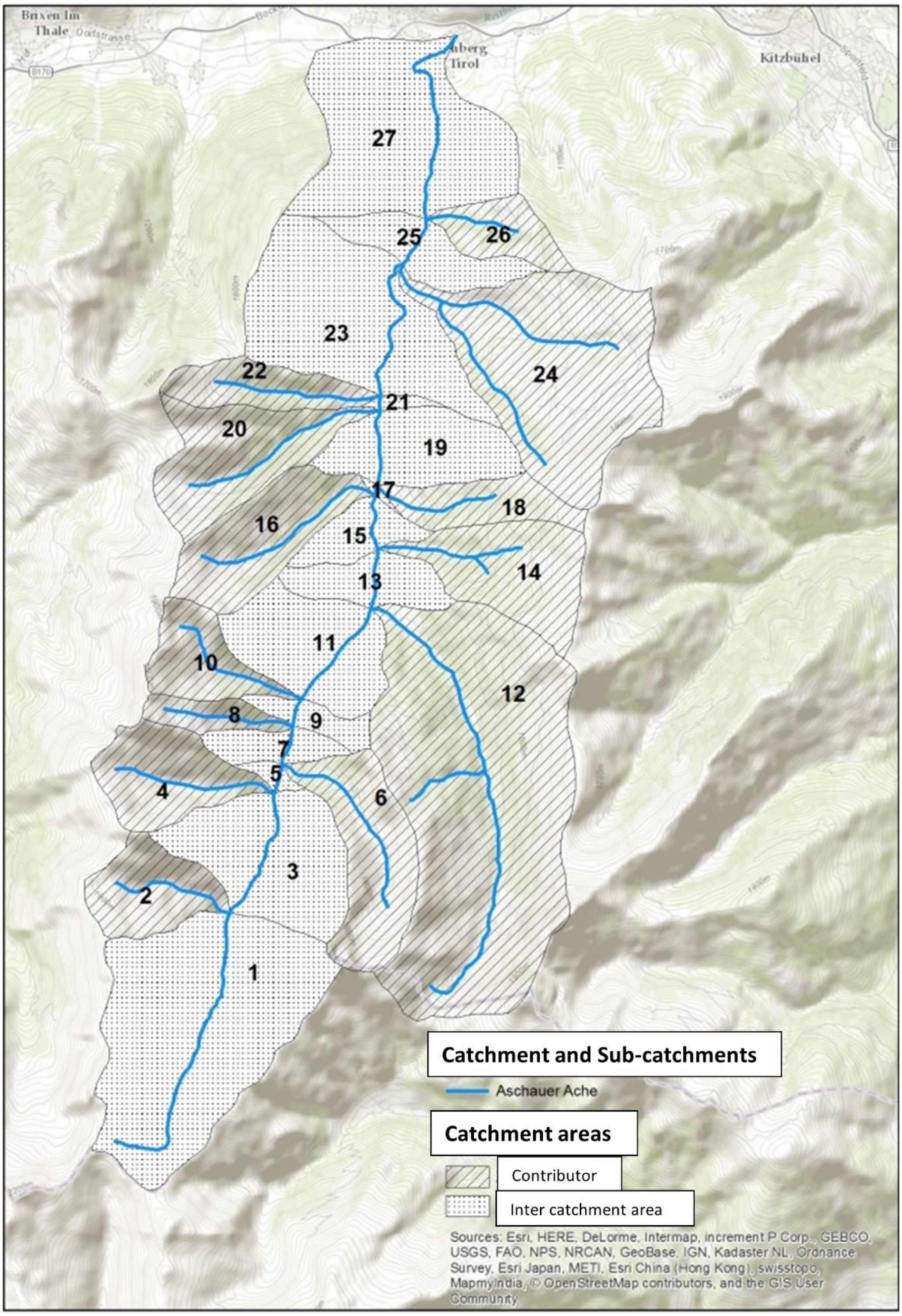

Figure 2 - Map showing the border of the catchment area, example Austria

For the relevant regions the mean values concerning precipitation and the climatic characteristic should be given. An overview concerning water resources and water management activities should be a necessary content.

3.3 Social structure

Usually the settlement of a region is closely related to the fertility of the soil and the availability of rain. These parameters allow primarily for the survival of the population.

An important factor is the historical development of the region and the knowledge about the ethnic groups and the demography of the geographical regions.
Depending on available local resources originating from mining, fisheries or agriculture the industrial and commercial structure has developed and the foundation of larger cities found its reason on these facts. An overview should be part of the study.
It is highly recommended to report on the development of the population, the density of population, the distribution in terms of gender and age and the distribution of different ethnic groups.

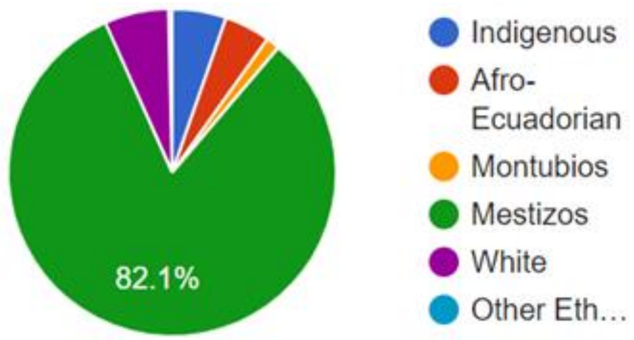

Figure 3 - Information about the population structure, example region Tungurahua in Ecuador (City Population, 2023_a)

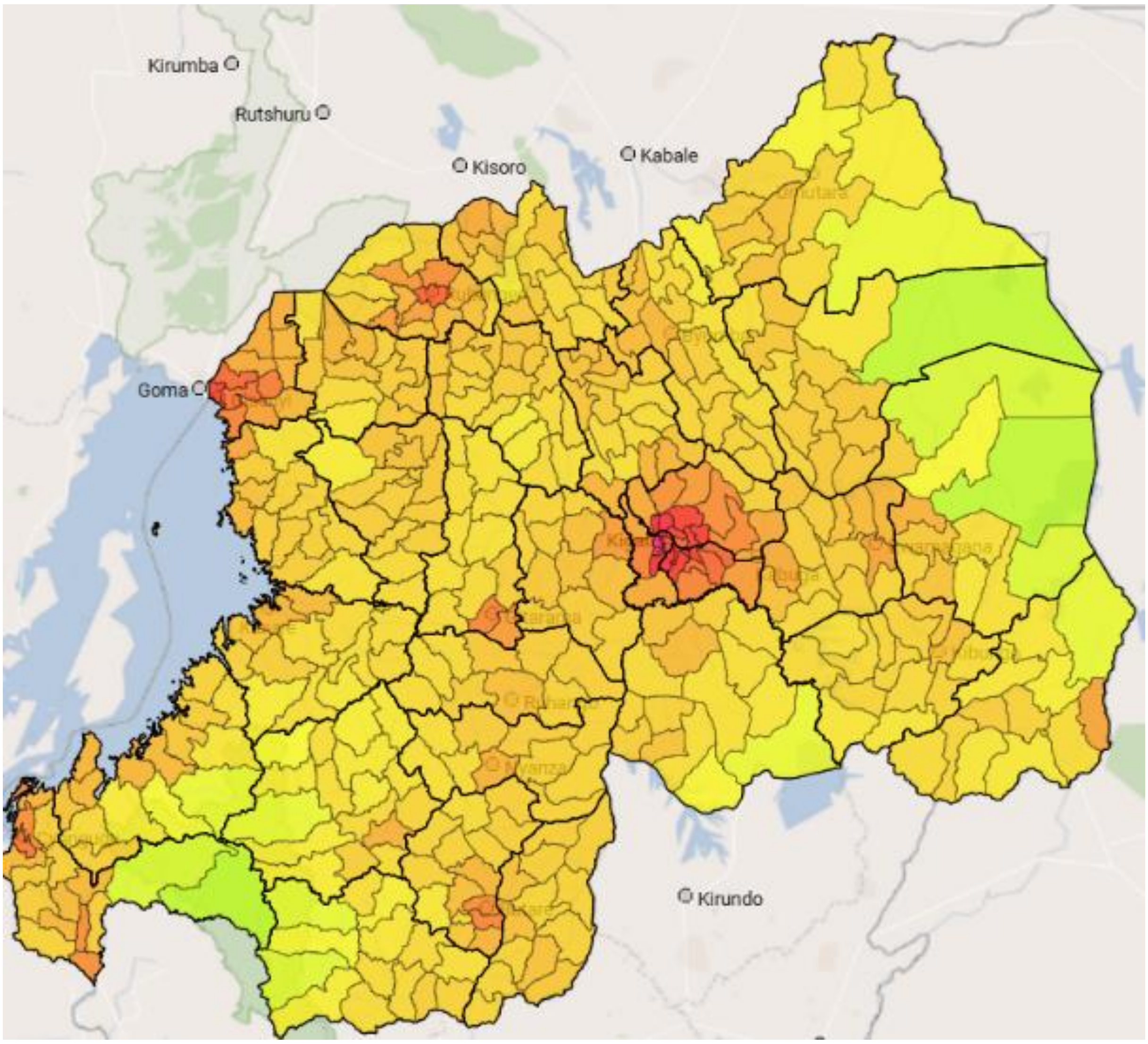

Figure 4 - Population of the districts and sectors, example Rwanda (City Population, 2023_b)

Aerial pictures can illustrate the settlement structures.

3.4 Energy consumption

Dealing with the exploitation of energy sources needs a good knowledge of the recent situation in terms of energy balance including consumption, production and import/export. Additionally, it is important to know about the share of different sources like hydropower, thermal power, biomass, wind, solar etc. An example is given below.

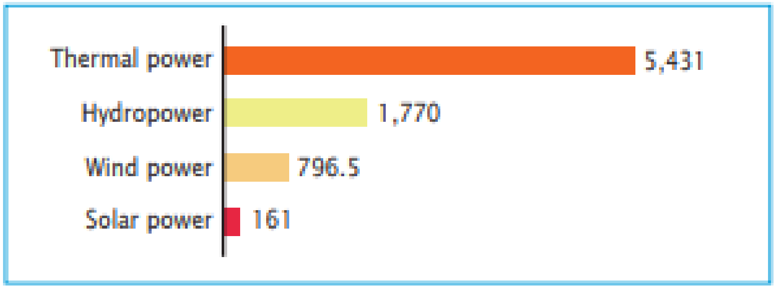

Figure 5 - Electricity generation by source, example Morocco (UNIDO, 2016)

Another important information is the structure of the transmission system – meaning lines, sub-stations and voltage levels. In this regard the study should include information on how to sell the electricity produced. Options are a fixed feed-in-tariff, a negotiated tariff and the duration of such support systems – a decisive economical element.
Already existing and operating small hydropower plants may provide important information on how to deal with the national energy bodies and the grid operators.

3.5 Climate

Usually climate maps (Köppen-Geiger) are available all over the world. It is recommended to include a map section indicating the position of the plant and to give a short description of the climate characteristics. If possible, some graphs should be included illustrating the number of rainy days/month and precipitation in mm/day. Such information will significantly help in planning site visits or flow measurements.

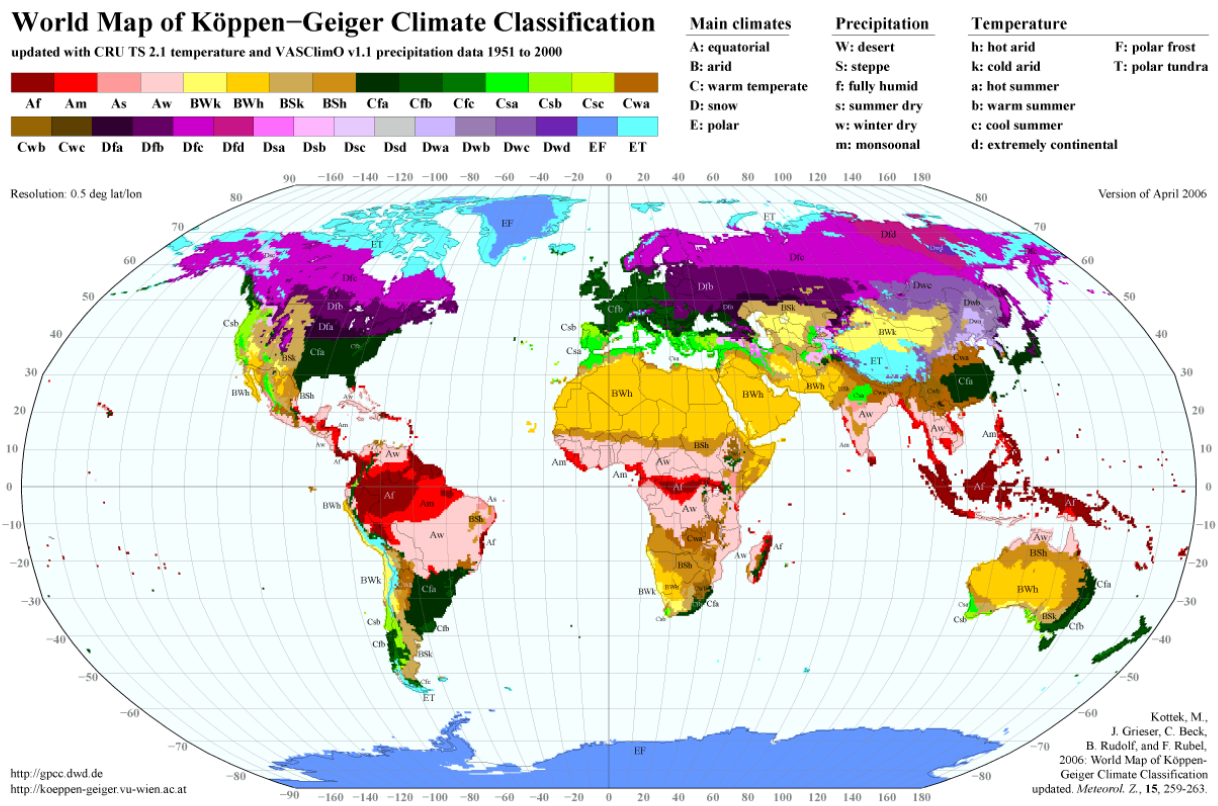

Figure 6 - Climate maps (Köppen-Geiger) (Vetmeduni, 2023)

4 General site description

The typological variety of hydropower plants recommends a first classification according to the following structure, based on three criteria:

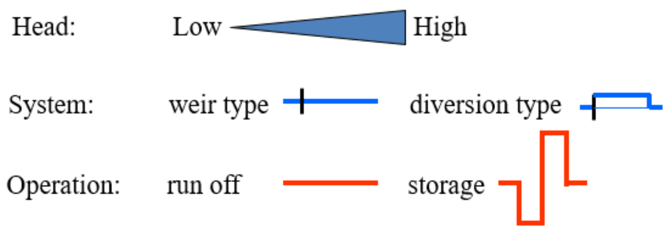

Figure 7 - Varieties of hydropower plant types (own graph)

Not all of the criteria can be combined, keeping in mind logics:

	low head	high head
weir type	run off / storage	run off / storage
diversion type	run off / storage	run off / storage

Figure 8 - HPP combinations (own table)

On the basis given, any project can be classified and described with its main constructive elements which are:

- Weir or dam (eventually spillway)
- Water Intake (lateral, bottom, others)
- Solid material protection (eventually: trash rack, intake sill, sand trap)
- Water conveyance (channel, tunnel, pipeline
- Powerhouse with EM equipment

4.1 Selected river and site location

The selection of the river reach to be exploited is usually the result of on-site exploration and work on maps. Gaia GPS – originally designed for trekking but not for hydropower design – is an excellent tool, offering information about topography with a rather precise height resolution and aerial view. A preliminary decision can be taken and illustrated in the tool.

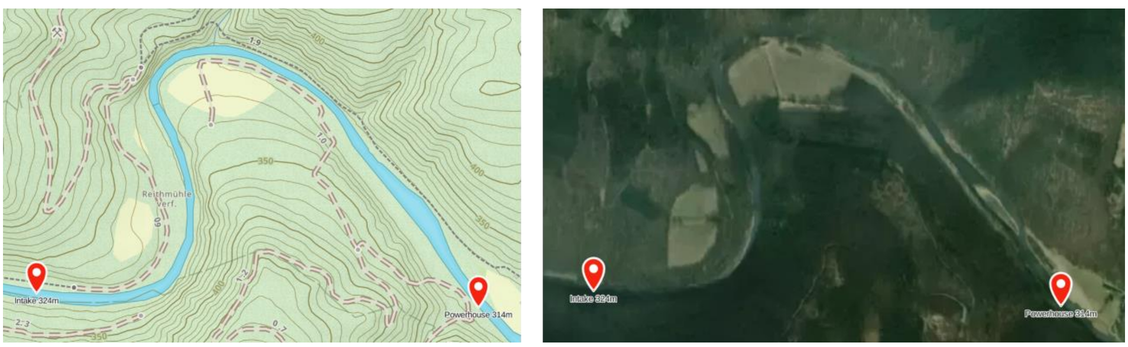

Figure 9 - Topographical (Mapcarta, 2023) and satellite image (Google Earth, 2023)

4.2 Existing studies or projects

Naturally, it is good to know if one is the first working on the project idea or somebody else made already some research work on the same topic. Probably this work can be used or conclusions can be considered helpful. Such work is not necessarily published. To ask local people or local government will be of help.

4.3 Available mapping

Aiming at the description of the site location, it is of help to provide topographic maps and thematic maps.

4.3.1 Topographic mapping

As already mentioned, Gaia GPS offers an excellent map and can be used as long as there is no more precise topography available. Supposedly the source for Gaia GPS is the same as for Openstreet Maps or Mapcarta but the tools are better like the opportunity to create longitudinal sections along a route selected as shown in the following example.

Figure 10 - Longitudinal profile from Gaia GPS (2023)

4.3.2 Thematic mapping

4.3.2.1 Administrative boundaries

Similar to chapter 3.1 but more in detail the administrative situation around the site is given, showing urban and suburban districts on a small scale of approx. 50 to 200 km². If available, a map is again very illustrative.

4.3.2.2 Main cities and roads

For several reasons cities and roads are important for a small hydropower project. Cities sometimes represent the business centre of the area and may offer workforce, necessary during construction. Cities need electricity and sometimes sub-stations to feed in the electricity produced are located close to them. Roads may serve not also for any transport reasons but sometimes they represent an excellent trace for evacuation lines. A map is recommended.

4.3.2.3 Land use

A specified map shows the distribution of different types of land use.

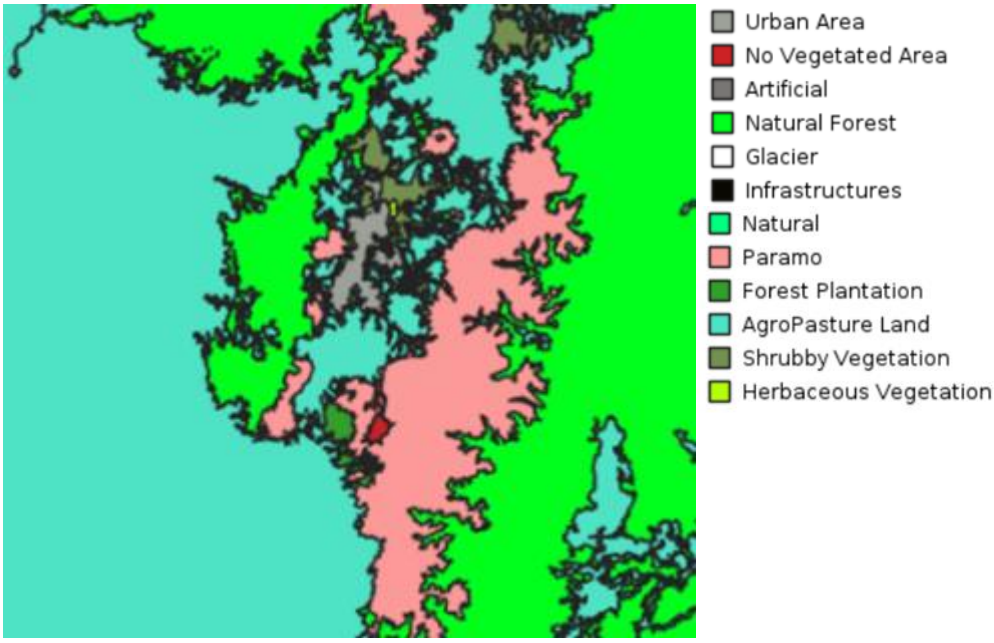

Figure 11 - Land use & cover Ecuador 2018 (Climate Justice Jean Monnet centre of Excellence, 2023)

4.3.2.4 Environmental restrictions (i.e., protected areas)

Protected areas can be found in a world-wide source named WDPA (World Database on Protected Areas), see below an example.

Figure 12 - Map showing a protected area in Cameroon according World Database on Protected Areas (Source: ArcGIS, 2023)

4.3.2.5 Geology and geotechnics

The geological conditions at the site are crucial for the further project development. Therefore a most detailed map is of high importance.

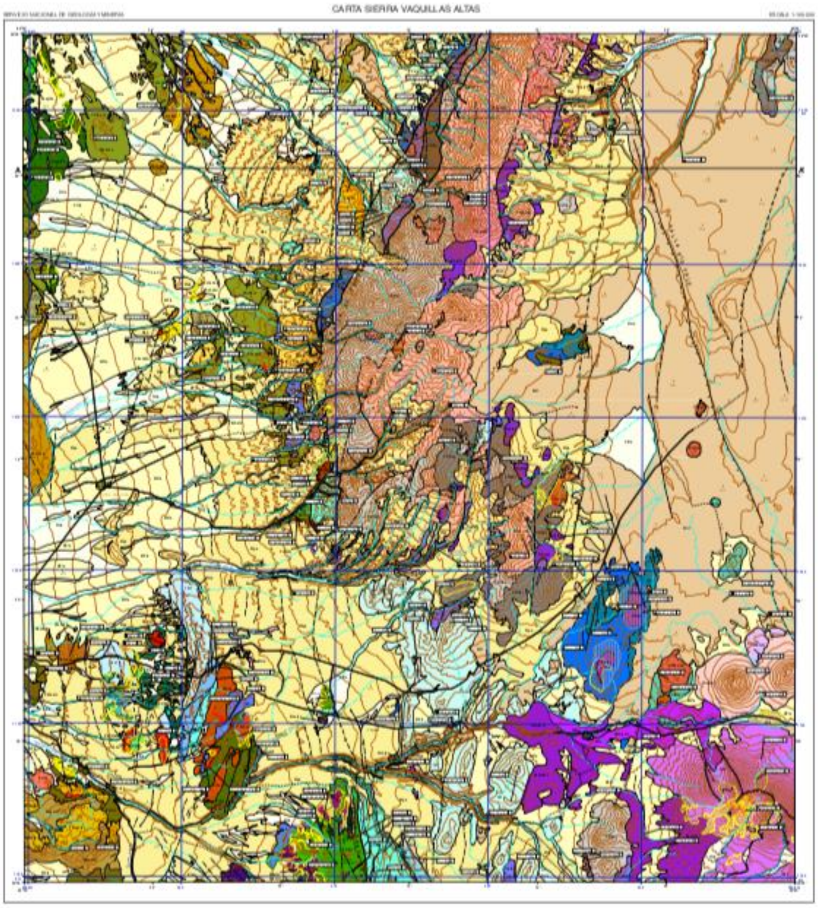

Figure 13 - Geological map, example from Chile (Plan Nacional de Geología, 2023)

4.3.2.6 Seismic activities

ThinkHazard! provides a general view of the hazards, for a given location, that should be considered in project design and implementation to promote disaster and climate resilience. The tool highlights the likelihood of different natural hazards affecting project areas (very low, low, medium and high), provides guidance on how to reduce the impact of these hazards, and where to find more information. The hazard levels provided are based on published hazard data, provided by a range of private, academic and public organizations.

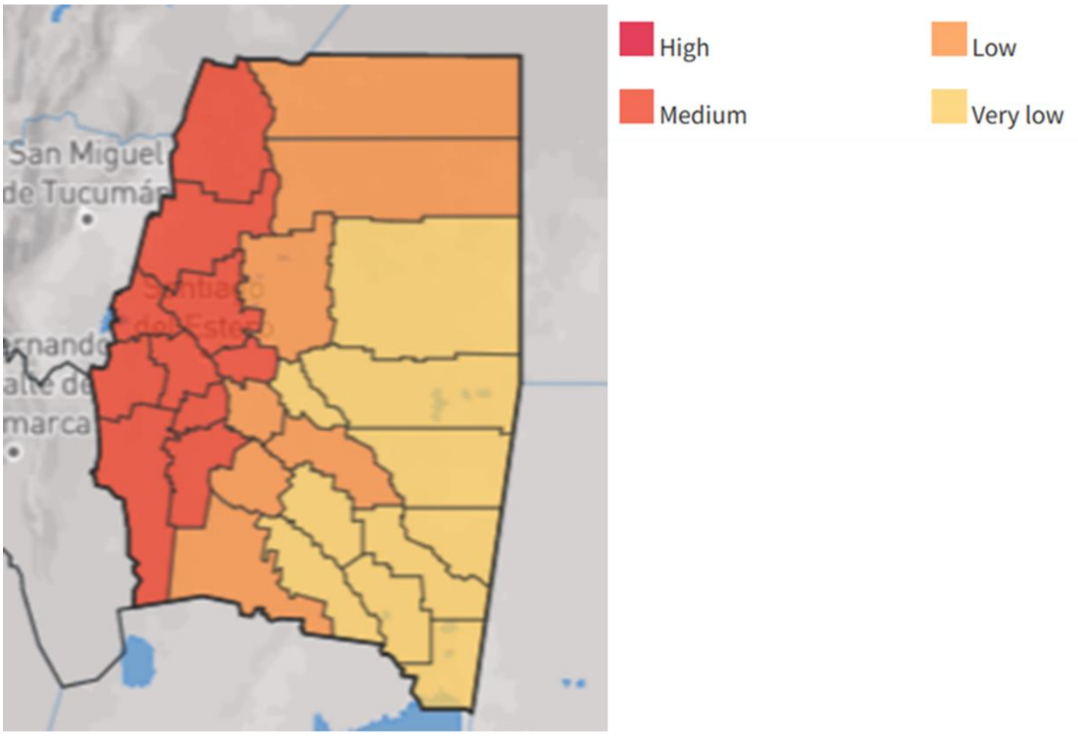

Figure 14 - Earthquake hazard map (ThinkHazard, 2023)

Google Earth offers a quite good material but not in equal quality all around the world. An alternative can be found with [OpenAerialMap](). Sometimes it is better – sometimes worse.

4.3.2.7 Gauging stations (discharge, precipitation, temperature)

As it can be seen in the following picture sometimes the existence of gauging stations is quite good at a first glance but recently a certain share of the stations is non-operational any more. To get old data is difficult and even to find out the former location of the station is difficult.

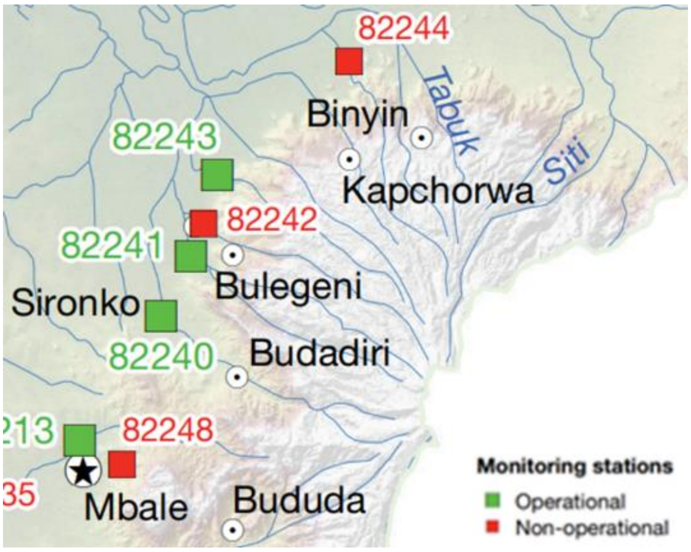

Figure 15 - Position of the gauging stations (Ministry of Water and Environment, 2017)

4.3.2.8 Digital Terrain Model

If available, a DTM may be of great help. Sometimes these models are called Digital Elevation Model (DEM) or Digital Surface Model (DSM). There is no universal usage of the terms (DEM), (DTM) and (DSM) in scientific literature. In most cases the term DSM represents the earth's surface and includes all objects on it. In contrast to a DSM, the (DTM) represents the bare ground surface without any objects like plants and buildings.

5 Hydrology and sediment transport

When designing a hydropower plant, the knowledge of the hydrological performance of the respective river is crucial. Of course, the final target of any hydrological research should be daily discharge values. An annual mean value is a first approach but does not allow for a reliable design and calculation of annual production. In best case there is a gauging station located at the river to be exploited. If this best case is not given, other hydrological methodologies have to be applied to generate reliable values. One of them is the availability of data from neighbouring catchments similar to the one exploited.

Additional to discharge values the knowledge of sediment transport will significantly help to design essential parts of the intake structure. Sediments are the enemy of mechanical equipment and special focus has to be laid on measures to extract sediments from turbine flow to avoid erosion and finally destruction. Unfortunately, in most cases there is no detailed information concerning bed load transport available. A first approach is a visual examination of the weir and intake location. Secondly the examination of the geological conditions in the catchment may provide an insight into the source of the bedload.

In the following chapter the main and characterising data of a catchment are summarised.

5.1 Catchment area

In most cases the catchment starting at the future intake is not available and has to be produced individually by means of a good topography. Again – Gaia GPS allows the measurement of the area.

Figure 16 - Border of catchment area on Gaia GPS (own graph on basis of Gaia GPS)

5.1.1 Size

It is obligatory to give numbers for the size in km^2, an estimation of the total length and the mean width of the catchment.

5.1.2 Max. and min. elevation

It is obligatory as well to give figures about the minimum elevation of the catchment which is given by the elevation of the water intake and the highest point of the catchment.

5.1.3 Gradient

Derived from the data given above it is possible to calculate the mean gradient of the catchment. Comparably the mean gradient of the entire river and the mean gradient of the exploited river reach can be given. The figure allow for a first estimation of the quality of the project.

5.1.4 Perimeter

Sometimes the perimeter is an interesting figure compared with the total size of the catchment. But this figure is not essential.

5.1.5 Gravelius index

Different geomorphologic indices can be used for the analysis of a watershed if its shape is taken into consideration. The most frequently used index is the Gravelius index KG, which is defined as the relation between the perimeter of the watershed and that of a circle having a surface equal to that of a watershed. The Gravelius index is a compactness index.

$KG = P/2*(\pi*A)^{0,5}$ = (approx.) $0,28 * P/A^{0,5}$

where:

KG	Gravelius's shape index
A	watershed area [km^2]
P	watershed perimeter [km]

Several values of the Gravelius's index for various shapes of watershed can be found in the following picture:

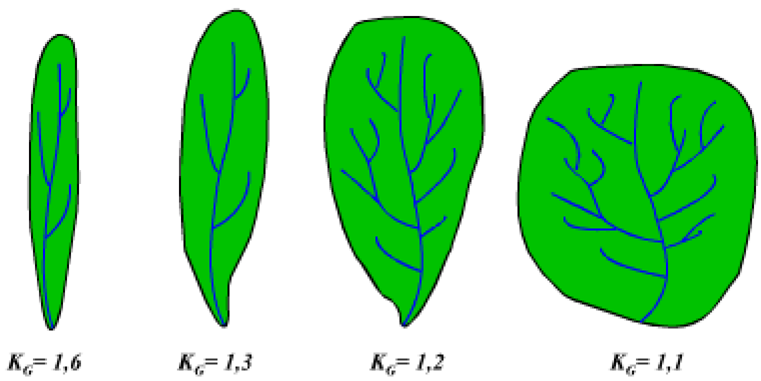

Figure 17 - Gravelius's index for various shapes of watershed (Musy, A. 1998)

This index allows for an estimation regarding flood events because the concentration time is closely related to it.

5.1.6 Geology

The geology was already addressed in chapter 4.3.2.5. Focussing on the individual river the geology impacts the bedload transport characteristic and further on the structural solution of the water intake. Additionally, the on-site river morphology will complete the picture.

5.1.7 Land use

To know about the land use at the areas impacted by construction works will significantly help to find the best design aiming at the minimisation of disturbance of the population.

5.1.8 Stream network

Information of the stream network relates to the river itself including contributors but neighbouring rivers as well as they may have strong similarities and probably flow data available.

5.2 Precipitation

Precipitation values are of course closely related to climate. It makes sense to give a regional overview containing the thermal regime Information can be found on climateknowledgeportal.worldbank.org . Precipitation maps usually can be found on national institutional sites like the example below – indicating the gauging stations as well.

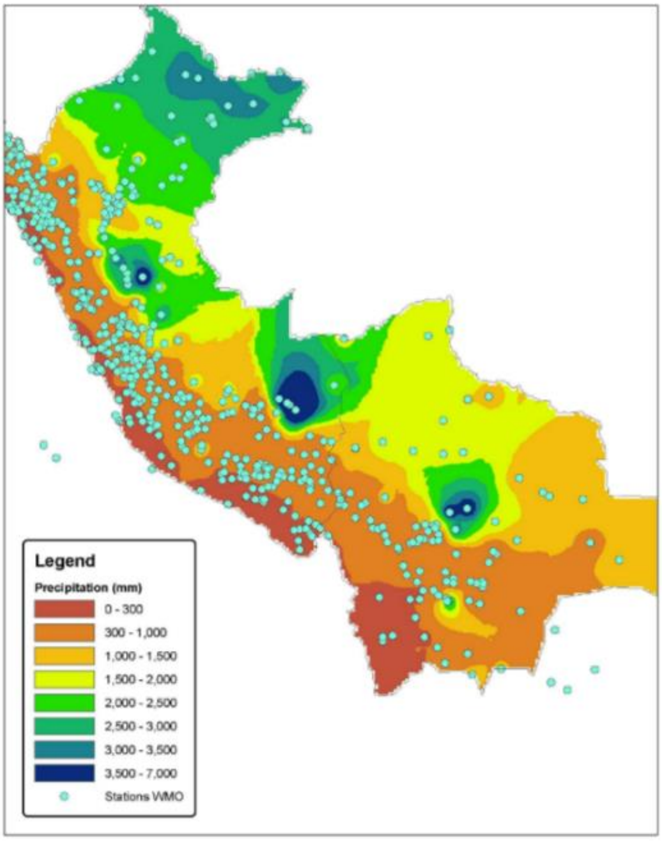

Figure 18 - Climate map of Peru (maps Peru, 2023)

5.2.1 Gauging stations

For the identification of weather stations providing rainfall data as well one can use RETSCREEN. The following example shows the data provided for the weather station in Quito.

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	13.8	77.3%	135.78	4.14	71.6	2.1	12.3	130	118
February	14.0	76.9%	149.80	4.35	71.6	2.0	12.4	112	112
March	13.9	77.4%	172.67	4.55	71.7	1.8	12.4	127	121
April	13.9	79.2%	196.50	4.33	71.7	1.8	12.2	123	117
May	14.0	77.0%	131.13	4.12	71.7	1.9	11.7	124	124
June	14.1	68.5%	69.90	4.02	71.7	2.4	10.8	117	123
July	13.9	62.8%	46.19	4.27	71.7	2.8	10.5	127	121
August	14.3	59.9%	40.30	4.46	71.7	3.0	10.8	115	133
September	13.9	68.3%	66.90	4.27	71.7	2.4	11.6	123	117
October	13.7	74.6%	96.72	4.24	71.7	2.0	12.2	133	115
November	13.6	76.5%	100.20	4.30	71.6	1.9	12.4	132	108
December	13.6	78.2%	108.50	3.98	71.6	2.0	12.3	136	112
Annual	**13.9**	**73.0%**	**1,314.59**	**4.25**	**71.7**	**2.2**	**11.8**	**1,500**	**1,420**
Source	Ground	Ground	NASA	NASA	NASA	Ground	NASA	Ground	Ground
Measured at					m	10	0		

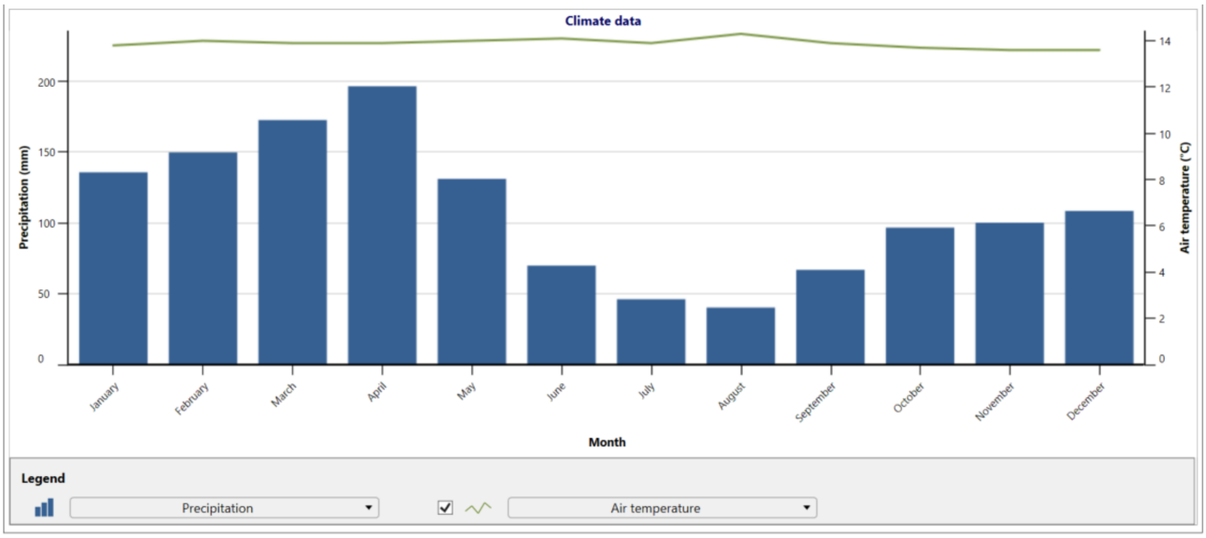

Figure 19 – Examples of values collected by a weather station in Ecuador (Government of Canada, 2023)

Of course, it must be recognised, that the values of the gauging station cannot directly be applied on the catchment of the project site. Several parameters have the be considered and it is recommended not only using one but several stations if available.

5.2.2 Calculation

In worst case – if no gauging station is available – a deeper research is necessary but usually exceeds the financial frame of a pre-feasibility study.

5.3 Rivers

If one or more gauging stations are available along the river to be exploited, it is not necessary to think about other rivers nearby with a similar characteristic. If this is not the case, it is helpful to check rivers around.

5.3.1 Gauging stations

Unfortunately, in most cases of small hydropower sites there are no gauging stations existing because the rivers are relatively small and the density of the official monitoring network is not sufficient. Even if there are gauging stations existing and in operation it is urgently recommended to examine carefully the installation and the cross section of the river in terms of suitability. The availability of even long time series data will not be any guarantee of quality and correctness. If there is time and budget available a control measurement should be made. Regarding small creeks it is possible to newly install simple gauging stations consisting of a level rod at a suitable cross section. Of course, several measurements have to be executed to create a stage-discharge curve.

Independent from the source the further on design process needs a hydrograph adjusted for the point of the intake and a flow duration curve. In both cases it is recommended to show all the years available in order to illustrate the variability.

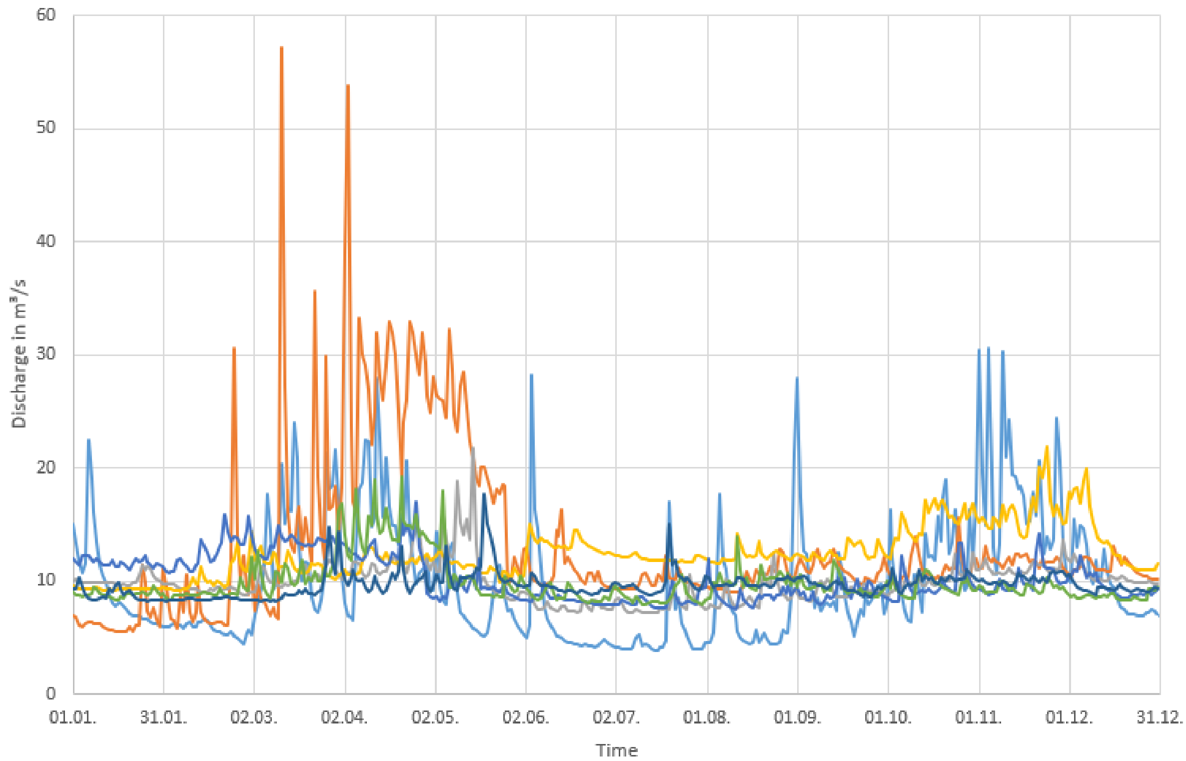

Figure 20: Hydrograph (own figure)

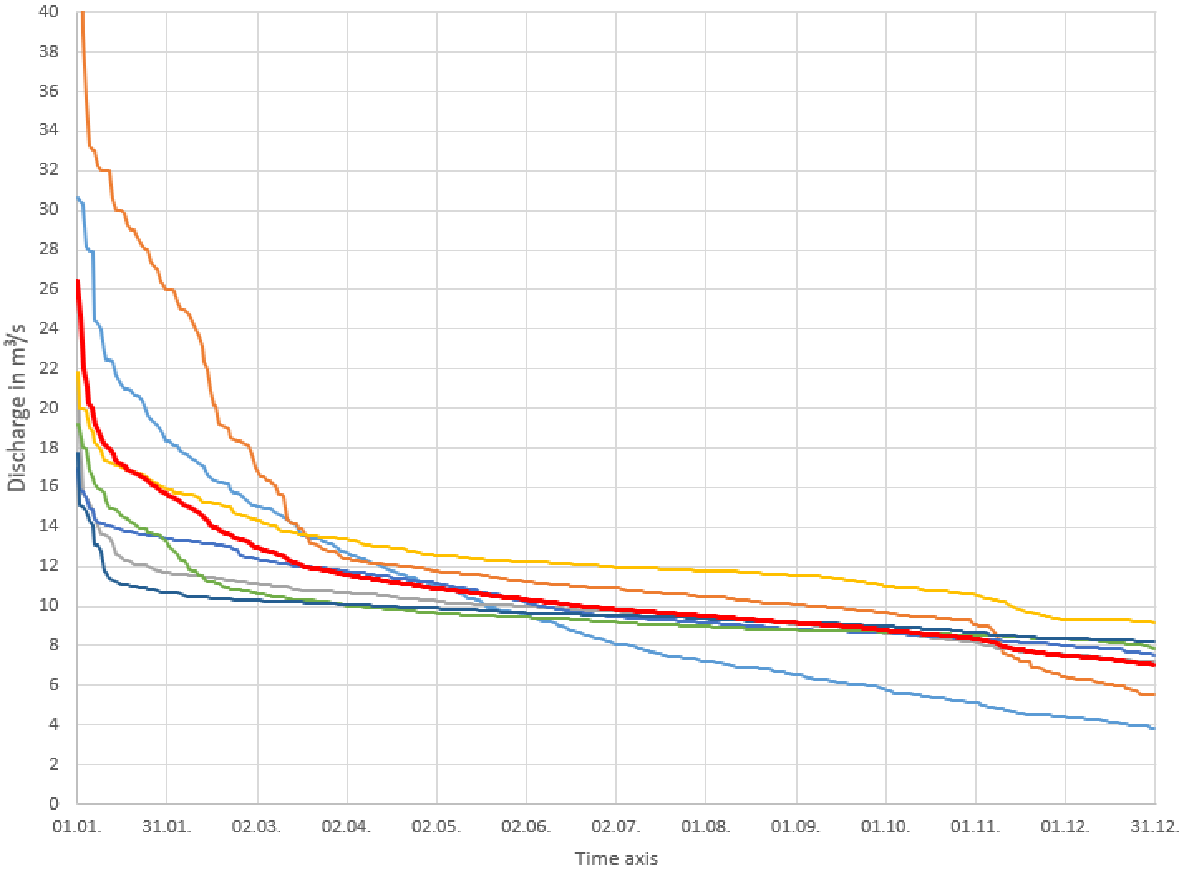

Figure 21 – Flow duration curve (own figure)

The red line is the mean flow duration curve, that can be used for further on calculation.

5.3.2 Discharge calculation

In case there is no data available for the respective river it will be necessary to find another data set as reference. The main criteria that should be considered is an acceptable similarity in

- size
- elevation
- land cover
- geology
- inclination and
- exposition

If these criteria can be met, an up- or downgrading of the values in relation to the size of the catchment is an acceptable strategy.

5.3.3 Runoff model

Usually the setup of a rainfall-runoff model will exceed the capacity within a pre-feasibility study. One must not forget that such a model needs very precise data of the catchment but precise rainfall data as well. The quality of the output data will be similar to the quality of the input data available.

6 Layout alternatives

The complexity and individuality of a hydropower plant is much higher than in any other renewable energy technology. A given situation along a river reach usually allows for several solutions – sometimes easy comparably in the overall quality of the project – sometimes very different. A certain decision depends not only on hydro-technical considerations but on very basic non-technical facts like landownership or ecological restrictions. All of them have to be treated equally and balanced. The final target is a sustainable, well-functioning and economical viable solution.

6.1 Setting of selection criteria

In order to identify the best alternative in a reproduceable way a set of selection criteria has been created. This catalogue is structured according to the main constructive elements of the plant.

In case of a diversion site the constructive elements are usually located far away from each other, facing very different conditions. Therefore, it was decided to evaluate the constructive elements individually.

Some criteria allow sort of numerical assessment – others need verbal description.

Due to the different character of the constructive elements the criteria applied are inhomogeneous to meet the individual demands best.

The evaluation process always compares several alternatives. That implies that the "Absolute value" is less important than the difference between alternatives indicating the "better" solution.

6.1.1 Weir

Access road

- Existing (%)
- Easy to build (%)
- Mean difficulties to build (%)
- Severe difficulties to build (%)
- Total length (m)

Function

- Reliability (%)
- Silt / sand/ gravel deposit (%)
- River dynamics considered (%)

Space available

- Weir
- Sand trap

Simplicity of civil works necessary

Geological conditions

Stable underground (%)
Unstable underground (%)
Unknown underground (%)

Land ownership

Public ownership (%)
Private ownership (%)

Safety risk

Natural hazard
Flood
Earthquake
Land slide
Vandalism (destruction, thievery)
Disturbance of function
Protecting measures necessary

Construction works necessary

Only core construction works
+20% additional construction works
+21 - 35% additional construction works
+36 - 50% additional construction works
>51% additional construction works

Maintenance

Low
Mean
High

6.1.2 Intake

Access road

Existing (%)
Easy to build (%)
Mean difficulties to build (%)
Severe difficulties to build (%)
Total length (m)

Function

Reliability (%)
Silt / sand/ gravel deposit (%)
River dynamics considered (%)

Space available

Weir
Sand trap

Simplicity of civil works necessary

Geological conditions

- Stable underground (%)
- Unstable underground (%)
- Unknown underground (%)

Land ownership

- Public ownership (%)
- Private ownership (%)

Safety risk

- Natural hazard
- Flood
- Earthquake
- Land slide
- Vandalism (destruction, thievery)
- Disturbance of function
- Protecting measures necessary

Construction works necessary

- Only core construction works
- +20% additional construction works
- +21 - 35% additional construction works
- +36 - 50% additional construction works
- >51% additional construction works

Maintenance

- Low
- Mean
- High

6.1.3 Trace of pipeline/channel

Access road

- Existing (%)
- Easy to build (%)
- Mean difficulties to build (%)
- Severe difficulties to build (%)
- Total length

Level of difficulty to build

- Low (%)
- Mean (%)
- High (%)

Geological conditions

- stable underground (%)
- unstable underground (%)
- unknown underground (%)

Land ownership
- Public ownership (%)
- One private owner (%)
- Few private owners (%)
- Many private owners (%)

Safety risk
- Natural hazard
- Flood
- Earthquake
- Land slide
- Vandalism (destruction, thievery)
- Disturbance of function
- Protecting measures necessary

Construction works necessary
- Only core construction works
- +20% additional construction works
- +21 - 35% additional construction works
- +36 - 50% additional construction works
- >51% additional construction works

Maintenance
- Low
- Mean
- High

6.1.4 Powerhouse

Access road
- Existing (%)
- Easy to build (%)
- Mean difficulties to build (%)
- Severe difficulties to build (%)
- Total length (m)

Simplicity of civil works necessary

Geological conditions
- Stable underground (%)
- Unstable underground (%)
- Unknown underground (%)

Distance to grid/transformer
- L < 300 m
- 300 m < L < 1500 m
- L > 1500 m

Land ownership

- Public ownership (%)
- Private ownership (%)

Safety risk

- Natural hazard
- Flood
- Earthquake
- Land slide
- Vandalism (destruction, thievery)
- Disturbance of function
- Protecting measures necessary

Construction works necessary

- Only core construction works
- +20% additional construction works
- +21 - 35% additional construction works
- +36 - 50% additional construction works
- >51% additional construction works

Maintenance

- Low
- Mean
- High

6.1.5 Optimisation of head / power

Usage of total head available

- >95%
- 75 – 95%
- 60 – 74%
- <60%

6.1.6 Maximisation of $H/L_{pipeline}$

- > 0,50
- 0,50 – 0,45
- 0,45 – 0,4
- 0,4 – 0,35
- 0,35 – 0,3
- < 0,3

6.1.7 Environmental and social impact

Reserved flow

- < 5% of MQ
- 5% - 10% of MQ
- 10% - 15% of MQ

15% - 20% of MQ
> 20% of MQ

Fish bypassing
necessary
not necessary
not yet decided

Backwater area
< 5 x width of the river
5 – 10 x width of the river
10 – 25 x width of the river
> 25 x width of the river

Water abstraction by local people
no
little
mean
high
not known

Fisheries by local people
no
little
mean
High
not known

Washing and leisure activities
no
little
mean
High
not known

6.2 Setting of alternatives

A given topographical situation allows in most cases more than only one solution. If only one solution seems to be available, one should return to the very start of considerations and review carefully again the decision chain. None of all imaginable solutions should be excluded to early and the best solution always appears when comparing all possible solutions.
Therefor the first step of evaluation is the setting of alternatives in the following topics:

- General system of the plant
- Position of the intake
- Kind and trace of water conveyance
- Position of the powerhouse
- Turbine equipment

6.3 Final layout

The alternatives found will individually be evaluated on the structure given in chapter 6.1. The final layout is the combination of the individually found solutions per topic.

7 Project description

The following chapter describes the decisions and consequences of the finally recommended options:

7.1 General layout

Aiming at an overview of the project one or more aerial pictures should be given showing the precise location of the intake, the trace of water conveyance and the precise location of the powerhouse.

Figure 22 – Location of some plant's component (Google Earth, 2023)

7.1.1 Rated head

The gross head is calculated by the elevation of the intake minus the elevation of the powerhouse. According to the experience approximately 3 – 5% of gross head are calculated as head loss. Accordingly, the net head or rated head can be found.

7.1.2 Rated flow

In the state of a pre-feasibility study the rated flow can be defined by defined approximately by the period of exceedance in the flow duration curve. Between 90 and 110 days will provide a quite traditional but economically viable approach, reflecting low flow periods. Of course, the amount of ecological flow will influence the respective decision.

7.1.3 System/type

The decision on the system will largely influence the construction works necessary but the type of operation as well. It may happen, that for certain reasons the decision is not "free". For example – a diversion of 100m³/s will practically not be possible due to topographical restrictions. Consequently, an in-river solution including some impoundment has to be taken.

7.1.4 Weir/dam

The weir (together with the water intake) is one of the most critical components of a hydropower concept. It is the point where the natural behaviour of the river and its discharge will be broken and the discharge will become "fuel" for the turbine. The construction works have to fully resist the enormous power during flood periods but in the same course minimise the ecological impact on the river and ensure the reliable separation of water from bedload and debris. Finally, the operation should not create continuous work like unsilting the backwater area.

7.1.5 Storage basin

Storage basin will significantly increase the value of the hydropower plant because the operation respectively production is not necessarily directly related to the recent flow conditions. On the other hand, a storage basin may cause significant ecological alteration. In case a storage basin is planned it is obligatory to calculate the storage volume and the flooded area depending on the impounded water level. A safely functioning spillway is mandatory for the dam, creating the storage basin.

7.1.6 Water intake / sand-trap

As already said at 7.1.4 the weir/intake section is crucial for the functioning of the entire plant. The prevention of solid material from the further on waterway has highest priority. Trash racks, sand traps, sills and flushing devices are essential. It should be mentioned that the flow necessary for flushing the sand trap can be used for ecological flow, minimising production loss.

7.1.7 Waterway

There are several options on how to conduct the water from the intake to the powerhouse – an open channel, a pipeline or a tunnel. Usually, it is a combination of several opportunities regarding the framework conditions. Several criteria like cost, space availability, simplicity of operation and maintenance will influence the decision. The waterway usually will consist of two or three different sections – in most cases due to different pressure conditions. The main task finally will be to find the best suitable solution and the best suitable material fitting precisely to the static and operational demands. Overqualification is costly without providing additional advantages.
In some cases, it will be necessary to deal with a spillway – getting into operation when a swift shut-down of the turbine is necessary.

7.1.8 Powerhouse incl. EM equipment

The heart of the powerhouse is for sure the turbine and its selection is not trivial. In many cases one has more than one type of turbine fitting into the situation and the decision on how many turbines should be installed may influence the type as well. As often in hydropower design the best solution is the result of an optimisation process aiming at a high production at reasonable cost. An important additional aspect is the disposability of the production – sometimes leading to a “two-turbine-solution”. Compared with production the maximum power is relatively irrelevant in run-of-river plants.
It must be mentioned that in high head plants the question of water hammer and how to manage it, has to be addressed imperatively.

7.1.9 Rated power

The rated power can be calculated by the rated head and the rated discharge including an overall efficiency. A precise calculation considering the individual efficiencies of all components does not make sense at this stage of engineering. In this chapter the relevant figures should be given:

- Rated head in m
- Rated flow in m^3/s
- Overall efficiency in % (recommendation: 80%)
- Rated power in MW

7.1.10 Estimated annual electricity generation

A precise calculation of the annual electricity generation does not make sense, because decisions are not yet taken finally. The purpose of calculating the annual output at least approximately is to finding out whether the project will be economically feasible or not.

Nevertheless, the calculation should be as precise as possible, meaning the use of the flow duration curve.

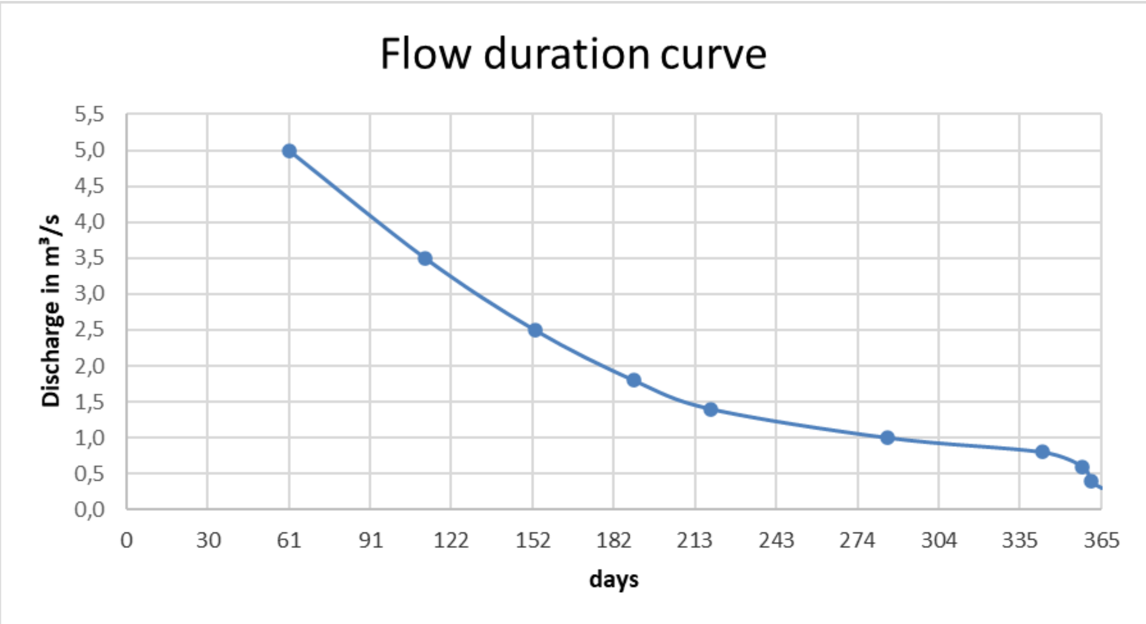

Figure 23 - Flow duration curve (own graph)

The simplified calculation is based on constant head, constant efficiency and year-round constant environmental flow. The following figure gives an example.

Hydro power plant						
Rated discharge		**3,50**	**m³/s**		**Year**	**average**
Rated head		**161,7**	**m**		η_{total}	**0,8**
environmental flow	Summer:	**0,30**	**m³/s**		**River**	
	Winter:	**0,30**	**m³/s**		**CF**	**0,50**
nat. discharge in m³/s	duration curve in days	usable discharge in m³/s	useable head in m	capacity in kW	duration in days	production in kWh
5,00	61	3,50	161,7	4442	61	6.502.467
3,50	112	3,20	161,7	4061	51	4.970.504
2,50	153	2,20	161,7	2792	41	2.747.178
1,80	190	1,50	161,7	1904	37	1.690.337
1,40	219	1,10	161,7	1396	29	971.563
1,00	285	0,70	161,7	888	66	1.407.091
0,80	343	0,50	161,7	635	58	883.239
0,60	358	0,30	161,7	381	15	137.054
0,40	361	0,10	161,7	127	3	9.137
0,30	365	0,00	161,7	0	4	0
			Annual production in kWh/year			**19.318.570**

Figure 24 - Estimation of the annual energy production (own table)

Attention should be paid on the capacity factor (CF), calculated by the formula:
CF = Annual production / (8760 x rated power)
In different countries the approach, which value should be achieved is quite different. Generally, a value around 0,5 indicates an optimised solution in the field of small hydropower. The CF of large hydropower is significantly lower at around 0,4.

7.1.11 Connection to the grid

The potential investment related to the grid connection varies extremely dependent on the continent, the country and the region. Individual important and additional criteria are the maximum capacity of the plant and the voltage of the line. In many cases overseas it is necessary to build evacuation lines with a length of around 10 km and more, representing a significant cost factor. In the pre-feasibility phase attention should be paid to existing mean or even low voltage lines and to existing sub-stations. In any case the cost for the lines have to be included in the cost estimation. Grid operators in some countries are obliged by law to contribute to the cost. In other cases, the line has to be built by the site owner and the grid operator takes it over after completion.

7.1.12 Isolated grid

Especially in rural areas the question of an isolated grid is evident if the distance to the existing grid is too long and local demand equals roughly the estimated production. The design of the plant will be quite different regarding the CF and storage options should be considered. The design will be directed by the recent and future electricity demand instead of optimising the exploitation of the available resource.

7.1.13 Access facilities

A small hydropower plant is usually not located at one single point but stretches sometimes on

several km. Of course, the intake and the powerhouse and eventually an intake basin are single points but a pipeline or an open channel create different challenges.
Similar to evacuation lines the access facilities may become crucial for the project. Consequently, it is recommended to consider existing roads in a very first stage of design as it is the pre-feasibility study.

7.2 Costs estimation

It is highly recommended to arrange the costs estimation with the support of local partners, who can supply the unit costs, which are typically site-specific.
The prices mentioned within this chapter should indicate the date of the offer if there are any. Even the exchange rate between the currency of the offer and the local currency should be referred.

7.2.1 Construction quantities and costs estimate

The construction costs were calculated using the bill of quantity of the most relevant categories of work, such as: excavations, demolition of rock, concrete, reinforcement bars, access roads; bearing in mind that they usually constitute 90 % of the total cost.
Regarding the unit price of these categories of work, local partners should be asked to provide the correct values, in relation to the specificity of the construction sites in their country.
The costs of the penstock were divided between civil works and the supply and installation of the pipeline. Civil costs have been estimated by increasing by 150 % the basic costs (excavations, rock demolitions, reinforced concrete) considering the greater difficulty of the works along the pipeline.
For the same reason, the basic costs at the intake and the powerhouse areas have been increased of 10% taking into consideration that the access to them is quite easy.
The cost of the pipeline, including installation, were taken from specific offers of European suppliers or from internal databases, considering the pre-sizing of diameters and thicknesses congruent with the rated flow and maximum pressures, including water hammer.
The shipment of the pipes will be managed by means of nesting to lower the number of containers and consequently the transportation costs. Therefore, the pipes will have different diameters.
The main electromechanical costs, i.e. generation units, electrical panels and others, come from specific offers of renowned European manufacturers, while for other lower value equipment, such as gates, valves, overhead cranes and the like, the internal database has been used.
The costs of equipment from Europe have been increased appropriately to consider transport costs and import taxes, according to the information received by the local partners.
Generally, it must be underlined that the main uncertainty related to the construction costs comes from tunnels, the amount of which represents the lion’s part (65 - 75%) of the total construction cost.

Therefore, very detailed topographic and geological surveys are needed before finalizing the construction design, also considering the selection of suitable storage areas for the huge amount of materials coming from the tunnel excavation.
Hereunder a template of the costs estimations is shown, referring to the main parts of the scheme.

Scheme part	Component	Item	Cost (€)	Total cost (€)
Intake	Diversion structure	Civil works		
		EM Supplies		
	Desilting	Civil works		
		EM Supplies		
Intake cost				0
Conveying Structure	Tunnels	Civil works		
	Forebay	Civil works		
	Gates / Valves	EM Supplies		
Conveying structure cost				0
Penstock	Excavation / supporting structures	Civil works		
	Pipe supply and erection	Civil works		
	valves, overspeed protection	EM Supplies		
Penstock cost				0
Powerhouse	Building	Civil works		
	Generation unit and cubicles	EM Supplies		
Powerhouse cost				0
Grid connection cost	Lines and protection devices	Civil works & EM supplies		
	sub-station	Civil works & EM supplies		
Grid connection cost				0
CONSTRUCTION COST				**0**

Figure 25 - Cost estimations (own table)

7.2.2 Indirect costs

In the following table the main indirect costs are listed, and, finally, the total investment needed, as a rough assessment related to the preliminary stage of the project.

Scheme part	Component	Item	Cost (€)	Total cost (€)
Indirect cost	Design and suprevision	7% of construction cost		
	Land acquisition			
	Authorization procedures			
	Administration and office			
INDIRECT COST				**0**
Construction cost				
Indirect cost				
Total cost				**0**
Contingencies	10% of total cost			**0**
TOTAL INVESTMENT				**0**

Figure 26 - Indirect costs (own table)

7.2.3 O&M costs estimate

The operation and maintenance costs can be estimated as follow.

Annual operation cost			
Description	**Unit**	**Unit rate / month (€)**	**Annual cost (€)**
Watchmen HE plant (2x3 (8h)			
Maintenance of tools, stock and consumables			
Maintenance of cars and motorcycles			
Administrator			
Electric technicians			
Water and other fees			
Insurances			
Total			**0**

Annual maintenance cost			
Description	**CapEx**	**annual %**	**Annual cost (€)**
Civil construction			
EM equipment and MV lines			
Total	**0**		**0**

Figure 27 - O&M cost estimates (own table)

8 Feasibility check and risk analysis

8.1 Feasibility check

Sustainability is an attempt to provide the best outcomes for the human and natural environments both now and into the indefinite future. It relates to the continuity of economic, social, institutional and environmental aspects of human society, as well as the non-human environment. It is intended to be a means of configuring civilization and human activity so that society , its members and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals in a very long term. Sustainability affects every level of organization, from the local neighbourhood to the entire planet.
A very short but excellent definition was given in the "Brundtland Report" 1987 saying:
"A sustainable development meets the needs of the present generation without compromising the ability of future generations to meet their own needs".
A feasibility check, carefully elaborated is an unavoidable part of a pre-feasibility study, uncovering critical items in a very early stage of planning. The following chapters give more precise explanations on the topics to be addressed. Of course – on a pre-feasibility level several topics cannot be answered deeply.

Feasibility check								
Project:		Example						
	Description	**easy**	**doable**	**mean**	**complex**	**difficult**	**Justification of the evaluation**
Legal feasibility	Permissions necessary						
	Land ownership						
	Import /export						
Technical feasibility	Accessibility						
	Geological stability						
	Special constructions						
	Grid connection						
Financial feasibility	Investor availability						
	Loans						
	Financing model						
Environmental feasibility	Protected areas						
	Environmental impact (+,-)						
	Mitigation measures						
Political feasibility	Stakeholder opinion						
	Financial support (FIT)						
	Cultural and social considerations						
Organisational feasibility	Project ownership						
	Project management						
	Maintenance						
Resources related feasibility	Manpower						
	Construction material						
	Equipment and machinery						
Socio-Economic feasibility	Local population opinion						
	Added value						
	Workplace						

Figure 28 - Feasibility table (own table)

8.2 Risk analysis

Risk Identification and Risk Allocation

Project:

		Risk Identification					Risk allocation			
	Description	**Small**	**Medium**	**High**	**Justification of the evaluation**	**Mitigation measures**	**Project company**	**Insurance company**	**Other contractors**	**Host Government**
Political risks	Political support risk									
	Expropriation /nationalization risk									
	Forced buy-out risk									
	Cancellation of concession									
	Import/export restrictions									
	Failure to obtain / renew permits									
Country commercial risks	Currency inconvertibility risk									
	Foreign currency exchange risk									
	Devaluation risk									
	Inflation risk									
	Interest rate risk									
Country legal risks	Changes in laws and regulations									
	Law enforcement risk									
	Taxation risk									
	Land acquisition risk									
Project development risks	Bidding risk									
	Design risks									
	Planning delay risk									
	Approval risk (permits)									
	Connection point risk									
Construction/ completion risks	Delay risk									
	Cost overrun risk									
	Completion risk									
	Force majeure risk									
	Loss or damage to work									
	Liability risk									
	Performance risk									
Operating risks	Associated infrastructure risk									
	Technical risk / breakdowns									
	Electricity off-take risk									
	Tariff risk									
	Hydrological risk									
	Water abstraction risk									
	Maintenance cost escalation risk									
	Management risk									
	Force majeure risk									
	Loss or damage of project facilities									
	Liability risk									

Figure 29 - Risk analysis (own table)

9 Conclusions and recommendations

This final chapter of any pre-feasibility study is of highest importance because it uncovers open questions and indicates the way forward. For sure the recommendations will always be site specific and individual but the following structure will ease the final check, avoid missing probably important topics and provide valuable information to the site representative.

9.1 Hydrology

Definitely not by chance the first topic is dedicated to the hydrology. In most cases the data available were not sufficient and fully reliable. This fact leads to the recommendation to perform control measurements at different stages. It is not understandable that huge money is invested in hydropower plants and nobody cares seriously about the availability and reliability of hydrological data. Without high quality data the design of hydropower plants will remain sort of gambling for high stakes.

9.2 Topography

In a pre-feasibility stage of a project it is unusual to have a full topography available. That compels the usage of unspecific topographic information as mentioned in the report. The comparison of different sources sometimes shows inconsistencies, that should be mentioned expressively in the report. Any further step in the design procedure needs a detailed geodetical survey of the entire intake area, eventually the tunnel portals, the intake basin, the trace of the pipeline/penstock and the powerhouse area.

9.3 Geology / Underground

In most cases the geological information available is suitable for a first evaluation on the pre-feasibility level. Further on a precise exploration / investigation of critical areas like the portal of the tunnel, the trace of the channel / pipeline and the trace of the tunnel is necessary. Even the more precise investigation of the position of the powerhouse could be necessary.
In case of larger storage basins, a precis survey of the position of the dam but the backwater area as well is strongly recommended.

9.4 Environment

The mayor environmental topics related to river ecology to be addressed are:

- Backwater areas (in case of damming up), the fish population should be investigated more in detail in order to evaluate the future impact, the recent use of flooded areas has to be examined
- Environmental flow (in case of diversion),
- Fish bypassing at weir sites depending on the fish species (to be examined more in detail)

It is possible to perform basic and preparatory work on these topics even at the pre-feasibility state.

9.5 Social aspects

The implementation of a hydropower plant will impact local population manifold:

- Creation of work places during construction
- Improvement of infrastructure (roads, bridges, electrical lines
- Better connection to the public grid
- Few work places during operation (maintenance)
- Creation of new secondary work places (i.e., in tourism)

9.6 Other water use

Most of the rivers to be exploited serve local people for different functions like:

- Irrigation water supply
- Cloth washing
- Fisheries and/or fish farming
- Leisure
- etc.

These functions have to mentioned in the pre-feasibility-study but have to be investigated deeper in the further on design steps. The future hydropower plant should ease the identified functions or provide the related infrastructure although not directly necessary for the function of the hydropower plant.

9.7 Construction

Any construction works needs the close interaction with the local population. It is recommended to include them in an early stage to create some identification with the project. During construction period, machines are on site. This could be a big chance to help local people in their activities. Such extraordinary work will put very little load on the total budget but very big help to the locals.

Especially in in the case of tunnelling, lot of material will be available. The deposition somewhere is the most simple but poorest solution. The usage of the material for road construction or any other purpose is for sure the better solution and therefor recommended.

9.8 Operation

During operation of a hydropower plant sometimes there occur "hidden dangers" like the start-up of a spillway in case of an emergency stop of the turbine. The spillway has to be secured to avoid accidents.

The flushing of backwater areas can be organised and prepared. A security concept and adequate warning systems have to be prepared and discussed with local population

Electrical evacuation lines may be destroyed by extreme weather conditions. Adequate information of the population is recommended.

9.9 Access

During the construction of the weir, the intake and a pipeline existing road will be used intensively for material transport. Some arrangements must be made to maintain the use of such roads especially in the tourist season.

In case of using existing bridges along the road, it is recommended to control the load-bearing capacity.

10 Annexes

10.1 Photographic report

To complete a pre-feasibility, study the inclusion of a photographic report is obligatory, illustrating the items addressed in the report.

10.2 Drawings

On the one hand, the study does not have to contain exact execution drawings. On the other hand, a reliable cost estimation – as well being part of the study - needs quantities and the calculation of these quantities need a quite detailed design. Consequently - seen from the authors point of view – at least a preliminary design of all parts of the plant has to be done.
The drawings that should be included are:

- General plan view on basis of a topographic map
- Plan view and cross section of constructive elements at the intake (weir, sand trap…)
- Longitudinal section and cross sections of the water conveyance (tunnel, pipeline, intake basin)
- Plan view and cross section of the powerhouse

References

ArcGIS, 2023: WDPA (World Database on Protected Areas). [Online] Available: https://www.arcgis.com/apps/mapviewer/index.html?layers=ae78aeb913a343d69e950b53e29076f7 [14.06.2023].

City Population, 2023_a: Tungurahua. [Online] Available: https://www.citypopulation.de/en/ecuador/parish/admin/18__tungurahua/ [14.06.2023].

City Population, 2023_b: RWANDA: Division in Sectors. [Online] Available: https://www.citypopulation.de/en/rwanda/sector/admin/ [14.06.2023].

Climate Justice Jean Monnet centre of Excellence, 2023: Land Use & Cover Ecuador 2018. [Online] Available: https://research.climate-justice.earth/layers/unburnable:unburnable:Cobertura%20de%20la%20tierra%202018 [14.06.2023].

Gaia GPS, 2023: Longitudinal profile from Gaia GPS. [Online] Available: https://www.gaiagps.com/ [14.06.2023].

Google Earth, 2023: Google CNES / Airbus Maxar Technologies. [Online] Available: https://www.google.at/earth [14.06.2023].

Government of Canada, 2023: RETScreen. [Online] Available: https://natural-resources.canada.ca/maps-tools-and-publications/tools/modelling-tools/retscreen/7465 [14.06.2023].

Mapcarta, 2023: Die offene Karte. [Online] Available: Mapcarta - Die offene Karte [14.06.2023].

maps Peru, 2023: Peru climate map. [Online] Available: https://maps-peru.com/peru-climate-map [14.06.2023].

Ministry of Water and Environment, 2017: Consolidated Hydrological Yearbook for Uganda 1978-2014, p. 58. [Online] Available: https://www.mwe.go.ug/sites/default/files/library/Consolidated%20Hydrological%20YearBook%201978-2014%20for%20Uganda.pdf [14.06.2023].

Musy, A. 1998. Hydrologie appliquée, Cours polycopié d'hydrologie générale, Lausanne, Suisse

Plan Nacional de Geología, 2023: Geología Regional. [Online] Available: https://plannacionalgeologia.sernageomin.cl/geologia-regional/ [19.06.2023].

Vetmeduni, 2023: World Maps of Köppen-Geiger Climate Classification. [Online] Available: https://koeppen-geiger.vu-wien.ac.at/ [14.06.2023].

WDPA, 2023: WDPA - World Database of Protected Areas. [Online] Available: https://www.arcgis.com/home/item.html?id=ae78aeb913a343d69e950b53e29076f7 [14.06.2023].

ThinkHazard, 2023: Santiago Del Estero. [Online] Available: https://thinkhazard.org/en/report/450-argentina-santiago-del-estero/EQ [14.06.2023].

UNIDO, 2016: The World Small Hydropower Development Report 2016: p 137. United Nations Industrial Development Organization, Vienna, and International Center on Small Hydro Power, Hangzhou. [Online] Available: https://www.unido.org/sites/default/files/files/2020-08/WSHPDR_2016_final_report.pdf [14.06.2023].

United Nations, 2017: Nepal: Administrative Unit Map. [online] Available: https://un.org.np/map/nepal-administrative-unit-map [14.06.2023].