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Impact evaluation and economic feasibility of a new auto-cleaning intake screen for small hydroelectric plants

TESI DI LAUREA MAGISTRALE IN
GREEN POWER SYSTEM ENGINEERING
INGEGNERIA ENERGETICA

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Abstract

The following Master Thesis deals about the analysis of three ***hydropower plants*** owned and managed by Iniziative Bresciane spa and about the potential application of a ***new concept*** of ***auto-cleaning water intake*** with the evaluation of the economic benefits given by the introduction of the new component in an existing power plant.

The plants are analyzed in a ***holistic approach***: from a ***technical*** point of view, highlighting the major characteristics and peculiarity and computing the water availability, to a ***regulation and legislative*** point of view, explaining the most important step in the authorization procedure, to an ***economic and financial*** perspective, using the unlevered Discounted Cash Flow evaluation method in order to compute the economic & financial performance and evaluate the profitability.

The potential application of a new auto-cleaning water intake is presented, highlighting the ***technical specification*** and the working principle of the device, and computing the actual ***economic and financial benefit*** of the introduction of the new self-cleaning water intake in an existing power plant, one of the previously analyzed. The benefits are related to the reduction in the maintenance costs and in an increase in the electricity production, thus to a better performance of the plant.

The data and information used in this Master Thesis come from the contribution of ***Iniziative Bresciane spa***, where I took an internship of three months, and from the company ***Hydrosmart srl***, involved in the development of the new auto-cleaning water intake.
My heartfelt thanks go to both the Company and the Professor, ***Nicola Fergnani*** also the Advisor of this Master Thesis.

Key-words: small hydropower plants; new water intake; economic & financial analysis; Iniziative Bresciane spa.

Abstract in italiano

La seguente Tesi Magistrale tratta dell'analisi di tre centrali idroelettriche possedute e gestite da Iniziative Bresciane spa e della potenziale applicazione di un nuovo sgrigliatore rotante autopulente applicato ad un'esistente opera di presa con la valutazione dei benefici economici derivanti dal suo utilizzo in un impianto esistente.

Gli impianti sono analizzati in un ***approccio olistico***: da un punto di vista ***tecnico***, evidenziandone le principali caratteristiche e peculiarità, calcolando la disponibilità idrica; da un punto di vista ***normativo*** e ***legislativo***, spiegando le fasi più rilevanti dell'iter autorizzativo; da un punto di vista ***economico e finanziario***, utilizzando il metodo di valutazione unlevered Discounted Cash Flow al fine di valutare le performance economico finanziarie e valutarne la redditività.

Viene presentata la potenziale applicazione di una nuovo sgrigliatore rotante autopulente, evidenziando le specifiche tecniche e il principio di funzionamento del dispositivo, calcolando l'effettivo beneficio economico e finanziario dell'introduzione della nuova opera di presa autopulente in un'impianto idroelettrico esistente , uno dei precedenti analizzati. I benefici sono legati alla riduzione dei costi di manutenzione e ad un aumento della produzione di energia elettrica, quindi ad un miglior profittabilità dell'impianto.

I dati e le informazioni utilizzati in questa tesi di laurea magistrale provengono dal contributo di ***Iniziative Bresciane spa***, dove ho svolto uno stage di tre mesi, e dall'azienda ***Hydrosmart srl***, che ha sviluppato il nuovo sgrigliatore autopulente.
I miei più sentiti ringraziamenti vanno sia alla Società che al Professore ***Nicola Fergnani,*** quest'ultimo anche Relatore di questa Tesi di Laurea Magistrale.

Parole chiave: mini-idroelettrico; nuovo sgrigliatore autopulente; analisi economico finanziaria; Iniziative Bresciane spa

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Introduction

The objectives of this Master's Thesis are on one hand to analyze three hydroelectric plants owned and managed by Iniziative Bresciane spa in a complete way, considering both the technical and economic-financial aspects. On the other hand, to evaluate a potential application of a new self-cleaning water intake in an existing power plant, quantifying the economic advantages derived from the installation of the new device.

In detail, after an overview of the hydroelectric sector both internationally and nationally, the operation and the main components of hydroelectric technology and mainly of mini and medium hydroelectricity are described. Particular attention is given to the classification of hydroelectric plants based on various parameters: filling rate, hydraulic head, nominal power, energy storage capacity, intake-discharge position.

In the first chapter, in addition to the above-mentioned topics, the company Iniziative Bresciane spa is presented, highlighting its characteristics, the business model and the owned plants. INBRE allowed the writing of this Thesis, thanks to the data of its own power plants.

Regulation and legislation are important aspects to be considered in all power plants, but in particular in hydroelectricity since the use of a sensitive resource, such as water, implies greater attention from public entities and regulatory authorities. The second chapter analyzes and presents the current legislation both at national and regional level, with particular attention to the Lombardy region, as regards: the concessions procedure for hydroelectric water use, the authorization to buildt the plant, the legislation on the incentive framework, environmental legislation and regulations.

As regards the third chapter, three different hydroelectric plants selected from the plant portfolio of Iniziative Bresciane spa are presented and analyzed. For each plant, the design solutions are analyzed and commented, the assessment of the availability of exploitable water resources is presented and the economic-financial performance is performed using the Discounted Cash Flow unlevered assessment method.

Furthermore, for each plant, attention is focused to specific characteristics of the plant itself: the authorization process and Project Financing for the former; the analytical quantification of the Minimum Vital Outflow for the second; the level and flow measurement system in the third plant.

The fourth chapter, after presenting a new type of self-cleaning water intake for mountain basins, studies the potential application in one of the plants analyzed in the previous chapter, quantifies the expected economic benefit in terms of increased electricity production, reduced O&M costs and impact over discounted cash flow of the plant. The authorization procedure related to the replacement of the water intake structure is also described.

1 Hydroeletricity and Iniziative Bresciane spa

A Hydroelectric power plant convert the potential energy of the water into electric energy. The water from a higher elevation can flow to a lower elevation position, gaining a kinetic head or pressure head that is converted by the hydraulic turbine into mechanical energy. This mechanical energy is transformed in electric energy thanks to a generator, after being elevated in tension into MT (tens of kV) or HT (hundreds of kV) with a transformer is injected into the grid.

The hydro power plants have characteristics that are very site-specific and can vary a lot from place to place. In general terms all the power plants have a structure able to capture the available water flow from a river, or generally from a water body: this structure can be a dam, a weir or a simple water intake without a barrage. The water derived from the river can pass in a short channel and go throw the turbine directly or flowing in longer path passing throw a diversion channel, a forebay, a penstock and at the end throw the turbine. The water after leaving its energy to the turbine, thanks to a tailrace channel is discharged downstream into his original river. The electric energy's voltage instead thanks to an electrical transformer is elevated in tension to higher voltage in order to minimize losses and to permit the injection in the grid.

The hydroelectric energy is classified as renewable source, except the share from pumping storage hydro plants. The hydroelectric technology has numerous and big advantages in comparison with other renewable technologies, like solar and wind: high level of reliability and availability, high efficiency, low O&M cost (operation and maintenance cost), great flexibility and dispatchability, higher quality of the electric energy produced, possibility of storage.

In the Pumping Storage Hydro plants (also PSH) is possible to reverse the flow of the water, using an electromechanical system of pump-generator-turbine in order to lift up a mass of water from a lower basin to an upper basin. The system can store big amount of energy when there is an excess on the grid (low price) and release power when more electricity is needed by the grid (high price).

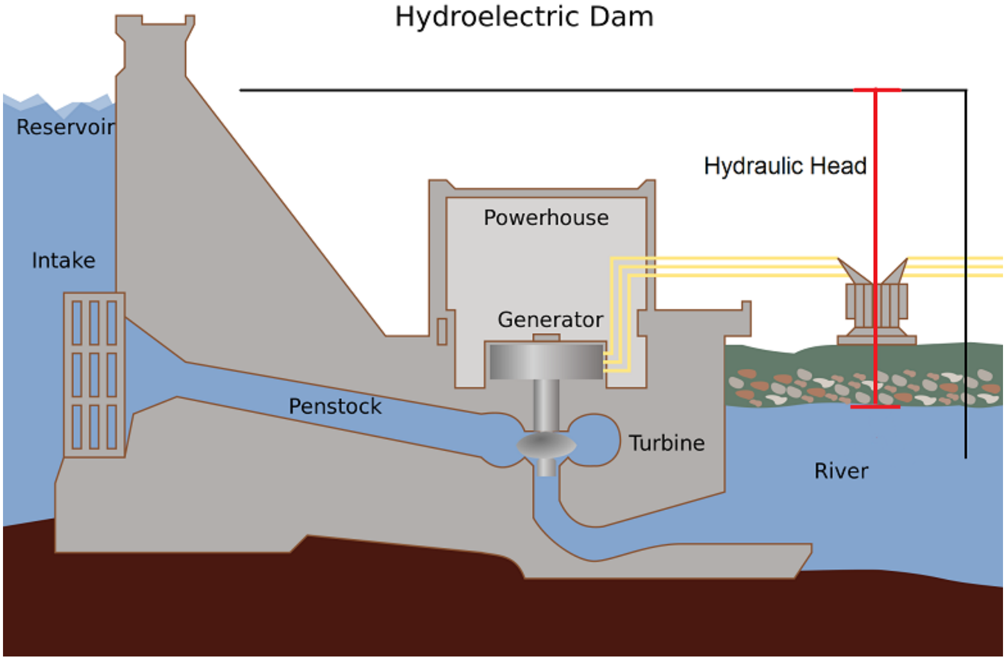

Figure 1.1: Diagram of a hydroelectric plant.

More in detail some specific quantity of a general hydroelectric power plant are reported in the following:

- **Gross Head (H_g):**
  defined as the difference between the upper level of the water and the lower level when water is not flowing;

- **Head losses (H_L):**
  loss of available head caused by the friction of the water in the plant, there are distributed heat losses ($H_{L,d}$) and concentrated head losses ($H_{L,c}$). Distributed head losses in cyclindrical pipes are computed using the Darcy-Weisbach equation (1.1), while the concentrated are computed using the equation (1.5);

- **Net Head (H_n):**
  defined as the gross head minus the head losses and the kinetic energy discharged at the outlet. Is the head available at the inlet of the turbine, also "effective head". Can be computer as in the equation (1.3);

- **Available flow (Q):**
  is the actual flow of the river that can be exploited;

- **Nominal flow (Q_{nom}):**
  is the flow effectively used by the power plant at its full capacity. It is used in order to size the turbine and the generator;

- **Average flow (Q_{avg}):**
  is average flow that is running on the river.

- **Ideal Power (P_{ideal}):**
  indicates the maximum theoretical limit of power. It can be computer as in the equation (1.4);

- **Nominal Power (P_{nom}):**
  is the power that give the size of the plant. It can be computed as in the equation (1.5);

$$H_{L,d} = \lambda \frac{L}{D} \frac{v_i^2}{2g} \tag{1.1}$$

$$H_{L,c} = K_i \frac{v_i^2}{2g} \tag{1.2}$$

$$H_n = H_g - H_L - \frac{v_{out}^2}{2g} \tag{1.3}$$

$$P_{ideal} = H_g Q\, g \rho \tag{1.4}$$

$$P_{nom} = H_n Q_{nom}\, g\, \rho\, \eta_{tot} \tag{1.5}$$

Where

λ	distributed friction factor	[-]
L	length of the penstock pipe	[m]
D	diameter of the penstock pipe	[m]
v_i	i-th velocity of the flow	[m/s]
G	gravity acceleration	[m/s^2]
K_i	concentrated friction factor	[-]
v_{out}	velocity at the outlet of the plant	[m/s]
ρ	water density	[kg/m^3]
η_{tot}	efficiency of the plant	[-]

Three very good parameters that indicate the productive performances of a plant and can be useful to compare different plant are: **equivalents hours** (1.6), **capacity factor** (1.7), **LCOE** (1.8):

- The parameter **Equivalents Hours**: indicates how many fictitious hours the plant run at its full potential in the whole year. It is the ratio between the total energy produced in the year and the nominal power. Can be computed as in the equation (1.6);
- The **Capacity Factor** or **Load Factor**: indicates the percentage of utilization of the plant during the year, it is the ratio between the equivalents hours and the total number of hours in the year equal to 8760. It can be computed as in the equation (1.7);
- The **Levelized Cost Of Electricity** (**LCOE**): indicates the cost of producing electricity during the lifetime considering all the costs, is the cost at which the electric energy can be sold in order to have a final NPV (Net Present Value) equal to zero. It can be computed as in the equation (1.8).

$$h_{eq}\left[\frac{h}{y}\right] = \frac{E_{tot}}{P_{nom}} \tag{1.6}$$

$$LF\ [-] = \frac{h_{eq}}{8760} \tag{1.7}$$

$$LCOE\ \left[\frac{€}{MWh}\right] = \sum_{j=0}^{lifetime} \frac{(CAPEX + OPEX)_j}{(E_{tot})_j} \tag{1.8}$$

Where:

E_{tot}	Annual energy produced	[kWh]
P_{nom}	Nominal power	[kW]
CAPEX	Capital expenditures, investments cost	[€]
OPEX	Operative expenditures: O&M costs, insurances, fees	[€]

The equivalents hours can vary a lot considering different renewable energy sources. Hydroelectric power plants generally have roughly 2000-2200 equivalents hours per year, with a variability from year to year due to the weather and availability of the water.
In the year 2019 the geothermal power plants has 7,471 equivalents hours (Capacity factor of 85%), the biomass power plants have 4,728 h_{eq} (CF of 54%), the hydro power plants has 2,443 h_{eq} (CF of 28%), the wind power plants has 1,928 h_{eq} (CF of 22%), solar power plants has 1,164 h_{eq} (CF of 13%). [1]

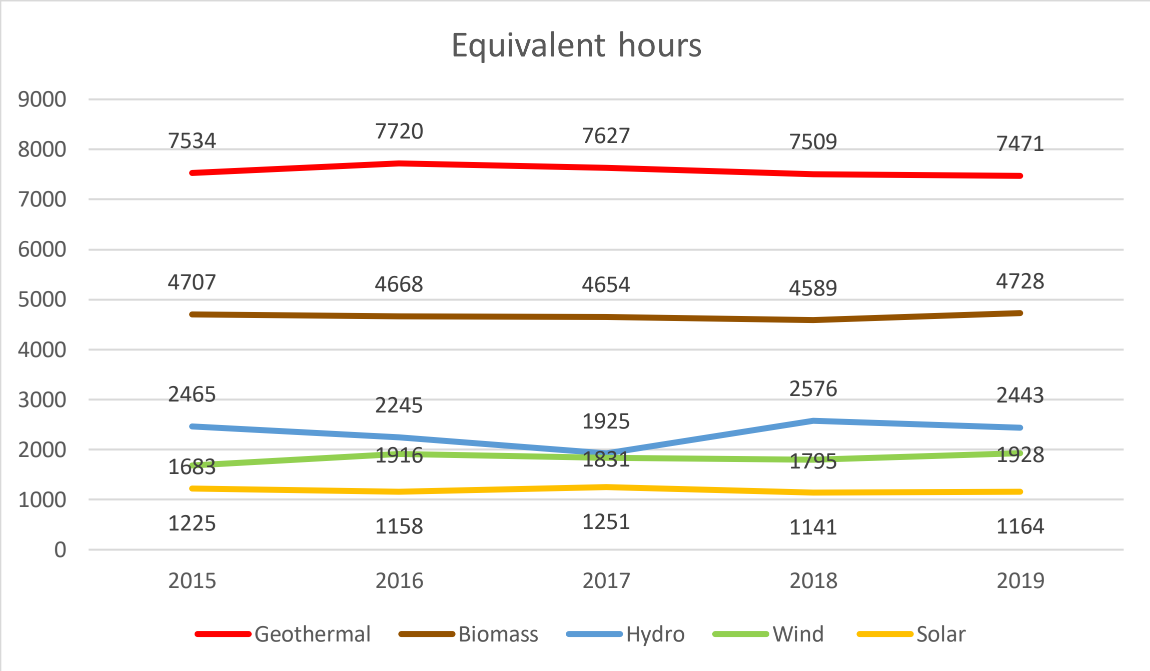

Figure 1.2: Equivalents hours of different renewable energy sources, data from GSE [1]

Considering the hydro energy source, the weather represents a major factor in the variability of the electricity generation, this fact lead to a difficult comparison between the production of different years. The European Directive 2009/28/CE gives a normalization equation (1.9) in order to mitigate the effect of variability of the climate in the calculation of the electric energy produced at national level. The production is normalized in function of the production observed and capacity installed in the last 15 years, distinguishing between natural contribution plants and pumping power station.

$$E_{norm} = C_N^{AP} \frac{\left[\sum_{i=N-14}^{N} \frac{Q_i^{AP}}{C_i^{AP}}\right]}{15} + C_N^{PM} \frac{\left[\sum_{i=N-14}^{N} \frac{Q_i^{PM}}{C_i^{PM}}\right]}{15} \quad [\text{GWh}] \tag{1.9}$$

Where:

N	Year of reference	
E_{norm}	Normalized electricity of the year N in the nation	[GWh]
C_i	Total installed power	[MW]
Q_i	Total electricity produced excluding the share of water previously pumped	[GWh]
AP	Natural contributions	[-]
PM	Mixed pumped storage contributions	[-]

1.1. Hydroelectricity in the World

Today the hydroelectric energy is the major source of renewable electric energy at global scale. It is the third largest energy source in the world electricity generation after coal and natural gas. In the year 2019 this sector made roughly the 61% of the renewable electric energy produced in the world and the 16% of the total electricity production in the globe. [2]

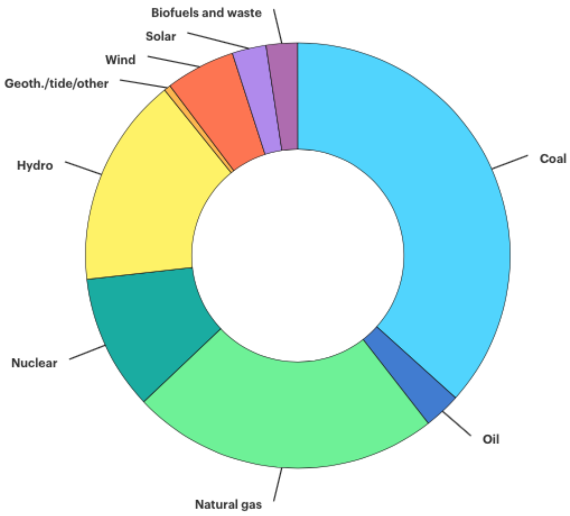

Figure 1.3: Global electric energy production by source [2]

The hydroelectric technology is spread around the world, is present in different size and quantity in all the continents from South America or China biggest plants, to the small or micro hydro located in developed country like Europe. In the year 2019 the installed capacity reached 1,191 GW for an annual electric production of 4,207 TWh. Considering the pumping power plants the capacity installed is equal to 127.6 GW for an annual electric production of 113 TWh. [1]

In the following table are reported the top 10 world producer of hydroelectric energy, excluding the pumping hydro power. China in the last decade had a huge increase in the installed capacity reaching the number one of the top 10 world hydroelectric producers.

	Installed capacity [GW]	Production [TWh]
China	327.75	1,272.54
Brazil	109.32	377.88
USA	83.62	289.80
Canada	81.22	379.63
Russia	51.08	195.92
India	45.48	144.78
Norway	32.80	125.52
Turkey	28.50	88.82
Japan	28.14	79.60
France	24.14	56.91
ITALY	18.89	46.32
WORLD	**1,191.57**	**4,207.13**

Table 1.1: Top 10 countries in terms of installed capacity and production of hydroelectric energy (excluding pumping), data from IRENA [3].

The probable future trend will be, on one hand a huge increase in the installed capacity in developing country (South America, China and Africa) with big size power plants, while on the other hand the development of small and micro hydroelectric plant in developed countries such as in Europe.
The reason why in developed countries the big size hydro cannot be done are various: starting from the lack of adequate location with the availability of hydraulic source that are not already exploited, the environmental and legal regulation that increase the time and the cost of a potential project in a considerably way, the NIMBY syndrome that push public opinion against big size infrastructure. The development and the investment can flow in revamping project of existing big size power plants that require maintenance increasing its installed power or in small and micro hydroelectric plants that have a low environmental impact, a better perception by the common people as green energy, a variety of numerous potential available site where the resource is available.

1.2. Italian Hydroelectric Context

Considering the Italian context, until the 19th century the hydraulic energy was exploited under the form of mechanical energy in order to run simple machinery in the food and in the metallurgy sector (mills, iron forging, etc..).
Later on the hydroelectric power generation until the 1950 was practically the only generation source, allowing the electrification of the Italy. In the following decades the share of hydro became lower and lower, at the same time the relevance of the thermoelectric generation increases drastically, being the major source of electric generation. In this phase the big part of the mountain basin suitable to be exploited by big size hydro dam are saturated. In the latest years the interest is shifted to the small and medium hydro power plants that can be economically convenient thanks to the technological progress and the incentivized policies.
In the recent years renewable plants have an exponential increase around the 2010, fueled by the incentivized policies, especially the photovoltaic and wind power. Later the development of renewable power slows down in velocity and the power installed grows at a constant rate. In the last decade the share of conventional thermoelectric plant decreases mainly for the decommissioning of old coal power plant. [4]

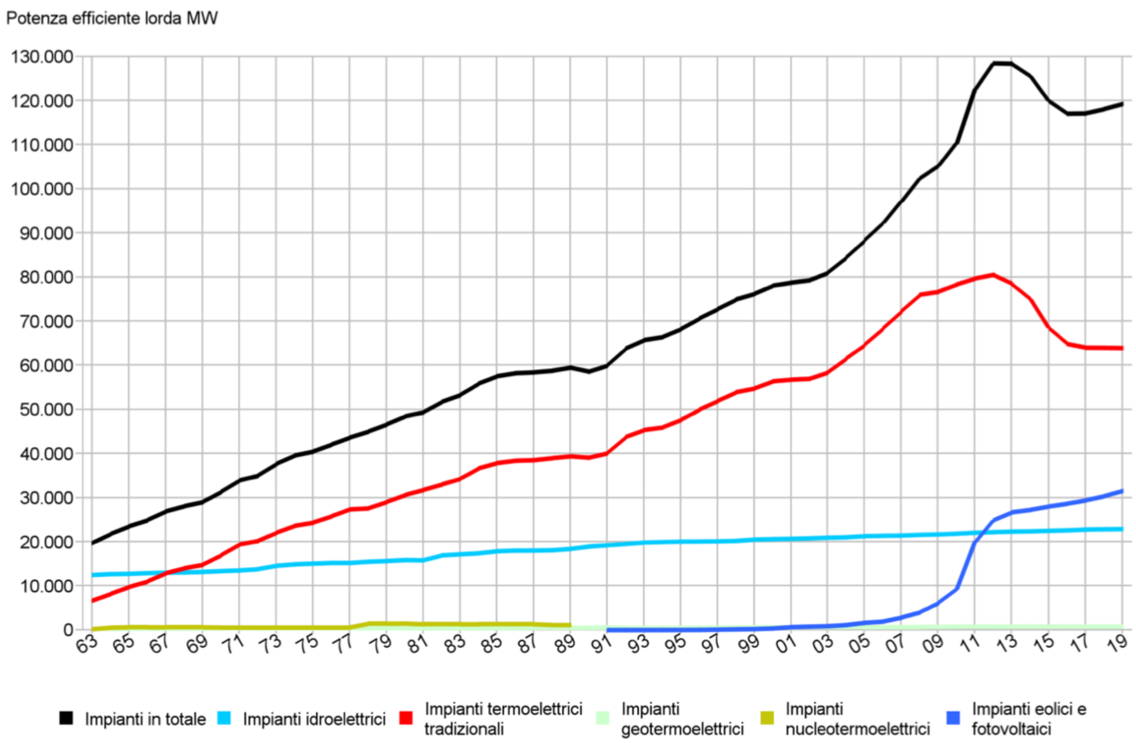

Figure 1.4: Net installed capacity by technology. Data from Terna spa [4]

Considering the data [2] at the end of the 2019 the total hydroelectric capacity installed is equal to **18,892.3 MW** for a total annual production of **46,318.5 GWh**. The total capacity installed in hydroelectric power plants weight for the 34% on the total renewable energy capacity providing power to Italy. The production instead weights for a 41% share of the renewable generation, showing the great contribution of this energy source in the decarbonized production of electric energy.
Excluding the pumped storage plant, the plants operative in Italy are 4,395. More than 3000 are small plants, however more than the 81% of the power installed is related to plant with a size greater than 10 MW. Most of the energy (75%) is produced by plants with a size greater than 10 MW thanks to the high amount or hydraulic source exploited, 19% by medium plants and the remaining 6% by plants with a size lower than 1 MW.

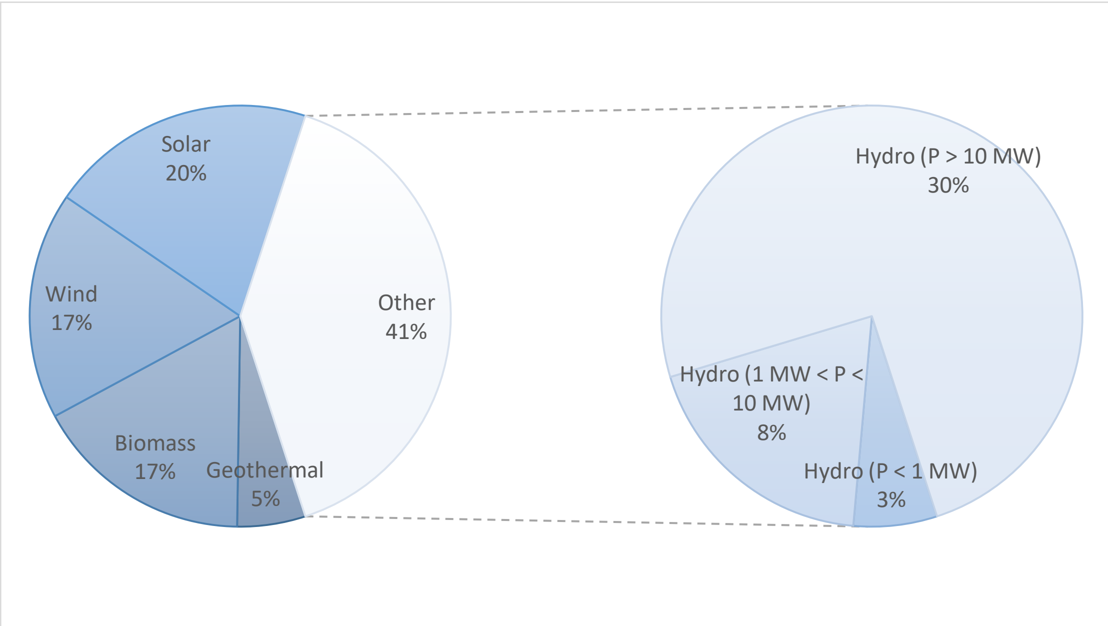

Figure 1.5: Italian renewable production in 2019, data form GSE and Terna spa [1] [4]

	n°	Power [MW]	Production [GWh]
P ≤ 1 MW	3,179	852	2,972
1 MW < P ≤ 10 MW	907	2716	8,767
P > 10 MW	309	15,415	34,579

Table 1.2: Subdivision in class of power for hydroelectric plants in 2019 [1] [4]

Considering the geographical distribution, most of the production is concentrated in the northern region, (Lombardy, Trentino, Piemonte) while the contribution of the southern region is very limited. In the following table can be seen in detail the subdivision for all the Italy's region of the number of plants, the power installed and the annual production.

	n°	Power [MW]	Production [GWh]
Piemonte	945	2,772	7,436.1
Valle d'Aosta	184	999.6	3,143.7
Lombardia	671	5,158.4	10,407.9
Provincia Autonoma di Treno	273	1,634.4	3,915.3
Provincia Autonoma di Bolzano	556	1,732.4	6,110.2
Veneto	396	1,172.6	4,338.6
Friuli Venezia Giulia	244	525.7	1,739.1
Liguria	91	92.3	244.5
Emilia Romagna	203	352.8	942.4
Toscana	215	374.8	744.8
Umbria	46	529.7	1,311.3
Marche	181	250.7	434.5
Lazio	100	411.2	1,048.2
Abruzzo	72	1,013	1,676.2
Molise	34	88.1	222.3
Campania	60	346.5	540.4
Puglia	9	3.7	8.1
Basilicata	17	134.3	230.5
Calabria	55	772.8	1,319.3
Sicilia	25	150.7	189.6
Sardegna	18	466.4	315.5
ITALY	**4,395**	**18,982.3**	**46,318.5**

Table 1.3: Regional installed capacity and production in 2019 [1] [4]

The probable future trend will be, since the limitation in big size power plant construction, in the development of small-medium hydro power plants in distributed generation, in the revamping of existing power plants and in construction of new pumped storage hydro power systems in order to store more and more energy.

Considering the small and medium hydropower sector the potential development is very high: these small plants can exploit numerous potential sites where the hydraulic source is located with small flow and small head but very diffuse on the territory. These plants use a proved and mature technology with a long lifetime with a low environmental and visual impact leading to a less contrariety of the public opinion. The investment price tag of one small hydro power plant can be sustained also by a SME[1] widening the potential investor in this sector. In the following pages this typology of plants is analyzed in all aspect, technical and economical, also considering the real plants of Iniziative Bresciane spa.

[1] SME: Smal & Medium Enterprises

1.3. Small & Medium Hydro Power Plants

In developed countries, since the saturation of the available hydraulic resources of big size in the past decades, the construction of big power plant is practically impossible. Moreover, the strict environmental legislation and the complex authorization procedure disincentivize big size plant, increasing the time to years or even decades. Another important factor is the Nimby[2] syndrome and the increasing opposition of the public opinion to big plant and investment in infrastructures.
Key aspects and major advantages of small hydro power plants are: the possibility of exploiting numerous site of small power but very diffuse in the territory, the low environmental impact and visual impact of the plant during operation and during construction phase, the low incidence of civil work in respect to the total investment, the better acceptability from public opinion and local residents. Moreover, the presence of monetary incentives at national level, in form of feed-in tariff, feed-in premium, and minimum guarantee prices, has given a huge boost in the sector.

1.3.1. Principal Structures

- **DAM – WEIR:**
  The dam is a fundamental infrastructure in the tradition hydropower plant, is a civil works that contain and store the water in an upper basin in order to provide the flow and increase the gross available head. Generally, are constructed in reinforced concreate, has huge dimensions and are located in mountains valleys, this implies high costs.
  The weir is a smaller structure, located on a river or channel and in all the run-off plants, with a limited height (under 15 meters of height[3]). Has the function to divert a portion of the flow from the water body to the intake of the plant, also increasing the upper level of the water.

- **INTAKE:**
  The intake has the important function of capturing the water from the river and redirect the flow into the plant systems. The design phase must give attention to the hydrogeological, structural, hydraulic aspects in order to size in a proper way the structure.

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[2] Nimby: Acronym for Not In My Back Yard: opposition by nearby residents to infrastructures in local areas.
[3] According to the ICOLD (International Committee of Large Dams)

- **METAL SCREEN:**
  Complementary structure with the purpose to minimize the inlet of material such as rocks or pieces of wood in order to protect all the downstream infrastructures from impact of big materials and give a cleaner water.

- **SETTLING BASIN:**
  Small water storage, that has the purpose to eliminate the fine part of the material that has passed in the metal screen. All the particle higher to 2 mm can sediment in the basin, leaving clean water in order to protect the turbine and avoid consumptions of moving parts and in the penstock.

- **DIVERSION CHANNEL:**
  Portion of channel that moves the water from the intake to the point where start the penstock (for high head plants) or to the inlet of the distributor of the turbine in the powerhouse (for low head plants).

- **PENSTOCK:**
  Portion of the plant necessary only for high head power plants, made of pipe that connect the end of the diversion channel to the inlet of the distributor of the turbine, where the water flow at high pressure. Generally made of steel tubes and reinforced concreate structure to face the huge forces and stress, for smaller plants can be constructed be underground without big concrete structures.

- **POWERHOUSE:**
  Is the "heart" of the hydroelectric power plant. Is the building where the turbine and the generator are located. Also contains the auxiliaries, the control systems and, form small plants, the transformer. Particular attention is focused on the turbine machine in the next paragraph.

- **TAILRACE CHANNEL:**
  After passing in the turbine, the water returns to its original water body using a tailrace channel. If the plant use a reaction turbine is very important the geometry and the quality of the tailrace channel in order to recover as much as possible of the remaining kinetic energy.

1.3.2. Hydraulic Turbine

The most important component of a hydro power plant is the hydraulic turbine, this device consents to convert the potential energy of the water in mechanical energy. The hydraulic turbine are mechanical machines that works with continuous flow of water and can convert the energy contained in the fluid in a variation of momentum among the axis of rotation. The machine therefore produces a torque that can drive an electric generator producing electricity.
Generally, a hydraulic turbine is composed by three main elements:

- **Distributor (or stator):** fixed component of the machine, its aim is to guide the flow of water into the rotor, regulate the flow and convert the potential energy into kinetic energy;

- **Rotor (or runner):** moving component of the machine, equipped with blade that enable the rotation of the shaft thanks to the kinetic energy of the water;

- **Diffuser (or draft tube):** component located downstream the rotor, is necessary only in *reaction* turbine with the aim to slow down the exiting flow in order to recover a share of the kinetic energy that otherwise it is wasted.

Can be defined the ***stage reaction*** of an hydraulic turbine as the ratio between the piezometric head change in the runner and draft tube, and the total piezometric head change. Can be calculated as in the equation (1.10).

$$\chi = \frac{H_{rotor}}{H_{total}} \tag{1.10}$$

Where:

H_{rotor}	Piezometric head change in the rotor and diffuser	[m]
H_{total}	Total piezometric head change	[m]

The turbine can be classified in reaction and action turbine according to the stage reaction number:

- **Impulse turbine (action turbine):** if $\chi = 0$, convert all the potential energy is converted in kinetic in the distributor, the rotor work at constant pressure. A typical example is a Pelton turbine.

- **Reaction turbine:** if $0 < \chi < 1$, the distributor converts a part of the potential energy and the rotor has a pressure difference between the inlet and the outlet enabling the conversion of potential energy into torque.

An aspect that is important to highlight is that for action turbine the elevation of the turbine must be some meters higher that the level of the discharge channel or water body. However, for the reaction turbine the elevation of the turbine can be the same or even lower since the use of the diffuser enable the recovery of kinetic energy creating a small depression downstream.

A brief overview of all the most used hydraulic turbines in hydropower plants is showed in the next pages, making a comparison in terms of technical parameters and highlighting the advantages and disadvantages.

- **PELTON TURBINE:**
  The Pelton turbine is the most common and known impulse turbine. It's a robust and reliable machine composed by a series of spoon-shaped buckets mounted around the outer rim of a drive wheel. The water coming from the penstock at high pressure is accelerated at high velocity in a nozzle (distributor). The high-speed streams of waters hitting the buckets of the runner, transfer the water jet's momentum to the wheel, producing a torque and spinning the turbine. The water jets do an "U-turn" and exits to the outlet of the buckets at low velocity. Two buckets are mounted side by side on the wheel in order to be symmetric and balance the side load forces of the impact.

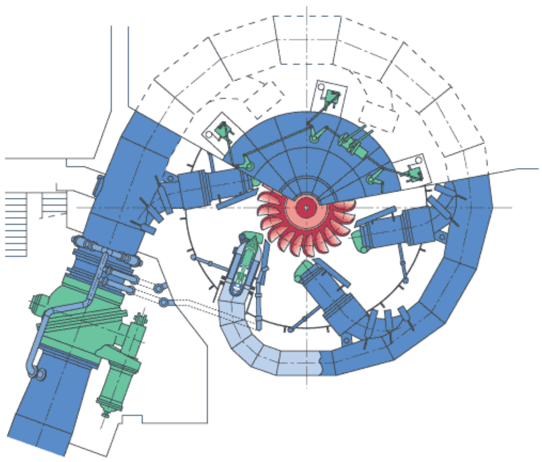

Figure 1.6: Graphical representation of a Pelton Turbine

A small portion of the water kinetic energy remain in the water in order to allow the emptying of the buckets at the same rate it is filled, allowing the flow to continue uninterrupted.

The Pelton turbine can have a numbers of water jets up to six, the higher the number of jets the higher is the capability of partialization the power produced without compromise too much the efficiency.
The main parameters range where the turbine work are: up to high head between 60 meters and 1.300 meters, variability of water flows from 0.02 to 7 m^3/s.
The advantages of this machine are: the high specific power and the high hydraulic efficiency over 90%, the high efficiency at partial load. The drawbacks of this machine are: the stream from one nozzle can impact one blade per time limiting the flow processed, the very fast run-away in case of grid or generator fault.

- **TURGO TURBINE:**
  The Turgo turbine is an impulse type turbine, the machine is very similar to a Pelton turbine with the characteristic of being an "half Pelton" with turbine blades that has only one bucket. The working principle is the same, a nozzle converts the potential energy into kinetic energy, the high speed jet hitting the blades spins the rubine runner and the turbine shaft. Generally, the Turgo runner is one half of the diameter of the Pelton turbine and have roughly the twice of specific speed, the flow can be higher because the water at the outlet of the bucket doesn't interfere with the other buckets. Like the Pelton the turbine can be equipped with multiple nozzle in order to partialize the power and increase the partial load efficiency.

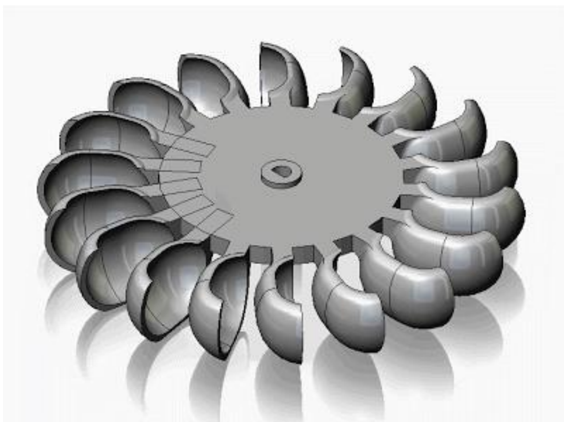

Figure 1.7: Graphical representation of a Turgo turbine

The main parameter range where the turbine work are: medium head between 50 meter and 250 meters, water flow of maximum 3 m^3/s. The advantages of this machine are: the runner is less expensive that a Pelton one, since the high velocity of rotation and the small dimension the coupling with electric generator is costs is lower, high hydraulic efficiency up to 90%. The drawbacks of this machine are: the lateral discharge and so the trust bearing required that add complexity and costs, since the runner is not symmetric like a Pelton, the efficiency that is lower than an equivalent size Pelton.

- **CROSS-FLOW TURBINE:**
  The cross-flow turbine is an impulse type, the pressure remains constant at the runner. The cross-flow is a simple turbine composed by a cylindrical runner with horizontal axis equipped with numerous radial blades. All the curved blades are welded to disks to create a single element, this module can be repeated and welded in order to create a bigger turbine enabling the increase in size at very cheap cost. The water flows from the outside of the turbine to its inside, transmitting some kinetic energy to the runner, then the water flow from the inside to the outside transferring the remaining kinetic energy before leaving the turbine. The water is regulated with a vane that varies the cross section of the water flow coming into the turbine.

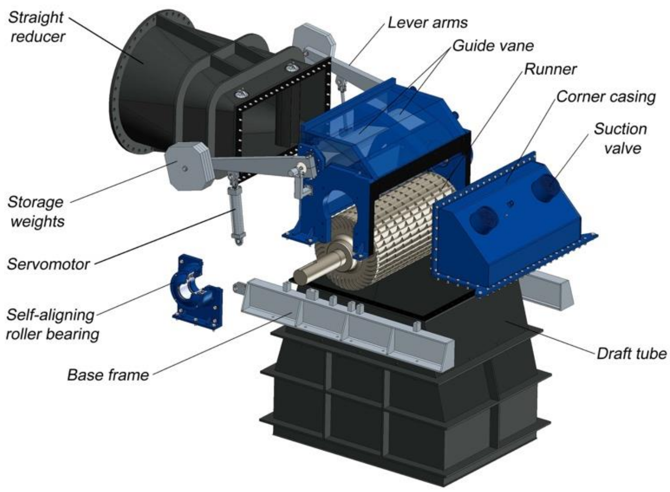

Figure 1.8: Graphical representation of a Cross-flow turbine, image from Ossberg Hydro

The main parameters range where the turbine works are: medium head between 5 meters and 200 meters, a wide flow rate range from 0.02 m/s up to 10 m^3/s. The advantages of this machine are: very cheap construction implies low costs, efficiency constant ad partial load. The drawbacks of this machine are: the low efficiency compared to other machine (around 80%), the usefulness only for low power application.

- **FRANCIS TURBINE:**
  The Francis turbine is a reaction hydraulic machine that combine the radial and axial flow of water. These machines are usually mounted with vertical shaft, to facilitate the installation and the maintenance.

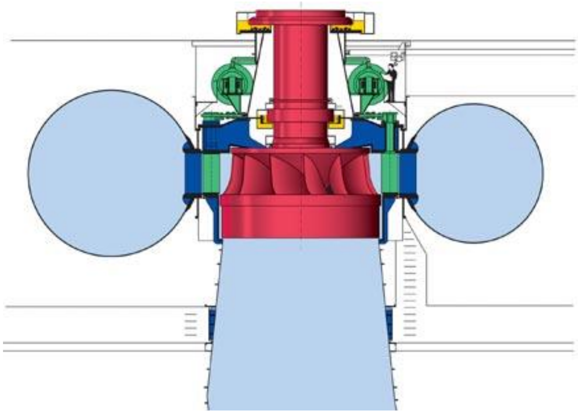

Figure 1.1.9: Graphical representation of a Francis turbine

The main parameters range where the turbine works are: medium head between 20 meters and 500 meters, a wide flow rate range from 0.2 m/s up to 100 m^3/s. The advantages of this machine are: the possibility of high flow rate up to 100 m^3/s, the high efficiency at nominal power up to value higher than 90%, the reaction type of turbine enable the recovery of kinetic energy in the diffuser. The drawbacks of this machine are: the costs of the turbine and the auxiliaries component (guide vane, regulation ring, ecc..), the low efficiency at part load.

- **KAPLAN TURBINE:**
  The Kaplan turbine is one of the most used turbines in the hydroelectric generation sector, this hydraulic machine is a reaction turbine, where the flow is axial. The common configuration is with vertical The distributor, that have the aim to deliver water in the proper direction to the runner, can have a fixed system or moving guide vanes. The runner has generally a low number of blades, generally 4 and not more than 7. The blades are adjustable and can be moved, in this case the turbine is a "double regulation Kaplan", if the distributor is fixed instead the turbine is a "single regulation Kaplan" or "semi-Kaplan", if the distributor and the blades are fixed the turbine is a "propeller". A draft tube is required to recover some of the kinetic energy at the outlet of the machine.

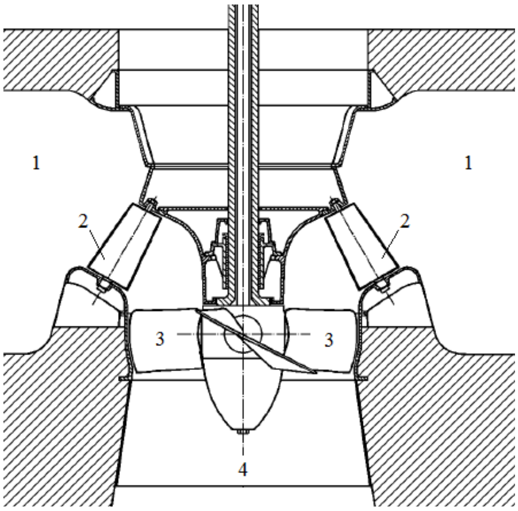

Figure 1.10: Graphical representation of a Kaplan turbine

The main parameters range where the turbine works are: low head between 2.5 meters and 40 meters, a wide flow rate range from 2 m/s up to 100 m^3/s. The advantages of this machine are: the high efficiency at nominal power, the possibility of regulation. The drawbacks of this machine are: the expensive regulation system, the draft tube required and the probable problem of cavitation.

- **BULB KAPLAN TURBINE:**
  The bulb Kaplan turbine is a particular typology of Kaplan turbine, used in low head plants. It has the characteristics of having the hydraulic machine and the generator inside a tubular structure, simplifying the construction. Is a horizontal axis turbine, with fixed blades and no regulation system.

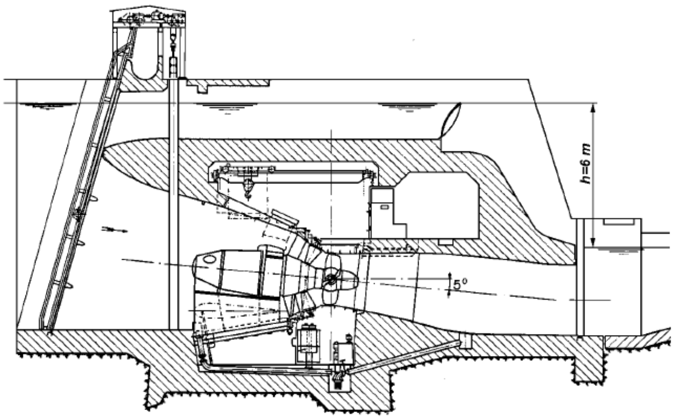

Figure 1.11: Graphical representation of a Bulb Kaplan turbine

- **VLH TURBINE:**

  The Very Low Head turbine (VLH) is a particular turbine with a self-supporting structure with upper rotational joint for maintenance. The electric generator and the pitch control are integrated in the shaft.

  The turbine runs at low velocity, the coupling is generally with a Permanent Magnet Generator (PMG) with frequency controller. This machine is usefull only for very low head site where the head is in the order of few meters. This turbine doesn’t require complex civil works, enable costs savings in the reinforced concreate structures. However, the efficiency is lower than the other turbine.

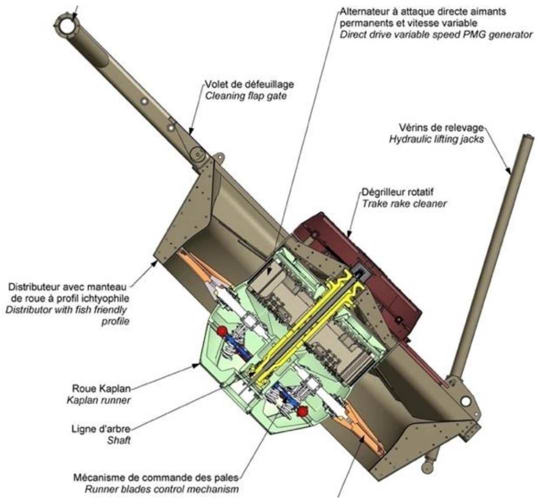

Figure 1.12: Graphical representation of a VLH turbine

The main parameters range where the turbine works are: very low head of some few meters, a wide flow rate range can be exploited using more modular machine in parallel. The advantages of this machine are: the small dimensions, the reduction of the civil structures required, the possibility to exploit very low head, the low visual impact. The drawbacks of this machine are: the cost of the machine, the small application range (3 – 4 meters), low efficiency at part load.

- **SCREW TURBINE:**

  This particular turbine has the shape of an “Archimedean screw”, is a positive dispacement machine, the water going down the screw leaves a torque to the shaft.

  It is modulable, the length of the screw is proportional to the head, while up to relatively big flow can be exploited using more system in parallel.

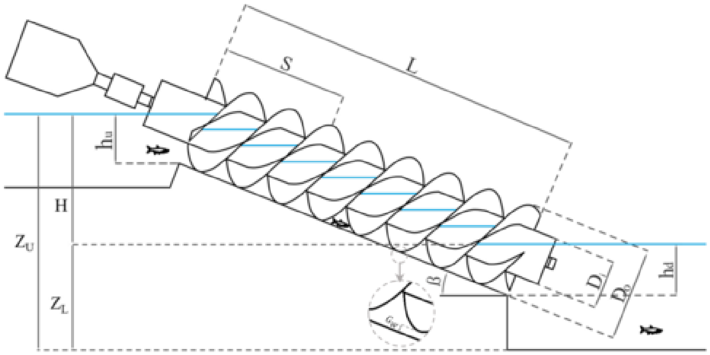

Figure 1.13: Graphical representation of a Screw turbine

The main parameters range where the turbine works are: low head between 1 and 6 meters, a flow rate that is generally lower than 7 m^3/s. The advantages of this machine are: the low cost and the low maintenance required, the reduction of civil works, the fish-friendly design. The drawbacks of this machine are: the lower efficiency at nominal power compared to a Kaplan, the visual impact, the limited flow and head range.

Considering all the hydraulic machine depicted in the previous pages, the choice of the good performing turbine in a power plant must be done taking into account the two major parameters, nominal flow and available head. As show in the picture (1.14) every hydraulic machine has a defined domain in a H-Q diagram where the turbine operates in a proper way (H = available head, Q = nominal flow).
For big power plants the best turbine are the Pelton, Francis and Kaplan respectively from high head to low head. For small and medium power plants are used also the Turgo, the cross-flow, the bulb-Kaplan, the VLH, the Archimedean screw, considering the peculiarity of each turbine that are very different each other.

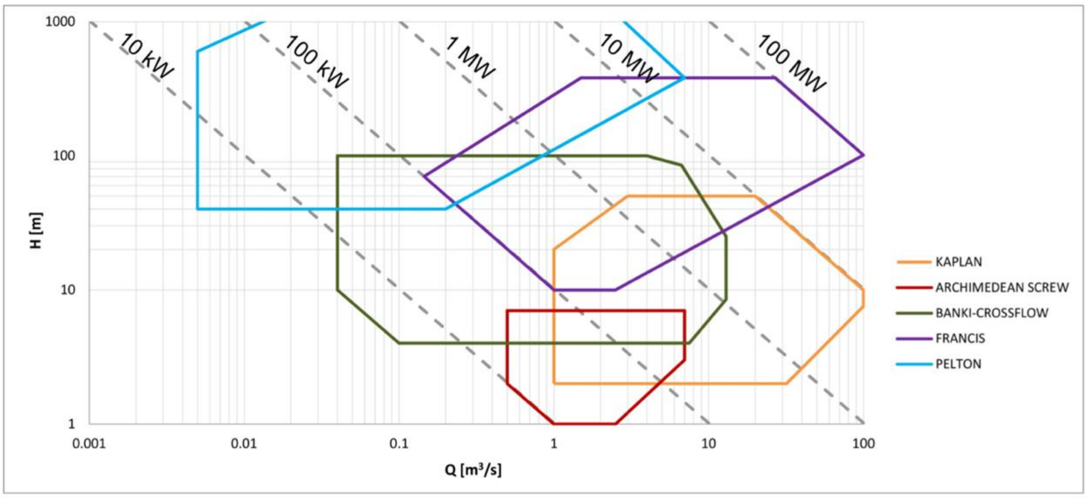

Figure 1.14: Graphical comparison of different turbine

1.4. Classification of Hydropower Plants

The hydroelectric plants can be subdivided in different classification considering different aspects of the technical specification:

- **LOCATION OF INTAKE-DISCHARGE:**
  Considering the typology and location of the intake and discharge.

  - **Weir integrated plant**:
    the intake point and the discharge point are very close each other, generally this plant have the advantage of not having the ecological flow request. The civil works are very limited in size and cost, no long channel or penstock are required. Since the closeness of the intake and discharge point the head is low or very low, while the water flow can vary from low to very high flow.

  - **Diversion channel plant:**
    the intake point and the discharge point are far each other. The water is captured from a river in his upper part, then is diverted in a channel with a very small slope and later a penstock in pressure carries the water to the power house. This typology of plant since divert the water from its original river cannot exploit all the available flow but must release an ecological flow. The cost is high since the presence of this infrastructure.

- **FILLING RATE:**
  The “filling rate” is defined as the storage capacity over the average river flow rate. It is the time required in order to fill the storage volume of the dam(o barrage) with the average river flow rate.

  - **Storage plants:**
    - **Pond plants:** filling rate between 2-400 hours;
    - **Reservoir plants:** filling rate > 400 hours;

  - **Run-of river plants:** filling rate < 2 hours.

- **HYDRAULIC HEAD:**
  Hydraulic head is defined as the difference between the height of the intake of the water and the height of the discharge.

  - **High head:** between greater than 100 meters. Diversion channel is needed, can be both storage or run-of-river plants;
  - **Medium Head:** between 30 – 100 meters. Diversion channel is needed, can be both storage or run-of-river plants;
  - **Low Head:** between 2 and 30 meters. In most cases run-of-river, can be weir integrated plant or with diversion channel.

- **ENERGY STORAGE CAPABILITY:**
  Capability of storing energy in an upper reservoir. During the period of excess of electric energy in the grid (low price) the plant can pump water in an upper reservoir, during period of high demand of electricity the plant run in production mode and discharge the energy stored.

  - **Pumped-Storage Hydroelectricity (PSH):**
    - **Only pumped:** operation in charge-discharge mode, without any additional contribution.
    - **Pumped and river:** the plant can operate in two different way, the plant can operate in two different way.
  - **Top-power:** non-pumping plant,
  - **Medium Head:** between 30 – 100 meters. Diversion channel is needed, can be both storage or run-of-river plants;
  - **Low Head:** between 2 and 30 meters. In most cases run-of-river, can be weir integrated plant or with diversion channel. IN MOST CASES run-off river, can be both weir integrated plant or with diversion channel.

- **NOMINAL POWER:**
  Classification based on the size of the hydropower plants. According to *ESHA* (European Small Hydro Association) and *UNIDO* (United Nation Industrial Development Organization):
  - **Large plants:** P > 10 MW
  - **Medium plants:** 1 MW < P < 10 MW
  - **Small plants:** 100 kW < P < 1 MW
  - **Micro plants:** P < 100 kW

1.5. Iniziative Bresciane spa

Iniziative Bresciane S.p.a starts its activities in the sector of electric energy generation from hydroelectric renewable source in the 1996. Iniziative Bresciane spa, also "INBRE", deals with the design, the construction and the management during the lifetime of small and medium hydroelectric power plants (concession power between 100 kW and 3 MW). The plants are owned directly, or indirectly with some partnership with public institution or private enterprises. The company has his headquarters in Breno (BS) and operates with his plants in the Norden Italy territory, specifically in the province of Brescia, Bergamo, Cremona, Trento and Lucca. [5]

At the date of 31.12.2021, Iniziative Bresciane spa manage 44 hydroelectric power plants, which the majorities have an incentivized production, from the GSE s.p.a.

The Group Iniziative Bresciane spa can be ranked, considering the number of plants and the electricity production, as one of the major players in the sector of the pure small and medium hydro power generation in the geographical areas where operates.

From the July 2014 the company is listed on the Italian Stock Exchange, in the segment Euronext Growth Milan. At the 31.12.2021 the total market capitalization is equal to 100.95 million euros, it is controlled by Finanziaria di Vallecamonica Spa that owns 52 % of the shares.

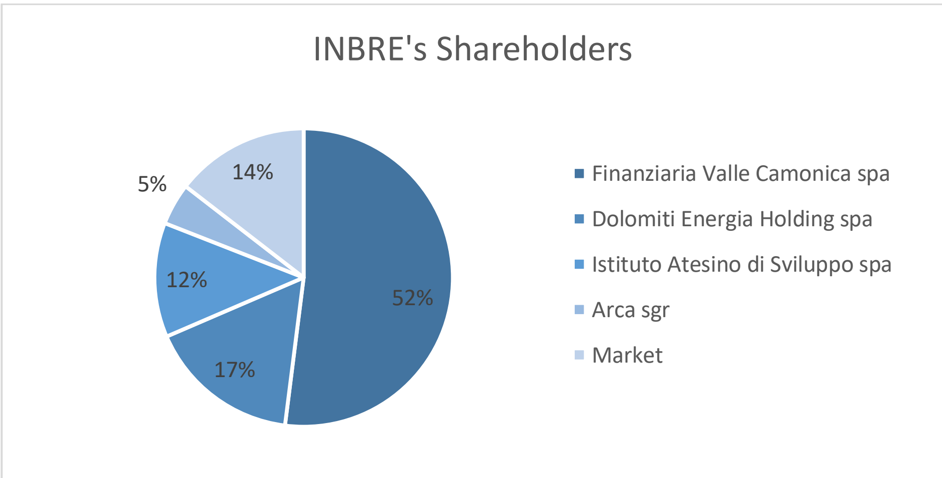

Figure 1.15: INBRE's shareholders structure [5]

1.5.1. Business model

The business model of Iniziative Bresciane spa deal about the selling of electric energy generated in hydro power plant of property, managed and constructed by the company. The company focuses its attention on the small-medium hydroelectric power plants (100 kW to 3MW), without diversifying in other generation technology in order to exploit all the possible synergies.
Besides from managing the portfolio of power plants, INBRE focuses his attention also into the development of new project in the reference territory, in order to guarantee a growth trend of the business of the company. Starting from the analysis of the hydraulic potential, the obtaining of the concession to use water for hydroelectric use, the engineering design with the aid of experienced partner, the construction by awarding contract to contractors.

In the year 2021, INBRE's revenue reached 22.52 million euros, with an EBITDA of 15.26 millions euros and a net income of 3.64 millions euros.

The group INBRE is composed by a number of controlled company: some companies are Special Purpose Vehicle (SPV) like Società Idroelettrica Prà de l'Ort s.r.l. or Iniziative Toscane s.r.l. with very specific activities in agreement with the local Municipality or Region, some companies are joint ventures or partnership with public entities or other private investor.

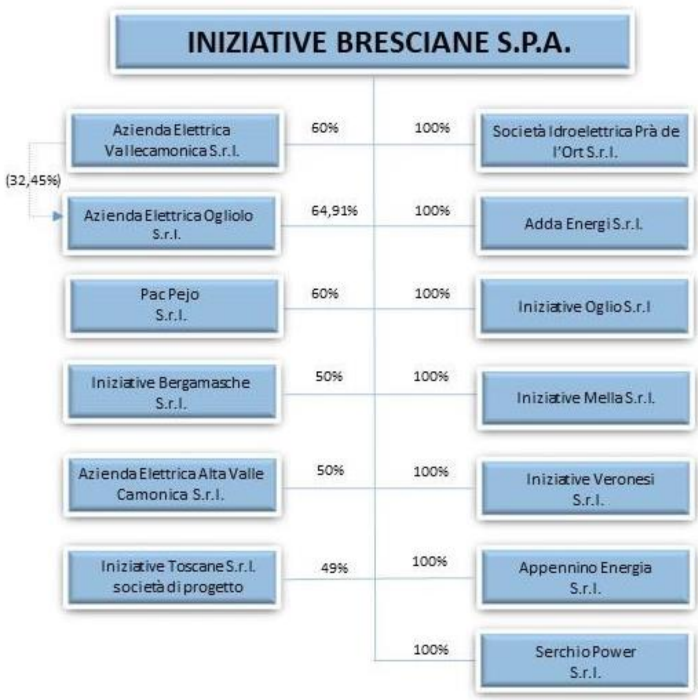

Figure 1.16: INBRE's company structure [5]

1.5.2. Geographical range of action

The INBRE company operates in the Northern Italy especially in the province of Brescia, Bergamo, Cremona, Trento and Lucca. The major river course were are located the INBRE's power plants are: Oglio river, Serio river, Brembo river, Chiese river, Adda river and Mella river. [5]

	N° impianti
Brescia	20
Bergamo	15
Cremona	4
Lucca	3
Trento	2

Table 1.4: Localization of the power plants

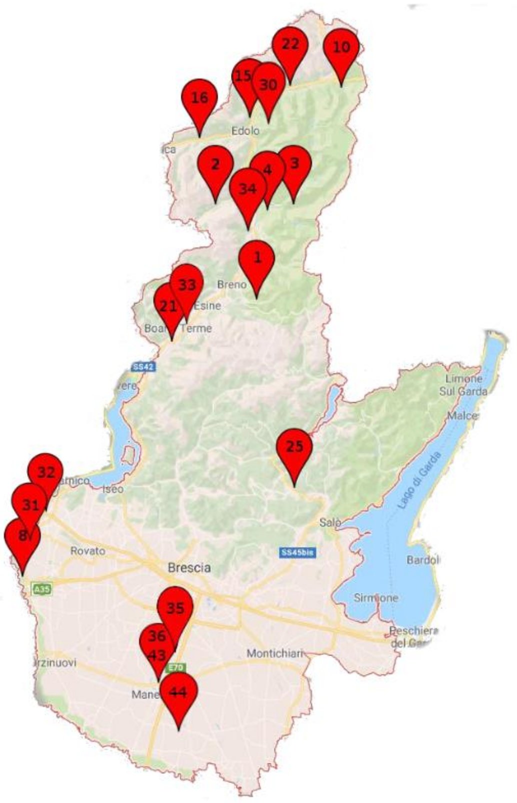

Figure 1.17: Localization of power plants in Brescia's province

Province of Brescia	
1	**Degna**
2	**Paisco**
3	**Fabrezza**
4	**Fresine**
8	**Urago**
10	**Pradelort**
15	**Monno**
16	**Lombro**
21	**Le Bosche**
22	**Vallaro**
25	**Barghe**
30	**Iscla-Edolo**
31	**DMV Urago**
32	**DMV Palosco**
33	**Le rive Darfo**
34	**Briglia Sellero**
35	**Calcagna**
36	**Bassana**
43	**Badia**
44	**Martinoni**

Table 1.5: List of power plants in Brescia's province

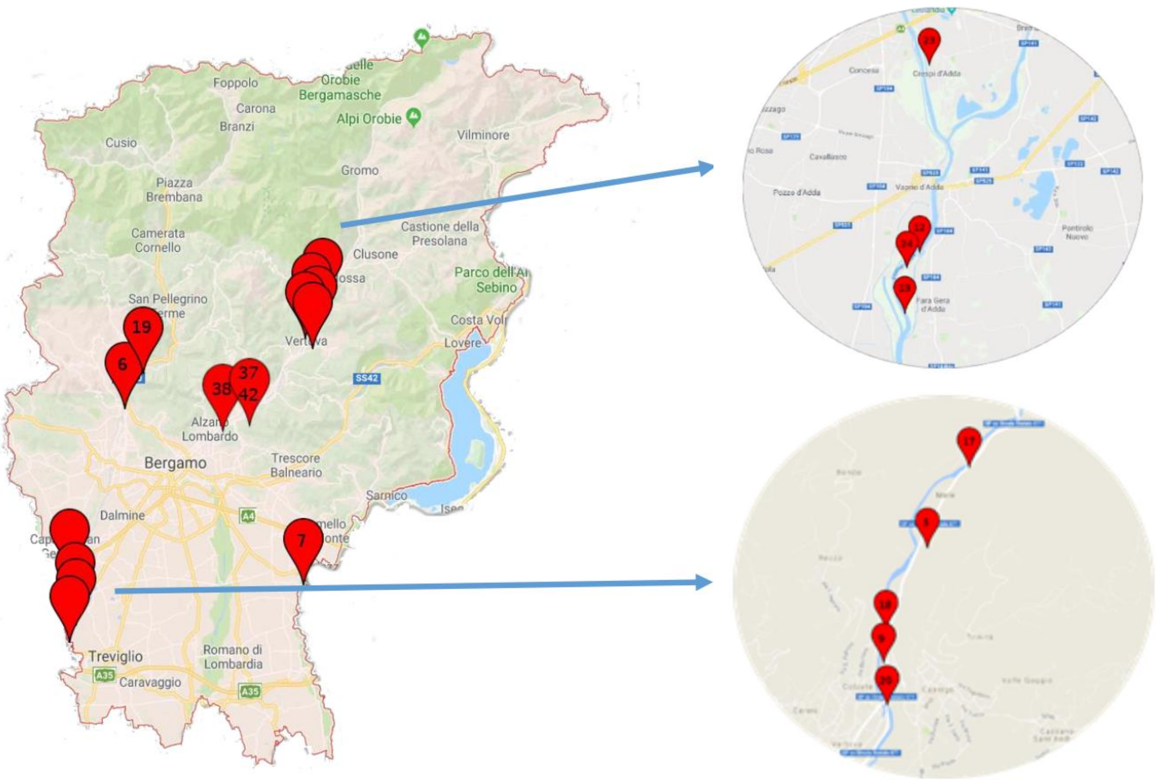

Figure 1.18: Localization of power plants in Bergamo's province

Province of Bergamo	
5	**Pratomele**
6	**Fonderia**
7	**Palosco**
9	**Casnigo**
12	**Fara 1**
13	**Fara 2**
17	**Pratomele DMV**
18	**Casnigo Monte DMV**
19	**Fonderia DMV**
20	**Casnigo Valle DMV**
23	**Crespi**
24	**Fara 3**
37	**Trav. S.Morlana Vecchia**
38	**Trav. S.Borgogna**
42	**Trav. S. Albino**

Table 1.6: List of power plants in Bergamo's province

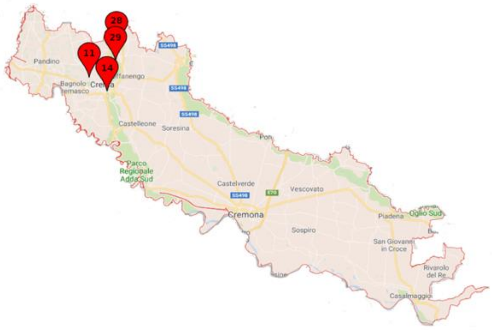

Figure 1.19: Localization of power plants in Cremona's province

Province of Cremona	
11	**Treacu**
14	**Bagnolo Cremasco**
28	**Babbiona**
29	**Malcontenta**

Table 1.7: List of power plants in Cremona's province

Figure 1.20: Localization of power plants in Lucca's province

Province of Lucca	
39	**Piaggione**
40	**Ponte a Moriano**
41	**Piastroso**

Table 1.8: List of power plants in Lucca's province

Figure 1.21: Localization of power plants in Trento's province

Province of Trento	
26	**Contra**
27	**Castra**

Table 1.9: List of power plants in Trento's province

1.5.3. Characteristics of the plants

All the hydropower plants owned by Iniziative Bresciane spa are small and medium hydro plants, with the great majority of this that are run-off plant. The technologies of turbine used in the power plants managed by the company are: Pelton, Francis and Kaplan. Currently, no Turgo, Cross-flow, Archimedean-screw or VLH are used. At the end of the 2021 year, the total number of hydro power plant managed by the company are equal to 44, for a net installed power of 57 MW delivering 154.1 GWh of electric energy production.

	2021	2020	Δ %
N° of Plant	44	32	+37.5 %
Installed Power [MW]	57.0	48.1	+18.5 %
Electricity production [GWh]	154.1	167.0	-7.7 %

Table 1.10: Classification of INBRE's power plant based on power and production [5]

The next table, show the subdivision of the plant in terms of head: high head, typically in mountain area, low head, typically in lowland areas or very low, exploiting the Ecological Flow release.

	N° of Plant	Installed Power [MW]	Electricity Production [GWh]
High Head	12	31.7	74.9
Low Head	21	21.0	63.5
On Ecological Flow	11	4.3	15.7

Table 1.11: Classification of INBRE's power plant based on nominal head [5]

Considering the small and medium hydroelectric plant, INBRE has different size of plant depending on location and water availability. In the following table the subdivision in "class" of plants considering the size of the power installed. The portfolio of the company has a great diversification considering the dimension of the hydropower plants, with tens of plant in every class of power.

	N° of Plant	Installed Power [MW]	Electricity Production [GWh]
< 200 kW	10	1.7	4
200 – 500 kW	15	9.6	21.4
500 – 1000 kW	10	14.3	38.2
> 1000 kW	9	31.4	90.5

Table 1.12: Classification of INBRE's power plant based on installed power [5]

1.5.4. Future development

The company has a great pipeline of project that are under construction, in authorization phase, or in procedure to obtain the concession to use water for hydroelectric purposes. In the following table is reported a recap of the stage of the pipeline.

	N° of Plant	Concession Power [MW]
In construction	12	9.5
Waiting for construction authorization	2	0.8
Concession's procedure	20	11.0

Table 1.13: Future plant and its stages of development [5]

The 12 plants in construction in the current time are located in the province of Florence, under the Iniziative Toscane srl subsidiary, for a total concession power of 9,520 kW.
The company is also committed in searching potential places with the hydraulic resources exploitable, in the implementation of the authorization procedure for new power plants with the aim to expand the asset base and increase production, also looking for opportunities of M&A of plants from other entities. The company is also focused in the development of new power plants with different technology like Very Low Head turbine (VLH) or Cross-flow turbine.

In futures further development should be done considering adjacent and complementary sector as energy storage or hydrogen production from renewables.

2 Regulation

This chapter will deal with all the regulations relating to hydroelectric plants. In detail, the legislation concerning the concessions for the use of water for hydroelectric purposes, both at national and regional level, is presented. At the regional level, it was decided to focus attention on the legislation of the Lombardy Region, as a region where there are a large number of hydroelectric plants and also the region in which the plants analyzed in the following chapters of this thesis are located.

Subsequently, the authorization legislations are analyzed, considering procedures and simplifications for authorizing the construction of plants for the production of electricity from renewable sources, in detail hydroelectric plants. The legislation at national and regional level is again exposed with the focus on the Lombardy Region.

Then it is considered the framework of the incentive scheme for the production of electricity from renewable sources. The Italian legislation and the implementation methods for obtaining incentive rates through the GSE are presented.
Finally, space is given to environmental legislation, both national and regional. Paying particular attention to environmental authorizations and, in the specific case of hydroelectricity, to the regulated Minimum Vital Flow. A focus is also carried out on the new Ecological Outflow which progressively replaces the old Minimum Vital Outflow.

In addition, at the end of the chapter, the Legislative Decree No. 199 of 08 November 2021[4] [6] is presented, which is the new framework for the following years both as regards the legislation concerning incentive schemes and as regards authorizations.

[4] Decreto Legislativo 08 Novembre 2021, n. 199 "Attuazione della direttiva (UE) 2018/2001 del Parlamento Europeo e del Consiglio, sulla promozione dell'uso dell'energia da fonti rinnovabili."

2.1. National and regional concession's legislation

As regards the national legislation, the reference point is the *Royal Decree N°. 1775/1933*[5] [7]which introduces and regulates for the first time the concessions for the use of public water. It introduces the definition of concessions for large derivation for those with a concession power greater than 3000 kW and small derivation for those with a concession power lower than 3000 kW.

Subsequently the *Legislative Decree n ° 79 of 16/03/1999*[6] [8]attributes the competence of the granting of concessions to the regions and autonomous provinces. For large derivations imposed the tender of expired concessions for a duration of 30 years.

As regards the Lombardy Region, through the *Regional Law n ° 26 of 12/12/2003*[7] [9] it attributes the functions and the competence regarding the concessions of small derivations to the provinces.

The subdivision therefore remains between **small derivations** (concession power lower than 3000 kW) and **large derivations** (concession power greater than 3000 kW), the responsibility for issuing concessions for large derivations is the responsibility of the Region while the responsibility for issuing concessions for small derivations is the responsibility of the Provinces.

Note that the power used as a measure to identify and classify the water derivations is the **concession power**, which considers the average flow rate and the maximum available head. It is calculated as specified in the following equation (2.1).

$$P_{conc} = Q_{aver} \cdot H_{gros} \cdot g \cdot \rho \tag{2.1}$$

Where:

Q_{aver}	Average annual water flow	[m^3/s]
H_{gros}	Gross piezometric head	[m]
g	Gravitational acceleration	[m/s^2]
ρ	Water density	[kg/m^3]

[5] Regio Decreto 11 Dicembre 1933, n. 1775 "Approvazione del testo unico delle disposizioni di legge sulle acque e sugli impianti elettrici."
[6] Decreto Legislativo 16 Marzo 1999, n. 79 "Attuazione della direttiva 96/92/CE recante norme comuni per il mercato interno dell'energia elettrica."
[7] Legge Regionale 12 Dicembre 2003 , n. 26 "Disciplina dei servizi locali di interesse economico generale. Norme in materia di gestione dei rifiuti, di energia, di utilizzo del sottosuolo e di risorse idriche."

2.2. Authorization legislation

The Legislative Decree N° 28 of 03/03/2011[8] [10] implementing the European Directive 2009/28/EC on the promotion of the use of energy from renewable sources, which incorporates the binding target, assigned to the Italian State, of the total share of energy from renewables on the gross final consumption of energy to be achieved by 2020 equal to 17 per cent.

In the art. 4, it regulates the administrative procedures for the construction and operation of plants for the production of energy from renewable sources according to a principle of proportionality with a **single authorization procedure** (*autorizzazione unica*), a **simplified authorization procedure** (*procedura abilitativa semplificata*) or a **communication of activities in free construction** (*comunicazione di attività in edilizia libera*).

The *Inter-Ministerial Decree 10/09/2010* issued in implementation of the *Legislative Decree N° 38 of the 29 December 2003* establishes "Guidelines for the authorization of plants powered by renewable sources" and confers the faculty fot the regions to adapt the respective disciplines within ninety day from the date of the entry into force of the decree.

Considering the Lombardy Region, the *DGR N° 9/3298 of the 18/04/2012* establishes and defines the regional guidelines for the authorization of plants for the production of electricity from renewable sources. For different energy sources and for different size of the plant, different authorization procedures are requested, specifically for hydroelectric plant:

- **Communication of activities in free construction:**
  for hydroelectric power plant that are built in existing building with a power lower than 200 kWe;

- **Simplified authorization procedure:**
  for hydroelectric power plants with a power lower than 100 kWe or for plants that exploit drinking water aqueducts with a power lower than 1 Mwe;

- **Single authorization procedure:**
  for hydroelectric power plants that are built in existing building with a power greater than 200 kWe or in all the other cases with a power greater than 100 kWe.

[8] Decreto Legislativo 3 Marzo 2011, n. 28 "Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili, recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE."

2.3. Incentive legislative framework

The *Dlgs n°28 of 03 March 2011* [10] establishes the guidelines of the incentive scheme, in particular then the Ministry of Economic Development (MISE) published the *Minister Decree 04 July 2019*[9] [11], replacing the previous D.M. 23 June 2016, containing provisions regarding the incentive system.
The decree in the period 2019-2021 establishes different time windows during which auctions are carried out to assign the right to the incentive, the last windows closed on 31.10.2021 but in any case until the date of effective entry into force of the implementing decree of the new Legislative Decree 199/2021 [6] there is a transitional period with the opening of a subsequent window.
The *D.M. 04/07/2019* [11] divides the plants that can access the incentives into four groups based on the type, energy source and category of intervention:

- **Group A:** includes the plants:
    - Newly built **on-shore wind** farms, full reconstruction, reactivation or repowering;
    - Newly bult **photovoltaics farms**;

- **Group A-2:** includes newly built **photovoltaic** systems whose modules are installed to replace **asbestos**-containing roofing;

- **Group B:** includes the plants:
    - Newly built **hydroelectric plants**, complete reconstruction (excluding aqueducts), reactivation or upgrading;
    - Plants running with **gas residues** from purification processes of new construction, reactivation or upgrading;

- **Group C:** includes plants subject to total or partial refurbishment:
    - **On-shore wind** farms,
    - **Hydroelectric plants**,
    - Plants running with **gas residues** from purification processes.

Depending on the power and the group to which they belong, different ways of accessing the incentives are provided:

- **Registration in the Registers:**
  The available power quota is assigned through priority criteria. For power

[9] Decreto Ministeriale, 4 Luglio 2019 "Incentivazione dell'energia elettrica prodotta dagli impianti eolici on shore, solari fotovoltaici, idroelettrici e a gas residuati dei processi di depurazione."

plants greater than 1 kW (20 kW for photovoltaics) and less than 1 MW belonging to groups A, A-2, B, C.

- **Auction procedures:**
  The available power quota is assigned, according to the higher discount offered on the incentive level, applying priority criteria in the event of an equal discount. For plants with a power greater than or equal to 1 MW.

There are 7 calls for bids for participation in the Registers and Auctions, with the timing reported in the following table, as visible the last window closed in October 2021, currently a transitory period with two extra-window period are in place unless the implementing decree from MISE of the D.lgs 199/2021. In each of the seven Register or Auction procedures, different power quotas are assigned, according to the group to which the plants belong. Moreover, in order to maximize the construction rate of the plants, the D.M. 04/07/2019 provides for specific methods for reallocating the quota of unassigned quotas.

Window period	Start	Finish
1	30.09.2019	30.10.2019
2	31.01.2020	01.03.2020
3	31.05.2020	30.06.2020
4	30.09.2020	30.10.2020
5	31.01.2021	02.03.2021
6	31.05.2021	30.06.2021
7	30.09.2021	30.10.2021

Table 2.1: Timing of the calls for bids

The incentives are recognized for the net electricity produced fed into the grid by the plant, calculated as the lower value between the net **electricity production** (equal to the gross production reduced by the consumption of auxiliary services, line and transformation losses) and **electricity actually fed into the grid**, measured with the exchange meter.

The D.M 04.07.2019 [11] provide three different tariff definitions:

- The *Reference Tariff* is determined according to the source and type of the plant and the power, by applying the tariff reported in the table (2.2).
- The *Offered Tariff* is calculated by applying reductions to the reference tariff when registered in the Registers or Auctions, in order to benefit from the relative priority criteria.

- The *Expectant Tariff* is calculated by applying further reductions envisaged by the D.M. 04.07.2019 for plants in useful position in the rankings of the Register or Auctions.

Source	Group	Typology	Power [kW]	Lifetime [years]	Reference Tariff [€/year]
Wind	A	On-shore	1<P<100	20	142.50
			100<P<1000	20	85.50
			P>1000	20	66.50
	C	On-shore	1<P<100	20	150.00
			100<P<1000	20	90.00
			P>1000	20	70.00
Photovoltaic	A		20<P<100	20	99.75
			100<P<1000	20	85.50
			P>1000	20	66.50
	A-2	Abestos removal	20<P<100	20	105.00
			100<P<1000	20	90.00
Hydroelectric	B	Run-off river	1<P<400	20	151.90
			400<P<1000	25	107.80
			P>1000	30	78.40
		Storage plant	1<P<1000	25	88.20
			P>1000	30	78.40
	C	Run-off river	1<P<400	20	155.00
			400<P<1000	25	110.00
			P>1000	30	80.00
		Storage plant	1<P<1000	25	90.00
			P>1000	30	80.00
Residual Gas	B		1<P<100	20	107.80
			100<P<1000	20	98.00
			P>1000	20	78.40
	C		1<P<100	20	110.00
			100<P<1000	20	100.00
			P>1000	20	80.00

Table 2.2: Reference Tariff according to the D.M 04.07.2019

There are two different incentive mechanisms, depending on the power of the plant:

- **All-inclusive Tariff (TO),** consisting of a single tariff, corresponding to the tariff due, which also remunerates the electricity withdrawn by the GSE;

- **Incentive (I),** calculated as the difference between the tariff due and the hourly energy price, since the energy produced remains available to the operator.

For power plants up to 250 kW it is possible to choose one of the two modes, with the possibility of switching from one mode to the other no more than twice during the entire incentive period. Plants with a power greater than 250 kW, on the other hand, can only access the Incentive.
All-inclusive tariffs and incentives are disbursed by the GSE starting from the date of entry into commercial operation, for a specific period for each type of plant equal to the useful life of the plant itself.

The Legislative Decree 387 of 29/12/2003[10] [12] introduces the "***certificates of origin***" (“***Garanzie di Origine***”). In fact, it establishes the assignment to the electricity produced by plants powered by renewable sources of "guarantee of origin of electricity produced from renewable energy sources". For each MWh of renewable electricity injected into the grid by renewable qualified plants, the GSE issues a GO title, in compliance with Directive 2009/28 / EC.
Starting from January 1, 2013, companies that sells the electric energy have the obligation to procure a quantity of GO securities equal to the electricity sold. To do this, each company is required to cancel a quantity of GO equal to the electricity sold as renewable before the March 31 of the following year.
The guarantees of origin (GO) can be negotiated on the GME market (*Gestore Mercati Energetici*) through competitive procedures. The types of GOs that can be traded in GME are divided in five categories, referring to the following renewable energy sources: hydroelectric, wind, photovoltaic, geothermal and other.

The incentive scheme analyzed in the previous lines ended in the October 31 2021, currently a transitory period are in place unless the implementing decree from MISE of the D.lgs 199/2021 are published. In this period the previous incentive scheme is used until the new system enter into service.
A more clear view and analysis will be done in the paragraph 2.5 about the Legislative Decree n° 199 of the 8 November 2021. [6]

[10] Decreto Legislativo 29 dicembre 2003, “Attuazione della direttiva 2001/77/CE relativa alla promozione dell’energia elettrica prodotta da fonti energetiche rinnovabili nel mercato interno dell’elettricità”

2.4. Environmental Legislations

The environment can be defined as the system of relationships between anthropic, naturalistic, chemical-physical, climatic, landscape, architectural, cultural, agricultural and economic factors.

The global Italian national framework for the environmental regulation is the *Legislative Decree 152 of the 3 April 2006*[11]. [13] The *Legislative Decree n°4 of the 16 January 2008*[12] [14] introduced some changes in the above mentioned D.gls, introducing the concepts of ***EIA*** *(VIA)*, ***SEA*** *(VAS)*, **IEA** (*AIA)* respectively ***Strategic Environmental Assessment*** (Valutazione Ambientale Strategica), ***Environmental Impact Assessment*** (Valutazione Impatto Ambientale) and ***Integrated Environmental Authorization*** (Autorizzazione Integrata Ambientale).

- **EIA – ENVIRONMENTAL IMPACT ASSESSMENT**
  The environmental impact assessment is the procedure by which the effects on the environment of a given project are identified. The general purpose of the EIA is to ensure that human activity is compatible with the conditions for sustainable development. The EIA procedure is divided into several phases which can be summarized as follows:
    - **Screening phase:** (*Verifica di assoggettabilità*): verification in order to assess whether the projects can have a significant impact on the environment and must be subjected to the EIA phase.
    - **Environmental impact study:** report that must be prepared by the proponent. The contents of this document can be defined through the prior consultation phase with the competent authority.
    - **Submission of the application:** it is carried out by the proponent of the work to the competent authority. The final executive design of the project, the environmental impact study, licenses, authorizations are attached to it.
    - **Consultation**: this is the phase characterized by extensive publicity and participation measures.
    - **Evaluation of the environmental impact study and the consultation:** this is the phase characterized by a technical check in which the documentation presented is evaluated.

[11] Decreto Legislativo 3 aprile 2006, n. 152 "Norme in materia ambientale"
[12] Decreto Legislativo 16 gennaio 2008, n. 4 "Ulteriori disposizioni correttive ed integrative del decreto legislativo 3 aprile 2006, n. 152, recante norme in materia ambientale"

- **Decision:** it is the final phase of the procedure which provides for the adoption of a motivated judgment to be made within 150 days following the submission of the application.

- **SEA - STRATEGIC ENVIRONMENTAL ASSESSMENT**
The strategic environmental assessment examines the impact of plans and programs over a "large area", and analyzes all the possible interrelations that the related decisions can cause to human health, the landscape, the environment, the economy, etc.
The SEA is carried out prior to the approval of the plan or program. It aims to ensure that the impacts resulting from the implementation of plans and programs are taken into account before their approval. The various stages of the procedure consist of:
  -
  - **Screening phase** (*verifica di assoggettabilità*): verification in order to assess whether the plans may have significant effects on the environment and whether they must be subjected to the assessment or not;
  - **Environmental report:** it is up to the proponent following consultations between the latter and the competent authority. The environmental report must identify, describe and evaluate the significant impacts that the implementation of the proposed plan could have on the environment;
  - **Consultations:** with the public following suitable forms of advertising by the proponent
  - **Evaluation of the environmental report:** by the competent authority which expresses its reasoned opinion.
  - **Final decision:** by the competent authority on the basis of the plan, the environmental report, the reasoned opinion and the documentation acquired during the consultation;
  - **Monitoring activity:** carried out by the proposer in collaboration with the competent authority.

- **IEA – INTEGRATED ENVIRONMENTAL AUTHORIZATION**
The IEA has as its object the prevention and reduction of pollution from industrial activities and reducing emissions into water, soil and air, achieving a high level of environmental protection. The IEA regulations have

been profoundly revised, with a view to procedural and provisional simplification, by *Legislative Decree 46/2014.*

2.4.1. Minimum Vital Flow and Ecological Flow

In accordance with current legislation (Legislative Decree 152/2006) [13] all derivations of public water in natural waterways are subject to the obligation to maintain a minimum water flow, defined as "***minimum vital flow***" (DMV). The Program for the Protection and Use of Water in Lombardy[13] [15] governs in detail the operational aspects for the implementation of the minimum vital flow.

The Resolution of the Institutional Committee of the Po River District Basin Authority[14] [16], with which the "Ecological Flow Directive" was adopted in the Po Valley district, introduced the definition of "**Ecological Flow**" (DE). The Ecological Flow is intended as the hydrological regime which, in a hydraulically homogeneous stretch of a watercourse, complies with the achievement of the environmental objectives defined by the Community Framework Directive on Water (*n°. 2000/60 / EC*).

Considering the Lombardy Region, the *DGR n° 2721 of the 23 December 2019*[15] [17] deals about the implementation of the Ecological Flow (DE) in Lombardy and the methodology for determining the corrective factors. The Ecological Flow is composed by two components: one hydrological component considering the catchment basin and the water flow, and one ecological component considering the morphology, the interaction between superficial and underground water, the pollution, the time modulation during the year.

$$Q_{DE} = k \cdot Q_{aver} \cdot S \cdot M \cdot A \cdot Z \cdot T \tag{2.2}$$

Where:

Q_{DE}	Ecological Flow	[l/s]
Q_{aver}	yearly natural average specific flow rate per surface unit of the underlying catchment basin	[l/(s km^2)]

[13] PTUA - Programma di Tutela e Uso delle Acque - DGR X / 6990 of 31 July 2017
[14] Delibera del Comitato Istituzionale dell'Autorità di Bacino distrettuale del Fiume Po - n°. 4 of 14 December 2017
[15] Decreto Giunta Regionale 23 dicembre 2019, n. 2721 "Metodologia per la determinazione dei fattori correttivi del deflusso ecologico"

k	parameter that expresses the percentage of the annual natural average flow that must be considered in the calculation of the DE	[-]
S	surface area of the catchment basin	[km^2]
M	Corrective factor related to the morphological characteristics	[-]
A	Corrective factor related to the contribution of underground aquifers	[-]
Z	Corrective factor function of the maximum value of other three factor	
T	Corrective factor related to the modulation in different periods of the year	[-]

Note that the terms ($k \cdot Q_{aver} \cdot S$) compose the hydrological component, while the product ($M \cdot A \cdot Z \cdot T$) represents the environmental component, where M, A, Z, T are the corrective factors.
The value of the parameter **k** is equal to 0.1 for all the rivere belonging to the regional natural water network, the basis for calculating the annual natural average specific flow rate (**Q_{aver}**) is provided by the *Regional Water Balance*, an implementation tool of the PTUA, with *DGR n. XI / 2122 of 09 September 2019*.
The corrective factor **M** is related to the morphological characteristics of the riverbed in the river section considered and expresses the ability of the riverbed to maintain the minimum flow rates in conditions compatible with the habitat and use objectives. The value has a range of application between 0.7 and 1.3.
The corrective factor **A** expresses the need for greater or lesser release due to the contribution of underground aquifers. The value has a range of application between 0.5 and 1.5
The corrective factor **Z** is identified by the maximum value assumed by the factors {N, F, Q} specified below:

- the corrective factor **N** expresses the need for greater protection for river environments with high naturalness;
- the corrective factor **F** expresses the need for greater protection for river environments which are subject to particular tourist-social use and of particular landscape interest.
- the corrective factor **Q** expresses the dilution requirements of the polluting loads carried into the waterways according to the existing anthropic activities;

The corrective factor **T** expresses the modulation needs of the outflows in the different periods of the year, allowing to articulate the releases in a differentiated way rather than through a constant value. The value has not a range of application.

2.5. New Legislative Decree No. 199/08.11.2021

The new Legislative Decree 199 of 8 November 2021 [6] defines the tools, mechanisms, incentives and the institutional, financial and legal framework necessary to achieve the objectives by 2030.
The decree is defined as "Implementation of the Directive (EU) 2018/2001 of the European Parliament and of the Council, of 11 December 2018 (also called "RED II"), on the promotion of the use of energy from renewable sources.

It radically reforms the incentive system for renewable energy sources, extending it to the production of biomethane and green hydrogen, as well as to new forms of consumer organization, identified in "Renewable energy self-consumers" (*Autoconsumatori di energia rinnovabile*) and "Renewable Energy Communities" (*Comunità Energetiche Rinnovabili*), to to which specific forms of support and incentives will be dedicated for the production and self-consumption, including collective ones, of renewable sources, not just electricity.

The new Legislative Decree 199/2021 largely replaces the previous Legislative Decree 28/2011 [10], and entered into force on 15 December 2021. In the terms of 90 days, and 180 days from its entry into force, the Arera, the Ministry of Ecological Transition - MITE - and GSE spa must respectively adopt resolutions, implementing decreesand implementing regulations of the various measures adopted to make the law fully operational.

In the transitional phase the GSE is authorized to extend the operation of the previous Ministerial Decree of 4 July 2019 [11], opening the eighth and ninth windows of tenders for Auctions and Registers (January - March 2022) (May - June 2022) if the implementing decrees of the new incentive system were not adopted in the meantime.

3 Analysis of Hydroelectric plants

In this chapter will be analyzed different power plant in terms of technical characteristics, authorization procedure and economic & financial performances. Since Iniziative Bresciane spa is listed in the Euronext Growth Milan, the Italian stock exchange for SME, the analysis of the plants are carried out without specifying the name of the plant, the precise localization and some sensible information, in order to maintain the confidentiality of the most critical data. The plant will be numbered and considered as "plant N°1" and so on.

Each plant will be analyzed first in a technical way: showing the hydraulic resource availability assessment, the major components and the construction choices, and a particular focus will be done on a peculiar characteristic of each plant as later specified. Secondly a detailed financial and economic analysis is performed of each plant. The analysis shows the parameters that influence the plant's profitability, using the Discounted Cash Flow (DCF) valuation method the actual value of the plants are computed. A comparison between the actual value using the original hypothesis and data and the actual value computed with the ex-post data is also done.

The plants analyzed in this document are three micro hydro power plants, located in the Province of Brescia, two of them in the Vallecamonica Valley. Each plant has a peculiar characteristic, more in detail:

The plant N°1 is an high head power plant built in 2009, it has a concession power of 404 kW, the technology of the turbine is a Pelton turbine. Particular characteristics of this plant is the fact that is built with a Project Financing scheme, with an agreement with the local Municipality for the construction and management of the power plant. Another peculiarity is the specific water intake works that uses a series of drainage wells into the slope of the mountain. During the description of the plant particular focus will be directed into the bureaucratic procedure of the Project Financing from the initial concession request, the agreement with municipality, the authorization procedure, the environmental requirements, the incentivized procedure, to the final testing and operation.

The plant N°2 is a medium head power plant built in 2016, it has a concession power of 213 kW, the technology of the turbine is a Pelton. During the description of the plant particular focus will be directed into the evaluation of the Minimum Vital Flow with different methodology. Note that nowadays there is a public consultation in the Lombardy Region, according to the *D.G.R. 23 december 2019 N° XI/2721*, concerning the transformation of the Minimum Vital Outflow into a new Ecological Flow composed by different parameters, as explained in the previous chapter (2.4.1). In the analysis of this plant are reported the methodology used in the design phase, not the new Ecological Flow model, however the approach is very similar to one case considered in the analysis.

The plant N°3 is a low head power plant built in 2020, it has a concession power of 176 kW, the technology of the turbine is a Kaplan.
The plant's peculiarity is the location on the hydrographic left across an existing barrage, the plant is an in-flow plant without the requirement of Minimum Vital Flow. However, an irrigation channel is present in the hydrographic left of the river that need to be always supplied of water in an adequate way. The level of the water upstream the barrage is maintained fixed through the regulation system of the turbine.
During the description of the plant particular focus will be directed into the evaluation of the water flow that can be exploited by the plant, the flow that must release for reducing the visual impact over the barrage, and the flow that source the fish ladder. In order to properly run the system some measurements instruments need to be placed.

In the following table (3.1) are reported a summary of the major characteristics of the three plants analyzed in the following pages.

	Plant N°1	**Plant N°2**	**Plant N°3**
Head	High head	Medium head	Low head
Water intake	Diversion channel	Diversion Channel	In-flow
Concession Power	403.75 kW	212.94 kW	175.88 kW
Turbine	Pelton	Pelton	Kaplan
Entering in service	2009	2016	2020

Table 3.1: Major characteristics of the power plants analyzed

3.1. Plant N°1

The plant N°1 is located in the upper part of the Vallecamonica valley, in the Municipality of Ponte di Legno. A distinctive characteristic of this plant is the integration with the drinking water distribution system of the municipality. Another important peculiarity of this infrastructure is the agreement with the Municipality for the construction with the modality of the *Project Financing*. The right to use water, the concession for hydroelectric and drinking water use, is owned by the Municipality, which has given a sub-concession for the construction, the financing and operation of the power plant for 35 years with the mandatory upgrade in the drinking water system. (New intakes of natural spring, settling basin, storage tank, tubes).
In fact downstream the powerhouse, a big water storage with a size of roughly 1800 m^3 is constructed in order to be the new reservoir of the drinking water distribution network, improving the security and reliability of the network.

The plant has two different non common typology of water intake: intake from natural spring already partially exploited from the old supply aqueduct of the municipality, and 10-15 meters long perforation with holed tubes in subsurface layer that capture the sub-surface water on specific draining lines on the hydrographic right of the small valley.

The plant is characterized by a gross head of 349 meters, exploiting an importante geodetic head between the loading tank located at 1735 m and the turbine location at 1386 meters. The plant has a nominal concession power of 403.7 kW, the generator has a maximum apparent power of 750 kVA and a maximum active power of 600 kW, the turbine has a maximum power of 580 kW. It is also present a transformer of 1000 kVA of maximum apparent power.

Main Data	
Gross head	349 m
Average flow	118 l/s
Nominal concession power	403.75 kW
Maximum flow	200 l/s
Turbine maximum power	580 kW
Generator maximum active power	600 kW
Generator maximum apparent power	750 kVA
Transformer apparent maximum power	1000 kVA

Table 3.2: Main data of power plant No. 1

The plant can be categorized as a high head small hydro, with diversion channel and Pelton technology of the turbine. Note that the settling basin at the top of the plant, works only as a loading tank it has no storage use of water. The plant, therefore, can be categorized as a run-off plant. In the following table are reported the main data of this hydropower plant.

3.1.1. Geological, hydrogeological and geotechnical analysis

In the following paragraph are synthetized the results of the geological, hydrogeological, and geotechnical studies performed by the designer during the technical design phase, in order to have the proper data for the drafting of the executive design of the power plant.

The hydrographic system has a main drainage line, that creates a river from the glacier, and a series of minor superficial draining lines that run through the right slope of the small valley, characterized by debris deposits along which the water drained from the upper basin flows.
From the hydrogeological point of view, the debris deposits on the slope are characterized by high permeability (of the order of $2x10^{-3}$ m/s) which translates into a high capacity of infiltration and a good water flowing under a limited depth of the surface. The water flows according to the lines of maximum slope and greater permeability under the surface at limited depth. The total surface of the basin underlying the drainage lines is estimated to be of the order of 2.81 km^2.

- **PLUVIOMETRY:**
  In the study phase of rainfall, the designer considered to deduce the average annual precipitation value from existing bibliographic sources:

  - *Carta delle precipitazioni medie annue del territorio lombardo (registrate nel periodo 1891-1990) – Regione Lombardia, 1999*
    The document was write using the data from the *Annali Idrologici – Parte prima* from the *Servizio Idrografico del Po*.

  - *Programma di Tutela e Uso delle Acque L.R. 12/12/2003 n. 26 art. 45 – Regione Lombardia – DG Servizi di Pubblica Utilità – U.O. Risorse Idriche – Novembre 2004*
    At the chapter "Bacino dell'Oglio sopralacuale" are reported the hydrogeological data for rainfall and snow metering that are

significant for the areas in question. (upper Valle Camonica sector)

In relation to the reliability of the data available it is considered appropriate to adopt the information reported in the second bibliographic source. The value of average precipitation considered is equal to **1050-1200 mm/year**.

- **ASSESSMENT OF WATER FLOW:**
  The assessment of the availability of the water flow is done in three different way in order to be sure of having a reliable and good estimation of the hydraulic resources that can be exploited.

  - *From direct survey on site:*
    an evaluation of the tributary flows along the draining line and at the springs was carried out, obtaining indicative water availability, as an average flow rate a value between 100 and 140 l/s.

  - From *duration curve* derived from the *regionalized synthetic curves – DGR 6/42446 of 12 april 1999:*
    Using the synthetic flow rate curves of water courses for the calculation of the average flow rate, the average flow rate of 95.7 l/s is obtained.

  - *Programma di Tutela e Uso delle Acque L.R. 12/12/2003 n. 26 art. 45 – Regione Lombardia-DG Servizi di Pubblica Utilità - U.O. Risorse Idriche – Novembre 2004*
    Using the regionalization formula for estimating average unit contributions in mountain basins:

$$q_s = q_m \frac{P_s}{P_m} \tag{3.1}$$

Where:

q_s	Average annual unit contribution in the section considered	[l/s]
q_m	Average annual unit contribution to the section with available measurements close to the area considered	[l/s]
P_s	Average annual precipitation at the section considered	[mm/year]
P_m	Average annual precipitation at the section equipped with measurements	[mm/year]

In the following table are reported the results from the three different analyses of the water assessment availability. Considering the results is possible to indicate a value between **100 and 140 l/s** as the average flow rate.

Estimated water flow	
From direct survey	100 – 142 l/s
From duration curve (DGR 6/42446 of 12.04.99)	95.7 l/s
From regionalization formula (PTUA 12/12/2003)	101.5 – 115.8 l/s

Table 3.3: Result of the water assessment availability

- **GEOTECHNICAL ASPECTS:**
  The geotechnical aspects of the land affected by the project activities are summarized below in the table (3.4). The geotechnical parameters were derived from direct observation of the excavations and from morphological and depositional assessment.

GEOTECHNICAL PARAMETER		Groundwater deposit	Alluvian deposit
Volume weight above groundwater	γ_s	19 kN/m^3	20 kN/m^3
Volume weight in groundwater	γ'	18 kN/m^3	11 kN/m^3
Friction angle	ϕ'	33 °	32 – 35 °
Cohesion	c'	0 kPa	0 kPa
Young's modulus	E	22 – 28 MPa	24 – 30 MPa

Table 3.4: Soil's Geotecnical parameters

3.1.2. Description of the components

In the following paragraph are analized the principal structures and works characterizing the plant.

- **UNDERGROUND WATER TANK STORAGE:**
  The underground water storage is located downstream the powerhouse, immediately before the start of the water distribution network of the municipality. This structure is the first that was completed, due to the agreement with the municipality, with a by-pass pipeline in order to be operative before the end of the construction and satisfy the need of the population.
  The specific request of the municipality is that the tank has a capacity of 1800 cubic meters. The main data on which the tank has been sized are:
  - Served inhabitants: 30,000
  - Average water requirements: 235 l/s
  - Compensation capacity: 1600 m^3
  - Fire reserve: 118 m^3
  - Emergency reserve: 10% of the capacity

  The tank has a rectangular shape, the external dimension are 39.90 x 13.50 meters. It is constructed with reinforced concrete in double prefabricated slab with a minimum thickness of 30 centimeters and is completely waterproofed.

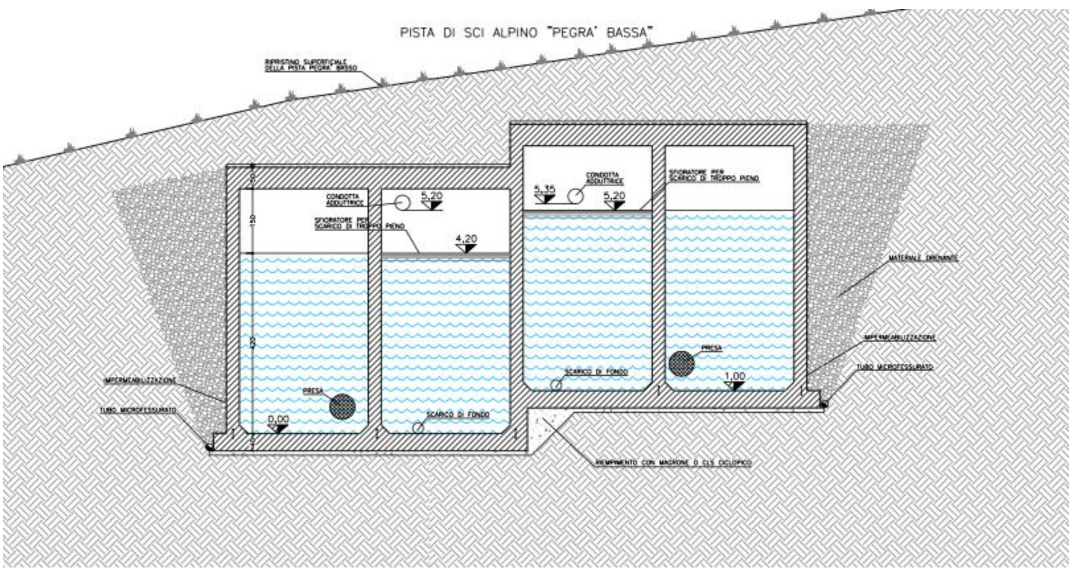

Figure 3.1: Technical drawing of the underground water tank storage

The internal structure is composed by two pool of internal dimensions equal to 34.00 x 6.30 meters and an height equal to to 5.70 meters. Particular characteristics is the location in two major steps of the two tanks, in order to follow the slope of the terrain.
Each tank is equipped with supply piping with shut-off gate, bottom drain with gate, safety spillway, distribution pipe and guard gate. The internal surfaces of the tanks are treated with epoxy glazing products compatible for aqueduct use.

- **ROAD WORKS:**
  The road works are functional to make access to the construction site and subsequently inspections and maintenance accessible to work vehicles. The main interventions are: the cleaning of debris on the existing road path, the construction of support cliffs for the upstream and downstream slopes, widening of the existing road in the most degraded sections, construction of gutters for the disposal of rainwater and water, regulation of the road surface by means of concrete and pebbles in the steepest sections and in limestone and beaten earth in the sections with limited slope.

- **INPROVEMENTS OF EXISTING WATER INTAKE ANCHE NEW WATER INTAKE OF THE EXISTING WATER SPRING**
  It is planned to build a small barrage and a collection structure equipped with trenches with wing walls, downstream of the existing intake basins. The water from the springs is collected and later is conveyed to the collection well and therefore to the existing pipeline.

  In the lower sector of the spring field, a new intake work is built downstream the existing water intake in order to collect the spring water not intercepted upstream, as visible in the figure (3.2). The intake has a horizontal length of 24.00 meters, where slits for the passage of water are positioned, which then is poured into the settling basin.
  All the new buildings are underground, any visible parts are covered with local "Opus Incertum" stone for environmental reasons.

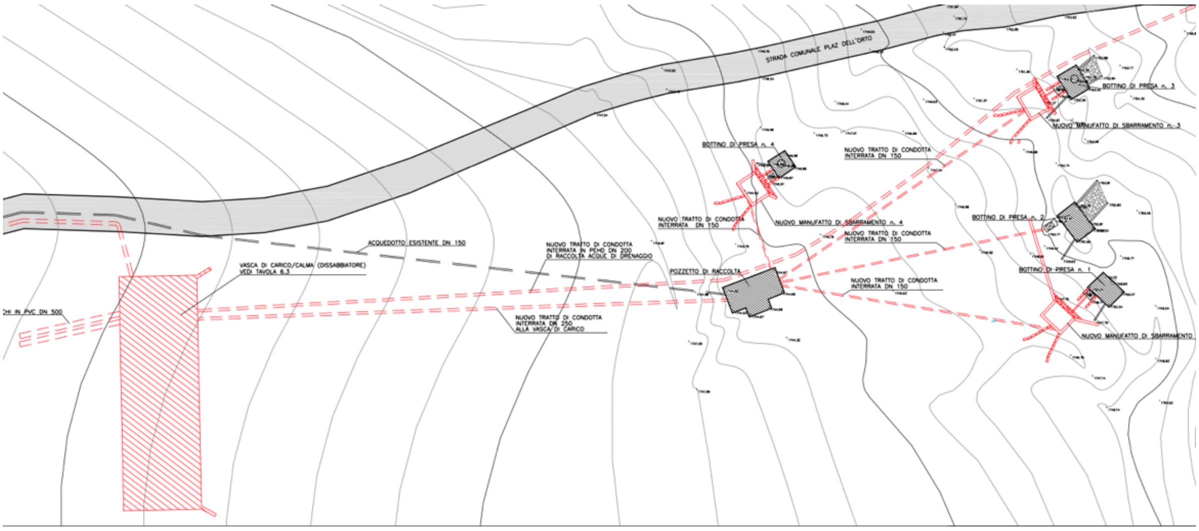

Figure 3.2: Technical drawing representing the spatial disposition of the water intake

- **SETTLING BASIN AND LOADING TANK**
  The spring waters collected upstream and channeled through underground pipes, together with the water coming from the new intake work are poured into the settling basin. It consists of a rectangular basin measuring 22.00 x 2.00 meters which ends with a discharge that pours into the loading basin measuring 3.10 x 11.80. There are sliding gates for maintenance activities and spillways that empty outside, as well as a penstock starting gate.
  The new building is buried with the visible parts made with local "Opus Incertum" stone cladding, improving environmental integration.

- **NEW UNDERGROUND WATER INTAKE WORKS**
  Since the amount of surface water at the source field is far lower than that granted by the water use concession, further intake works are required in order to reach the necessary amount of water.
  It is considered necessary to build subsurface collection water intake to a depth between 1.5 and 5 meters from the ground level at the interception of the drainage lines. Sub-horizontal drainages works are made by drilling starting from the axis of the drainage line, for a length of at least 10-12 meters within the covering deposits or by laying holed pipes in trenches with open pit and filling with drainage material (pebbles and gravel) and protected by a waterproof layer.
  The solution adopted allows to capture a greater amount of water by limiting the uncertainty of the surface flows, limiting the effects of surface flow

excursions throughout the day and limiting the effects of frost that hardly affects the sub-surface water table.

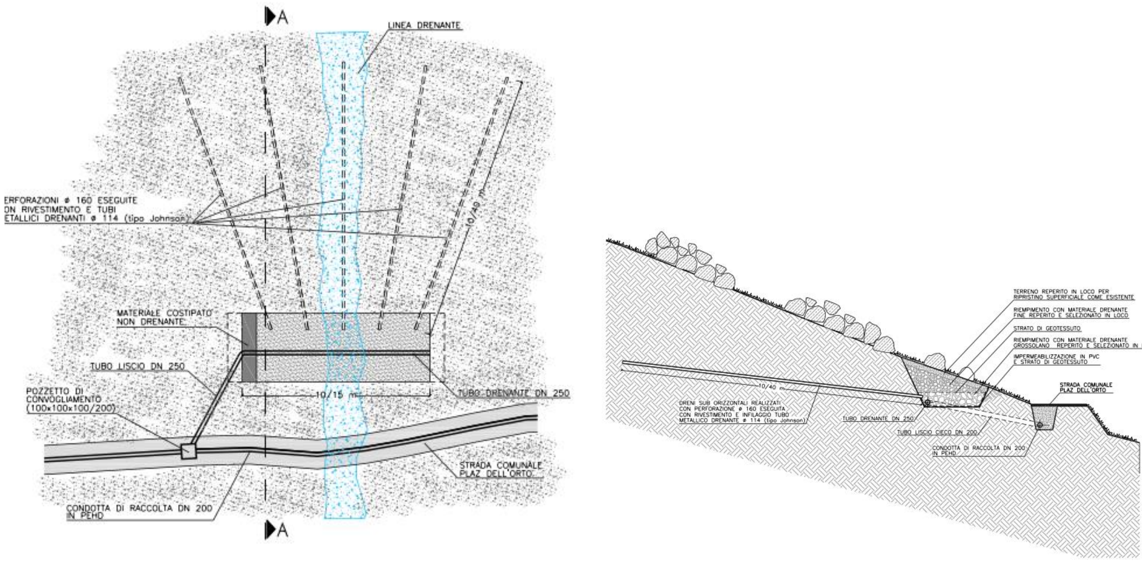

Figure 3.3: Technical drawing of the new underground water intakes

- **NEW PENSTOCK – AQUEDUCT PIPELINE**

  The new penstock and aqueduct pipeline consists of a single section with a diameter od 350 mm. from the settling tank at an altitude of 1735.00 meters to the turbine in the engine room at an altitude of 1386.00 meters with a geodetic head of 349 meters.

  The piping is in electro-welded steel for drinking water pipes, that meets the standard UNI EN 10224.2003, protected externally with heavy bituminous coating and internally with epoxy paint without solvents. The nominal diameter is 350 mm, the path is planned along the hydrographic right side of the valley and under the road at a depth of about 1.00 meters. Parallel to this pipeline is layed down a cable duct of ϕ125 for fiber optic cables for signals.

- **POWER HOUSE ED ELECTROMECHANIC EQUIPMENT**

  The central building has dimensions of 12.10 x 6.10 meters with expansions of 4.75x2.00 m for the valve compartment and 4.70x3.70 m for the ENEL delivery room and measurement room. The building is partially buried, the above-ground visible part has the typical construction type of mountain huts, with part of stone walls and part covered with wooden. The roof is two-pitched with a wooden supporting structure and a slate slab roof.

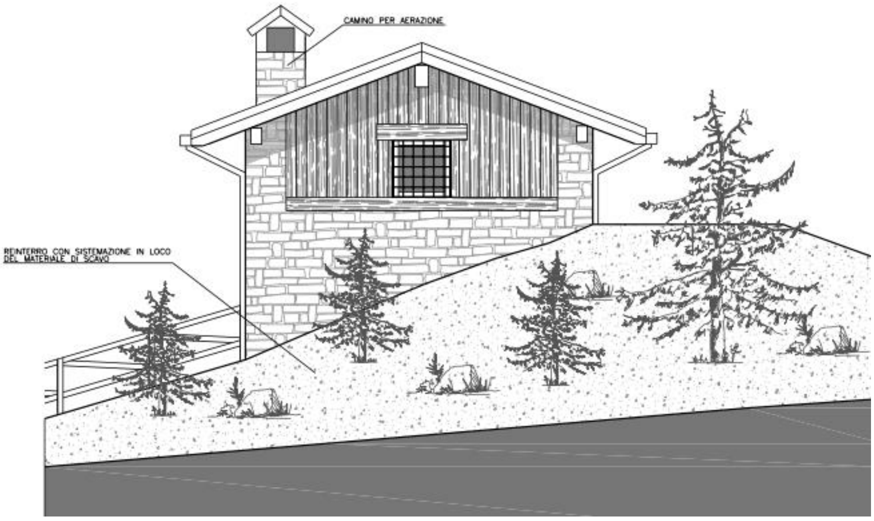

Figure 3.4: Technical drawing of the powerhouse

The turbine discharge pours directly into the collection storage. The turbine is equipped with a by-pass to maintain efficient operation of the aqueduct even when the power plant is out of service. The entire system is equipped with automation devices for the operation of the plant without surveillance. In the machine room there is the generator-turbine complex, the transformer, the armored compartments and the control panels.

The turbine consists of a horizontal axis Pelton-type turbine with two injectors with impeller mounted cantilevered on the generator shaft. The characteristic data of the turbine are:

Turbine Data	
Gross head	349 m
Max flow	200 l/s
Turbine maximum Power	580 kW
Generator's maximum Power	600 kW
Generator's apparent power	750 kVA
Generator's voltage	400 V

Table 3.5: Turbine's main technical data

The turbine is composed of an impeller with blades in stainless steel GX5 Cr Ni 13.4, hub in tempered, turned, and bored steel. A welded steel case protect the turbine, that has also a corrosion protection and sandblasting. The injectors are with curve, nozzle, pin and jet deviators in AISI 304 steel.

Upstream there are two valves, in ductile iron GS 500-7 UNI-ISO 1083-91, one for the turbine and one for the by-pass circuit.
All paints used are suitable for food use due to drinking water operation.

The three-phase synchronous generator is able to an apparent power of 750 kVA at a voltage of 400 V, with bearings to withstand radial and axial forces with a useful life of at least 100,000 h. The three-phase oil-filled transformer for indoor installation raises the voltage from 400 V to 15,000 V.

The annual electricity production is estimated equal to 2,518,191 kWh/year as specified in the following equation (3.2) using an estimated availability of the plant of 350 day/year since the plant has a constant availability of water, and an average efficient power of 299.78 kW

$$EE = P_{eff} h_{operation} \tag{3.2}$$

Where:

EE	Yearly expected electric energy produced	[kWh/year]
P_{eff}	Average efficient power	[kW]
$h_{operation}$	Hours of operation per year	[h/year]

3.1.3. Major milestones

In the following paragraph are reported the major milestones of the awarding process to obtain the concession to use water for hydroelettric use, the main event during the authorization procedure, and the steps to obtain the incentivized tariff from GSE.

The process started in 2002 while the plant was operative in 2009. The seven year period for the authorization and construction is a common problem of this projects in the Italian context. However this seven year period is not so long compared to other project where between the first design document and the fully operation of the plant can pass decades. Moreover, this specific plant The bureaucratic burden is high, numerous opinions and constraints are issued by various public entities which cause a slowdown in authorizations and an extension of the time before construction.

As you can imagine, this datas are very confidential therefore the following milestones are reported without entering in the detail of the sensible content, without naming the counterparts, and without specificying the exact date but only the period of time in order to have a comprehensive view avoiding leakeages of private information. Since Iniziative Bresciane spa is a public listed company on the Milan stock exchange this precautions are necessary.

- **Concession to use water for hydroelectric uses:**
  Obtained in December 2002 by the Lombardy Region, owned by the municipality of Ponte di Legno which obtained it for a maximum flow rate of 200 l/s and an average flow rate of 118 l s for hydroelectric use and a maximum flow rate of 82 l/s and a average flow rate of 52 l/s for drinking water uses.

- **Public information notice for Project Financing:**
  In June 2005 public information notice for the search for offers for the construction and operation of the plant.

- **Awarding:**
  In April 2006, the municipality awarded to Temporary Association of Company (INBRE + Construction Company spa) and approved the related executive project presented, the construction and management concession for the construction of the work.

- **Special purpose veihcle:**
  In July 2007, the special purpose vehicle company was established, owned by the promoters which is authorized to sign the agreement with the municipality.

- **Agreement with the Municipality:**
  In July 2007, the sub-concession agreement was signed between the Municipality and the special purpose vehicle company at which are entrusted for a duration of 35 years: the executive design, the execution of the works, the functional and economic management of the work (included the ordinary and extraordinary maintenance), and the financing.

- **Conferenza dei servizi:**
  On February 2008 approval of the executive project by all the competent public entities that have given the following prescriptions:
  - **Local Sanitary authority (ASL Vallecamonica-Sebino)**:
    - All the material that is in contact with the drinkable water must be certified for food use, without contamination of the water;
    - Before the entering in service, particular and detailed analysis of the water must be carried out.
  - **Local environmental agency (ARPA):**
    - during construction the emission in the atmosphere must be contained to low level, in similar way the acoustic emissions must be reduced during construction and operation of the plant;
    - the measurement of the water flow is mandatory during the operation of the plant.
  - **Local Park (Parco dell'Adamello):**
    - the earth movements works must be completed at the latest in 36 months;
    - the drainages channel of the road must be done in wood not steel, the pavement of the road must be done showing the concrete the less possible;
    - a surety policy of roughly 20 thousand euros is requested;
  - **Province of Brescia's Environmental office (Ufficio Vincoli Ambientali e Pianificazione):**
    - All the slopes must be reprofiled and regreened with the native flora after the construction phase;
    - the cutting of a section of the forest in order to build the plant implies a compensation charge of roughly 8 thousand euros;

- **Authorization of the construction (Autorizzazione Unica) and start of the construction works:**
  In June 2008, release of the authorization for the construction of the hydroelectric plant, reaffirming the requirements expressed at the Conference of Services. Immediately after the authorization the construction works are started.

- **Recognition of IAFR (Impianto Alimentato da Fonti Rinnovabili):**
  In November 2008, the GSE recognized the plant as IAFR (Impianto Alimentato da Fonti Rinnovabili) propedeutical step to obtain the incentivized tariff.

- **Authorization of provisional operation:**
  In May 2009 the Province authorized the provisional operation of the plant.

- **Entry into commercial service:**
  On June 1, 2009, the plant entered commercial service and the all-inclusive incentivized tariff was requested.

- **Technical and administrative testing:**
  In May 2010, the technical and performing testing of the work was carried out.

- **Technical testing of the Brescia's Province:**
  In November 2012 the test was carried out by an engineer appointed by the Province of Brescia.

- **Final exercise authorization:**
  In January 2013 the Province of Brescia authorized the definitive exercise of the derivation.

3.2. Economic & Financial Analysis – Plant n°1

This economic & financial analysis in order to maintain the discretion and confidentiality, is completely independent from the original business plan written by Iniziative Bresciane spa during the feasibility study of the investment. However, this analysis is performed starting from the real data available from the "plant n° 1" by INBRE, showing the major results, without entering into deep analysis of the more confidential data.
The analysis is composed by two different scenarios in order to highlight the performances that can be predicted before the construction, as in a business plan, and the performances at nowadays until 2021 with the prediction for the following year until the end of the lifetime. All the cashflow are actualized to the year 2007, when the decision of the investment was made.
Two scenarios are:

- **Ex-ante:** using the same data, hypothesis and assumptions available before the construction in the year 2009, (mean annual producibility, CAPEX, OPEX, financial yields, ecc..);

- **Ex-post:** using the real performing data of the plant, until the year 2021 and the same data, hypothesis and assumptions adapted with the information available in 2021.

3.2.1. Data & Hypothesis

The total investment is influenced by technical standard required for drinking water plants and the output is not "on a river" but in a specific water storage tank of roughly 3,000 m^3.
Considering the **CAPEX** the value of the estimation in the executive design documents permits to quantify the expenditures in the *ex-ante* case. The total planned cash-out is around 3.750 million euros as specified in the following graph and table showing the subdivision in category of cost. The cash-out is equally distributed in two years of construction.

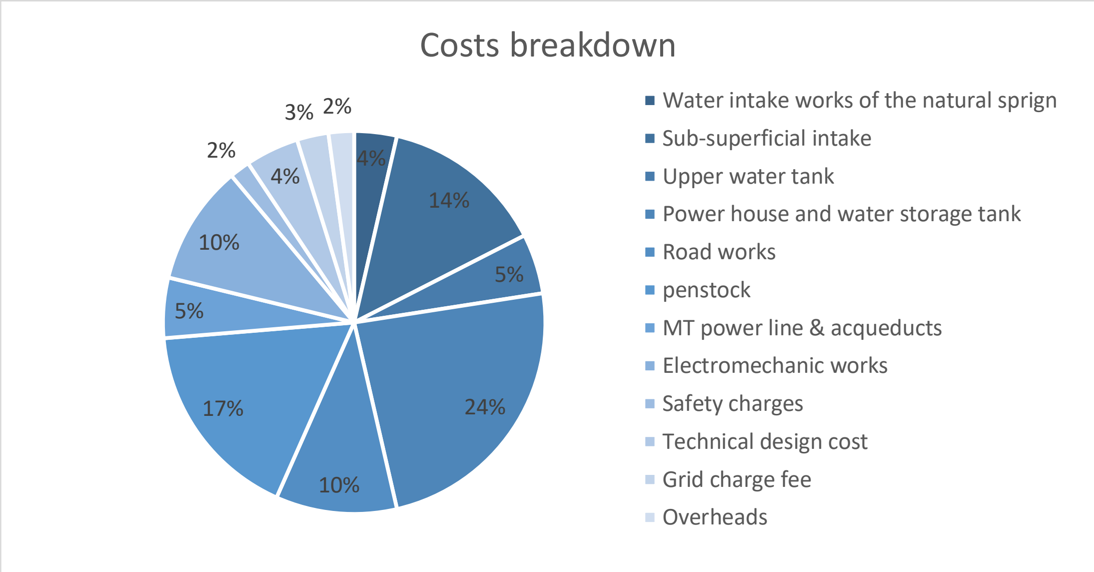

Figure 3.5: Graphical representation of the powerplant's CAPEX

CAPEX breakdown	
Water intake works of the natural sprign	135,000.00 €
Sub-superficial intake	521,000.00 €
Upper water tank	190,000.00 €
Power house and water storage tank	894,500.00 €
Road works	384,500.00 €
penstock	639,000.00 €
MT power line & acqueducts	191,000.00 €
Electromechanic works	380,000.00 €
Safety charges	65,000.00 €
Technical design cost	170,000.00 €
Grid charge fee	100,000.00 €
Overheads	81,000.00 €
TOTAL	3,751,000.00 €

Table 3.6: CAPEX breakdown into categories of cost

About the *ex-post* valuation, the effective CAPEX is valued considering the effective book value in the balance sheet equal to 4.004.764,38 €, as clearly noticeable there is an over-cost of roughly 250,000.00 €, that means some +6.67%

Considering the **O&M costs** it has been signed a contract with another company that makes all the ordinary maintenance and runs the plant with the correct set-up

and prescription for a tariff of 4.5 €/MWh. This value is considered for *ex-ante* and *ex-post* valuation.
Considering the **insurance costs**, an All-Risk insurance contact has been signed. In the *ex-ante* valuation a initial premium o 6,500.00 € adjusted for inflation over the years, in the *ex-post* valuation are considered the real premium paid until 2021 and later the 2021 value adjusted for inflation.

Considering the **regional concession fees** and the **concession extra-fees**, in the *ex-ante* valuation were considered the value of 2009, respectively of 14.25 €/kW and 20.35 €/kW, adjusted for inflation over the years. In the *ex-post* valuation are considered the real concession fees paid until 2021 and later the 2021 value adjusted for inflation.

Considering the amortization plan, since the plant is constructed with in Project Financing agreement, the amortization timeline is the lifetime of the concession agreement between the municipality and INBRE, signed in 2007. Therefore, the **lifetime** of the plant is 33 years of effective production, while the **amortization rate** is 3.03% equal to 33 identical tranches of 113,666.67 € for the *ex-ante* case. In the *ex-post case* until 2021 are used the real value from balance sheets, the amortization rate was roughly 4.19%, in the following years is considered of 2.3% in order to end the amortization plan with the lifetime of the plant.

Considering the **electricity price** at which the energy is sold, the plant had access to an incentivized tariff according to the Minister Decree 18 December 2008 with a fixed value of 220 €/MWh for 15 years. After this period the plant can sell the energy to the GSE with the "RID – Ritiro Dedicato" with some minimum guaranteed prices for the first 1,500 MWh, under the "Prezzi Minimi Garantiti" scheme.
In the table are reported the minimum guaranteed prices for hydroelectric electricity for the year of 2009, in the *ex-ante* the weighted average of this value is considered as price of reference for the 16-th year, later is adjusted for inflation during years. This price of reference is equal to 92.89 €/MWh.

Data	Price [€/MWh]
Less than 250,000 kWh	140.4
Over 250,000 kWh less than 500.000 kWh	107.3
Over 500,000 kWh less than 1,000,000 kWh	86.7
Over 1,000,000 kWh less than 2,000,000 kWh	80.5

Table 3.7: Minimum guaranteed prices for the year 2009

The current market price of electricity in 2022 is in the order of magnitude of 200 €/MWh very similar to the incentivated tariff, however there is not a certainty that the price in the future will maintain this value. In a conservative approach also for the *ex-post* valuation is considered as reference the weighted average of the minimum guaranteed price for the year 2021 adjusted for inflation. This weighted price of reference is equal to 86.07 €/MWh.

Data	Price [€/MWh]
Less than 250,000 kWh	156.4
Over 250,000 kWh less than 500.000 kWh	107.4
Over 500,000 kWh less than 1,000,000 kWh	67.7
Over 1,000,000 kWh less than 1,500,000 kWh	58.6

Table 3.8: Minimum guaranteed prices for the year 2021

Considering **production** of **electricity**, in the design documents the mean annual producibility estimated is 2,518.19 MWh/year, this value is used in the *ex-ante* case with the hypothesis of fixed production. In the *ex-post* case the effective real production is considered until the year 2021, while for the following years, since the production for the last 13 years was always higher than 3,000 MWh as reported in the table (3.9), two different scenarios are considered. One *worst case*, in which the production is estimated in a qualitative and conservative way in 3.000MWh. One *historical case*, in which the production is estimated with the average electricity production of the past years, equal to 3,427.07 MWh.

Year	Production [kWh]	Year	Production [kWh]
2009	2,796,397	**2016**	3,331,079
2010	3,308,006	**2017**	3,178,375
2011	3,372,604	**2018**	3,528,637
2012	3,341,808	**2019**	3,443,086
2013	3,657,480	**2020**	3,718,810
2014	3,808,328	**2021**	3,359,278
2015	3,708,044		

Table 3.9: Electricity production of the power plant No. 1

3.2.2. Hypothesis & Assumptions

The following assumptions are considered in this economic & financial analysis, considering respectively the information available in 2009 and 2021:

- **Tax Rate = 27.5% + 3.9%**
  Considering the 27% tax rate coming from Italian corporate tax (IRES) plus a 3.9% of regional tax (IRAP), from 2017 the IRES was reduced to 24%.

- **Inflation Rate = 2%**
  Considering the average inflation rate of the past 10 years and the medium-long term target of the European Central Bank.

- **Debt yield = 5 %**
  Expected yield required by the bank on a long term bank loan related to the investment in the plant.

- **Equity return = 8 %**
  Expected return required by the shareholders on the project in order to remunerate the capital investment.

- **Equity to Debt ratio: E/(E+D) = 35%**
  from the concession agreement between the municipality and INBRE mandatory equity investment of at least 35% of the total investment.

- **Discount rate (or actualization rate) = WACC**
  considering the WACC, the Weighted Average Cost of Capital, based on the debt yield and the equity return considered with the debt-to-equity ratio. Can be computed as in the equation (3.3)

$$WACC = K_e \frac{E}{E+D} + K_d(1-t)\left(1-\frac{E}{E+D}\right) \tag{3.3}$$

Where:

K_e	Cost of equity	[%]
K_d	Cost of debt	[%]
E/(E+D)	Equity to debt ratio	[%]
t	Marginal tax	[%]

In the following table are synthetized the main assumptions used in the two cases.

Data	Ex-Ante	Ex-post_worst	Ex_post_historical
Inflation rate	2%	2%	2%
Tax rate	27.5% + 3.9%	27.5% + 3.9% (24% + 3.9%)	27.5% + 3.9% (24% + 3.9%)
E/(E+D)	35%	35%	35%
Debt yield	5%	5%	5%
Equity return	8%	8%	8%
WACC	5%	5% (5.1%)	5% (5.1%)
CAPEX	3,751,000.00 €	4,004,764.38 €	4,004,764.38 €
O&M	4.5 €/MWh	4.5 €/MWh	4.5 €/MWh
Production	2,518,191 kWh	3,000,000 kWh	3,427,072 kWh
Lifetime	35 years	35 years	35 years
Amortization rate	3.03%	4.19% - 2.3%	4.19% - 2.3%

Table 3.10: Main assumptions and hypothesis for the three scenarios

3.2.3. Economic & Financial Indexes

The analysis is carried out performing the calculation of different useful indexes in order to evaluate the economic and financial performances of the two cases. To make the analysis clearer a small summary of the definitions of the parameters considered is presented.

The *Net Present Value* (**NPV**) is the cumulative value of the actualized cash flow and is calculated as:

$$NPV = \sum_{i=0}^{lifetime} \frac{(cash\ flow)_i}{(1+r)_i} \tag{3.4}$$

The *simple Payback Time* (**sPBT**) is the time required to recover the investment considering the initial cash out and the recurring cash flow during the lifetime of the plant. The *discounted Payback Time* (**PBT**) is the time required to recover the investment considering the initial cash out and the cash flows actualized to the current year. It is more reliable and meaningful with respect to sPBT.

The *Internal Rate of Return* (**IRR**) is the value of the discount rate that should be considered in order to obtain a NPV equal to zero.

The *Levelized Cost of Electricity* (**LCOE**) is the cost at which the energy can be sold in order to have a final NPV equal to zero. It is computed as in the equation (3.5).

$$LCOE = \sum_{I=0}^{lifetime} \frac{(CAPEX + OPEX)_i}{(EE_{produced})_i} \tag{3.5}$$

The LCOE is useful to highlight the actual performance of the plant, since is not affected by the price at which the electricity is sold but only depends on the costs and the energy production. This index is also very useful to compare different plant located in different places and with different technologies, in order to evaluate the effective cost of the production.

3.2.4. Results

The results of the *ex-ante* case are reported in the following table showing a general positive judgment of the investment.

RESULTS	
NPV	1,271,347.58 €
sPBT	10
PBT	14
IRR	8.10 %
LCOE	133.98 €/MWh

Table 3.11: Results of the Economic & Financial analysis, ex-ante case

The performances are positive since the NPV is around *1.4 million euros* and medium level of Internal Rate of Return equal to *8.60%* showing an acceptable level of profitability.
The investment is repaid in 10 years considering the simple payback time or in 14 years considering the discounted payback time. Taking into account that the lifetime is of 35 years, the investment is repaid in less than the half of the lifetime and before the end of the incentivized period.

However, the LCOE is considerably high at a level of 133.98 €/MWh, showing that the plant is profitable only with an incentivized tariff since the price in 2009 was lower than this level. This level of LCOE is affected to the high cost related to the civil works of the drinking water tank and other works need for the water supply of the water distribution network of the municipality as signed in the Project Financing agreement that an not strictly linked to the power plant.

Considering all these aspects, the plant is ***profitable*** and can be considered a "good investment". The incentivized tariff covers the costs and guarantees an ***high single-digit return*** that can be interesting.

The results of the two cases in the *ex-post* scenario are reported in the next table. The values show a more interesting and very positive judgement of the investment.

RESULTS	Worst case	Base case
NPV	2,547,617.57 €	2,775,486.77 €
sPBT	8	8
PBT	10	10
IRR	10.98 %	11.23 %
LCOE	109.31 €/MWh	103.86 €/MWh

Table 3.12: Results of the Economic & Financial analysis, ex-post case

Considering the *base* case, the performances are very positive, since the NPV is around *2.8 million euros*, more than the double of the ex-ante case, and a double-digit Internal Rate of Return of *11.23* % showing a good level of profitability.
The investment is repaid in 8 years considering the simple payback time or in 10 years considering the discounted payback time. Taking into account the lifetime of the plant of 35 years, the investment is repaid in a relatively short period of time and nowadays is fully repaid, before one third of the lifetime and before the end of the incentivized period.
The LCOE is equal to 103.86 €/MWh. The reduction compared to the *ex-ante* scanario is given by the higher than the expected electricity production that leads to an increase of the load factor and a decrease in the LCOE.
This level of LCOE with the nowadays market price of electricity is very competitive also in a incentives-free environment. However, considering the last decade electricity prices, around 60 €/MWh, is considerable high.

Considering the *worst case*, the results are very similar. The NPV is around 2.5 M€, the IRR is slightly lower and the LCOE is higher of 6 €/MWh. The simple payback time and the discounted payback time are the same of the *base case*.

Considering all aspects, the plant was profitable in the last years and can increase very much the profitability in the future years delivering further value for the shareholders. Moreover, this analysis is performed with a conservative approach not considering the huge increase of the market price of electricity in the recent month. If the market price stabilized in the current range of prices the profitability can have a huge boost implying ***higher double-digit return***.

In the following graph are represented the *cumulative actualized cashflows* of the two scenarios. It can be easily seen the difference in the profitability, that is mainly related to the higher effective electricity production, even if the investment (CAPEX) is increased of roughly 250,000.00 € (6.67%).

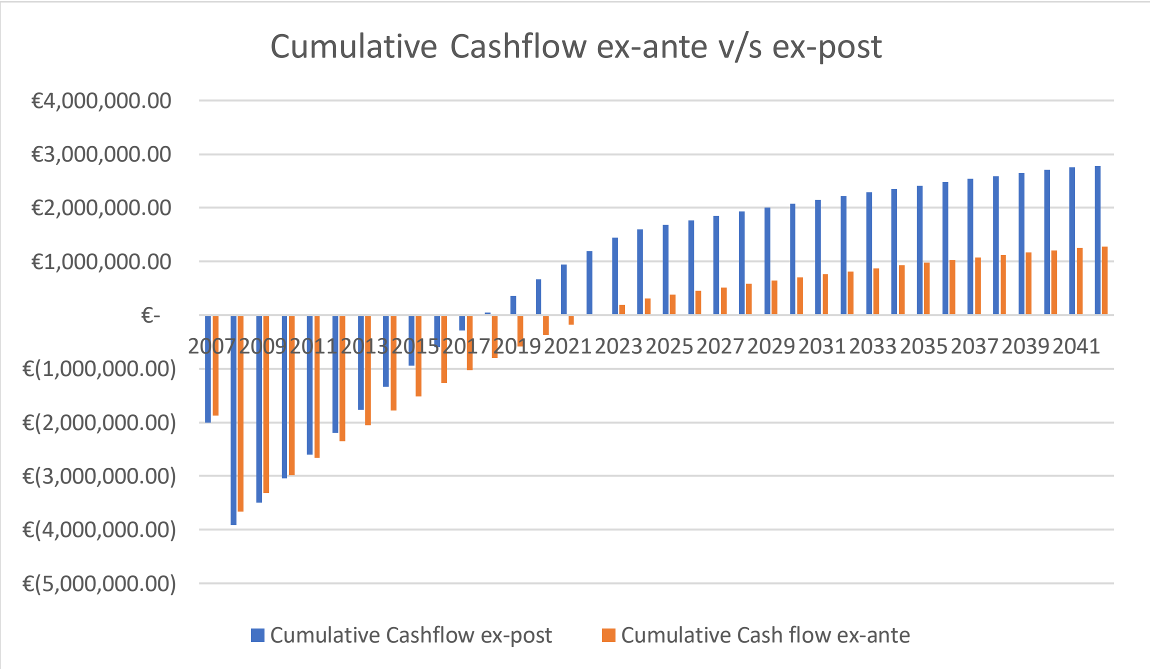

Figure 3.6: Comparison of the cumulative cashflows of the two cases

You may note that in the *ex-ante* scenario, the discounted payback time is in the year 2022, the *ex-post* (*base case*) data show that the payback time was already reached in 2018, four years before the expected. This trend is considered in the *ex-post* scenario where the payback time is in the year 2018 having fully repaid the investment before the end of the incentivized period.

The NPV is clearly visible as double of the ex-ante case, overperforming in a considerable way the ex-ante planning. The higher production has a greater positive impact on the performances, even if the price of the electricity considered after the end of the incentivized period is lower than the ex-ante, the G.O. “Garanzie di Origine” are not considered in this analysis, in order to be more conservative, and there is an over-cost of roughly 250,000.00 €,

At the end of the incentivized period, if the current market price will hold the actual quotations with a price near to the incentivized tariff, the plant can increase his profitability to a higher level, delivering more cash flow, increasing the IRR and the NPV.

3.3. Plant N°2

The plant N°2 is located in the upper part of the Vallecamonica valley, in the Municipality of Vione. This plant is a run-off river plant, with a medium-high head and medium water flow. It has one horizontal axis Pelton turbine and a synchronous three-phase generator.

The plant is characterized by a gross head of 144.8 meters, exploiting an important geodetic head between the loading tan, located a 1235 m, and the turbine location at 1090.20 meters. The plant has nominal concession power of 212.94 kW, the generator has a maximum apparent power 650 kVA, the turbine has a maximum power of 600 kW, and a transformer of 800 kVA.
This plant can be categorized as a medium head small hydro, with diversion channel and Pelton technology of the turbine. No storage of water is in place at the top of the plant. In the following table are reported the main data of this hydropower plant.

The river exploited born in the upper small sub-valley, it receives the tributaries that descend from the local mountains. The catchment basin area is equal to 6.56 km^2. The average flow of water that is exploited is 150 l/s, while the maximum exploitable water is 450 l/s.
This hydroelectric power plant has a very low environmental impact, the only consistent intervention is related to the water intake works on the riverbed and the settling tank. All the penstock and the discharge channel is underground, the powerhouse is built like a residential building and covered with wood and local rocks. The annual electricity production is estimated equal to **1,495,00 kWh/year**.

Main Data	
Gross head	144.8 m
Elevation intake	1235.00 m
Elevation of discharge	1090.20 m
Average flow	150 l/s
Maximum flow	450 l/s
DMV	50 l/s
Nominal concession power	212.94 kW
Turbine maximum power	600 kW
Generator maximum apparent power	650 kVA
Transformer apparent maximum power	800 kVA

Table 3.13: Main data of power plant No. 2

3.3.1. Hydrogeological and hydraulic analysis

In the following paragraph are synthetized the results of the hydraulic and hydrogeological studies performed by the designer during the technical design phase, in order to have the proper data for the drafting of the executive design of the power plant.

The river exploited born in the upper small sub-valley, it receives the tributaries that descend from the local mountains. The basin area upstream the water intake is equal to 6.56 km^2 with a maximum height of 2960.60 m and a minimum height of 1235 m, the river length is 3890 meters.
The shape factor of the basin is equal to 1.39 showing an elongated oval course in a North - South direction. The ipsographic curve is reported in the following figure, showing the height of the terrain in the basin as function of the area of the basin.

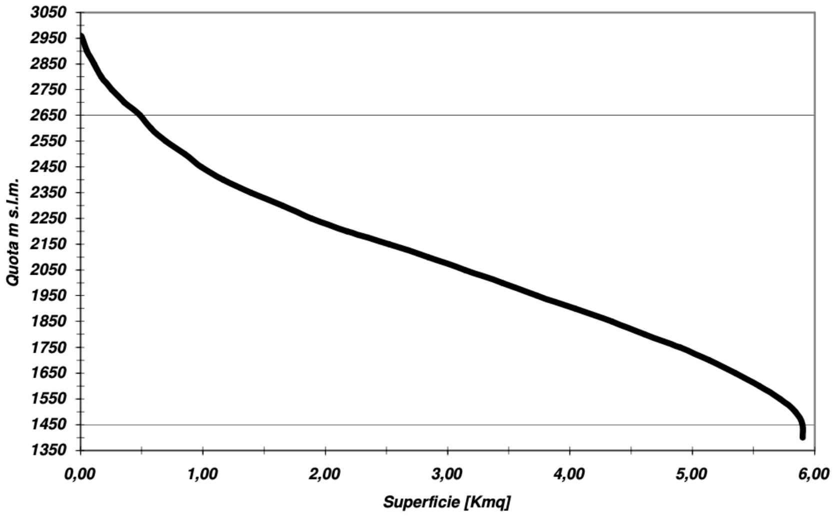

Figure 3.7: Ipsographic curve of the cathment basin

- **PLUVIOMETRY**
  The average annual precipitation value is deduced from existing bibliographic sources, using the data of the average yearly rainfall from the *Programma di Tutela e Uso delle Acque L.R 12/12/2003 n. 26 art. 45 – Regione Lombardia – DG Servizi di Pubblica Utilità – U. O. Risorse Idriche – Novembre 2004*, where are reported the hydrogeological data for rainfall and snow metering that are significant for the areas considered.
  In relation to the reliability of the data available it is considered appropriate to adopt the value of average precipitation of **1220 mm/year**.

- **ASSESSMENT OF WATER FLOW:**
  The assessment of the availability of the water flow is done in three different ways in order to be sure of having a reliable and good estimation of the hydraulic resources that can be exploited:

  - From the *Programma di Tutela ed Uso delle Acque (LR 12/12/2003 n.26 art.45 comma 3)* can be used the equations (3.6)(3.7), starting from the calculation of the average yearly runoff obtaining an average yearly flow rate of 208.08 l/s.

$$q = 0.026\,P\ [\frac{l}{s\,km^2}] \tag{3.6}$$

$$Q = q\,S\ [\frac{l}{s}] \tag{3.7}$$

Where:

q	Average flow per km^2 of basin	[l/(s km^2)]
P	Average yearly precipitation	[mm]
S	Area of the basin	[km^2]
Q	Average flow	[l/s]

  - From *duration curve* derived from the regionalized synthetic curves – DGR 12 april 1999, using the synthetic flow rate curves of water courses for the calculation of a value of the average flow rate equal to 198.9 l/s. In the next figure the flow duration curve is represented.

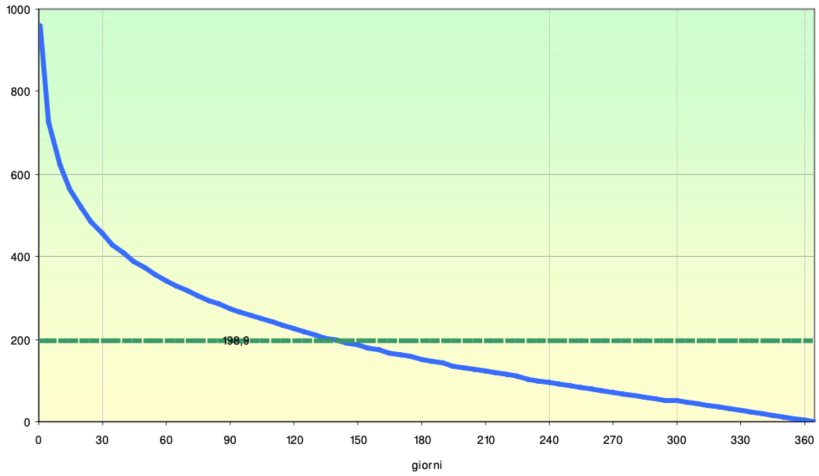

Figure 3.8: Flow duration curve using the DGR 12 april 1999

- From the the *Programma di Tutela ed Uso delle Acque* in the sub-champter for the computation of the average flow in the river not measured with a measurement station. Using the regionalization formula explained in the equation (3.8), that uses the data from nearby measument station and the pluviometry in order to evaluate the average flow.

$$q_s = \left(\frac{q_{m2}A_{m2} - q_{m1}A_{m1}}{P_{m2}A_{m2} - P_{m1}A_{m1}}\right) P_s \tag{3.8}$$

Where:

q_{m1}	Average unitary flow for km² at the measurement station n°1	42.36 [l/(s km²)]
q_{m2}	Average unitary flow for km² at the measurement station n°2	37.5 [l/(s km²)]
A_{m1}	Area of the basin n°1	119 [km²]
A_{m2}	Area of the basin n°2	287 [km²]
P_{m1}	Average yearly precipitation at the measurement station n°1	1231 [mm/year]
P_{m2}	Average yearly precipitation at the measurement station n°1	1284 [mm/year]
q_s	Average flow in the river	[l/(s km²)]

The result from this computation is an average flow rate equal to 206.25 l/s.

Considering all the three calculations of the average available flow rate in the river that are reported in the next table, since the results are very close, the value of **208.1 l/s** can be considered as the value of average available water flow rate.

Estimated water flow	
From "runoff method"	208.08 l/s
From duration curve (DGR 6/42446 of 12.04.99)	198.90 l/s
From regionalization formula (PTUA 12/12/2003)	206.25 l/s

Table 3.14: Results of the water assessment availability

3.3.2. Minimum Vital Outflow (Ecological Flow)

Considering the evaluation of the Minimum Vital Outflow, the designer has performed an analysis based on four different methodologies. In order to evaluate in a complete and exhaustive way the Minimum Vital Outflo. The four methodologies are proposed from: *Lombardy Region Dgr 12.04.1999, Lombardy Region D.c.r. 28.07.2004, Autorità di Bacino del Fiume Po, Piano Acque Parco Adamello.*

- **LOMBARDY REGION DGR 12.04.1999**
  The resolution of the regional council n°VI/42446 of the 12.04.1999 named as *"Approvzione delle direttive per la valutazione delle domande di piccole derivazioni d'acqua ad uso idroelettrico"* establishes the methods of calculating the Minimum Vital Constant Outflow in terms of unit of surface of the catchment basin, area of the basin and dimensionless coefficient, as specified in the following equation (3.9):

$$Q_{DMV} = 1.6 \cdot P \cdot A \cdot Q \cdot N \cdot S \tag{3.9}$$

Where:

Q_{DMV}	Minimum Vital Outflow	[l/s]
P	Precipitation (for 1220 mm/year)	1.03 [-]
A	Altitude – (greater than 800 m)	1.2 [-]
Q	Quality of the river (not polluted)	1 [-]
N	Naturality index (natural areas)	2 [-]
S	Surface of the catchment basin	[km^2]

The value of the Minimum Vital Outflow using this methodology is equal to 25.96 l/s.

- **LOMBARDY REGION D.C.R 28.07.2004 VII/1048**
  The resolution of the regional council n°VII/1048 of the 28.07.2004 named as *"Atto di indirizzo per la politica di uso e tutela delle acque della Regione Lombardia - Linee strategiche per un utilizzo razionale, consapevole e sostenibile della risorsa idrica."*
  This methodology suggests the following equation (3.10) in the calculation of the Minimum Vital Outflow.

$$Q_{DMV} = k \cdot q_{average} \cdot S \cdot M \cdot Z \cdot A \cdot T \quad (3.10)$$

Where:

Q_{DMV}	Minimum Vital Outflow	[l/s]
k	Experimental parameter for the zone)	0.1 [-]
$q_{average}$	Average yearly water flor per unit of surface of the basin	[l/(s km²)]
S	Surface of the catchment basin	[km²]
M	Morphological parameter	1 [-]
Z	Complex parameter concerning the natural environment, the social and truistical importance, the reduction of pollution	2 [-]
A	Parameter concerning the interaction of superficial and groundwork waters	1 [-]
T	Parameter concerning the modulation of release during the year	[-]

The value of the Minimum Vital Outflow using this methodology is equal to 38.88 l/s.

- **LOMBARDY REGION DGR 12.04.1999**
  The resolution of the regional council n°VI/42446 of the 12.04.1999 named as *"Approvzione delle direttive per la valutazione delle domande di piccole derivazioni d'acqua ad uso idroelettrico"* establishes the methods of calculating the Minimum Vital Constant Outflow in terms of unit of surface of the catchment basin, area of the basin and dimensionless coefficient, as specified in the following equation (3.11):

$$Q_{DMV} = 1.6 \cdot P \cdot A \cdot Q \cdot N \cdot S \quad (3.11)$$

Where:

Q_{DMV}	Minimum Vital Outflow	[l/s]
P	Precipitation (for 1220 mm/year)	1.03 [-]
A	Altitude – (greater than 800 m)	1.2 [-]
Q	Quality of the river (not polluted)	1 [-]
N	Naturality index (natural areas)	2 [-]
S	Surface of the catchment basin	[km²]

The value of the Minimum Vital Outflow using this methodology is equal to 25.96 l/s.

- **AUTORITÀ DI BACINO DEL FIUME PO**
  This methodology is proposed by the *Commissione di Studio Autorità di Bacino del Po per la Valtellina"*. It applies numerous coefficient, concerning different aspect of the catchment basin, in order to compute a value of the Minimum Vital Outflow using the following equation (3.12):

$$Q_{DMV} = A \cdot B \cdot C \cdot D \cdot E \cdot F \cdot G \cdot H + M \qquad (3.12)$$

Where:

Q_{DMV}	Minimum Vital Outflow	[l/s]
A	Surface of the catchment basin	[km²]
B	Specific release	1.6 [-]
C	Average precipitation coefficient (value for 1220 mm/year)	1.2 [-]
D	Altitude coefficient (value for height > 800 m)	1.3 [-]
E	Permeability parameter of the catchment basin (medium)	1.1 [-]
F	Biologic quality coefficient (*IBE's model – Indice Biotico Esteso* – non inquinato)	1 [-]
G	Naturality coefficient (Adamello's Park)	1.8 [-]
H	Parameter concerning the length between the intake and the discharge of the water[16]	1.055 [-]
M	Flow modulation[17]	[-]

The value of the Minimum Vital Outflow using this methodology is equal to 37.43 l/s.

- **METHODOLOGY FROM "PIANO ACQUE PARCO DELL'ADAMELLO"**
  This methodology must be used for new power plants for catchment basin with a surface lower than 50 km², using the following formula (3.13). Note that the value of the environmental coefficient Q has a value of 1.57. The value of the Minimum Vital Outflow computed is equal to 46.35 l/s.

[16] Computed as H = 1+(L · 0.05) where L=1.1 km is the length of the river between the intake and the discharge water

[17] Computed as M = 0.10 · (P_{na} – A·B·C·D·E·F·G·H) where the P_{nat} is considered equal to 60 l/s

$$Q_{DMV} = 4.5\, S\, Q \left[\frac{l}{s}\right] \tag{3.13}$$

Where:

Q_{DMV}	Minimum Vital Outflow	[l/s]
S	Surface of the upstream catchment basin	[km^2]
Q	Environmental coefficient	1.57 [-]

The value of the Minimum Vital Outflow using this methodology is equal to 46.35 l/s.

In the following table are reported the result from the four methodologies applied, as clearly visible all the value of the Minimum Vital Outflow are greater than 50 l/s. In order to be conservative and to complain with the rules from the Regional Park of the Adamello the value of **50 l/s** is considered as the reference for the Minimum Vital Flow.

Minimum Vital Flow	
Lombardy Region (DGR of 12.04.99)	38.88 l/s
Lombardy Region (DCR of 28.07.04)	25.96 l/s
Autorità di Bacino PO	37.43 l/s
Parco Adamello	46.35 l/s

Table 3.15: Result of all the methodologies applied to compute Minimum Vital Outflow

3.3.3. Main Components of the Power Plant

In the following paragraph are reported and commented the main components of the power plant from a technical point of view. Especially in the constructive characteristics of the civil structures and the data sheets of the electromechanical components.

- **WATER INTAKE**

  The works consists of a small barrage on the riverbed with a length of 7.80 m, of which 0.50 m occupied by the channel for the Minimum vital outflow, with a 6.50 m grid where the water is captured. The first section of the riverbed downstream of the traverse is paved with a ballast of large stones. All the works are in reinforced concrete and form a monolithic structure. The exposed walls, not covered with vegetal soil, are covered with local stones for a better environmental integration.

  The flow of water captured is conveyed in the settling basin located between the collection channel and the loading tank. The settling tank has been sized in order to maintain a sufficiently low speed of the flow rate of the derived water in order to allow, even in conditions of considerable derivation, the sedimentation of solid particles.

  At the end of the settling basin is located the loading tank with a section of 2.50 x 2.00 from where the penstock originates.

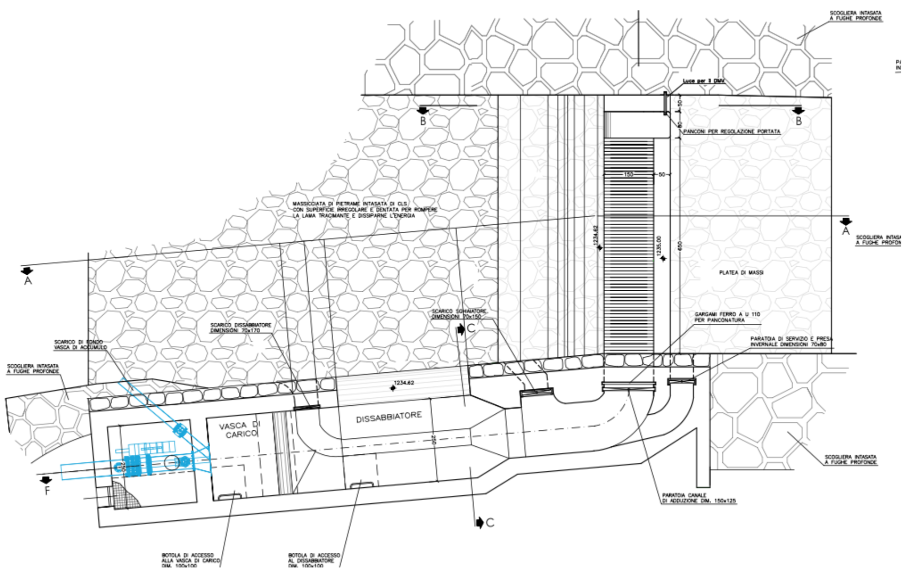

Figure 3.9: Technical drawing of the water intake

- **PENSTOCK**
  The penstock is built with a steel pipe with a diameter of DN 450 mm and a development of approximately 550 m. In parallel to the pipeline two protected pipes in plastic material DN 100 mm is placed, for the automation signal cables and the power cable serving the intake structure. In correspondence with the changes in the elevation of the penstock suitable anchoring blocks are placed in order to counteract the thrust of the curves, the blocks are buried underground.

- **POWERHOUSE**
  The central building is on two levels, has plan dimensions of 8.80 x 12.00 with an external appendix measuring 5.00 x 5.10.
  Inside the room there is the Pelton turbine, the generator, the machine valves, the turbine distributors and accessory mechanisms, AND the transformer compartment. On the ground floor there is the switchboard room with control and maneuvering station and the MV compartments.
  The vertical bearing walls are built in reinforced concrete and covered externally with local stones and wood, referring to the local customs of the typical huts of the place. The roof in wood with a stone slab roof. The building is equipped with windows and doors in solid wood. The remaining areas are lawn, integrated with vegetation of local species.

Figure 3.10: Technical drawing of the powerhouse

- **DISCHARGE CHANNEL**
  The discharge channel is completely underground and is built with a pipe approximately 120 m long and discharged upstream of the existing Edison water intake. The entire route of the canal is buried and covered with topsoil.

- **TURBINE – GENERATOR**
  Electricity is produced at a nominal voltage of 400 V and then raised by means of a step-up transformer to be delivered to the 15 kV network. The production group consists of: one horizontal axis Pelton turbine with rated power of 600 kW manufactured by TSCHURTSCHENTHALER TURBINE coupled to a synchronous brushless generator, manufactured by MARELLI MOTORI spa, with a rated power of 650 KVA. The principal technical data are reported in the following table.

Turbine Data	
Nominal head	144.8 m
Max flow	450 l/s
Turbine maximum Power	600 kW
Turbine velocity	600 min^{-1}
Generator's apparent power	650 kVA
Generator's voltage	400 V
Generator's cos φ	0.8
Frequency	50 Hz

Table 3.16: Turbine's main technical data

The annual electricity production is estimated equal to **1,495,00 kWh/year** as specified using an estimated availability of the plant of 350 day/year.

3.4. Economic & Financial Analysis – Plant n°2

This economic & financial analysis, as all this document, is done maintaining the discretion and confidentiality. It is completely independent from the original business plan written by Iniziative Bresciane spa during the feasibility study of the investment. However, this analysis is performed starting from the real data available from the "plant n° 2" by INBRE, showing the major results, without entering into deep analysis of the more confidential data.
In analogy with the plant N°1 this analysis is composed by two different scenarios in order to highlight the performances that can be predicted before the construction, as in a business plan, and the performances at nowadays until 2021 with the prediction for the following year until the end of the lifetime. All the cashflow are actualized to the year 2014, when the construction was authorized.
Two scenarios are:

- **Ex-ante:** using the same data, hypothesis and assumptions available before the construction in the year 2016, (mean annual producibility, CAPEX, OPEX, financial yields, ecc..);

- **Ex-post:** using the real performing data of the plant, until the year 2021 and the same data, hypothesis and assumptions adapted with the information available in 2021.

3.4.1. Data & Hypothesis

Considering the **CAPEX,** the value of the estimation in the executive design documents permits to quantify the expenditures. The total planned cash-out was 1.755 million euros considered in the *ex-ante* case. About the *ex-post* valuation, the effective CAPEX is valued considering the effective book value in the balance sheet equal to 1.816.527,63 €, as noticeable there is an over-cost of roughly 61,527.63 €, that means some +0.03%. The investment is divided in categories as specified in the following graphs and table (3.17):

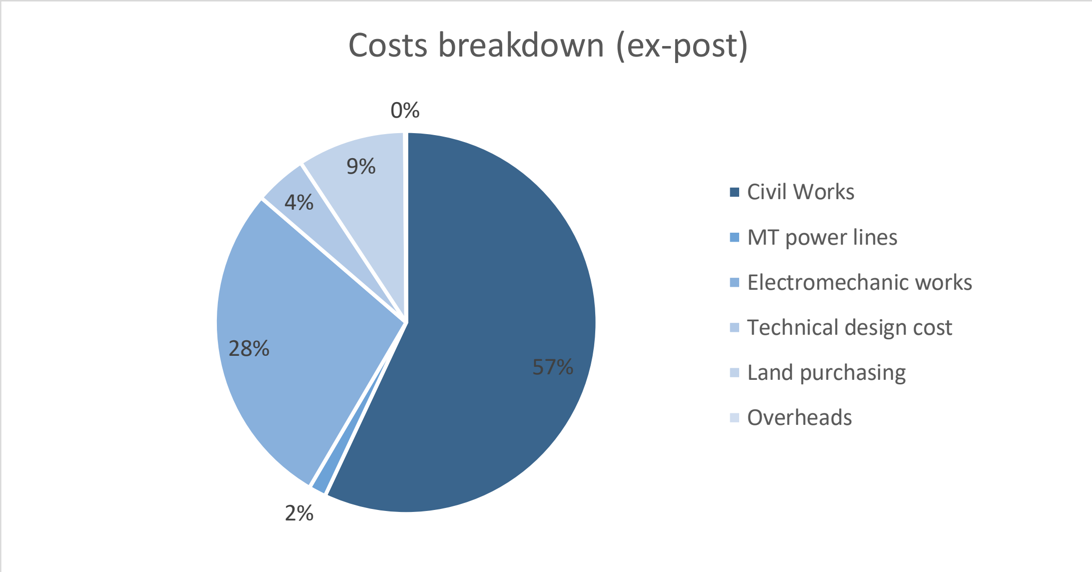

Figure 3.11: Graphical representation of powerplant's CAPEX

As clearly visible, the major sources of costs are the civil works, water intake, powerhouse, tailrace channel, penstock and road works that account for almost 57% of the total investment. A big share of the cash-out is related to the electromechanical works and a consistent amount is spent into land purchasing and right of use of the land. The cash-out is estimated equally distributed in two years of construction.

CAPEX breakdown (ex-post)	
Civil Works *(Water intake works, powerhouse, tailrace channel, penstock, road works)*	1,035,000.00 €
MT power line	26,708.25 €
Electromechanic works	505,960.00 €
Technical design cost	80,000.00 €
Land purchasing	166,966.08 €
Overheads	1,892.80 €
TOTAL	1,816,527.63 €

Table 3.17: CAPEX breakdown into categories of cost

Considering the **O&M costs** it has been signed a contract with another company that makes all the ordinary maintenance and runs the plant with the correct set-up

and prescription for a tariff of 4.5 €/MWh. This value is considered for *ex-ante* and *ex-post* valuation.
Considering the **insurance costs**, an All-Risk insurance contact has been signed. In the *ex-ante* valuation, an initial premium of 4,000.00 € adjusted for inflation over the years, in the *ex-post* valuation are considered the real premium paid until 2021 and later the 2021 value adjusted for inflation.

Considering the **regional concession fees**, in the *ex-ante* valuation were considered the value of 2014, 15.59 €/kW adjusted for inflation over the years. In the *ex-post* valuation are considered the real concession fees paid until 2021 and later the 2021 value adjusted for inflation. **No concession extra-fees** are in place since the concession power of the plant is lower than 220 kW.

Considering the amortization plan, since the concession of the right of use the water of the river for hydroelectric use last 30 years from the 2012, the **lifetime** considered is equal to 30 years ending in the 2042, therefore the effective years of production are 26.
The amortization rate would be subdivided in category according to the fiscal rules, as specified in the table (3.18). However, for simplicity all the ***civil works*** are jointed into one **amortization rate** of 3.70% considering an amortization time of 27 years according to the end of the concession in 2042. All the electromechanical costs and the other instrumental goods are jointed into one **amortization rate** of 8.33% considering an amortization time of 12 years.

Amortization Rate (fiscal rules)	
Buildings *(powerhouse)*	3.00 %
Fixed Hydraulic Works	1.00 %
Penstock	4.00 %
Electromechanical works	7.00 %
Equipment	10.00 %

Table 3.18: Italian fiscal rules for the amortization rate of powerplant's component

Considering the **electricity price** at which the energy is sold, the plant had access to an incentivized tariff according to the Minister Decree 06 July 2012 with a fixed value of **210.24 €/MWh** for 20 years. After this period the plant can sell the energy to the GSE with the "RID – Ritiro Dedicato" with some minimum guaranteed prices for the first 1,500 MWh, under the "Prezzi Minimi Garantiti" scheme.
In the next table is reported the minimum guaranteed prices for hydroelectric electricity for the year of 2016, in the *ex-ante* the weighted average of this value is

considered as price of reference for the 21-th year, later is adjusted for inflation during years. This price of reference is equal to 84.58 €/MWh.

Data	Price [€/MWh]
Less than 250,000 kWh	153.4
Over 250,000 kWh less than 500.000 kWh	105.5
Over 500,000 kWh less than 1,000,000 kWh	66.6
Over 1,000,000 kWh less than 1,500,000 kWh	57.7

Table 3.19: Minimum guaranteed prices for the year 2016

The current market price of electricity in 2022 is in the order of magnitude of 200 €/MWh very similar to the incentivized tariff, however there is not a certainty that the price in the future will maintain this value. In a conservative approach also for the *ex-post* valuation, similarly to the analysis of the plant n°1, is considered as reference the weighted average of the minimum guaranteed price for the year 2021 adjusted for inflation. This weighted price of reference is equal to 86.07 €/MWh.

Considering **production** of **electricity**, in the design documents the mean annual producibility estimated is 1,495.00 MWh/year, this value is used in the *ex-ante* case with the hypothesis of fixed production. In the *ex-post* case the effective real production is considered until the year 2021 as reported in the following dtable , while for the following years the production is estimated with the average electricity production of the past 5 years, equal to 1,629.351 MWh.

Year	Production [kWh]	Year	Production [kWh]
2016	1,422,175	**2019**	1,736,480
2017	1,313,459	**2020**	1,829,112
2018	1,575,753	**2021**	1,691,950

Table 3.20: Electricity production of the powerplant No. 2

3.4.2. Hypothesis & Assumptions

The following assumptions are considered in this economic & financial analysis, considering respectively the information available in 2016 and 2021. Some hypothesis and assumptions are the same of the analysis of the plant n°1. In order to not be repetitive all the hypothesis and assumptions, for ex-ante and ex-post cases are synthetized in the following table (3.21).

Data	Ex-Ante	Ex-post_worst
Inflation rate	2%	2%
Tax rate	27.5% + 3.9%	27.5% + 3.9% (24% + 3.9%)
E/(E+D)	25%	25%
Debt yield	5%	5%
Equity return	10%	10%
WACC	5.1%	5.1% (5.2%)
CAPEX	1,755,000.00 €	1,816,527.63 €
O&M	4.5 €/MWh	4.5 €/MWh
Production	1,495,000 kWh	1,629,351 kWh
Lifetime	30 years	30 years
Amortization rate	3.70% - 8.33%	3.70% - 8.33%

Table 3.21: Main assumption and hypothesis for the two cases

3.4.3. Economic & Financial Indexes

The analysis is carried out performing the calculation of different useful indexes in order to evaluate the economic and financial performances of the two cases. As in the evaluation of the plant n°1, during the analysis are computed:

- the *Net Present Value* (**NPV**)
- the *simple Payback Time* (**sPBT**),
- the *discounted Payback Time* (**PBT**)
- the *Internal Rate of Return* (**IRR**)

Another important index is the *Levelized Cost of Electricity* (**LCOE**), it is very useful to highlight the actual performance of the plant, since is no affected by the price at which the electricity is sold by only depends on the costs and the energy production. This index is also very useful to compare different plant located in different places and with different technologies, in order to evaluate the effective cost of the production.

3.4.4. Results

The results of the *ex-ante* case are reported in the following table showing a general positive judgment of the investment.

RESULTS	
NPV	1,227,227.85 €
sPBT	9
PBT	11
IRR	11.46 %
LCOE	108.73 €/MWh

Table 3.22: Results of the Economic & Financial analysis, ex-ante case

The performances are positive since the NPV is around *1.2 million euros* and double-digit level of Internal Rate of Return equal to *11.46%* showing a good level of profitability.
The investment is repaid in 9 years considering the simple payback time or in 11 years considering the discounted payback time. Considering that the lifetime is of 30 years, the investment is repaid roughly in one third of the lifetime and at the half of the incentivized period.

However, the LCOE is medium-high at a level of 108.73 €/MWh, showing that the plant is profitable only with an incentivized tariff since the price of electricity in 2016 was lower than this level. This level of LCOE is affected by the relatively high cost of the civil works in respect to the size of the plant that has a small electricity production. The plant without the incentivized tariff cannot be sustainable from and economic and financial perspective.

Considering all these aspects, the plant is ***profitable*** and can be considered a "good investment". The incentivized tariff covers the costs and guarantees a ***low double-digit return*** that can be interesting.

The results of the *ex-post* case are reported in the following table. The values show an interesting and positive judgement of the investment, it is very similar to the ex-ante case but the economic indexes are slightly better since the production in the past years was higher.

RESULTS	
NPV	1,456,766.59 €
sPBT	8
PBT	11
IRR	12.30 %
LCOE	103.83 €/MWh

Table 3.23: Results of the Economic & Financial analysis, ex-post case

The performances are very positive, since the NPV is slightly higher than *1.45 million euros*, roughly 200,000.00 € more than the *ex-ante* case. The Internal Rate of Return is on a double-digit level, equal to 12.30%, showing a good level of profitability.
The investment is repaid in 8 years considering the simple payback time or in 11 years considering the discounted payback time. The PBT is similar to the previous case since the electric production is greater, but the investment cost is slightly higher. Considering the lifetime of the plant of 30 years, nowadays the investment is near to be fully repaid considering the simple PBT while considering the discounted PBT the investment will be fully repaid in 4 years from now. A relevant aspect is that the investment will be fully repaid before half of the incentivized period and one third of the total lifetime, being a very good investment.

The LCOE is equal to 103.36 €/MWh. The slight reduction of 5€/MWh compared to the *ex-ante* scenario is given by the higher than the expected electricity production that leads to an increase of the load factor and a decrease in the LCOE.
This level of LCOE with the nowadays market price of electricity is very competitive also in an incentives-free environment. However, considering the last decade electricity prices, around 60 €/MWh, is considerable high.

A remarkable aspect in this plant operation is the risk management during the years. As previously written an All-risk insurance contract is in place, with the payment of an annual premium in the order of some thousands of euros the plant is insured against damages caused by adverse weather events, third party liability damages, and the value of lost production due to extraordinary maintenances caused by adverse events.

In fact, in august 2020 a flood event occurred, damaging the water intake and the auxiliaries component, leading to a forced stop of the plant due to the extraordinary maintenance. The plant was remained out of service for 449 hours, for a total lost production estimated in roughly 105 MWh quantifiable in 22 thousand euros. The restoration works impacted for roughly 151,000.00 €. The All-risk insurance has covered all the expenses, repaying the damages and the lost production the following year.
This example shows how a correct risk management plan, using All-risk insurances, can mitigate the impact of a potential unpredictable adverse event. Paying an insurance premium during the years protects the cash flows in case of consistent damage at the plants.

Considering all aspects, in the past years the plant was profitable and can increase very much the profitability in the future years delivering further value for the shareholders. Moreover, this analysis is performed with a conservative approach not considering the huge increase of the market price of electricity in the recent month. If the market price stabilized in the current range of prices the profitability can have a huge boost implying ***higher double-digit return***.

In the following graph are represented the *cumulative actualized cashflows* of the two scenarios. It can be easily seen that the difference in the profitability is very small, no big differences are in place. This is related to the fact that there was almost no-over cost in the construction phase, moreover the increase in the profitability of the ex-post case is roughly all related to the higher electricity production in the past years.

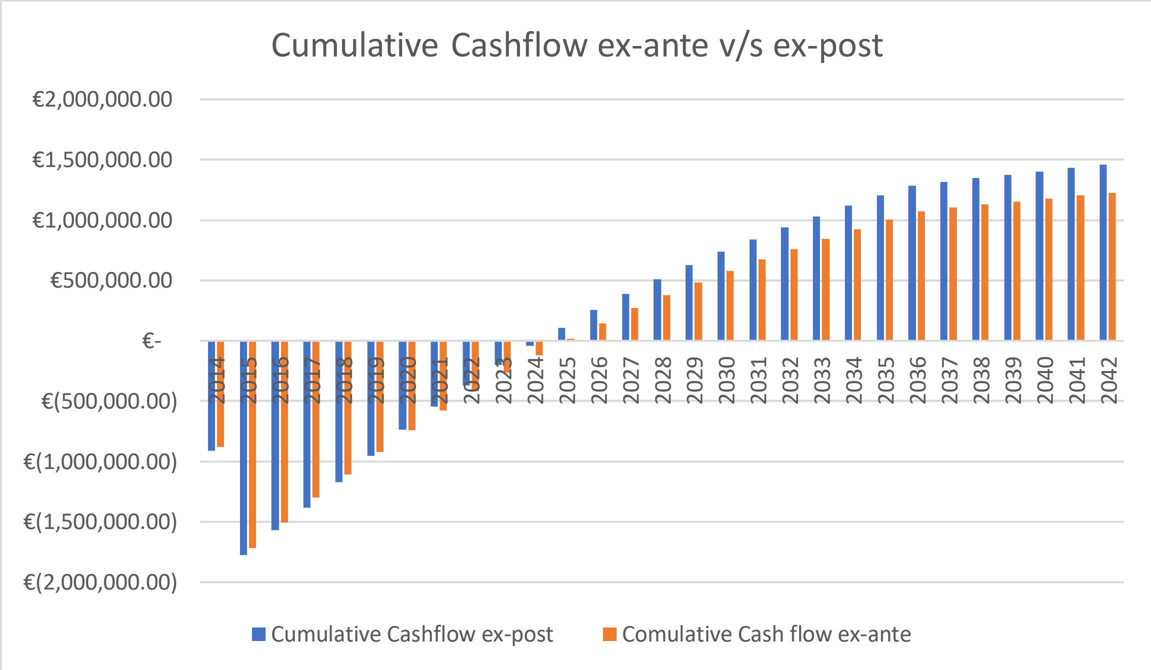

Figure 3.12: Comparison of the cumulative cashflows of the two cases

You may note that in the *ex-ante* scenario, the discounted payback time is in the year 2024, the *ex-post* data show that the payback time is in the same year but reached before than the expected. The end of the incentivized period is in 2036, so the payback is reached at half of the incentivized period, leading to considerably long time of profitability after the having fully repaid the initial investment.

The NPV is clearly visible as greater of roughly 200,000.00 € of the *ex-ante* case, overperforming the *ex-ante* planning. The higher production and the similar CAPEX have a positive impact on the performances, even if the price of the electricity considered after the end of the incentivized period is lower than the ex-ante. Moreover, the G.O. “Garanzie di Origine” are not considered in this analysis, in order to be more conservative, and there was a flood event that damaged and stopped the plant.

At the end of the incentivized period, if the current market price will hold the actual quotations with a price near to the incentivized tariff, the plant can increase his profitability to a higher level, delivering more cash flow, increasing the IRR and the NPV. The extra 10 years of remuneration at high price can provide ***higher double digit return*** to the shareholders.

3.5. Plant N°3

The plant N°3 is located in the Province of Bresica, in the Municipality of Offlaga, on the Mella river. This plant is a run-off river plant, with very low head and medium-high water flow. It has one horizontal axis Kaplan bulb turbine.

Characteristic of this plant is the fact that is in the hydrographic left of the river in the proximity of an existing barrage built for an irrigation channel derivation that starts in the hydrographic right of the river. No minimum vital flow or ecological flow is required, since the plant is a in-flow plant: the discharge of the water is located immediately after the barrage. However, a fish ladder is built near the power plant, in order to enabling the correct passage of fish between the barrage, restoring the continuity of the river.

The plant is characterized by a gross head of 2.3 meters, exploiting an very small geodetic head between an existing barrage on the Oglio river. The plant has nominal concession power of 175.88 kW, the generator has a maximum apparent power 350 kVA, the turbine has a maximum power of 305 kW, and a transformer of 400 kVA. This plant can be categorized as a low head small hydro, in-flow scheme, and Kaplan technology of the turbine. No storage of water is in place at the top of the plant. In the following table are reported the main data of this hydropower plant.

Main Data	
Gross head	2.3 m
Average flow	7.80 m^3/s
Maximum flow	15 m^3/s
Nominal concession power	175.88 kW
Turbine maximum power	305 kW
Generator maximum apparent power	350 kVA
Transformer apparent maximum power	400 kVA

Table 3.24: Main data of power plant No. 3

This hydroelectric power plant has a very low environmental impact, the flow of the river is immediately discharging downstream the intake, the plant is small and located on the shore of the river, the restoring of the river's continuity has a positive impact in the river's fauna. The annual electricity production is estimated equal to **1,100,000 kWh/year**.

3.5.1. Hydrogeological and hydraulic analysis

The proposed hydrological study is based on the procedure for the transposition of the flows from instrumented sections to non-instrumented sections identified in Annex 2 tof the PTUA of the Lombardy Region with the variant that in this discussion the procedure is applied to daily and not to monthly or yearly flows.

In the municipality of Manerbio, ARPA Lombardia has installed a hydrometric station for which river levels are available on a daily basis. The flow rate scale is also available: for this section it is therefore possible to compute the flow rate values.
The use of data on a daily basis allows to avoid overestimation errors of the water resource available for hydroelectric purposes that derive from the use of monthly aggregated data.
The precipitation data adopted are contained in Annex 2 of the PTUA of the Lombardy Region for the respective sub-basins of the river closed to the calculation sections "Reference section" and "Hydropower", respectively the one where the hydrometric station is located and the one near the location of the powerplant.

Flow in the section with measurement station	
Average annual anthropogenic flow	14.22 m^3/s
Natural average annual flow	19.26 m^3/s

Table 3.25: Flows measured by the instruments

The flow data of the river at the measuring station are related to the flows actually passing through the measuring section, net of the derivations present upstream along the course of the river; the recorded flows are therefore to be considered as anthropized flows.

In order to have a greater reliability of the proposed elaboration, natural flows are used, for this reason it was preferred to derive the value of the natural flows from the anthropized flows by adding the main irrigation derivations present upstream of the measurement section, as reported in the PTUA of the Lombardy Region .

$$Q_{nat} = Q_{ant} + Q_{IRR} \tag{3.14}$$

Later, considering the area of the two sub-basins and the precipitations, the average mean precipitation in the two sections, it is possible to compute the **natural flow** in the section of the power plant.

The natural flow computed is then reduced of the value of the main irrigation derivations present upstream the section, as reported in Annex 2 of the PTUA of the Lombardy Region, in order to obtain the **anthropogenic flow**. The **available flow** is computed subtracting to the natural flow the water flow discharged on the top of the barrage (200 l/s) and on the fish ladder (300 l/s).
The **useful water flow** is obtained considering the maximum and minimum flow processes by the Kaplan turbine. ($Qmax = 15\ m^3/s$, $Q_{min} = 3.75\ m^3/s$)
Data and results are reported in the following table.

Data & result for the computation	
Surface of the basin at the section with measurements	859 km^2
Surface of the basin at the section of the powerplant	716 km^2
Mean annual precipitation in the section with measurements	1186 mm
Mean annual precipitation at the section of the powerplant	1223 mm
Natural average annual flow	16.06 m^3/s
Average annual anthropogenic flow	11.04 m^3/s
Average annual available flow	10.58 m^3/s
Average annual useful flow	7.80 m^3/s

Table 3.26: Data & results useful for the computation of the flow duration curve

In the next table are reported the duration curve data of the four water flow considered in the section of the hydroelectric power plant. In the graph (3.12) are represented the duration curves.

Duration [days]	Q_{nat} [m^3/s]	Q_{ant} [m^3/s]	Q_{avai} [m^3/s]	$Q_{usefull}$ [m^3/s]
10	42.85	40.53	40.03	15.00
30	30.10	24.73	24.23	15.00
60	22.39	17.59	17.09	15.00
90	18.65	13.82	13.32	13.32
184	12.72	8.11	7.61	7.61
290	9.24	3.26	2.76	0
350	6.17	0	0	0
365	1.89	0	0	0
Annual	**16.06**	**11.04**	**10.58**	**7.80**

Table 3.27: Flow duration curve datas

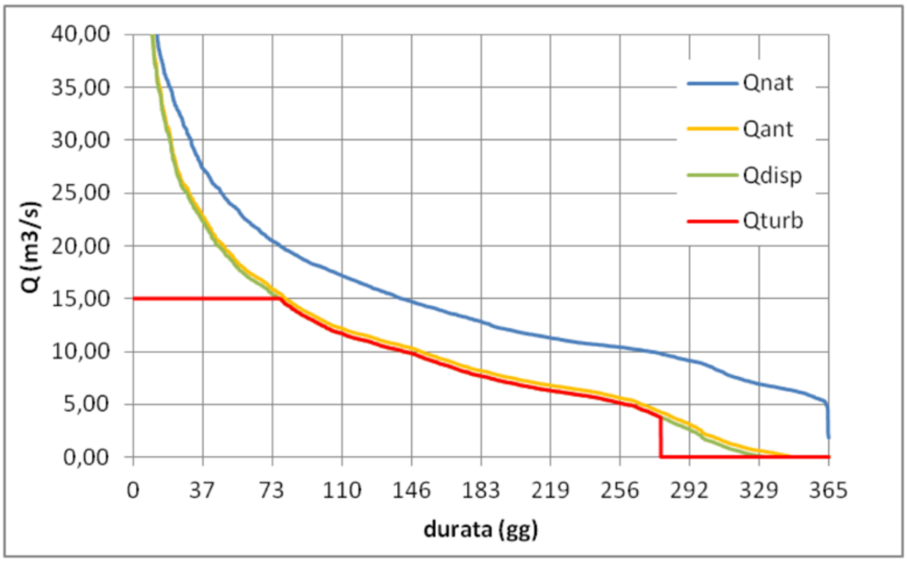

Figure 3.13: Flow duration curves, natural, anthropogenic, available, in the turbine

3.5.2. Electricity estimated production

The electricity production estimation is done in a conservative way, reducing the value obtained by a 3% (utilization factor of 97% equal to 3500 h/year) in order to consider the stop of the plant for maintenance, and another reduction of 3% in order to consider additional energy losses.

The data used for the calculation are the flow duration curve previously presented, the variability of the net head in fuction of the flow rate processed by the plant, and the yield of the turbine, generator and auxiliaries. The computation was done on daily basis using as reference the flow duration curve. The total estimate electricity production is computed as in the following equations (3.15) (3.16) please note that the gross electricity estimation not consider the conservative hypothesis while the net electricity estimation does.

$$EE_{gros} = \sum_{d=1}^{365} \eta_{tot_d} \cdot \gamma \cdot H_{net_d} \cdot Q_d \cdot 24 \tag{3.15}$$

$$EE_{net} = E_{gros} \cdot \frac{8500}{8760} \cdot 0.97 \tag{3.16}$$

Where:

η_{totd}	Total efficiency in the i-th day	[-]
γ	Specific weight of the water	[N/ m^3]
H_{netd}	Net head in the i-th day	[m]
Q_d	Water flow in the i-th day	[m^3/s]
EE_{gros}	Gross estimated electricity production	[kWh]
EE_{net}	Net estimated electricity production	[kWh]

Considering all the computation, the total net estimated electricity production is equal to **1,100,000 kWh/year**. This value will be used during the financial and economic analysis of the plant as value of reference for the electricity production.

3.5.3. Focus on Water Flows

The hydroelectric plant uses the same derivation barrage already serving the irrigation derivation from the river of the local Irrigation Consortium. Following the construction of the new hydroelectric plant, it is possible to measure the flow of the river at the intake section of this plant, net of the flows derived for irrigation purposes. As visible in the following picture (3.14) the irrigation derivation is in the hydrographic right while the hydroelectric power plant is located in the hydrographic left of the river. The following lines will describe how are measured the flow rates passing through the intake section of the hydroelectric plant.

Before the construction of the hydroelectric plant, the flow that was not derived from the intake work for irrigation continued downstream in the riverbed, spilling above the existing barrage. Following the construction of the hydroelectric plant, the flow rate that is not derived from the intake work for irrigation is divided into the following fractions:

- Flow rate derived from the inlet of the hydroelectric plant and discharged downstream of the existing barrage (Q1)
- Effluent flow over the existing barrage (Q2)
- Effluent flow in the fish ladder (Q3)

The sum of the flows listed above provides, in every hydraulic condition of the river, the total of the flow arriving from the river, that is the flow not derived from the irrigation derivation. Keep in mind that the new system works by keeping the water level upstream of the existing crossbar constant, by adjusting the turbine.

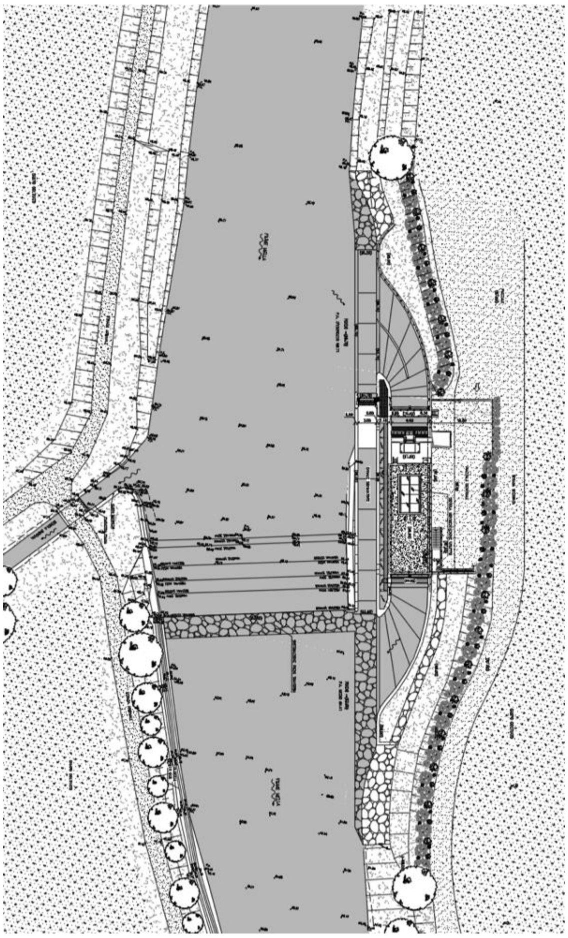

Figure 3.14: View from the top of the river and power plant

- **Flow rate derived from the inlet of the hydroelectric plant (Q1)**

All the flow derived from the hydroelectric plant is returned to the river downstream of the existing traverse. Given the system configuration, with very short water passages, the flow rate is measured using Winter-Kennedy probes, which are pressure transducers that measure the pressure difference between suitable points, and which derive from this difference the value of the flow through a relationship such as in the equation (3.17):

$$Q = K \cdot \Delta P^{1/2} \tag{3.17}$$

Where:

ΔP	Pressure difference	[Pa]
K	Constant function of the section's geometry	[-]

- **Effluent flow over the existing barrage (Q2)**

The calculation of the effluent flow over the existing barrage can be done according to the hydraulic using the following equation (3.18):

$$Q = \mu \cdot b_i \cdot h_i \cdot \sqrt{2g \cdot h_i} \tag{3.18}$$

Where:

Q	Effluent water flow	[m^3/s]
μ	Discharge coefficient	[-]
b	Length	[m]
h	Water head on the threshold	[m]

The upper level of the barrage is at an altitude of 66.69 meters above the sea level. The width of the barrage in the direction orthogonal to the current, is 32.20 m. During normal plant operation, the upstream water level is maintained at an altitude of 66.71 meters above the sea level, which corresponds to a outflow above the barrage of about 200 l / s.

The formulas shown, combined with the instantaneous value of the water level upstream, which is acquired by means of an ultrasonic level meter placed upstream of the dam, allow to calculate the effluent flow rate from the traverse in any hydraulic condition of the river, both with the active rather than active hydroelectric derivation.

- **Effluent flow in the fish ladder (Q3)**

The fish ladder is composed by the succession of basins with lateral vertical slot and hole in the bottom. The flow rate passing through the openings is the sum of the flow rate passing through the lateral slot and the flow rate passing through the bottom hole.
Under normal operating conditions of the plant, the upstream water level will be kept constant at an altitude of 66.71 meters above sea level, which corresponds to a flow rate in the fish scale of about 300 l / s, which will remain substantially constant.

The flow rate passing through the lateral slot as the value of h varies is calculated with the following formula (3.19):

$$Q_{slot} = \frac{2}{3} \cdot \mu \cdot \sigma \cdot s \cdot \sqrt{2g \cdot h^3} \tag{3.19}$$

$$\sigma = \left[1 - \left(1 - \frac{\Delta h}{h_m}\right)^{1.5}\right]^{0.385} \tag{3.20}$$

$$\Delta h = \frac{h - h_v}{N_s} \tag{3.21}$$

Where:

Q_{slot}	Water flow in the lateral slot	[m³/s]
μ	Discharge coefficient (0.4)	[-]
s	Width lateral slot (0.25)	[m]
σ	Coefficient considering the regurgitating effect	[-]
h_m	Upstream level of the water	[m]
h_v	Downstream level of water	[m]
N_s	Number of basins of the fish ladder (12)	[-]
Δh	Difference between upper and lower level of the basins of the fish ladder[18]	[m]

[18] As computer in the equation (__)

The water flow passing in the bottom hole is computed using the following equation (3.22):

$$Q_{hole} = \varphi \cdot b^2 \cdot \sqrt{2g \cdot \Delta h} \tag{3.22}$$

Where:

Q_{hole}	Water flow in the bottom hole	[m³/s]
φ	Coefficient (0.6)	[-]
b	Diameter of the hole	[m]

Known the water level upstream and downstream of the fish ladder, which will be detected by two level meters placed respectively upstream of the weir and downstream of the last basin of the fish ladder, the formulas described allow to calculate the flow through the fish scale in all hydraulic conditions.
The overall water flow that is able to pass through the fish ladder is therefore:

$$Q_{tot} = Q_{slot} + Q_{hole} \tag{3.23}$$

The measurement of the flow not derived from the irrigation canal takes place in the manner described above. The monitoring of the released water flow is carried out by continuously acquiring the following values:

- Water level upstream of the weir (ultrasound level sensor)
- Water level downstream of the dam (ultrasound level sensor)
- Flow rate used by the hydroelectric plant (Winter Kennedy probes

The information on the values detected by the Winter Kennedy probes and by the two ultrasonic level sensors are acquired automatically and in real time by the signal acquisition system. There is also a hydrometric rod next to the barrage, sized to be easy to be visually seen in order to check the level of the water.

3.5.4. Components of the plant

- **EXISTING BARRAGE:**
  The existing barrage is built in reinforced concrete, with a horizontal development of 32 meters. It creates a head of 2.30 meters between the upstream and downstream section of the river, the threshold elevation is 66.69 meters above the sea level.
  Some consolidation interventions are done in the foundation apparatus of the foot of the barrage, by filling with cyclopean boulders for the entire length in order to reduce the erosive capacity of the current of water.

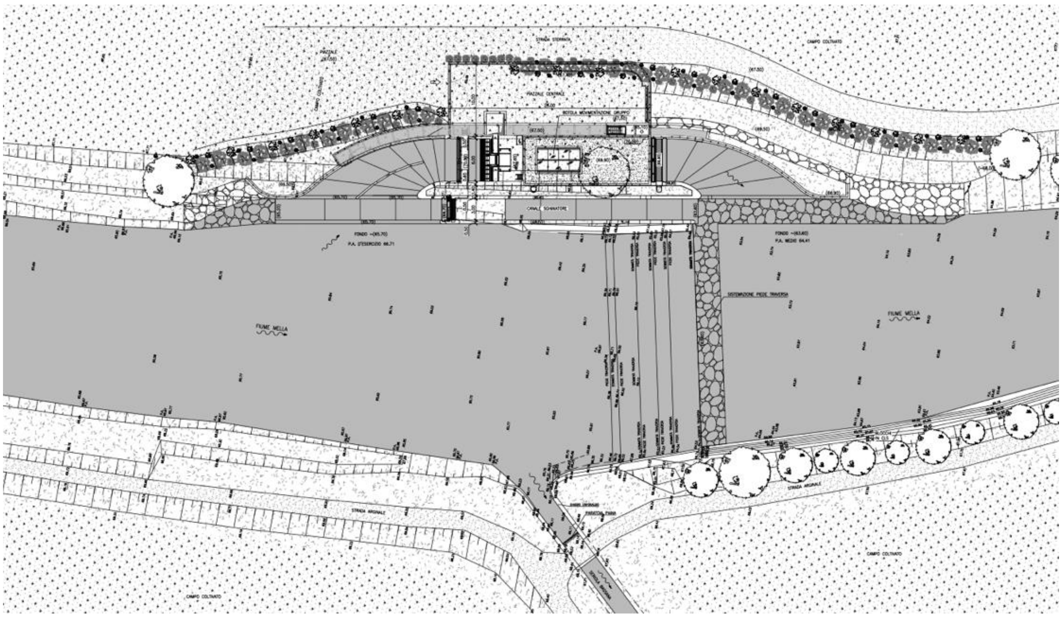

Figure 3.15: Technical drawing of the powerplant

- **WATER INTAKE:**
  On hydrographic left the water intake work capture the available water flow that can go throw the turbine. The sizing of the intake is done considering a low velocity of the flow in order to reduce turbulent effect and head losses. A concrete step on the riverbed prevent the entry of sediments and unwanted materials. The total length of the aperture of the intake is 16.20 meters, the threshold elevation is 65.70 meters.
  Immediately downstream of the intake, at the entrance to the sand removal channel, vertical gate is positioned. The vertical gate allow periodic discharge of the bottom sediment toward the river to ensure good cleaning of the area.

- **CHANNEL:**
  A short channel, of roughly 11 meters, consent the water to flow toward the turbine. It has a rectangular section of 6.60 x 6.00 meters. In the channel are located the gate cleaner and the machine's vertical gate.

- **POWERHOUSE:**
  The powerhouse is built partially underground, under the river slope, in reinforced concreate. It has rectangular dimensions equal to 18.10 x 7.10 meters, with an height of 3.70 meters. Inside the powerhouse are located: the turbine, a horizontal axis Kaplan turbine with a maximum power of 305 kW with a maximum water flow of 15 m^3/s; the alternator, a synchronous generator of 350 kVa at 400 V and 50 Hz; the transformer, for a maximum power of 400 kVa and the control systems.

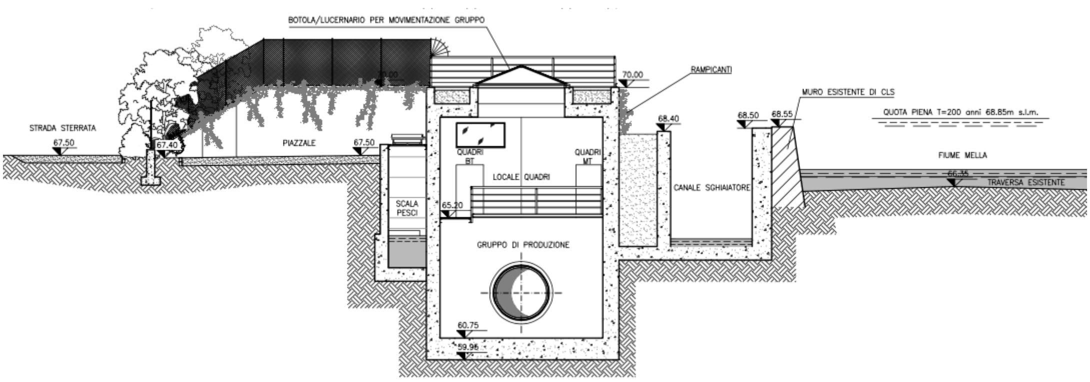

Figure 3.16: Technical drawing of the powerhouse

- **TAILRACE CHANNEL:**
  A 16 meters long channel is built in order to discharge the water flow downstream, with a height of 5.70 meters immediately after the diffuser of the turbine and an height of 3.30 meter for the last part. The channel is in reinforced concrete in order to face the erosion due to the turbulent flow. For the same reason, in correspondence with the outlet of the channel, a cliff of boulders clogged with concrete are built. The water is discharged at an elevation of 63.60 meter above the sea level.

- **FISH LADDER:**
  In order to guarantee the river continuum a passage for fish is planned, consisting of a series of small basins defined by concrete partitions. The fish ladder has the purpose to divide the overall head of 2.30 meters more modest jumps easily overcome by migratory fish. The fish ladder is 41 meters long with 19 small basin, each one with dimension of 2.00 x 1.40 meters.

3.6. Economic & Financial Analysis – Plant n°3

This economic & financial analysis, as all this document, is done maintaining the discretion and confidentiality. It is completely independent from the original business plan written by Iniziative Bresciane spa during the feasibility study of the investment. However, this analysis is performed starting from the real data available from the "plant n° 3" by INBRE, showing the major results, without entering into deep analysis of the more confidential data.
Since the plant has entered in service recently and has not an history, a comparison between the ex-ante and ex-post scenarios would be not significative. Therefore, differently from the analysis of the plant N°1 and N°2, this analysis is composed by only one scenario: the ***ex-ante*** scenario that highlights the performances that can be predicted before the construction as in a business plan. All the cashflow are actualized to the year 2019, when the construction was authorized.

The analysis use the same data, hypothesis and assumptions available before the construction in the year 2019 (mean annual producibility, CAPEX, OPEX, financial yields, ecc). Note that some information of the actual real performances of the first year of operation are available, therefore the hypothesis and data if completely different from the actual real data will be highlighted.

3.6.1. Data & Hypothesis

Considering the **CAPEX,** the value considered derived from the result of the competitive and negotiated procedure done in the year 2019. This competitive procedure permits to lower the investment cost instead of the direct awarding to construction companies. The total planned cash-out was 1.811 million euros.
Note that the peculiarity of this plant that is realized at the same time with other 3 similar and near plants permits to lower the price and the cost of construction: for the turbine-alternator and for the electromechanical works a common competitive procedure has been done in order to exploit the economies of scale in a better way.

The investment is divided into categories as specified in the following graphs and table (3.28):

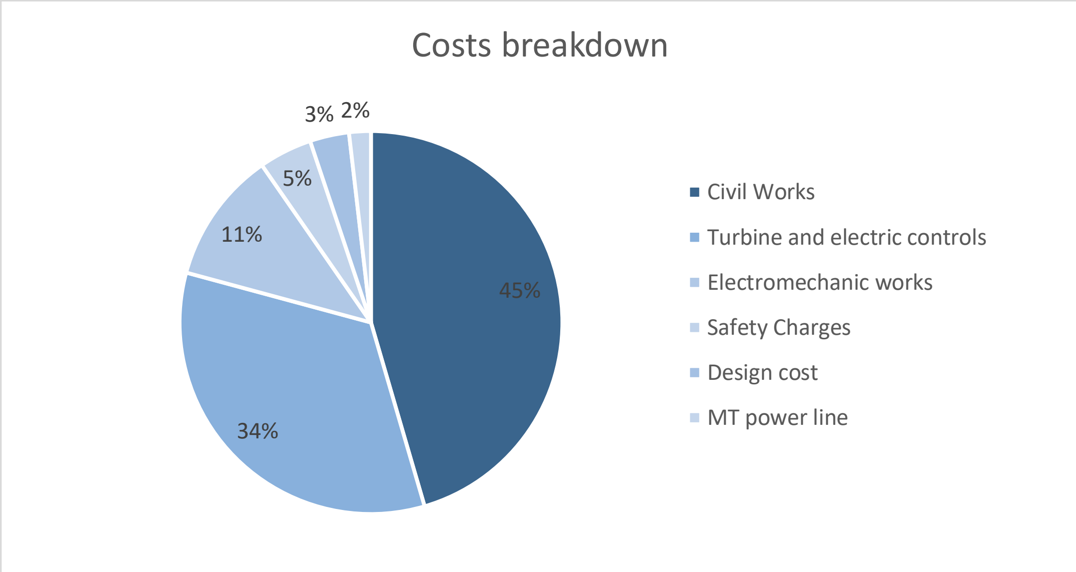

Figure 3.17: Graphical representation of the powerplant's CAPEX

As clearly visible, the major sources of costs are the civil works, that account for almost 45% of the total investment. Another big share of the cash-out is related to the turbine and electric control. The cash-out is estimated equally distributed in two years of construction.

CAPEX breakdown	
Civil Works	823,885.21 €
Turbine and electric controls	610,830.00 €
Electromechanic works	202,000.00 €
Safety Charges	81,513.49 €
Design cost	60,000.00 €
MT power line	33,333.34
TOTAL	1,811,561.34 €

Table 3.28: CAPEX breakdown into categories of costs

Considering the **O&M costs**, the management and the ordinary maintenance is done internally by INBRE spa, in order to be conservative a value of 20.000,00 € of O&M costs is considered for the first years, in the next years is adjusted for inflation.

Considering the **insurance costs**, an All-Risk insurance contact has been signed. In the valuation, an initial premium of 3,500.00 € is considered then is adjusted for inflation over the following years.

Considering the **regional concession fees**, in the valuation is considered the value of 2019, 16.19 €/kW adjusted for inflation over the years. **No concession extra-fees** are in place since the concession power of the plant is lower than 220 kW.

Considering the amortization plan, since the concession of the right of use the water of the river for hydroelectric use last 30 years from the 2018, the **lifetime** considered is equal to 30 years ending in the 2048, therefore the effective years of production are 28.
The amortization rate would be subdivided in category according to the fiscal rules, as specified in the next table. However, for simplicity all the ***civil works*** are jointed into one **amortization rate** of 3.57% considering an amortization time of 28 years according to the end of the concession in 2042. All the electromechanical costs and the other instrumental goods are jointed into one **amortization rate** of 8.33% considering an amortization time of 12 years.

Amortization Rate (fiscal rules)	
Buildings *(powerhouse)*	3.00 %
Fixed Hydraulic Works	1.00 %
Penstock	4.00 %
Electromechanical works	7.00 %
Equipment	10.00 %

Table 3.29: Amortization rate according to Italian fiscal rules

Considering the **electricity price** at which the energy is sold, the plant had access to an incentivized tariff according to the Minister Decree 23 June 2016 with a fixed value of 210 €/MWh for 20 years. After this period the plant can sell the energy to the GSE with the "RID – Ritiro Dedicato" with some minimum guaranteed prices for the first 1,500 MWh, under the "Prezzi Minimi Garantiti" scheme.
In the following table are reported the minimum guaranteed prices for hydroelectric electricity for the year of 2019, the weighted average of this value is considered as price of reference for the 21-th year, later is adjusted for inflation during years. This price of reference is equal to 85.92 €/MWh.

Data	Price [€/MWh]
Less than 250,000 kWh	156.1
Over 250,000 kWh less than 500.000 kWh	107.2
Over 500,000 kWh less than 1,000,000 kWh	67.6
Over 1,000,000 kWh less than 1,500,000 kWh	58.5

Table 3.30: Minimum guaranteed price for the year 2019

The current market price of electricity in 2022 is in the order of magnitude of 200 €/MWh very similar to the incentivized tariff, however there is not a certainty that the price in the future will maintain this value.

Considering **production** of **electricity**, in the design documents the mean annual producibility estimated is 1,100.00 MWh/year, this value is used with the hypothesis of fixed production.

3.6.2. Hypothesis & Assumptions

The following assumptions are considered in this economic & financial analysis, considering respectively the information available in 2019. Some hypothesis and assumptions are the same of the analysis of the plant n°1. In order to not be repetitive all the hypothesis and assumptions, are synthetized in the following table:

Data	Ex-Ante
Inflation rate	2%
Tax rate	24% + 3.9%
E/(E+D)	25%
Debt yield	4%
Equity return	8%
WACC	4.2%
CAPEX	1,811,561.34 €
O&M	20.000,00 €/year
Production	1,100,000 kWh
Lifetime	30 years
Amortization rate	3.57% - 8.33%

Table 3.31: Main hypothesis and assumptions utilized

3.6.3. Economic & Financial Indexes

The analysis is carried out performing the calculation of different useful indexes in order to evaluate the economic and financial performances of the two cases. As in the evaluation of the plant n°1, during the analysis are computed:

- the *Net Present Value* (**NPV**)
- the *simple Payback Time* (**sPBT**),
- the *discounted Payback Time* (**PBT**)
- the *Internal Rate of Return* (**IRR**)

Another important index is the *Levelized Cost of Electricity* (**LCOE**), it is very useful to highlight the actual performance of the plant, since is no affected by the price at which the electricity is sold by only depends on the costs and the energy production. This index is also very useful to compare different plant located in different places and with different technologies, in order to evaluate the effective cost of the production.

3.6.4. Results

The results are reported in the following table showing a general positive judgment of the investment, however the performances are not so high.

RESULTS	
NPV	524,397.29 €
sPBT	12
PBT	16
IRR	6.97 %
LCOE	146.50 €/MWh

Table 3.32: Results of the Economic & Financial analysis

The performances are positive since the NPV is around *0.5 million euros* and single-digit level of Internal Rate of Return equal to *6.97%* showing a medium level of profitability.
The investment is repaid in 12 years considering the simple payback time or in 16 years considering the discounted payback time. Considering that the lifetime is of

30 years, the investment is repaid roughly in one half of the lifetime and before the end of the incentivized period.
However, the LCOE is medium-high at a level of 146.50 €/MWh, showing that the plant is profitable only with an incentivized tariff since the price of electricity in 2019 was lower than this level. This level of LCOE is affected by the relatively high cost of the civil works in respect to the size of the plant that has a small electricity production. The plant without the incentivized tariff cannot be sustainable from and economic and financial perspective.
As you many notice the plant has not a huge profitability, since all the indexes are positive but not so high in performances. This is related to relatively high cost of construction compared to the production estimate.

Considering all these aspects, the plant is ***profitable*** and can be considered a "medium-good investment". The incentivized tariff covers the costs and guarantees a ***medium single-digit return*** that can be interesting.

In the first year of operation of the plant the production was around 400 MWh, while the O&Ms costs was lower than the expected. This lower electricity production is related on one side to the fact that the plant is fully operative from March 2021 and one the other side to the exceptional low rainfall during the year.

This implies that after the start-up phase a better scenario, with an increase in the rainfall and the O&Ms costs decrease, can lead to an increase of the economic and financial performances. Moreover, the price of the electricity after the incentivized period can be much greater that the budgeted, leading to another increase in the profitability. Another conservative hypothesis is the fact that, the G.O. "Garanzie di Origine" are not considered in this analysis that can give an extra revenue stream to the plant.
Considering all the conservative hypothesis and data used, an increase of the profitability in the future years can be probable, delivering further value for the shareholders reaching a level of ***double-digit return.***

In the next graph (3.18) are represented the *cumulative actualized cashflows*. You may note that the discounted payback time is in the year 2034. The end of the incentivized period is in 2040, so the payback is reached before the end of the incentivized period, leading to considerably time of profitability after the having fully repaid the initial investment.

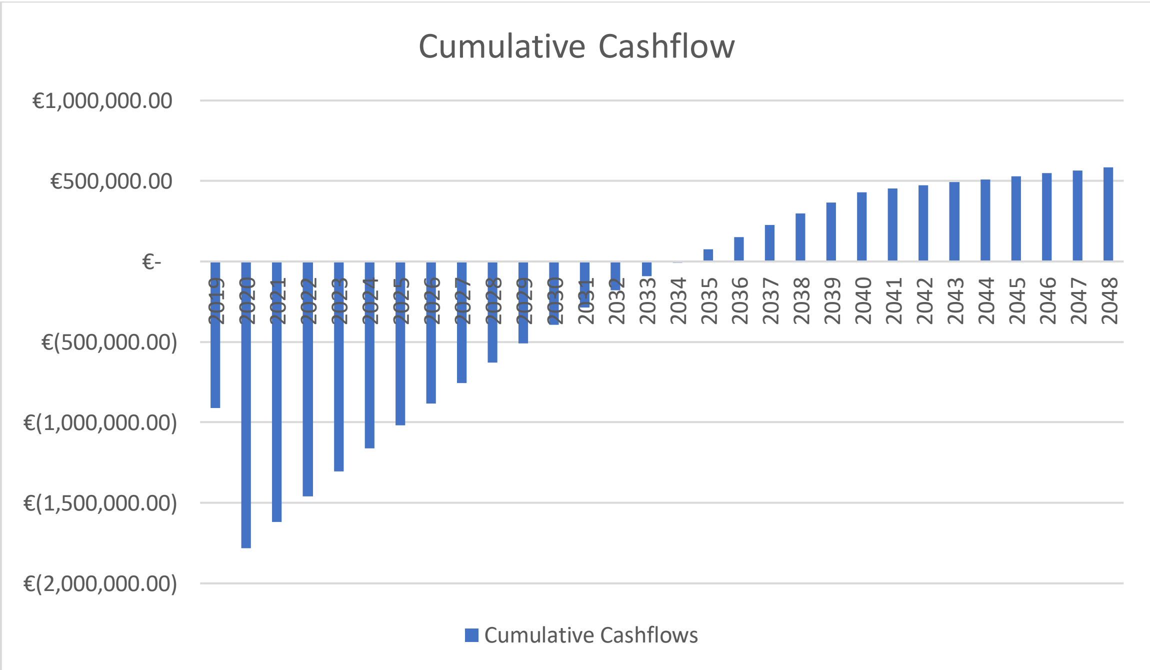

Figure 3.18: Graphical representation of the cumulative cashflows

At the end of the incentivized period, if the current market price will hold the actual quotations with a price near to the incentivized tariff, the plant can increase his profitability to a higher level, delivering more cash flow, increasing the IRR and the NPV. The extra 10 years of remuneration at high price can provide ***higher double digit return*** to the shareholders.

4 A new water intake

In this chapter a new typology of auto-cleaning off-grid water intake will be analyzed. In detail, a new concept of auto-cleaning water intake is presented, showing the main characteristics and the advantages of this new water intake.
Then the assessment of the water intake of the previously analyzed plant N°2 is done, focusing in the evaluation of the OPEX related to the ordinary maintenance and the estimate of the lost production of electric energy related to the clogging of the intake.
Subsequently, a qualitative analysis of the possible implementation of the new component into the existing hydropower plant is carried out, from a technical point of view and from a legal-authorization point of view, highlighting the possible criticalities.

4.1. Description of a new water intake

The new concept of water intake is described in the following paragraph without entering too much into the technical detail and in the sizing criteria in order to maintain the discretion and confidentiality since the water intake is in the patent pending phase.

The idea behind this new concept is to solve common problems of the water intakes of small power plants on mountain rivers: the frequent clogging due to the deposit of leaves and branches. This event is problematic in places where the accessibility to the site is critical and in off-grid application where an electric power line is not available, implying the impossibility to the installation of automatic cleaning devices. In the following picture (4.1) an example of an intake that is clogged of leaves is reported, in order to have a clearer view of the typology of problem that the new device aims to solve.

Figure 4.1: Example of a clogged intake

The new water intake is an auto-cleaning device, the leaves or branches those deposits on the intake after a while are removed, so the nominal intake capability is restored, improving the performances of the plant. The peculiarity of this water intake is the fact that is completely off-grid, no electric power is required in order to activate the autocleaning functions.

The system is composed by a rotating cylinder that is mounted on a support structural frame made of steel that has also the function to anchor the metal device to the local reinforced concreate structure with bolts. The cylinder is made of bars with a variable spacing according to plant design criteria, normally ranging from 0.5 to 2 millimeter. In the following picture (4.2) can be easily seen the device and the major part during operation in a real operation test campaign.

Figure 4.2: Photo of the device during a test

During the standard operation of the water intake the cylindrical grid is in a steady state position, the water flow is captured by the holes of the grid in the first tens of centimeters of the holed cylinder.
When the leaves or other debris are present in the river, some of these go away by itself, while others remain attached to the grid inhibiting the passage of the water flow though the grid in the first tens of centimeter of the device. This lead to a forcing of the flow to enter into the cylinder in a position that is further downstream in respect to the standard condition of operation.
Inside the cylinder are welded some spoon-shaped buckets positioned in order to capture the water that enters in the second half of the cylinder when the leaves and debris clog the first half. This imbalance of the weight distribution inside the cylinder activates the system's rotation. A rotation of roughly 90 degrees happens cleaning the intake from the debris, which are piled up outside the intake downstream the device, as clearly visible in the picture (4.2).
The device is modular, the size of the cylinder can be adjusted in order to be compatible with the water flow required by the plant. In particular the length of the cylinder can be lengthened or shortened as needed at a relatively low cost.

A test campaign was done in order to verify the effectiveness and the reliability of the water intake. The system was installed in an existing plant, that had a nominal water flow of 250 l/s and a planar grid with spacing of 1 millimeter that needed a huge amount of manual maintenance in order to clean the intake.
The results of this operation test, lasting for 18 months, show a positive impact: no manual cleaning of the intake grid during all the time of the test, no maintenance to the device and no deterioration to the cylinder or the frame, increase of the average flow of water captured of about 10% - 20% in comparison with the previous situation.

4.2. Application in plant No.2 – Evaluation of the OPEX

This paragraph analyzes in detail the intake work of the hydroelectric plant N ° 2. As can be seen from the technical drawings (4.3), the intake structure consists of a trap-intake grid with plan dimensions of 6.5 x 1.5 meters. Maximum water flow processed by the water intake is equal to 450 l/s. The water flow after being captured by the grid trap goes to the settling basing, in order to remove all the gravel and sand particles from the water.
The aim of the following analysis is to evaluate on one side the incidence of the maintenance costs for the cleaning of the water intake, on the other side estimate the reduction of electricity production related to the debris and the non-optimal functionality of the intake due to the clogging.

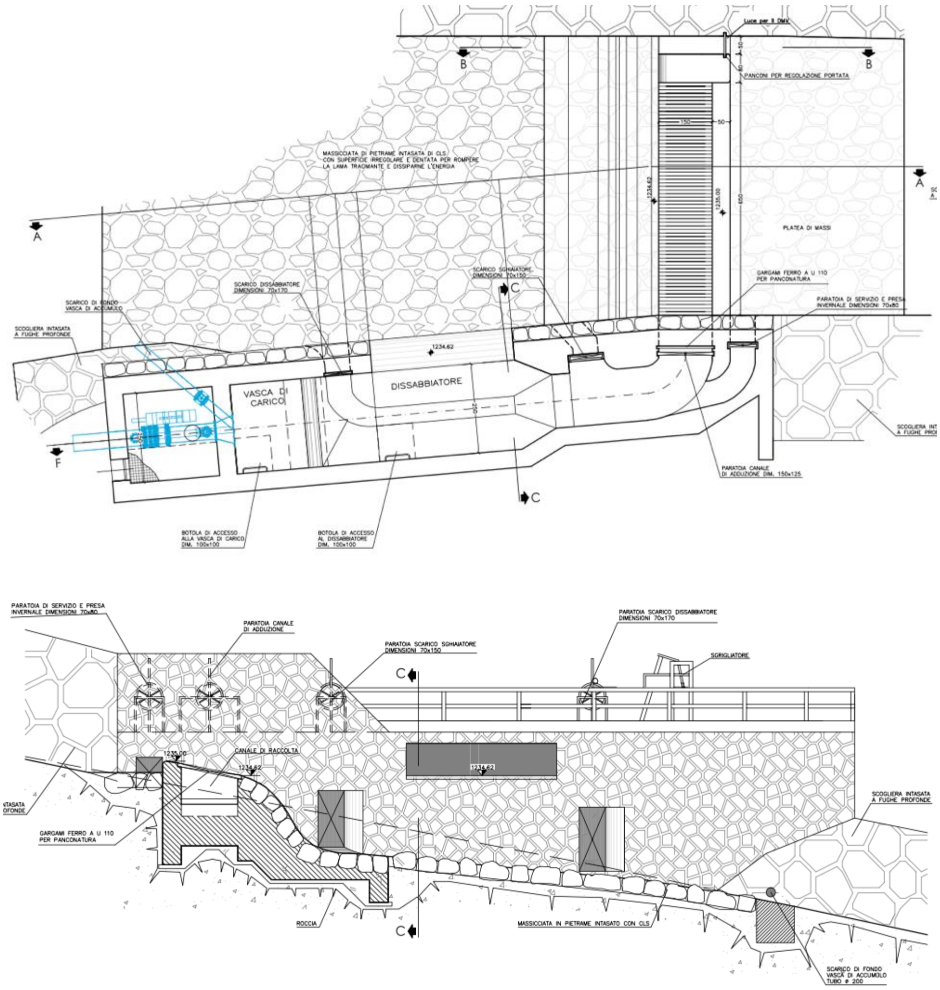

Figure 4.3: Technical drawings of the plant No.2’s water intake

Considering the **maintenance costs**, as specified in the chapter (3.4.1) this plant has an Operation & Maintenance contract with a specialized company that makes the ordinary and periodic maintenance, including the cleaning of the water intake, for a fixed tariff of 4.5 €/MWh. This tariff is dependent on the electiricty production not on the effective amount of money spent for the single maintenance, leading to an incentive to the servicing company to maintain the plant always at the best efficiency. However, the service company redacts monthly a report pointing out all the maintenance interventions carried out and the relative duration, it possible to extract the time required for the cleaning of the water intake during the year 2021.
In the following table are reported the data and the duration of the cleaning activities performed during the year 2021, as clearly visible the cleaning is done in the summer months, when the clogging of the intake is more critical and also because there is a greater amount of available water.

Data	Duration [h]	Data	Duration [h]
11 June 2021	1:00	**20 August 2021**	1:30
14 June 2021	1:00	**30 August 2021**	1:00
24 June 2021	2:00	**06 September 2021**	1:30
25 June 2021	1:00	**08 September 2021**	2:00
30 July 2021	2:00	**06 October 2021**	0:30
17 August 2021	0:30	**08 October 2021**	1:00
TOTAL		**15 h/year**	

Table 4.1: Cleaning activities performed during the year 2021

The total amount of working hour needed to clean the water intake in the year 2021 are equal to 15 hours. Considering a monetary valuation of 30 €/h as the hourly cost of the worker that do the manual cleaning of the intake and settling basin, can be computed a value of **450 €/year** of annual expenses related to the cleaning of the water intake and the settling basin.

Considering the estimation of the **potential increase** in the **electricity production** due to the cleaning of the intake works, a qualitative analysis is performed focusing the attention on the relevant data that can be significative in terms of difference of electricity production.
Starting from the punctual data of hourly electricity production of the entire years of 2021, the data are selected between the day when the maintenance is done: excluding the non-significant data related to flood or variation of meteorological condition some days of reference are extracted in the month of June, September and October.
In the following graphs are reported the electricity production in the period of June, September and October, as visible and highlighted by the red arrow in the days after the maintenance and cleaning of the water intake work there is an increase of the electricity production.
Please note that from all the available data, some period are not considered and discharged in the analysis since are not relevant and influenced by other variables and not totally related to the cleaning of the water intake. In fact, considering the pluviometry data from the *ARPA Lombardia – Agenzia Regionale Protezione Ambiente Lombardia*, in a pluviometry station of measurement located in a nearby municipality in the days analyzed no rain event occurred. Moreover, in the first decade of June month, the data are discharged since an relevant increase of the temperature measured by the meteorological station of ARPA lead to the melting of the snow in the upper part of the catchment basin. Farther in the July and August months exceptional rains and a flood happens leading to a clogging of the intake that cannot be considered as standard condition.
So for the selected data, after the discharge of the not totally linked to the cleaning of the water intake, can be considered that all the increase in production is related to the cleaning of the water intake.

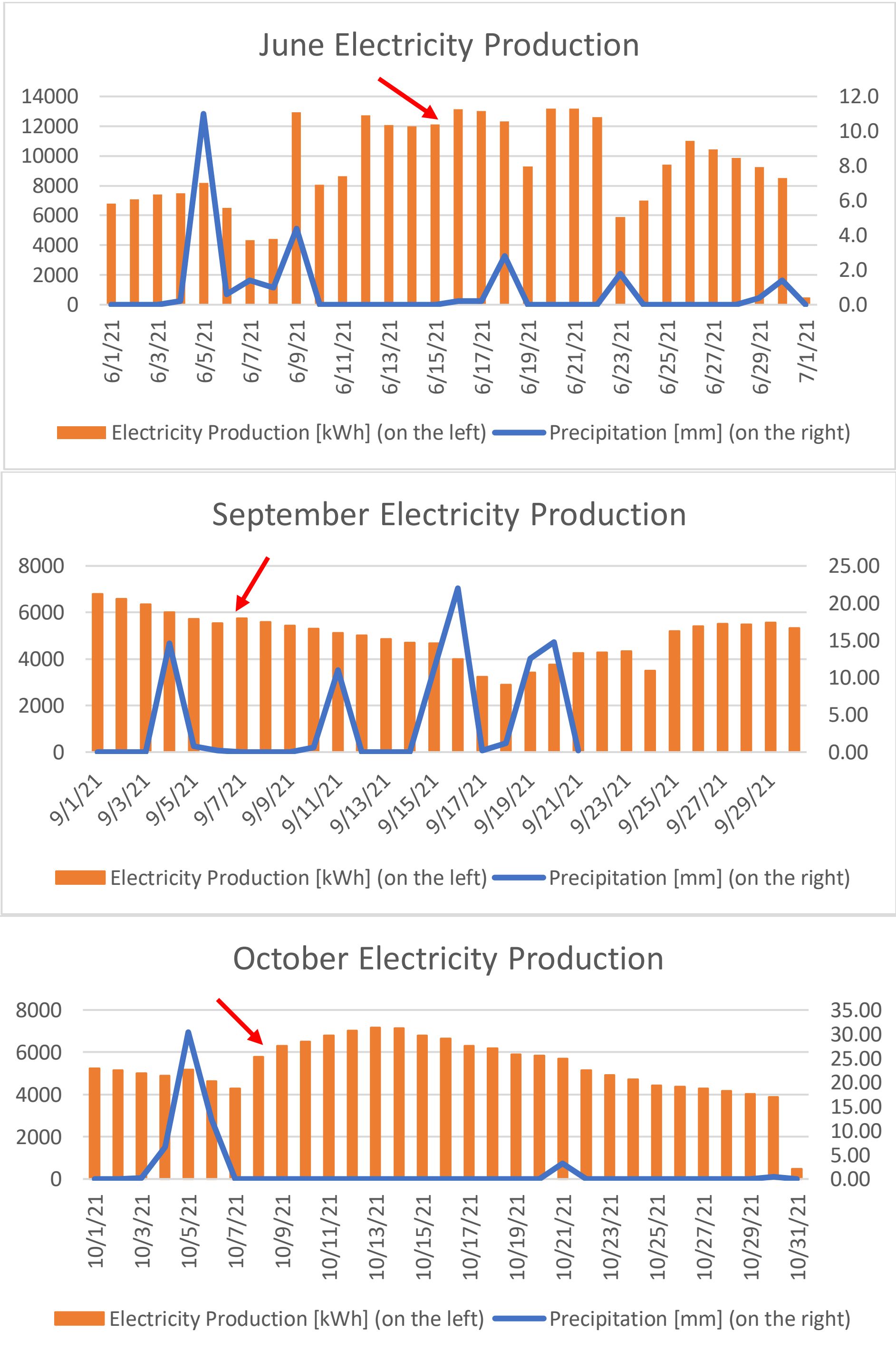

Figure 4.4: Electricity production and precipitation during June, September, October

Considering all these aspects and hypothesis, a percentual increase of electricity production can be computed for each day considered, as reported in the next table. The result can be then averaged in order to obtain a value of the estimated average increase in the production due to the cleaning of the water intake, equal to **2.66 %.**

Data	Increase [%]	
11 June 2021	47.83 %	Discharged
14 June 2021	1.26 %	Considered
24 June 2021	34.57 %	Discharged
25 June 2021	16.82 %	Discharged
17 August 2021	71.85 %	Discharged
20 August 2021	21.61 %	Discharged
30 August 2021	37.23 %	Discharged
06 September 2021	3.51 %	Considered
08 October 2021	3.22 %	Considered
AVERAGE INCREASE	**2.66 %**	

Table 4.2: Percentual increase in the electricity production (day v/s day)

4.2.1. Estimation of the present value related to the installation of the new autocleaning device

Considering now a methodology in order to annualize the punctual increase in electricity production, it is proposed to use a linear behavior of the clogging of the water intake with a period between the cleaning of roughly 30 days, excluding 5 months during the year, when the cleaning is not necessary, as represented in the following graph. This hypothesis led to a value of the annual lost production percentage related to the clogging of the water intake equal to **0.887 %**

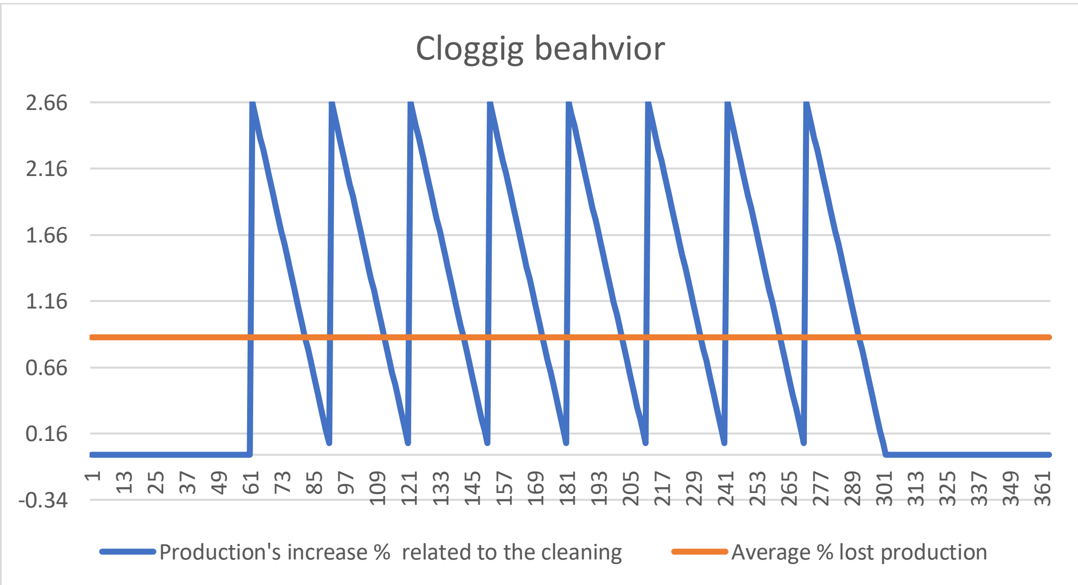

Figure 4.5: Graphical representation of the clogging behavior during the year

Using the value of the percentage of lost production due to a non-ideal water intake and recalling the data of the plant N°2 reported in the chapter (3.4.1): the annual expected production of 1,495 MWh/year and the price of the incentivized tariff of 210.24 €/MWh lead to a value of lost production due to the clogging equal to 3,237 €/year during the incentivized period and a value of roughly 1600 €/year for the following years until the expiry of the concession. (Values that are the same used for the Economic & Financial analysis performed for the whole plant No.2)

A potential improvement in the water intake work can be considered in order to recover the lost production, previously computed of 13 MWh/years, using an ideal intake device that doesn't need maintenance and remains always clean. The device presented in the paragraph (4.1) have all the characteristics that can improve the situation of the powerplant's intake. This new water intake potentially recovers all the lost production and doesn't require the actual maintenance of roughly 450 €/year that are currently spent.

Performing an economic and financial analysis during the remaining lifetime of the plant with the hypothesis of recovering all the lost production computed and deleting the cost of the maintenance of cleaning the intake, can be computed the actualized monetary value of the improvement with a new water intake device, showing the level of investment that can justify an improvement and must not be overcame in order to improve the profitability of the investment. The NPV of the improvement is equal to **24,738.60 €** actualized at the year 2022, considering the same parameters of the financial analysis performed for the plant N°2 in the chapter (3.4.2) and the expiry of the concession

4.3. Authorization procedure for the installation of the new device

Assuming the installation of the new self-cleaning intake system previously presented in substitution of the current trap intake work present in the hydroelectric plant No. 2, there are constraints both of a technical nature and of a legal-authorization nature.

Firstly, from a technical point of view, the space available for the installation of the new water capture system are equal to 6.5 x 1.5 meters, while the maximum processed water flow is equal to 450 l/s as the maximum licensing regulations.
The standard module of the new device has a frame dimension of approximately 1.5 x 1.25 meters, allowing the passage of a maximum water flow of 250 l/s.
Can be proposed that 2 modules would be enough to satisfy the maximum water flow limit, however using all the available space 4 modules of the standard device can be positioned. In order to not capture all the available water in the river and consequently release the minimum vital flow prescribed by the law, is necessary to adapt the intake in order to release the same amount of 50 l/s.

Secondly, from a legal-authorization point of view, the changes at the water intake of a hydroelectric power plant are always critical for authorization. An important step is the classification if the change in the water intake is a relevant change or not-relevant change from the point of view of the water exploiting. According to the concession for the use of water for hydroelectric use, if the quantities of average and maximum flow are respected and the dimension of the water intake are the same, the change can be considered as non-relevant from a legal point of view. Consequently, this intervention on the water intake can be considered as extraordinary maintenance.

The authorization procedure therefore requires that there be a “Autorizzazione Unica” procedure where public bodies can express their opinions and binding prescriptions in a single event called "Conference of Services" where they are highlighted.

Particular attention must be paid to landscape and environmental constraints, given the potential visual impact of the new system: the steel frame and the silver-colored grid have a significant visual impact even in the distance, the geometry and the overall dimensions greater than traditional trap increase this impact.
Furthermore, the fact that the plant falls within the Adamello Park poses further problems in terms of environmental permits and / or special requirements that

could considerably increase the costs associated with improving the intake work. The times for the authorization of the intervention could lengthen and consequently decrease the expected benefit in terms of increased production.

Given all the arguments set out above, the benefits expected from the improvement of production and the reduction of O&M costs are not negligible. If the change of the water intake can be authorized considering it as a non-relevant from a legal point of view by the Public Entities, since the dimensions and the flow are the same of the original configuration, the upgrade is profitable and very good to implement from a technical and economic point of view.

However, if the change of the water intake can't be considered as a non-relevant from a legal point of view by the Public Entities, the improvement with the new self-cleaning system can be considered as an addition to other extraordinary maintenance or in a bigger revamping of the plant at the end of the concession. Moreover, must be considered the risk of extra costs and prescriptions of public bodies can increase costs and lead to a non-profitable choice.

5 Conclusion

The future energy scenario is highly uncertain, with a foreseeable and continuous increase in the costs of fossil energy supply, amplified by the situation of recent geopolitical instability, renewable sources can contribute to lowering the energy costs of Western countries by helping to reach the climate targets of CO2 reduction. In this scenario, the hydroelectric source exploited by small hydroelectric plants, even if impacted by a climate change that exacerbates the dry summer periods, provides a renewable electricity production with zero emissions with a very low environmental impact and limited land consumption. Furthermore, widespread and decentralized production in the area will allow, also through the new tools of the Renewable Energy Community (CER), to optimize the production and consumption of electricity in the local area, relieving the national transmission grid from increasing congestions.
Although hydroelectric technology has been highly tested and used for many decades, the sector is no stranger to the development of new technologies and new components, which can increase energy efficiency and reduce operating costs, guaranteeing an increase in economic performance.

In this paper, three different hydroelectric plants owned by Iniziative Bresciane spa have been analyzed. Following the analyzes carried out, it is possible to highlight that the profitability of small hydroelectric plants is closely linked, on one hand, to a correct estimate of water availability during the design phase, and on the other hand to a correct construction phase respecting the budget without extra costs or delays. In addition, during the plant management phase, a correct maintenance plan carried out by qualified specialists helps to keep electricity production high maintaining high cashflows; moreover, correct and prudent risk management is important. Taking risk mitigation actions, through All-risk policies makes it possible to overcome even extreme events such as floods and natural disasters.

The following table shows the numerical results of the 3 cases mentioned above.

	Plant No.1	Plant No.2	Plant No.3
NPV	1,271,348.00 €	1,227,228.00 €	524,397.00 €
sPBT	10	9	12
PBT	14	11	16
IRR	8.10 %	11.46 %	6.97 %
LCOE	134 €/MWh	109 €/MWh	146 €/MWh

Table 5.1: Result of the Economic & Financial analysis of all the power plants

A new type of water intake was also analyzed in the Master Thesis, focusing attention on the expected benefits of an upgrade of an existing power plant with the new device.
Using the daily electricity production data and the reports of the maintenance carried out daily by the staff, implemented also by the rainfall and meteorological data of the area, it was possible to extrapolate the percentage of reduction in hydroelectric production resulting from the clogging of the intake structure.
It was also possible to easily estimate the waste of time used by the operator who takes care of maintenance for cleaning the clogging of the grids from leaves and other material.

Economic benefits are obtained both in terms of reduction in operating costs, in particular labor for cleaning the intake, equal to 450 €/year and increase hydroelectric production equal to 13.26 MWh/year. The discounted value of a revamping of an existing plant with the addition of this new type of water intake leads to an expected benefit of approximately 25 000 €. The results of the analysis are grouped in the table (5.2).

Economic benefits of the new water intake	
Decrese in maintenace costs	450 €/year
Increase in electricity production	13.26 MWh/year
Increase in revenue	3,267.00 €/year
NPV	24,740.00 €

Table 5.2: Economic benefits of the new water intake during the lifetime of plant No.2

In conclusion, a potential revamping of the water intake can be evaluated, given the economic and financial benefits deriving from an improvement in the intake: the investment, if lower than the expected discounted benefits, brings added value to the system.
From an authorization point of view, the adaptation can be considered an extraordinary maintenance which is not substantial to the intake work, as all the concession parameters (water flow, useful head, minimum vital flow) are kept intact.

Further future developments may derive from deepening the study of the authorization process for revamping of plant through direct dialogue with the public bodies concerned in this process. Furthermore, a precise numerical quantification of the cost of the new device, thanks to an ad hoc sizing and to a quantification of the material and production costs, leads to a comparison with the expected benefit value obtained in this document useful for the final decision of implement the upgrading of the plant.

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