Interreg - IPA CBC
Bulgaria - Serbia

Renewable Energy for Smart Growth and protected Environment

Hydropower

A practical guide to using water energy

The project is co-funded by EU through the Interreg-IPA CBC Bulgaria–Serbia Programme

THE CONTENT

Hydropower

A practical guide to using water energy

Zajecar, 2022

ABBREVIATIONS AND THEIR MEANING

RES - Renewable energy sources

ROI - Return on investment time

ICT - Information and communication technologies

HE - Hydropower plants

MHE - Small hydropower plants

HPP - Hydropower plants

ICT – Information and communication technologies

LCOE - Levelized Cost of Energy

PPA – Long-term energy supply agreement

IoT - Internet of Things

This publication was made with the help of European Union funds through Interreg-IPA Cross-border cooperation program Bulgaria-Serbia under number CCI No 2014TC16I5CB007.

The sole responsible person for the content of this publication is RARIS - Regional Agency for development of Eastern Serbia and cannot in any way be interpreted as the position of the European Union or the Governing Body of the program.

INTRODUCTION

1. IMPORTANCE OF ENERGY IN CONTEMPORARY WORLD AND TRENDS

Along with water, energy is one of the two most important resources that are crucial for the current and future survival of the human community. It may sound a bit scary, almost cataclysmic, but everyday life confirms that without one of these two resources, there can hardly be any sustainable development of society or even preserving of the existing state of the art. Energy has always been a significant factor that ensured progress, starting with very basic use for food preparation, light and heating, until today where there is NO activity that is feasible without more or less energy. The consumption of this key resource began to grow exponentially with technological development in the 17th and 19th centuries, especially after the First Industrial Revolution, where energy began to be used extensively in the mass production of goods for an increasingly demanding and growing markets. Consumption is proportional to the level of industrial development, but also to the level of living standard. From 1965 to 2021, consumption in some countries increased up to 500 times (Oman), in a number of developing Asian countries ten or more times, while in a number of very poor countries it even fell by 50%, due to reduced industrial activity (Syria, Gabon, North Korea...) or the reductions are the result of the introduction of more efficient technologies and strict energy efficiency programs (Great Britain, Denmark, Luxembourg...).

During the last twenty years, the demand for electricity has been growing rapidly due to efforts to reduce the impact on climate change, i.e. because of increasingly strict measures for the introduction of decarbonisation, i.e. industries that do not emit or have a significantly lower emission of CO_2, being it the main cause of the global warming. The consequences are already clear to everyone, because the incremented average temperatures cause a change in the movement of air masses and water flows, which results in extreme climatic phenomena, large droughts throughout the year, and on the other hand, huge amounts of precipitation in a short time, even at the time of the year when there has never been such climate turmoil. Electricity is perceived as the cleanest form of energy that is not polluting the environment, although this is must not always be the case. Take, for example, the production of electricity from thermal power plants, where large amounts of polluting gases, especially CO_2 and PMs are emitted, even when the installations have very complex and very expensive air purification systems. At the same time, the use of hydro or nuclear energy are driving controversies. Large hydroelectric plants do not emit CO_2, but have a great impact on the microclimate, conditions on groundwater, on habitat and biotope and also at the social level when entire settlements and infrastructure are moved from areas where reservoirs are formed. Nuclear power plants are potentially at very high risk due to the even the smallest possibility of a nuclear accident and/or due to the demanding storing of nuclear waste.

The events from recent years have only brought up all these issues to the fore front, particularly the conflict in Ukraine, which resulted with massive displacements and huge disruptions to the food and energy supply chains, therefore some almost forgotten capacities for dirty fuels, primarily coal, are resurrected by force of circumstances and returned to production.

For all these reasons, the whole world, and especially the European Union, has been trying for a number of years to introduce programs aimed at producing clean energy in sufficient quantities, aiming at sustainable development goals (RIO process, Kyoto Protocol, Green Agenda, Fit for 55).

2. WHAT ARE RENEWABLE ENERGY SOURCES

Renewable energy sources (RES) are sources that are renewed at least the same rate at which they are exploited. Everything in nature what could be renewed is done spontaneously and without side effects, thus RES are considered to be clean energy and the right choice for solving energy needs without polluting the environment with no, or very little, impact on climate. Unlike RES, non-renewable resources are depleted over time and cannot be renewed, at least not on timescales comparable to our understanding of time. Non-renewable energy sources are all fossil fuels (coal, oil, natural gas), for example, because they cannot be renewed even during the time that was sufficient for the creation of human civilization.

Renewable energy sources include:

The energy of water is the energy of rivers, the energy of waves and tides. It has been used to run mills or any other installations that require mechanical energy, threshing machines, saw mills, weaving mills... Since the 19th century, the production of electricity has emerged and since then, water is one of the most common way of using energy sources that are constantly renewed.

The energy of the sun is the energy that our star radiates to the earth's surface and is of both heat and light nature (although they are of the same, electromagnetic origin, but in different spectrums of radiation). This is also a form of energy that has always been available. In the beginning, the sun was only used as a thermal source, for heating homes, for boiling water and in very early stage to dry and preserve the food because, in addition to heat, the sun also radiates ultraviolet rays, which are excellent disinfectants, thus very good for preserving the food. For this reason, the sun is used to dry meat, plants and plant products. It was only in the 20th century when it was discovered that, when crystallized silicon is exposed to the sun, it causes electric voltage on its ends. This phenomenon is widely used today to make photoelectric panels that generate electricity.

Geothermal energy is the energy of the earth which is a huge heat reservoir. The earth radiates its own energy and the miners know this best because the temperature in the pits is much higher than on the surface. The earth is a great generator and this feature was used, above all, for balneological and health purposes. Each spa utilizes warm water from depth. Thermal waters, however, can be used for the production of electricity, for heating swimming pools, residential areas, for heating roads and streets (Iceland, which is all resting on geothermal springs, uses them abundantly for exactly these purposes), greenhouses and fish ponds. However, geothermal energy is not used only for heating, but for also electricity production and can be put to work with the heat pump technology for both heating and cooling.

Biomass - Energy obtained from burning plant residues, using bio gas as a product of decomposition of plant mass and from bio fuel (fuel obtained from processing high oil content plants). Biomass is the oldest form of renewable energy since the humans used wood for heating, to prepare food and as a source of light ever since. Woods grow, so if used carefully, it will always be there. Biomass are both plants and residues from agricultural production and in general, all biological material that can be used as fuel. This is the primary way of using biomass (straw, residues from harvests, residues from vegetable crops, dry branches and plants, etc...). Biomass could be collected from special energy plants that are grown only for this purpose (fast-growing willows, for example). Today, biomass is commonly available in shape of pellets, compressed plant residues that provide uniformity and easy way to use it as a fuel.

Wind energy - Wind is a result of the movement of large air masses in the earth's atmosphere, due to climatic, thermodynamic phenomena, differences in temperature and air pressure above the earth's surface. Wind occurs occasionally and we cannot precisely nor predict with certainty when it shall blow, albeit it was also used as a source of energy. In the beginning, it was a driving force for ships with sails which were energy "catchers", and later on, as a driver for mills and everything that could be powered by external energy (water pumps, saw mills...). The energy that was initially used to propel vessels is now largely used to generate electricity with the help of wind generators.

3. WHICH ARE THE ADVANTAGES OF USING RENEWABLE ENERGY SOURCES

Renewable energy sources are available in some form everywhere and can be exploited in any place, immediately and without the need to transport any fuel. This means that the infrastructure for exploiting energy from renewable sources is more compact, simpler and less demanding. Large facilities such as large storage and/or reversible hydropower plants or facilities for the massive use of geothermal water, such as exist in Iceland, for example, are not considered in this publication.

The energy security status is much more favourable when it comes to dispersion of energy sources on smaller units, rather than large energy installations, with the capacity to overwhelm significant consumption. Failure of a small plant shall not jeopardize the power system, while failure of a large power installation leads to very serious problems in the energy production and distribution.

From purely technical perspective, the generation of energy in small plants provides distribution throughout the electrical grid at a lower voltage, which reduces losses in energy transport and makes it more efficient.

The price of energy production from renewable sources has a downward trend and on the other hand, the market price of energy has a tendency to increase, which justifies investments in RES.

The green economy, and therefore the industry of renewable energy sources, is, in addition to ICT, the fastest growing industry, since the transition to RES requires development of new technologies and considerably greater production of equipment and services in this particular niche, so the benefit is twofold, on the one hand energy is significantly cleaner and safer to use than the one from conventional sources and on the other hand, the level of energy security is increased and the dependence on other sources and/or energy providers has been reduced. Finally, the price of energy production from renewable sources is falling down because of the number of equipment manufacturers increases, thus the equipment becomes cheaper.

4. WHICH ARE THE CHALLENGES IN USING RENEWABLE ENERGY SOURCES

The biggest challenge in using energy from renewable sources is that the two most popular and easiest to exploit, wind and solar energy, are of such a nature that they are not produced continuously. Energy from those two sources is generated when it is available, that is, when there is sun or wind, which is predictable only to a certain extent. The electric power system, roughly speaking, rests on three key pillars: the producer, the distributor and the consumer. Energy distribution is carried out through the electrical distribution grid, which, in order to operate in an optimal mode, must have a constant load. An analogy could be made with water pipes where also must be water all the time. Otherwise, air can enter the pipe and reduce the flow, or impurities can accumulate in the pipe due to stagnant water, which reduces flow rates.

In order to ensure the optimal load to the grid, more or less the same amount of energy must flow through it, for which we need to have uniform or harmonized consumption and production. This requires energy contingency that will be introduced to the grid when lacking sun or wind. That additional energy is the, so-called "balance energy" and must be provided in whatever way. So far, the grid operator is required to acquire balance energy, in accordance with the regulations both in Serbia and Bulgaria. However, in the future, most likely part or all of the obligation will be transferred to energy producers from renewable sources, which will make investments more expensive and less attractive, at least for large systems because small ones shall be exempted from it, in whole or in part.

It is also necessary to secure environmental safety with no impact on the environment (this especially applies to small, run-off hydroelectric power plants and large scale installations on biomass)

Although energy from renewable sources is cheap, the system must be regularly maintained (cleaning the panels, pruning trees so that they do not cast a shadow on the panels, checking the fluid in the solar collectors, checking the fluid in the heat pump system, maintaining the channels and catchment at the hydroelectric power plants, cleaning the stoves and chimneys in case of biomass stoves...) and replacing parts that exhausted their life span (accumulators, for example).

HYDRO ENERGY

5. WHAT IS HYDROENERGY, ITS FORMS AND POTENTIALS

The simplest definition of hydropower would be that it is the energy of water in motion. Whether it is tidal energy, wave energy or, most often, the energy of watercourses and water flow in general, their availibility is a subject to location and access to type of energy.

The hydropower potential of watercourses has been an important source of energy for centuries and it can be traced back to ancient Egypt, Persia and China.

Roughly speaking, the available energy of the water depends on its mass and the speed of its movement, thus the potential of large and slow river is greater than of a small one, despite its potentially faster flow. The wave energy can be also huge, but the problem is in uneven movement of the water, thus uneven energy that can be obtained from them.

The early applications, primarily of watercourses, were for mechanical purposes, for running simple machines and devices (large bucket wheels for watering fields i.e.) and later also to run mills, various agricultural devices for processing plants (stupas) or for sawmills. At the beginning of the First Industrial Revolution, in the second half of the 18th century, water began to be replaced by steam engines and in the late 19th century, hydropower became one of the main sources for the production of electricity.The first hydroelectric power plant was built at Niagara Falls in 1879 as the project of Nikola Tesla, and in 1881, the street lamps of the city of Niagara Falls were powered by hydropower.

Photo: MHE Moravica in Ivanjica

The first hydroelectric power plant in Serbia was built in 1911, in Ivanjica and is one of the oldest in the Balkans. The power plant has a power of 200 kW, was revitalized and is still in operation.

The oldest hydroelectric power plant in Bulgaria is HPP "Pančarevo", installed power of 372 kW, the first in the Balkans and was built in 1900.

Photo: HE "Pančarevo",

Current demand for electricity in Europe has returned to pre-pandemic levels from 2021, and hydropower is still the leading source of renewable energy. In the EU-27 countries, all renewable sources together contributed 37 percent of the total electricity production in 2021, which is approximately equal to the share of fossil fuels, and the rest of the needs are mainly provided by nuclear power plants.

Hydropower will play a key role in Europe's energy transition, as stated by the European Commission. The first IEA (International Energy Agency) report on the hydropower market, published in 2021, predicts a growth of about 8 percent of the total installed capacity in Europe by 2030, whether it is new, greenfield hydropower projects, or are modernization and expansion of the existing infrastructure. In response to the conflict in Ukraine and the disruption of natural gas flows from Russia, the European Commission announced plans to accelerate the transition to renewable energy sources, including hydropower. In this regards, European countries have started building new and revitalizing old capacities for hydropower (Turkey 500 MW, Norway 396 MW, etc.)

Serbia and Bulgaria have almost identical installed capacity of hydropower plants (Serbia 3,133 MW, Bulgaria 3,263 MW) although Bulgaria has a grater capacity in reversible power plants. Serbia's total hydropower potential is estimated at around 25 TWh and Bulgaria's at around 12 TWh.

In Bulgaria, there are 242 HPPs that participate with 14% in total electricity production, while in Serbia there are 16 large hydropower plants with 3,015 MW of installed power and another 110 small hydropower plants.

Bulgaria currently has a goal of using 27% renewable energy sources (RES) by 2030. Planned investments in the renewable energy sector are insufficient to transform the energy mix. Some analysts argue that Bulgaria should shift its focus from large energy projects to decentralized electricity production with households and small and medium-sized enterprises playing a leading role.

Serbia plans to have 47% RES in final consumption by 2030, and that is why new capacities must be built, that is, at least 5 GW in RES is needed by 2030.

In addition to the above, the development of hydro technology and new types of turbines have enabled more efficient use of hydropower in small watercourses with low flow and low water heads. Provided that the priority conditions for the protection of the environment, as well as plant and animal species in the waters are respected, small hydropower plants provide certain advantages because the installation is relatively small by size, simple to construct and can be aesthetically appropriate and environmentally friendly. Under these assumptions, small hydropower plants became even more attractive and do contribute to general energy security because, if their construction is carried out by respecting necessary standards and according to appropriate regulations, their impact to the environment is negligible comparing to large hydropower plants. Large reservoirs have a negative effect on the environment because they have negative effect to microclimate condiions but even more than that.

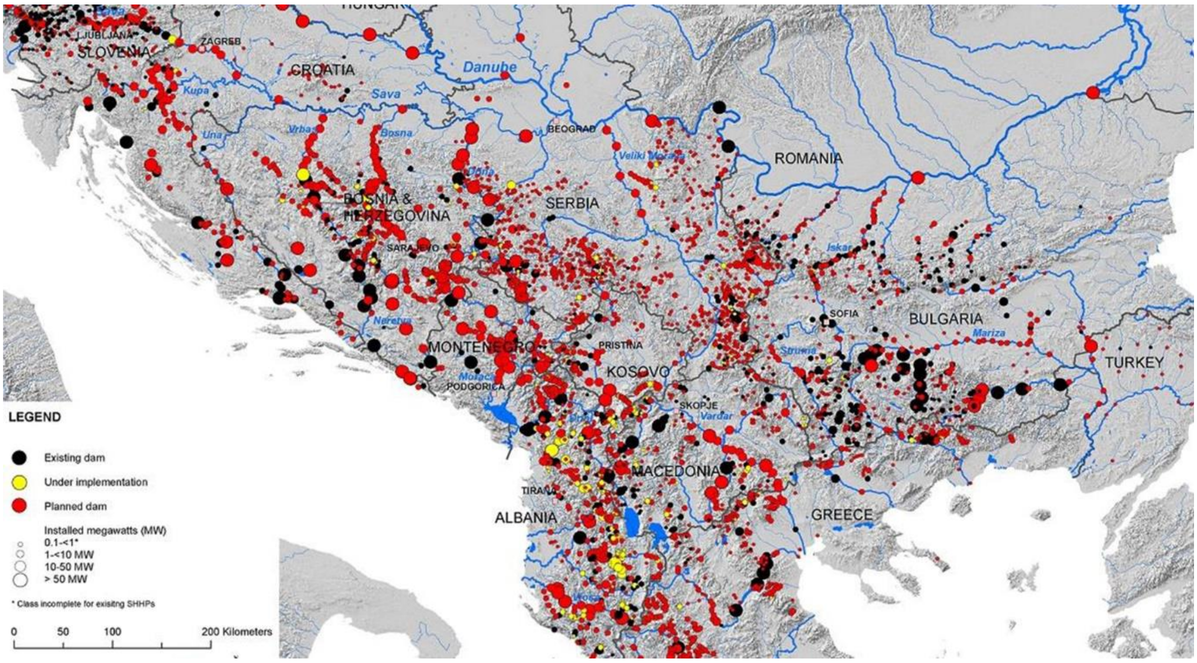

Illustration: map of the region with hydroelectric power plants that are active, those that are under construction and planned capacities.

Huge acumulations raise the level of groundwater and change the hydrological status of the ground, dams often block fish migratory routes, while sludge and waste materials settle at the bottom of the lake, since the flow of the river are virtualy stopped and the spontaneous cleaning of the bed has slowed down. Finally, the construction of large hydropower plants generaly requires the displacement to other locations, which is a great sociological shock and logistic and financial endeavor of the project implementation.

Hydroelectric power plants use a renewable energy source to run andthe every, even a smallest hydroelectric power plant replaces the consumption of coal (about 1.4 kg for every kWh of electricity produced) or natural gas, which is compatible to sustainable development in terms of preserving existing natural resources.

Although there is no accurate cathegorization of HPP, the most frequent division of hydropower plants is by installed power and that into large hydropower plants, small, mini and micro (or even pico) hydropower plants. There is no strictly defined limit, but the classification is most often within the following frameworks:

1. Micro HPP - up to 100 kW of installed power

2. Mini HPP – from 100 kW to 1 MW of installed power

3. Small HE - from 1MW to 10 MW or up to 30 MW of installed power

4. Large HPPs – over 30 MW of installed capacity

This classification is introduced due to fiscal measures and financial support because MHPs are a relatively expensive investment per unit of installed power, thus the price of electricity produced in such plants is high for which investors are handicapped by non-competitiveness on the market. Today, politicians everywhere, even in Serbia and Bulgaria, advocate greater use of renewable energy sources and RES projects are supported by subsidies and/or market privileges.

However, the biggest obstacle to safe investments in hydropower are climate changes. We have witnessed, especially in the past decade, extremes in the climate, with strong and long dry periods, on the one hand and on the other, massive and flooding precipitation at times and in places where there was none before. This complicates the design and stable use of hydropower plants and introduces element of uncertainty into investments, which can cause a decrease in interest in this way to exploit water energy. At the same time, the lack of water in watercourses can cause excessive use of disposable quantities and, especially in the case of run-off MHPs, drying out of riverbeds and streams can easily occur which is disastrous for all flora and fauna in those waters and is severe violence to the environment.

For this reason, it is necessary to introduce new parameters in the HPP design that will take into accountn such extremes, despite statistically insufficiently predictable, but they can be of catastrophic proportions.

It is essential to support the development of the so-called "green energy", but in a way that is sustainable, where the role of the state and state administration is crucial. Drafting the regulations that take into account multi-layered interests (from economic, through social to environmental) and especially their implementation are of key importance for the promotion and propulsion of RES use which is of paramount importance for energy suppla in future.

6. METHODS OF USING HYDRO ENERGY

There are several ways to produce electricity from hydropower:

Impoundment facility - The largest hydropower facilities are of this type, with dams on watercourses and water accumulation in lakes behind the dam. The potential energy of the water stopped by the dam is converted into kinetic energy by the flow of water through the turbines, and this energy depends on the mass of the water, its speed and the height difference between the water entering and leaving the system.

The dam has a dual role in the hydroelectric power plant. The first is to accumulate sufficient amounts of water for long-term electricity production and to ensure a sufficient height difference, and the second is to control water flows for use for other purposes, for soil irrigation or for human use, for example. If there are torrential rains and the influx of large amounts of water, the dam holds part of the flood wave and releases the excess water in a controlled manner into the river bed.

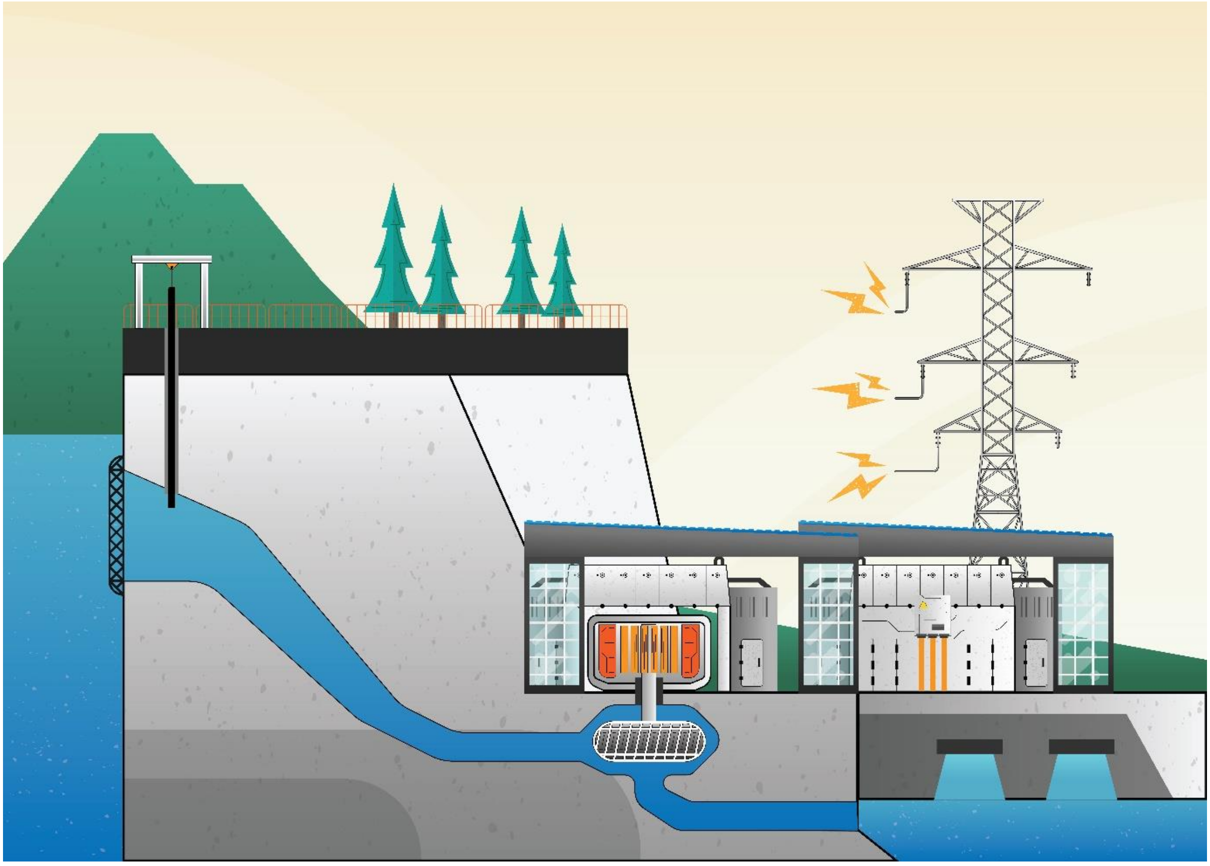

Illustration: impoundment facility

Reversible/pumped storage hydroelectric power plants - This is a way to transfer part of theavailable water from the dam lake to a new, higher reservoir, thus saving the water and its potential energy for later. This pumping of water is done at a time when there is enough water in the reservoir, and the consumption of electricity is less than the production, so the surpluses are used to start the pumps. In dry period or when there is a need for additional electricity production, the water from the upper reservoir is released through the turbines and produces the required amount of electricity in the electric generators. Pumping hydroelectric power plants are an important means of energy storage, which will be discussed in more detail later on.

Run-of-river hydropower plants are those that have small reservoir capacities or no reservoir at all but with only small water catchment on entry point and pipes that forward the water to a generator downstream, thus the available water is used immediately or it just runs down the river and is lost, from energy perspective. This is an ideal method for streams or rivers with minimal reduction in flow during dry periods or for those regulated by a much larger dam and reservoir upstream.

Tidal power plants use tidal energy. The most common form of tidal conversion is double-sided generators that generate electricity in both directions of rotation. They can be freely placed in the sea or, more effectively, on a baffle that channels the flow through the turbines.

This form of water energy is still not sufficiently used and in the future, more evaluated solutions are expected that will provide exploit it efficiently and effectively

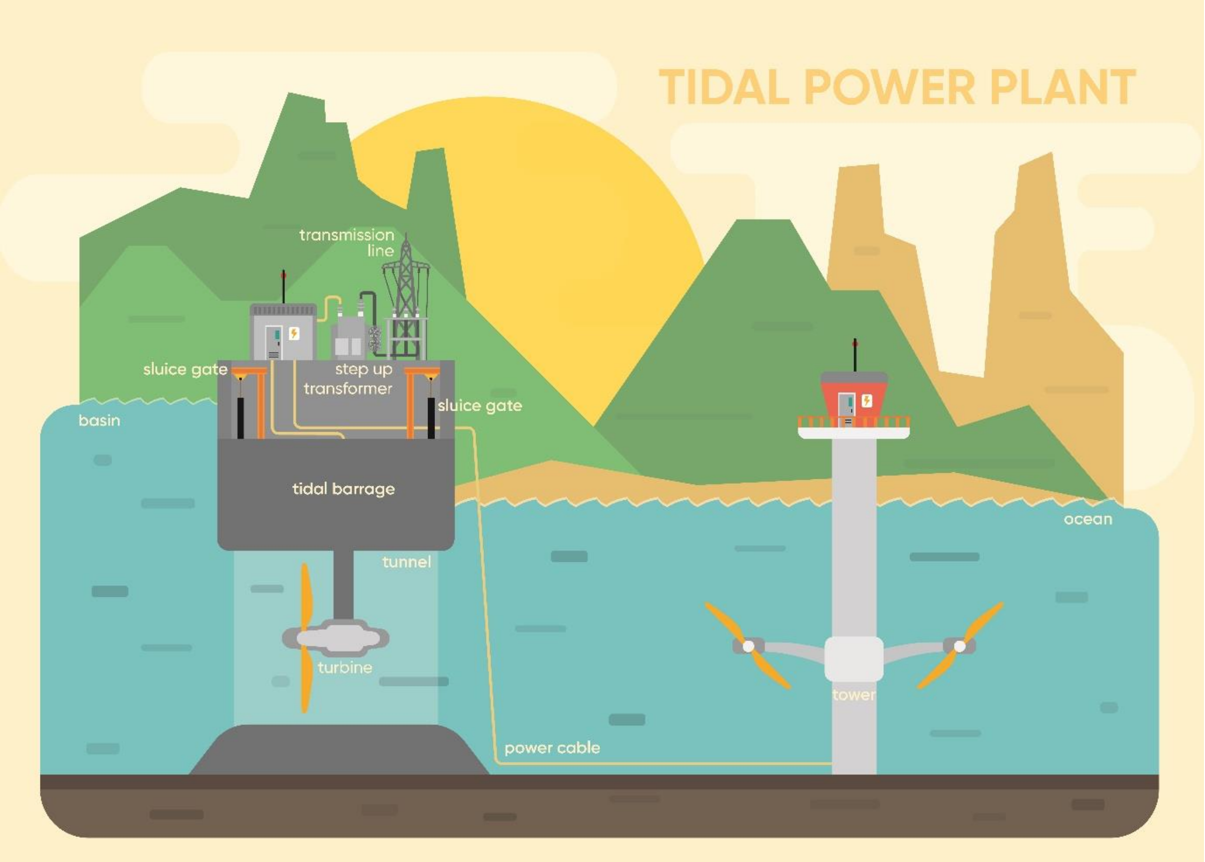

Illustration: Tidal power plant

Hydropower plants with a low head

We wanted to put forward these hydropower plants as an outstanding type, even though they can be considered as small impoundmernt ones, but given that they have a low head of the dam, i.e. the height of the dam is up to 10m, exploitation of water energy is somewhat different. The system that we will discuss here is based on the principle of the Archimedes screw turbine and is used as a water engine for small power plants that transmit energy directly to the electrical distribution network via asynchronous generators. It is used for small height differences and unstable water flow. Hydrodynamic auger can be used as an additional hydro generator for alredy installed turbines, using overflow energy.

Wave hydroelectric power plants - Huge amounts of energy are generated by the movement of waves. The waves are result of winds that move the surface of the water and in many parts of the world, the wind blows continuously and with sufficient force to produce permanent waves. The challenge is how to convert the movement of the waves into electricity, and this is done today in several ways: floating buoys, which by their vertical movement up and down produce electricity in lined generators, then by introducing the waves into narrow channels, which concentrates their power and is directly used for electricity production in a manner similar to tidal power plants

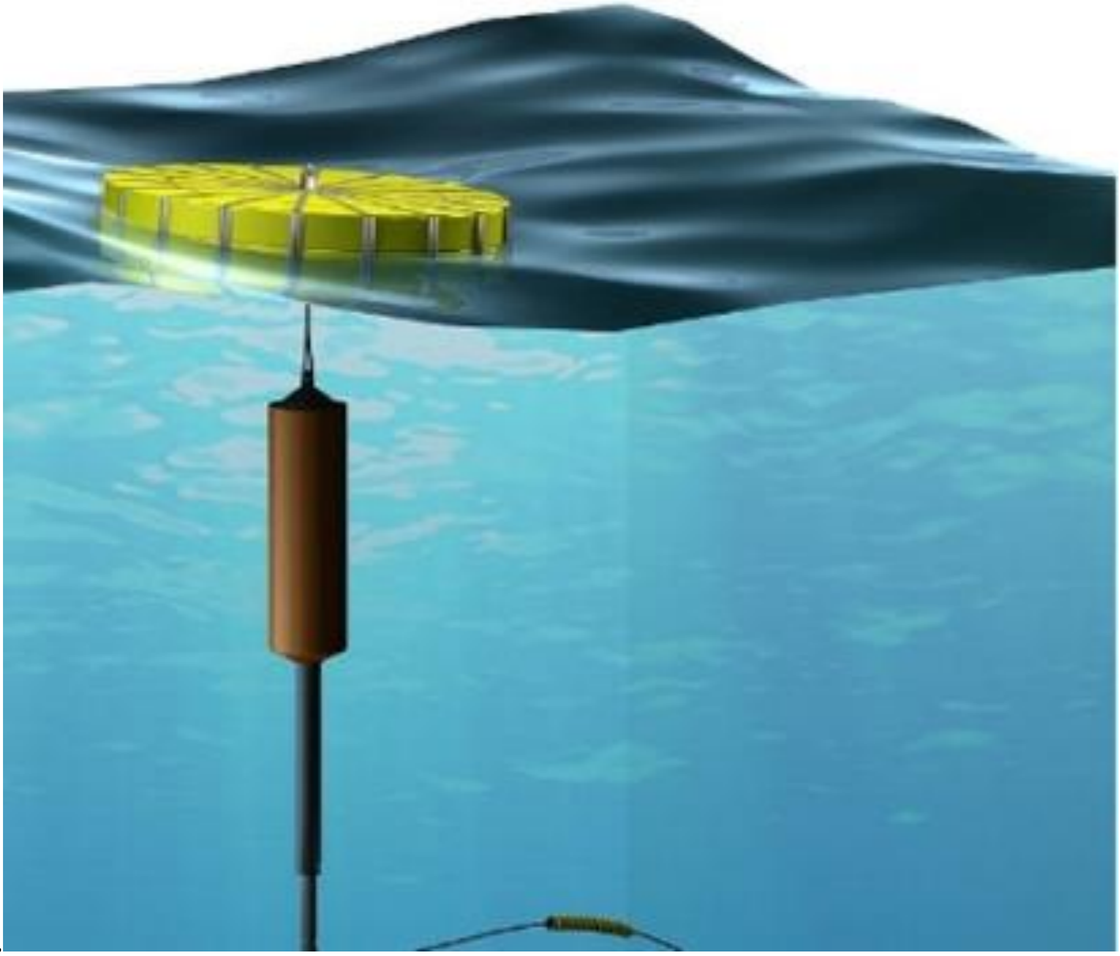

Illustration: Hydroelectric generator that uses wave energy

There is also a system that generates electricity using the air where waves are channeled into large air chambers and then the water pushes or sucks in the air, which in specially constructed tubes produces electricity, such as a wind generator.

7. MICRO AND MINI HYDRO POWER PLANTS

Hydroelectric energy is obtained in two phases. In the first phase, the kinetic energy of the water mass runs the hydraulic turbine and is converted into mechanical work, and in the second phase, this mechanical energy drives the generator, which converts mechanical into electrical energy. The power of the produced electricity depends on the mass of water, flow rate and the difference in hight between the source and the outlet of the water flow, which determines the speed of the water as well as the type of turbine required and electric generator.

In this Guide, we will deal primarily with small powerplants, up to 1MW of installed power as a potential solution for local initiatives and small investors and with a positive effect on the energy balance. In particular, we will cover two types of small hydropower plants:

- screw or Archimedes hydroelectric power plants, as a significant potential for smooth watercourse with, lower speeds and for cases where there are already dams, floodgates or backwaters and

- vortex hydropower plants, as a relatively unknown way of exploiting the water energy from small streams and in mountainous areas.

As an introductory type of hydroelectric power plant, we will explain the principle of operation and features of the most common and well-known run-off hydroelectric power plants.

Flow-through, run-off-river power plants

Flow-through,run-off-river hydropower plants are those, most often mini or small hydropower plants that use almost exclusively the kinetic energy of water, without a special accumulation, but take water at a small watercatchment that is at a higher altitude than the place where electricity is generated. The water is only collected and piped down to the engine room and generators that are relocated from the source. Such power plants are built on small watercourses and with small capacities (up to 1 MW) and their operation depends a lot on the hydrological status of the watercourse. At the same time, in order to be effective, it is necessary that the height difference is at least 15 m, which, with relatively small water flows, can provide enough energy for the production of electricity. For this reason, such power

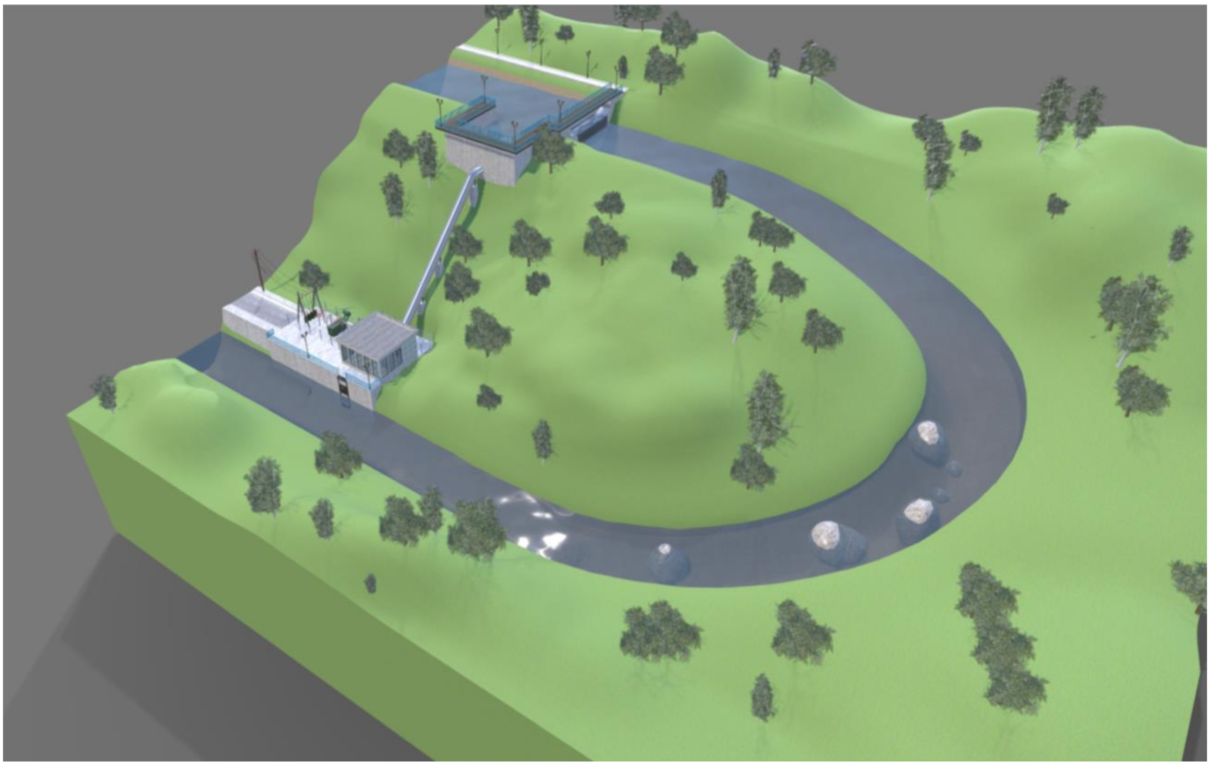

Illustration: principle of operation of run-off hydroelectric power plant

plants are installed in hilly and mountainous areas where the necessary kinetic energy of water can be used for short distances under conditions that are commercially profitable (the shortest derivation pipe and the largest quantity of available water). However, with all the advantages of such utilization of water resources, like relatively small investments, lesser construction works and quick implementation, there has been a great resistance to the installation of run-of-river power plants all over the world, lately and also in Serbia and Bulgaria. The reason is burried in the fact that their construction greatly affects the environment and local habitat. Pipes are most often placed in the very bed of the river or in the immediate vicinity, which completely dries up the existing water stream and jeopardizes the living creatures in it.

This is almost the regular practice and it is easier to get permits from public companies that manage the coastal part of watercourses, than from individual owners through whose property the pipes would have to run through, thus investors choose an easier and, essentially, much more destructive option for the environment.

Illustration: A dried-up river bed due to inadequate use of water resources

Another problem with run-off-river power plants is the excessive use of watercourses. The water is moved from the water intake and then, several kilometers long pipes lead to the machine building. The pipelines are usually between 1 and 3 kilometers long and the forcing the water into the pipes can deprive the water flow or to dry up the river bed in months when the flow is low and when, by the rule, the owners divert the entire amount of water through the pipes, leaving no biological minimum in the riverbed. In the case of small watercourses, biological minimmum ranges between 10-20% of the average ten-year volume of water in the bed.

In addition, micro, mini and small hydropower plants contribute insignificantly to the energy supply balance and it is questionable whether their construction is fully justified, where only weight they can have is that they operate at the local level where energy is produced and distributed through the low-voltage grid, provided, of course, that they do not harm the environment.

It is possible to build a micro or mini run-of-river hydroelectric power plant even with a small reservoir that can ensure the secure the operation for several days and which would regulate the minimmum flow of water in the part of the riverbed that is surpassed by pipes, thus to esure that biota in the river is protected. Practice often does not mimic projects, and therefore the recommendation would be to avoid small or mini hydropower plants of the run-off-river type, in general because it is difficult to control the strict implementation of regulations on the ground. True, a rigorous penal policy that would apply to all the partakers in the electric power system, regardless of their size, that is, the amount of electricity produced, could help to efficiently put in order this sector.

Hydropower plants with a low head dam (screw and vortex hydropower plants)

In the case of low-speed and low-flow watercourses, as well as in case of existing river banks, islands and branches of rivers and low dams, water energy can be used by applying solutions with the screw, spiral or Archimedes turbines or with the so-called Vortex turbines. Those types of turbines with a low number of revolutions are very efficient for low head dams (from 1 to 10 m) and relatively small amounts of accumulated water, taking into account the second type is among the smallest, micro power plants with powers that do not exceed 70-80 kW.

These types of turbines do not fall under special regulations for their installation. The asynchronous generator provides optimal energy production for the electrical distribution network in the range of 10 - 100% of the production capacity, whereby high efficiency of conversion into electrical energy is ensured even at low flows.

The main advantage of the aforementioned method of using water resources for energy purposes is that no water is taken from the river and its entire water remains in the bed without interruption of the course of the river. This is extremely important for reducing the negative effects that derivation power plants often have.

Screw turbines. In smaller lowland and mountain rivers, with average flows of several m^3/sec. and above, it is possible to use overflows by use of screw or spiral turbines. With these turbines, the individual installed power of the generator can be up to 500 kW or significantly less, and if there is a need for greater electricity production, several parallel turbines and generators can be installed. A large number of these power plants exist in the Netherlands, England, Germany, Belgium, the Czech Republic, i.e. in countries where the canal network is developed, but these power plants can also be installed on smaller rivers where there are already dams or water catchnment or they can be easily built. One of the solutions are rubber dams with a small reservoir where the construction is very simple and does not require major infrastructure works.

Illustration: screw hydroelectric power plant

Features of screw/helical turbines:

Output power: up to 500 kW

Required water flow: 100 - 10,000 l/s

Head of dam: 1 - 10 m

Turbine inclination: 22 - 36°

ADVANTAGES:

• Low costs for construction work, no complex excavations

• Lower costs compared to traditional turbines

• Simple installation

• Long life span

• High efficiency

• Reliability even with low flow (at 20% flow efficiency is 74%)

• Simple handling - low maintenance costs

• Easy access to working parts

• Applicable on existing dams

• Improves water quality through aeration

• Does not endanger fish - the channel in which the turbine is located is open and serves as an effective fish path

• Free passage of floating debris - large solid pieces, such as plastic, wood or small stones can pass through the turbine without any impact on its efficiency.

• For safety measure only a grid at the entrance to the helical turbine is sufficient.

• The turbine can be designed for constant or variable speed, taking into account the flow and head of water.

• The helical turbine does not require lubrication of a lower bearing. This improves efficiency and reduces operating costs.

• The lifespan is at least 30 years, and the efficiency remains constant over the years.

• The screws can be coated with a ceramic composite material that is highly wear resistant.

FLAWS

The main shortcoming of Archimedes' turbines is the change in the available water hight, that is, the water level on the dam during the year, which is reflected to production of electricity. This shortcoming is directly affecting the selection of the nominal water flow and design of turbines, since increase of water flow in some cases does not necessarily result with a larger increase in production. As the net drop decreases, the efficiency of the turbine also decreases, and if the turbine is too large, there will be no electricity generation during periods of low water. These indicates that special attention must be paid to the design of installed capacity in relation to water flow, which prevents the full use of available water resources. This problem can be solved by installing several parallel turbines, but in this case the investment costs increase. In addition, the low speed of the turbine requires a mechanical assembly to increase the speed, which reduces efficiency. For the high efficiency of the hydroelectric power plant with Archimedean, spiral turbines, the possibility of speed regulation is required.

RECOMMENDATION

Exploitation of hydropower with screw turbines is a good solution. In mountain watercourses that have a steeper bed, it is almost always easy to find a place where such power plants could be installed that do not jeopardize the biotope in any way. This can be done on the main stream or on some natural let-off and the most difficult part in the construction of such a plant can be the connection to the electrical distribution grid, especially if the main power lines are not in vicinity while construction is rather easy. Power plants do not have large dams or pipes and all used water is immediately returned to the riverbed.

Vortex turbines are low-pressure water turbines that use the kinetic energy of water movement due to gravity, but also the additional kinetic energy that the water has due to the rotation of the earth, so that for the same flow and height difference, more energy can be gained using vortex than with conventional turbines. The flow of water creates a vortex that turns the rotor of the generator. Since only low water pressure is required to drive the turbine, this allows the system to be built in areas of relatively shallow, slow-moving water, but can literally be used on all types of watercourses to generate power for both local use and resale. The capacities of these power plants are small (that's why they fall into the category of micro power plants), but that's why the construction costs are proportionally significantly lower than for other types of turbines.

One of the significant advantages of vortex turbines is that they do not humper fish and other animal life in the water, and for the operation of the turbine, a height difference of only 1.5 meters is sufficient. Placing the turbine in optimal locations, therefore becomes simpler and appropriate locations can be found almost anywhere and much easier then for other types of hydroelectric power plants.

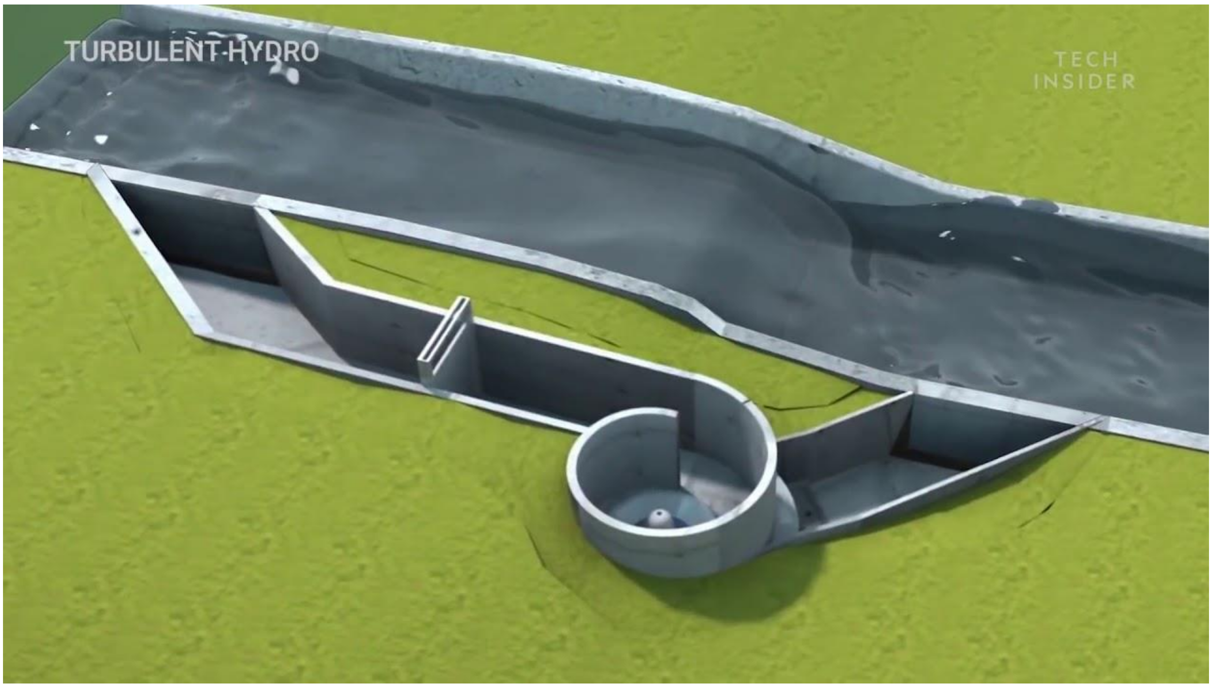

Illustration: vortex hydroelectric plant

The construction is not demanding and can be carried out with local labourmwhile all the energy produced can be used locally. Considering that the power plant works 24 hours a day, it is necessary to provide energy storaging during the night, thus it would be good if the power plant was connected to the electrical distribution grid to which excess energy could be leased or sold or ensure consumption during the night.

As the prices of electricity and other types of energy will rise, the construction of vortex turbines to cover needs at the local level is very attractive.

For this type of turbines, no special permits are required, except energy permits, and they are obtained relatively quickly and easily, since the natural flow of the river is not interrupted by vortex turbines, which means that their impact on the environment is practically negligible. Easy to build and easy to use, they can be an excellent solution in areas where there are opportunities to install them. The life span is long (40 years) and after the investment return time, which ranges from 7-10 years (at least according to current energy prices) and certainly faster considering current trends, it can be shorter.

In addition to the numerous advantages of using these micro hydroelectric plants, vortex turbines also have some limitations. For example, the power of the largest turbines is still below 100 kW, which would be enough to supply only about 170 households.

Turbines do not work when the water freezes, although this does not happen with quick water flows, but can be a problem in the case of small reservoirs, dams and watercetcments, that is, with stagnant water.

RECOMMENDATION

With all types of power plants, especially hydropower plants, the assessment of resource potential is of key importance. If underestimated, the full utilization will not be possible, thus the investment will be less profitable and the effect of energy production lower than possible. The addition and subsequent expansion of capacity can be proportionally significantly more expensive than if an optimal power plant were built immediately.

If, on the other hand, the potential is overestimated, the consequences may be that we cannot start production with small flows or plant shall be extremely inefficient, which will induce unprofitability of the investment and the return of capital beyond the depreciation time of the equipment, which is a loss of investment, instead of a gaining a profit.

With micro hydropower plants, such as those that work with vortex turbines, evaluation process is simpler and measurements are softer because turbines are much more flexible for the different capacities of the water stream to which they are connected. This can be additionally solved by small barrier on the access channel, which regulate the water flow. Bearing in mind that they usually use only a part of the watercourse, it is always possible to determine the capacity it in a way that enables optimal operation throughout the year. For this reason, the general recommendation is to invest in such facilities, because the investment will always pay off really quickly, and the current maintenance and operating costs are almost negligible.

8. SELECTION OF THE OPTIMUM SYSTEM AND ESTIMATING COSTS – CASE STUDIES

In this Guide, we will elaborate two cases of mini or micro hydropower plants that can be attractive for construction and use in the cross-border region of Serbia-Bulgaria. We focused on small plants that are not of run-off-river type (water is not directed from the water intake to the trurbines through pipes, i.e. the river bed is not surpassed), since they are easier to install and can be financed by individual or a limited number of small investors where the rivers and their flora and fauna are not endangered, whatsoever. In addition, have not addressed the run-off-river mini hydroelectric power plants because they have been subject tp controversy for a number of years, due to their potentially harmful impact on the local environment and small watercourses, with a negligible contribution to the energy supply mix. However, hydropower plants are seldom built for individual use, only but they are plants that deliver excess or all electricity to the electrical distribution grid. For this reason, the method of assessing the profitability of the investment is different and cannot be compared with, for example, investing in solar panels on the roof of a household. Furthermore, the use of water resources requires different project preparation, approvals and permits that are not required for, for example, the exploitation of geothermal energy or biomass energy, and it is necessary to undertake significantly more infrastructural works in order to ensure sufficient water intake for optimal operation of the power plant. Finally, unlike other RES (except biomass), water cannot be boundlessly used because this resource is limited and has other, important utilizations that have higher priority to energy production (water is used for drinking, for agriculture or for conservation of biodiversity). A large number of solar panels will not, in any way reduce the radiation of the sun or affect the abundance of energy, the problem can only be excessive covering of some space or aesthetic reasons, but the degree of using the sun for energy purposes is still far from the mass occurrence of this problem.

For all these reasons, it is difficult to make a comparative analysis in relation to other renewable energy sources (only the use of wind could be somewhat comparable), but the assessment of profitability relies on market conditions, which, especially recently, are very volatile. Nevertheless, energy will be needed more and more and its price will only increase, and in this regards, all the investments in energy production, including investments in hydropower, are profitable to the extent of the availability of the resource itself and the way in which it can be used without threatening the environment and needs of local population.

To prepare the investment properly, it is necessary to consult authorized accredited entities (designers) who can prepare project documentation based on actual data and hydrological situation. It is necessary to take the following steps and determine a location with sufficient potential and where exploitatation would not humper other needs and to evaluate, as follows:

- Abundance of resources that will determine the capacity of the power plant
- Stability of water flow throughout the year
- The method of capturing and managing water, considering the configuration of the terrain, the selection of the type of power plant
- Proximity and type of available power grid
- Construction costs and expected income, rough investment return time
- Method of financing

• Timelines and operational plans

Only after these assessments and if the pre-feasibility study justifies the investment, the design of the power plant and obtaining the necessary permits can start.

Capacity assessment

The assessment of capacity is carried out on the basis of hydrological and statistical data, but it would be mandatory to explore in particularly data from the last two decades, the period with significant changes and extremes in the climate that brought great droughts and heavy, torrential rainfall, often above the hundred-year maximum, which is a standard relevant for design. Despite estimates of hydrological capacities in both Serbia and Bulgaria, they are unreliable and do not give a true picture of real possibilities. Over time, the climate conditions have changed, and in the determined potentials, the true configuration of the location is often not visible, which sometimes makes the construction of any energy facility pointless. Finally, small watercourses are most often found in hilly and mountainous areas that are less developed, so the availability of electricity distribution infrastructure is weak, which makes investments more expensive with questionable profitability. In addition, the inadequate construction and inproper use of water resources in cases od run-off-river power plants, has largely caused resistance and opposition from the academia and the local population what makes the theoretical advantages of using small watercourses are preposterous from poor application of technologies. However, if a constant and full flow of water is ensured through the river bed and its exploitation is carried out in a non-aggressive way, there is no reason not to use water energy.

Selection of the power plant

Once the assessment of the abundance of water resources and the topography of the terrain is done, the choice of the way to use water for energy production is on the table. The available height in the water course, the configuration of the riverbed, the existence of eddies, stops in the river or some barriers and constitutions, the forks of the river and its tributaries, all determine the way to choose the type of hydroelectric power plant and the type of optimal turbine. When we add the requirements for the preservation of watercourses and biota in the rivers, the proper selection becomes all the more important.

Since hydroelectric power plants are built with the intention of transferring part or all of the produced energy to the electrical distribution grid, it is necessary to check the proximity and type of electrical network. On the basis of all these input data, a rough estimate of the costs and duration of the construction, as well as the approximate return of investment time is made, taking into account market conditions, the possibility of receiving subsidies or other types of assistance. Finally, the ability to access funds and loans should be checked, if not possible to finance the project from own sources. All this determines the way of investment in the power plant and indicates the profitability of the venture. It is also good to check good and bad practice examples and to learn from them. Of course, the design and execution of the works must be done by a professional and authorized company.

Costs of produced energy

A commonly used indicator is the levelized cost of energy (LCOE) that is the price at which electricity must be produced from a particular source to pay of over the life span of the project. Hydropower plants of medium to large size have the lowest LCOE. In general, the larger the hydroelectric plant, the cheaper the price per kilowatt-hour for the electricity produced. The indicator depends on the investment cost of construction, the cost of capital, the market or contracted price of electricity (whether the production from the facility can be subject to incentives through feed-in tariffs or some other type of benefits, or whether a long-term contract for the supply of electricity - PPA has been concluded). LCOE is the cap value of profitability that is relevant only for the rough assessment of the amount of the investment, i.e. if this indicator is significantly lower than the market price of energy, it means that the investment will pay off in a time that is much shorter than the lifetime of the power plant. For mini and micro power plants, the investment payback time should not be longer than 10-12 years in the worst case, and more often not longer than 8-10 years, with a tendency to shorten over time due to the trend of rising energy prices.

Economic and environmental impacts

The costs and economic aspects of a hydropower project that belongs to infrastructure projects, no matter how small, are of an intensively capital nature at the time of their construction. However, the amount of costs directly depends on the type and dimensions of the associated dam, if the power plant has one, as well as on the construction work necessary for the construction of the facility. However, the advantage of these power plants is that their operating costs are very low.

• Capital cost consisting of:

- Building/construction materials and installation, (generally 40-50% of the total price)
- Purchase and installation of mechanical equipment, (generally 10-20% of the total price)
- Purchase and installation of electrical instruments and controls (5% of total costs)
- Indirect project costs, fees and contingencies and (10-15% of total costs)
- Expenses of the investor/project owner (5-7% excluding project financing costs)

From the entire amount, the investor needs to provide at least 20-30% of his own funds, while the rest can be financed from loans. Recently, banks have a much more flexible financing policy for such projects because in practice, they have proven to be very profitable, provided they are well designed that took into account accurate input parameters on the hydrological situation and terrain configuration. The so-called "Project financing" is very common, which assumes that the project itself is accepted as security (collateral) on which the bank puts a mortgage until its realization and commissioning.

• Operating and maintenance costs include:
- Fixed maintenance costs are those that do not significantly depend on the capacity of the power plant
- Variable maintenance costs are costs related to the production of electricity and which vary depending on it.
- Major maintenance costs

The price of power plants ranges from 2,000 to 5,000 EUR per kW of installed power. The unit cost is indeed highly dependent on site conditions and the complexity of the associated construction work. It can be higher for pumping hydroelectric power plants (the cost of the dam is an important item) or lower for run-of-river power plants with favorable hydraulic and topographical characteristics. Even more favorable conditions for investment are in the case of hydroelectric power plants that are installed on already existing water accumalitions or do not even need water intake. These are usually mini or micro power plants and, with the limited power that such types of power plants have, they are most attractive when a low level of electricity production is required.

ADVANTAGES OF MICRO AND MINI HYDRO POWER PLANTS
• low cost of electricity production:
• generally limited negative impact on the environment and with reduction of CO_2 emissions in energy production
• very well-known and reliable technology
• stable daily electricity production
• full production capacity can be available within seconds.
• low operating and maintenance costs
• long exploitation time. Life expectancy is projected to be at least 50 years.

FLAWS
• require proportionally large initial investments
• small installed power
• have a somewhat undefined status, so the issue of permits must be resolved on a case-by-case basis, especially if connection to the electrical distribution grid is required.
• are sensitive to changes in the flow and capacity of the watercourse
• sensitive to climate change
• run-off-river poiwer plant has an unstable power supply. During an unforeseen period of low production (eg an exceptional drought), backup systems (based on another type, usually fossil energy) are required to deliver balancing electricity to ensure continuity of supply. This does not fully apply to micro and mini hydropower plants, neither in Serbia nor in Bulgaria,

where the balance energy of this hydropower plant is provided from the system, that is, by the operator of the electrical distribution grid.

CASE STUDY 1

The first example we will discuss is related to screw or Archimedes spiral turbines, which are, as explained earlier, part of hydropower systems for small height differences and dam heads, but are of the open type, have low rotation speeds and are very acceptable for the biotope in rivers. The impact of the exploitation of water resources for energy purposes in this way is practically without any effect to the environment. For the operation of such power plants, only a very small reservoir is needed, which can be on some dam or a slightly larger water catchment.

Analysis of hydro potential at the location

We will assume that we have a small watercourse with an average flow of 8 m^3/sec and with annual changes as in the table, where the monthly flow values are given with 50% probability. There is already a 3-meter-high weir on the watercourse that serves to regulate the flow, as well as a small accumulation.

probability p(%) 50	Average monthly discharge,$Q_{sr,mes,p\%}$ (m^3/s)											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Discharge Q (m^3/s)	7.01	9.7	14.5	19.5	14.3	8.75	4.15	2.08	1.97	2.46	3.41	5.4

p(%) 50	Average daily discharge,$Q_{sr,dav}$ (m^3/s)															
	1	7	15	30	60	90	120	150	180	210	240	270	300	330	360	365
Q (m^3/s)	52.07	30.84	24.50	18.67	13.35	10.39	8.33	6.85	5.45	4.35	3.35	2.82	2.37	2.04	1.86	1.66
H (m)	1.93	2.21	2.29	2.37	2.44	2.47	2.50	2.52	2.54	2.55	2.57	2.57	2.58	2.58	2.59	2.59

Table: average discharge at the selected location

This was used to investigate the possibility of installing an overflow, screw power plant that uses excess water. During the year, the height of the water changes and this needs to be taken into account when designing the turbine so that it can use the potential of the water to the maximum in all conditions. In this particular case, the average net value of the overflow height is 2.51 m in the case of using one turbine, or 2.4 m in the case of two turbines.

As can be seen from the table below, the minimum flow for starting the turbine is about 1000 l/sec and the minimum flow for full electricity production is almost 1.5 m^3/second.

Here, relatively large helical turbines of 3.2 meters in diameter (one or two) and 5 meters in length were used to achieve a 30° drop.

Solution I		Solution II	
Q_{mean} (m^3/s)	8	Q_{mean} (m^3/s)	8
Q_{95} (m^3/s)	1.94	Q_{95} (m^3/s)	1.94
Q_{95}/Q_{mean}	0.243	Q_{95}/Q_{mean}	0.243
Q_{FP} -fish pass (m^3/s)	0.4	Q_{FP} -fish pass (m^3/s)	0.4

Q_{HPPin} design flow (m^3/s)	7.1	Q_{HPPin} design flow (m^3/s)	14.2
Q_{HPPin}/Q_{mean}	0.89	Q_{HPPin}/Q_{mean}	1.78
Net head -for Q_{HPPin} (m)	2.51	Net head -for Q_{HPPin} (m)	2.4
Number of turbines	1	Number of turbines	2
Q_{suf} Turbine start up flow (m^3/s)	1.065	Q_{suf} Turbine start up flow (m^3/s)	1.065
Minimum flow for power ($Q_{suf}+Q_{FP}$) (m^3/s)	1.465	Minimum flow for power ($Q_{suf}+Q_{FP}$) (m^3/s)	1.465
Maximum HPP power (kW)	137.2	Maximum HPP power (kW)	275
Annual production (kWh)	687262	Annual production (kWh)	925008

Table: proposed solutions for energy production with one and two screw turbines

In the case of one turbine and an installed 150 kW generator, it is possible to produce slightly less than 700 MWh per year on this watercourse, and in the case of two turbines, 925 MWh. Of course, a larger number of turbines is a more efficient but more expensive solution, and in this particular case, the construction of a smaller capacity at a location where there is already a constitution would amount to about 420,000 EUR, while for two turbines and associated works, it would be necessary to allocate about 800,000 EUR, considering the increased requirements in construction and equipment.

In the case of such small plants, the cost-effectiveness assessment is qualified with the way of usage, i.e. whether the power plant is intended to be on the grid or not, whether the energy is used only for individual needs or is also sold, whether the power plant is exclusively commercial and whether it uses the system of energy storage in the electrical distribution network (prosumer model), as well as the distance and type of electrical distribution grid.

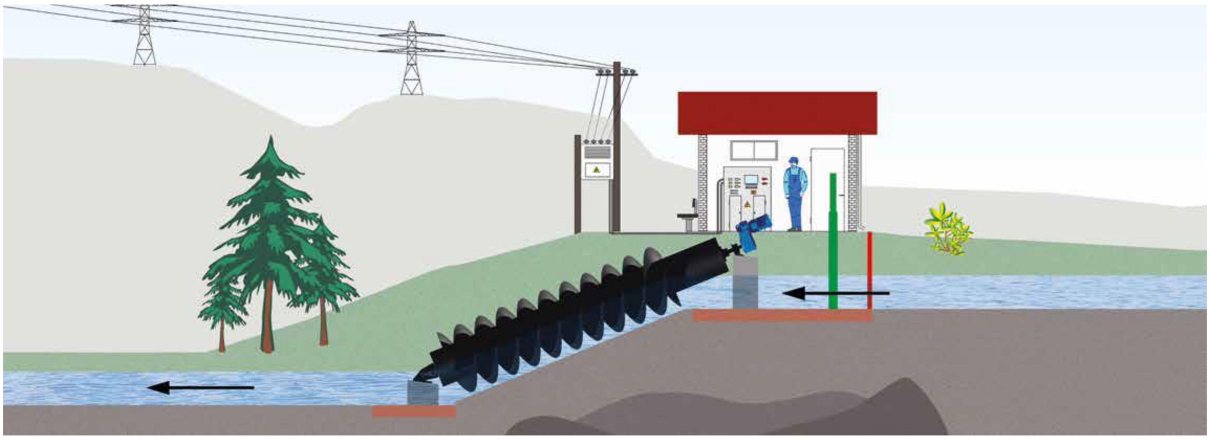

Illustration: appearance of an Archimedean, spiral or screw turbine

The policy of prices and incentives in Serbia and Bulgaria are not the same. While in Serbia the feed-in tariff scheme is still used for micro and small hydropower plants as well as for power plants that use biogas, in Bulgaria, incentives have been reduced and the market mainly determines the price of energy. At the same time, it should taken into account that the energy market is currently very turbulent with a trend of price grow, but still quite uncertain for investors considering the growth of interest on loans. However, the profitability of investing in the electricity production is unquestionable and depends only on the ability of the investor to carry out the investment of the facility. The investment will pay off for sure, and probably faster than the design calculations indicate.

In the case of flow-through power plants, the investment depends on the conditions under which it is installed. It doesn't matter if there is already a dam and some water catchment or if the use of the watercourse can be carried out by a side channel or an island and so on. The prices of hydroelectric power plants range from EUR 2,000 to EUR 5,000 per kW of installed power, and these, together with the expected production, are the basis for assessing profitability. The fact that hydropower plants are long-lived, no less than 40 years, and that they do not require special maintenance during their operation, except for the cleaning of watercourses at the intake point and ongoing maintenance, should also be taken into account.

For micro and small hydropower plants where there is no construction of dams or complicated construction works, the capital return time ranges from 7-10 years.

CASE STUDY 2

The second case study refers to an example of a micro power plant with the aim to pinpointing the possibility of using very small water streams in a simple way that does not require large investments and can contribute to the energy independence of individual households. We are talking about the so-called "vortex" turbines that use the physical phenomenon of the vortex to start and produce electricity. These turbines have a limited power (up to 100 kW) and are usually much smaller, from 5 to 15 kW, and belong to individual energy plants, such as, for example, solar panels. Unlike solar panels, micro hydropower plants produce electricity 24 hours a day, which gives them an advantage over the sun and wind, whose exploitation is conditioned by the availability of sources (there is no sun at night and the wind does not blow constantly). This fact results in a shorter ROI time and raise profitability of the investment.

Analysis of hydro potential at the location

Vortex power plants do not require special tests or the process of obtaining permits for their work. It is only necessary that the connection to consumers and/or to the grid is performed according to existing regulations and by an authorized person. Vortex hydropower plants are most often installed in places where is enough water that could run the turbine. For our analysis case, the vortex turbine is placed on an old backwater that used for a mill. The flow of water through the side channel is about 1000 l/sec and the height difference at the old dam is 2.2 m. It has been estimated that considering the flow and height difference, a vortex synchronous generator can be installed, with an installed power of 10 kW. A small valve is placed at the entrance to the inlet channel, which regulates the flow through the turbine.

The whirlpool has a diameter of 2.4 m and a support holder with a generator is placed above it. For this type of micro power plants, no special machine halls are built, but the connection to the grid/consumers is made through a connection cabinet. The only important thing is to

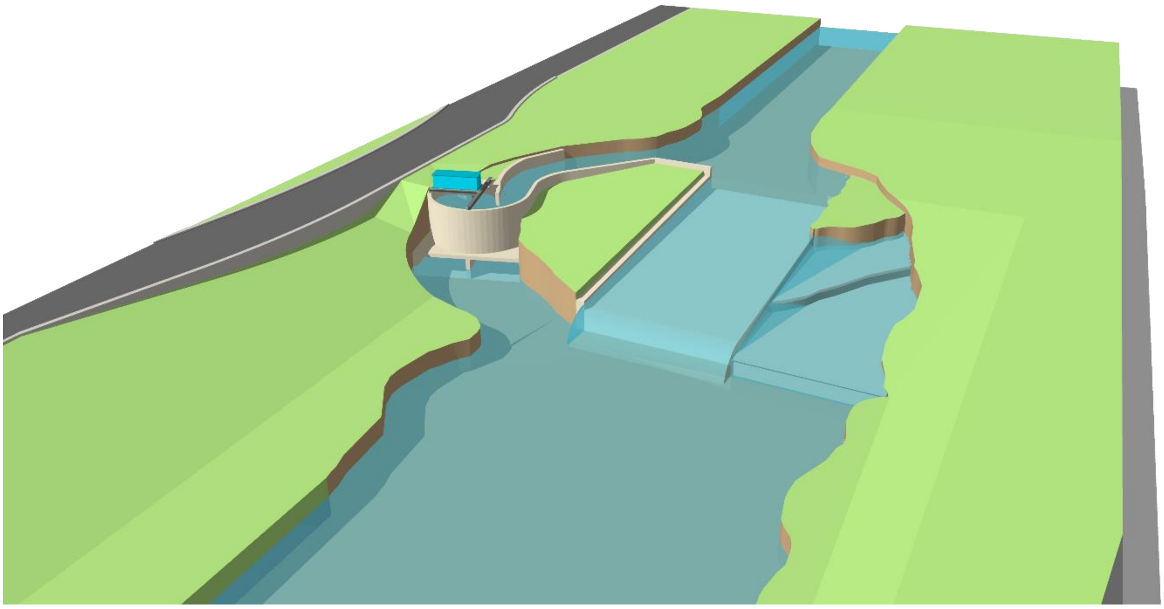

Illustration: vortex hydroelectric power plant

protect both the generator and the cabinet from atmospheric influences. The hydroelectric power plant in question was built with automatic regulation of the barrier on the inlet channel, which regulates the flow in relation to the quantities measured by means of an analog metering in the water current.

It is necessary to install about 10 m^3 of reinforced concrete in the channel and the tub, and the equipment needs systems for stabilizing the frequency and output voltage level. The energy is delivered at a low voltage of 3x400V and can be used immediately for individual needs. The price of this complete power plant, according to the given parameters is cca 13,500 EUR. However, in order to transfer energy to the network, we would to raise the voltage to at least 1 kV, that is, one network transformer of 15 kVA is required, the price of which starts from 5,000 EUR and upwards.

Investment estimates depend on all these elements, including project documentation and obtaining permits, where necessary, but with these micro-plants the total investment should not exceed 1,000 - 1,500 EUR/kW, in the case of using energy for individual purposes and about 2,000 EUR /kW in case electricity is supplied to the grid.

Calculation of savings and investment payback time

The price of installation and profitability, thus the investment payback time, depends on the utilization of produces electricity. If the production is used for own needs and the surplus is handed over to the grid, the calculation has one form. If all the produced energy is sold, either to the grid or to a known customer, then the calculation is different and depends on the conditions and the sale price.

If the project is financed from a loan, the investment return time is extended and if the user has access to incentive funds, it is shortened. In addition, energy will become more expensive over time, so the return on investment will accelerate.

9. HYDRO ENERGY STORAGE SYSTEMS

Water energy can be stored in potential and used in kinetic form. Namely, mechanical energy is used and does some work only in kinetic form (when it moves), while in potential form it only has that possibility. With hydropower, unlike solar and wind, it is possible to save the potential of the water mass for later use. This can be done by raising a dam on the watercourse, which accumulates the water mass that is used at the time and in the volume that suits us.

However, in conditions of torrential rains and a large inflow of water, it is not possible to save excess water in the reservoir and it is lost in terms of energy. Likewise, during dry periods, the reservoirs are depleted and then the dam does not do a lot because there is not much water to store, but it is utilized in the amount that flows in. The most efficient and practically the only way to storing raw hydroenergy (we will not talk about the secondary storage of electricity here) is that the excess water is pumped into an additional reservoir, i.e. a lake. In practice, such lakes are located at a higher elevation than the reservoir formed by the dam, and the water thus gets additional part of the potential energy that is later used when the water returns to the generators and, due to the height difference, produces electricity.

Such power plants are called pumped power plants since a reversible, i.e. return process of energy conversion is used: kinetic-potential-kinetic with the mediation of mechanical energy that generates electricity, which in turn runs the pumps.

It is clear that the construction of such facilities is demanding for several reasons. The first is the need for massive infrastructural interventions because it is necessary to find a location that could act as a reservoir for pumped water. In practice, already existing natural lakes are used, if they exist, because they already have a favorable hydrological status, an impermeable bottom and the possibility of collecting water considering the geomorphology. If there is none, then this type of installation is even more difficult because you need to prepare an area to capture large amounts of water. In addition, the distance from the hydroelectric power plant should not be too great because of the costs but also because of the losses in the pipes.

The electrical energy produced in such power plants is often used as so-called "balance energy", i.e. at times when there is no optimal load in the distribution network or at times when consumption is high and additional amounts of missing energy are needed, in the regular cycle of exploitation or during dry periods when there is a lack of water in reservoirs.

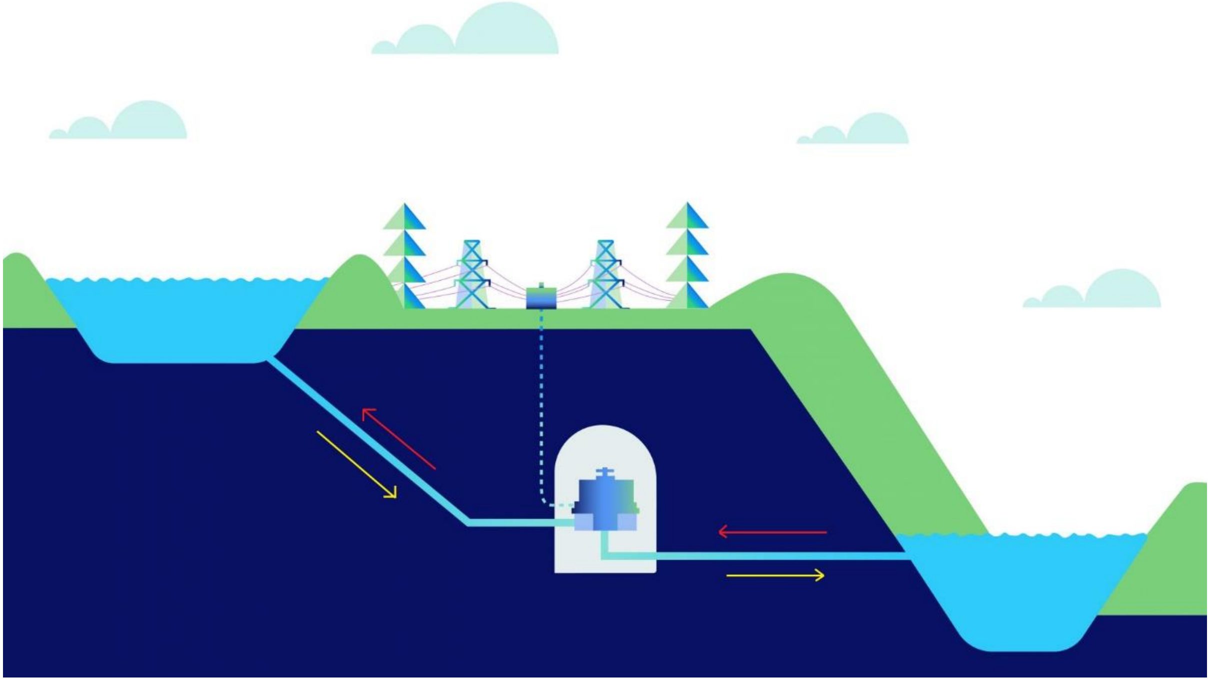

Illustration: principle of operation of a pumped hydroelectric power plant

On the other hand, investments in such facilities are important not only from the energy aspect, but also because of the possibility of using water for long-term purposes, for human use, for agriculture, animal farming, tourism...

In the past twenty years, more and more investments have been made in hydropower storage and in pumped power plants, both in Europe and in the rest of the world.

There is one pumped hydroelectric power plant in Serbia, Bajina Bašta. The maximum power of the power plant in generator mode is 614 MW, with an average annual production of about 800 to 1,000 GWh. The maximum input power in pumping mode is 620 MW.

For many years, the construction of two more reversible hydropower plants, with a total power of about 3MW, has been planned.

Bulgaria has three reversible hydroelectric power plants, of which HE Chaira is the largest hydroelectric power plant in Southeast Europe, with 864 MW in production and 788 MW in pumping mode. The upper reservoir of HPP Chaira is the Belmeken dam, which has a usable volume of 140 million m^3 and is also the main water storage for the Belmeken-Sestrimo hydropower cascade power plants, and the lower reservoir is the Chaira dam, which has a opetrational volume of 4.2 million m^3.

The largest water storage and reversible hydroelectric power plant in Europe is the Cortes-La Muela complex located in the Hucar River (Spain) with a total installed capacity of 1.8 GW, while the largest reversible power plant in the world is located in China, in Hebei province. The 3.6 GW facility consists of 12 reversible generators/pumps each rated at 300 MW with a total energy storage capacity of 6.612 billion kWh.

Recently, systems have been developed to store the produced electricity using huge batteries, but even the largest existing systems (currently with a capacity of 450 MWh) cannot store significant amounts of energy that could be used independently for a number of users and for a period of at least a week or two. An alternative to previous is the transformation of one energy into another, such as electricity into hydrogen production, which enables the storage of energy to smaler units and for purposes that do not have to be only for the electricity production. It is primarily about "green" hydrogen that is produced by simple electrolysis of water with the use of energy from renewable sources. By the way, hydrogen is increasingly used for fuel cells that produce electricity from hydrogen, and keeping the energy for the long time is feasible.

10. SMART HOUSES

Smart houses/buildings are facilities that have monitoring and management systems which are using modern technologies, integrated for achieving maximum efficiency and self-sufficiency of all systems. Internet of Things (IoT) plays an important role in this concept.

These are homes that have autonomous energy solutions using renewable energy sources to produce electricity and heat, heat pumps that enable air conditioning throughout the year and with minimal energy consumption for their work. Digital systems monitor water consumption and its processing into technical water, for home use and all the way to programmed watering of the yard and the use of rainwater for technical use, but also to monitor house lighting, ventilation and the security of the house that can be controlled by cameras as well as fire/smoke and/or flood sensors. Control systems can even support the planning of tenants' activities, with reminders and management of entertainment and leisure devices, the charging electric devices management and need to optimize their consumption by redirecting it to times of cheaper energy. The extent of automation of current processes is only a matter of requirements, investment possibilities and abilities and if such systems makes sense because there are no limitations in technological solutions. These objects mimic the ideal model of completely self-sufficient and independent units in terms of energy use as well as with a high degree of independence when it comes to water, whereby their environmental footprint, i.e. the impact on the environment and climate change through CO_2 emissions, is negligible.

Although smart homes are not directly related to the use of hydropower, each RES that powers a smart home can be seen as part of an comprehecive solution that, in addition to autonomous energy, good insulation, optimal orientation, efficient air conditioning and indoor lighting, uses IoT technologies to optimize consumption and for the safety of the facility .

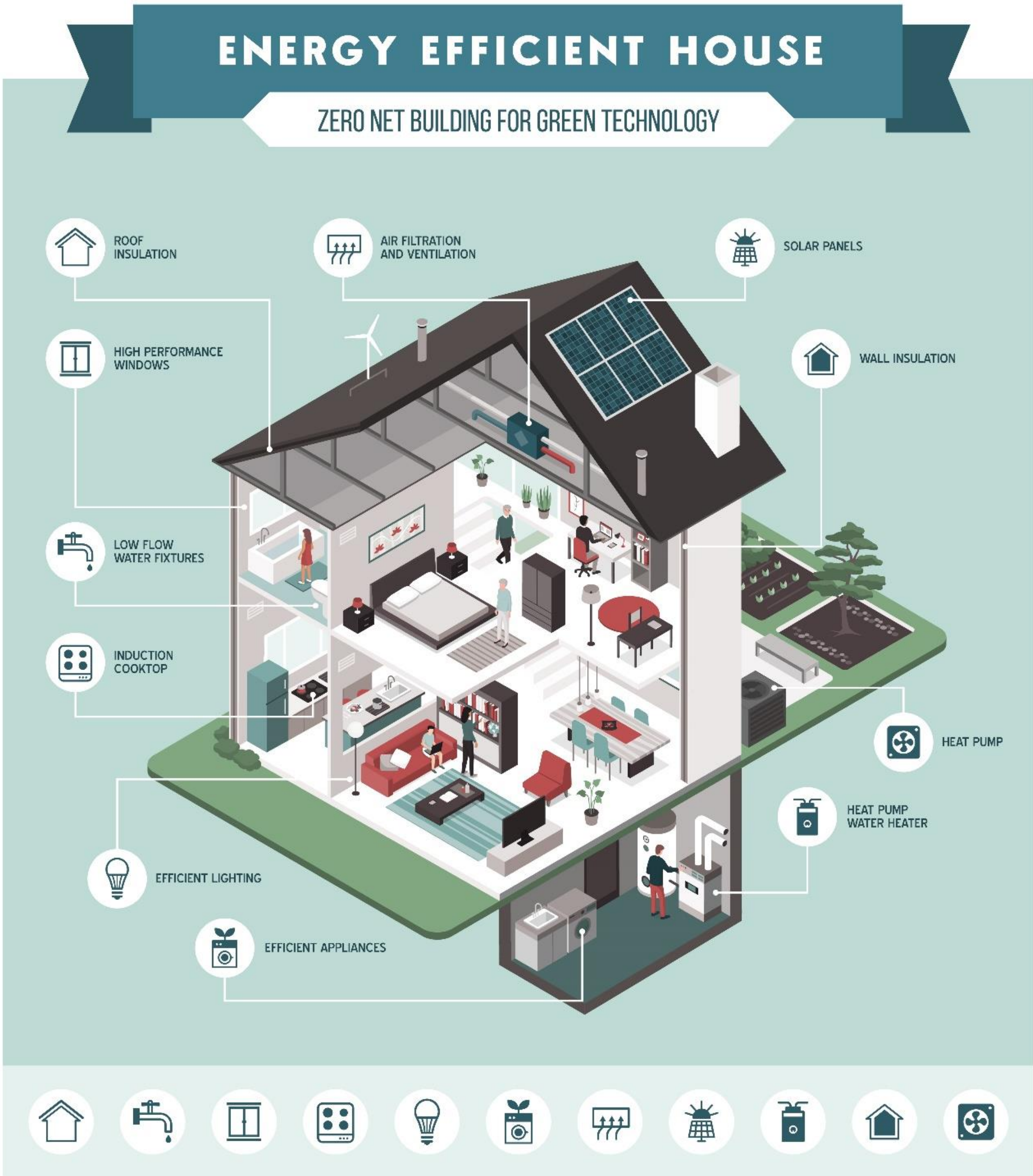

Illustration: smart house and energy supply systems consumption management

11. PRACTICAL WAYS FOR CROSS-BORDER COOPERATION

Although it is not possible to physically connect projects for the use of energy from small watercourses, this does not mean that there are no other ways to achieve cross-border cooperation.

The exchange of experiences and examples from practice are of valuable importance for the development of the exploitation of local rivers and streams because the configuration of the terrain and the potentials in the border area are similar, which means that there are also ways to use water energy without harmful consequences for the environment. The limitations and obstacles are alike. The difference may be at legal regulations in this area, as well as in the development level of the infrastructure. However, by promoting good practice, most of these limitations can be outbalanced. There are several possible forms of cooperatio:

• Joint meetings, forums and places for the exchange of knowledge and experiences, where the best and most effective solutions would be promoted.

• Model projects that could be used on both sides of the border, with different contractors but with the same goal. The results of the implementation and exploitation of such projects would be an excellent basis for a comparative analysis of success in similar conditions and a good guide for mitigating potential problems.

• Seting up joint energy cooperatives, that is, a pool of small investors who could invest in projects within cross-border cooperation.

• Development of tourism with an emphasis on "green tourism" and the use of renewable energy sources, promoting self-sustainability and new values in the offer, for space conditioning, for supplying electricity, for heating sanitary water, for swimming pools...

• Supporting SMEs for activities related to the exploitation of energy from renewable sources: production of parts for the system, specialized activities for the construction of micro and mini hydropower plants, installation and maitenance of the installations, design and aplication services, power management etc. These products and services could be used in both countries.

12. GOOD PRACTICE EXAMPLES

Penllengare, Great Britain

A twelve-metre Archimedean screw turbine has been installed next to a waterfall in Penllergare, UK. This turbine generates electricity for the visitor center, which is located nearby, while the excess is fed into the national grid. The screw turbine is characterized by high efficiency and allows easy passage of fish.

Year of construction 2012.

Water flow through the turbine 4.5 m3/sec

Water head 3.2 m

Installed generator power 101 kW

During 2017, the power plant was renovated, the water intake was increased and the installed power of the synchronous generator was increased to 348 kW.

Totnes, Great Britain

Totnes Weir Hydroelectric Station was built in 2015 and started generating electricity in December, same year. It worked better than expected, and the electricity production was higher than expected. Two large helical turbines, each 3.7 meters in diameter, produce clean, renewable electricity. The installed power of the plant is 328 kW and the annual production is 1,250 MWh, with an average water flow of 2x 6.5 m^3/sec - enough to supply about 300 homes for at least 40 years. A fishway has been installed next to the turbines to facilitate the migration of salmon and trout. An automatic counter has also been installed to monitor the number and sizes of fish which are using the lane. Extensive research has proven that fish can pass through a slowly rotating turbine without adverse effects. A recreation area with water sports and an information center around the hydroelectric power plant has been created. Emission saving on an annual level is 598 tons of CO_2. The construction cost is around 700,000 EUR.

Suez, Versailles, France

A 5.5 kW hydroelectric plant was installed at the Versailles wastewater treatment plant with a nominal flow of 0.7 m^3/s and a head of water of 3.2 m. The turbine was installed to supply electricity for the Carre de Reunion, a chemical-free wastewater treatment plant in Versailles, France. The small hydroelectric power plant is connected to the electricity distribution grid and produces total electricity for the average consumption of 6 households. The reduction of CO_2 emissions is 34 tons per year.

Vortex turbine in Donihue

This micro turbine was commissioned in January 2018 and has been operating at full capacity since March of the same year. The micro hydroelectric power plant produces electricity for the local farm and has an installed capacity of 15 kW. The turbine pool was made of reinforced concrete in two weeks. Components and equipment were installed in two days. The water flow is 1.65 m^3/sec and the height difference is 1.7m. Pieces of wood or stones and other debris up to 10 cm in diameter can pass through the turbine unhindered.

The turbine runs 24 hours a day, every day.

Austrian example of good practice

The Austrian government approved a financing program for the reconstruction of existing MHEs of less than 1 MW of installed power, which from 2004 to 2011 upgraded 243 small existing hydroelectric power plants, and most of them were simultaneously renovated and environmentally friendly. MHE owners received up to 25% of the investment for technical upgrading and ecological restoration, in a maximum amount of up to €50,000. The total funds amounted to €4.8 million. Total investments encouraged by this support amounted to 7.7 times the amount, i.e. €37.3 million. The capacity expansion resulted in an additional production of 80 GWh, which represents the energy need for about 20,000 households. The environmental benefit was also significant. Since 2012, there has been a national investment financing program for upgrading existing and new plants. The state budget amounts to EUR 33 million per year, half of which is for small plants (up to 30% of investments). Alternatively, plant owners can apply for guaranteed feed-in tariffs (period of 13 years). Whoever applies for a license must ensure the flow of the river and comply with environmental requirements (BAT). The national program is accompanied by an investment financing program from Upper Austria for plants smaller than 1 MW, but under the condition that the hydropower plants comply with strict environmental requirements (additional financing up to 25% of the investment and a maximum of €50,000). In Upper Austria, the financing program should result in the improvement and environmental restoration of more than 100 plants and an increase in hydropower production of around 150 GWh. The goal of these measures prescribed by the state is to respect and improve environmental protection measures in the process of using water for energy purposes, with the help of incentives that will be achieved through facilitating fiscal measures, financial assistance, as well as the rigid application of punitive measures for non-compliance with regulations in the field of environmental protection environment and with the simultaneous exploitation of water for energy purposes. A good and effective example from practice which indicates that sustainable use of water towards RES can be achieved.

An example of a storage MHE with a cascade fishway

13. INSTEAD OF CONCLUSION

Energy is crucial both for global development and for every individual, and solving a stable supply is of priority importance.

The use of renewable energy sources provides an exceptional opportunity to solve the energy security of the state and its citizens.

The 10 most important advantages of RES are:

1) It is available everywhere
2) It is easy to use and suitable for both small and large consumers
3) Stimulates the local economy
4) Reduces dependence on energy imports and geopolitical influences
5) Low exploitation costs
6) Plants can be easily expanded.
7) They do not pollute the environment.
8) They are safe
9) They are not so expensive anymore
10) They enable an increase in the standard of living.

The 5 most important challenges in using RES are:

1) It is not always and everywhere to the same extent
2) Higher initial investments
3) Lack of infrastructure
4) Insufficient knowledge and practice
5) Saving energy

This Guide aims to explain the nature and use of hydropower and to point out practical solutions, along with any challenges that may arise along the way.

Advantages of hydropower plants:

• No fuel is used so pollution is minimal;

• Water for running hydroelectric power plants is provided by nature for free;

• Hydropower plants play a major role in reducing greenhouse gas emissions;

• Relatively low operating and maintenance costs;

• The technology is reliable and proven;

• Renewable source of energy - water circulates in nature independently of us and the resource is constantly renewed.

Hydroelectric plants are not perfect and have some flaws:

• Relatively high initial investment cost

• They depend on rainfall and climatic conditions

• In cases of large accumulations, they can cause flooding of land and wildlife habitats

• It cozuld happen that the fish migratory rutes are cut off and thus fish habitats are lost or changed

• In some cases, the quality of water used for energy purposes changes, especially when it comes to accumulations or reduction of water flows through riverbeds.

• When it comes to large hydropower plants, the local population is evicted and that creates additional costs and social tension.

However, taking into account everything presented above, and especially the fact that energy will be increasingly needed in the further development and survival of human society, investments in this sector, especially in RES, are fully justified as it solves energy supply issues, in a way that is least aggressive towards the environment, of course if the rules and regulations on the sustainable use of water resources are respected.

14. ABOUT THE PROJECT

Project name	Renewable energy for smart growth and protected environment
Leading partner	Vidin Chamber of Commerce, Bulgaria
Partner	RARIS, Regional Agency for the Development of Eastern Serbia, Serbia
Priority axis	Environment
Project objectives	The main objective of the project is to increase capacity and improve awareness of environmental issues such as renewable energy sources and energy efficiency among the target groups: SMEs, local authorities, environmental organizations and institutions, the general public

Trg oslobođenja bb

19000 Zaječar, Serbia

Tel. +381 (0)19 426 376

Fax: +381 (0)19 426 377

office@raris.org

www.raris.org

3700 Vidin, Bulgaria

19 -21 "Tsar Alexander II" street

office@vdcci.bg

www.vdcci.bg/bg/

The project is co-funded by EU through the

Interreg-IPA CBC Bulgaria–Serbia Programme