IMPACT OF THE HYDROELECTRIC POWER PLANTS ON THE MOUNTAIN ECOSYSTEMS

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Abstract*: In the last decades, there was identified evidence of climate change. These climate changes are associated with various effects on different types of ecosystems and with changes in mountain ecosystems. To respond to these challenges, some states have started the implementation of general and specific measures, among them being the measures taken within the energy sectors*.

1. INTRODUCTION

In the last decades there has been identified evidence of climate changes. These climate changes are associated with various effects on different types of ecosystems and with changes in mountain ecosystems. It can be highlighted a direct and indissoluble relationship between climate change, hydropower plants, and the impact of the latter on the environment.

Mountain regions, complex and diverse in their nature, are central to policies for environmental protection and sustainable development; their problems and difficulties in adapting to climate change require appropriate, rapid, and, above all, permanent measures (sustained continuously). Inhabitable mountain regions usually belong to the geography of the environment, but can also be analyzed from an economic, social, cultural, etc. perspective, their multidisciplinarity being recognized both by the academic-university environment and by decision-makers directly involved in territorial development.

The economic outlook is particularly important at the level of large regional interest groups, and especially at the local and regional level, for the communities directly dependent on the conditions, resources and services offered by the mountain areas.

Increasingly visible, the negative impact of economic activities on upland areas, both high and low, must lead to a shared vision and a sustainable approach to its biodiversity status, as habitat damage can lead to destroying the ecological balance. Based on the above considerations, the article aims to provide an overview of the relationship between mountain biodiversity and the effects of the economic and social development on it (design, construction, operation, and decommissioning of hydroelectric installations), mainly using national documentary sources, but also, international sources, data, and statistical information, which come to complete the global picture of their evolution of the relationship, in time and space. At the time, the relationship between climate change and hydropower plants is considered, the same former bringing a significant contribution to the impact on the environment, with direct cumulative negative effects.

2. METHODOLOGY

The paper is based on research and analysis of scientific papers and research found in international scientific and professional journals, as well as specialty books in the field of environment protection and energy production. Given that the subject of the research is in an area of confluence between the field of energy engineering and the field of environmental protection, studies were investigated in international databases that include papers from the two fields of research. For this reason, there have been analyzed papers from IEEE, Scopus, Elsevier, Wiley databases.

3. ABOUT THE IMPACT ON MOUNTAIN ECOSYSTEMS IN RELATION TO THE SECTORS INVOLVED

Mountain areas are areas of these ecosystems form a relatively populated environment, but increasingly exposed to economic pressures with consequences that accompany zonal economic development: air, water and soil pollution, effects on flora and fauna, hydrological change etc.

The products and services offered by mountain ecosystems are of vital importance to local and regional communities, being an important source of raw materials for agriculture, forestry, tourism, mining, and industrial energy (*Figure 1*). [1]

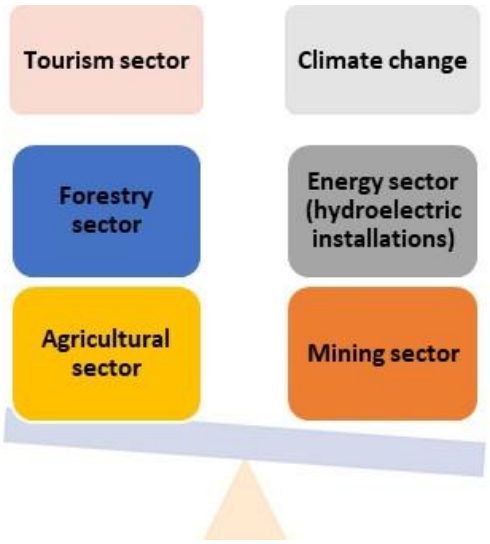

Figure 1. The change in the balance of the impact on mountain ecosystems in relation to the sectors involved

The development of mountain agriculture in different regions of the world is a real threat to some species, local biodiversity.

Uncontrolled deforestation in many mountainous areas around the world has led to a substantial reduction in the forest fund, with sometimes catastrophic effects not only on local flora and fauna, but also on land, not least in situations where the population has been affected by landslides. And even if tree planting activities are undertaken later, they cannot restore the ecosystems impoverished by extinct species.

The expansion of tourism activities in mountain areas, in addition to the economic benefits it brings, affects mountain ecosystems and biodiversity.

The activities of extracting useful mineral resources have many forms of impact, even after their decommissioning: water pollution, soil erosion, negative effects on landscapes, biodiversity, risks of chemical contamination of groundwater. [1]

Climate change in the form of global warming is adversely affecting mountain ecosystems. Some species have experienced declines in their population, and in some cases even their extinction. There are also changes in the precipitation regime, with effects on the flows of watercourses.

Mountain watercourses are often used to generate electricity. But even if they use a renewable energy resource, water, both during construction and in operation, hydroelectric power plants are associated with some form of environmental impact (Table 1).

At the same time, mountain ecosystems are also vulnerable to climate change, which is why it is necessary to monitor the effects these changes have on them. Protecting these ecosystems must be a priority in the design of any development strategies.

To respond to these challenges, some states have started the implementation of general and specific measures, among them being the measures taken within the energy sectors.

Table 1. Different types of activities and impacts associated with energy production and transport (adapted and updated after [2]

Types of activities	Air pollution	Electromagnetic pollution	Impact on biodiversity	Land use and pollution	Noise	Use of hazardous materials	Vibration	Visual pollution	Waste generation	Water use and pollution
Electricity transport	X	X	X	X	X			X		X
Geothermal plants	X			X						X
Hydropower plants*	X		X	X	X		X	X	X	X
Nuclear power plants	X		X	X		X		X	X	X
Solar power plants	X			X		X				
Thermal power plants	X		X	X				X	X	X
Wind power plants			X	X	X			X	X	

*micro-hydropower plants are included in this category

Use of renewable energy sources, like bioenergy, solar, wind, geothermal, hydropower energy, more environmentally friendly, offers an alternative solution to hydrocarbon-based power plants, in the attempt to reduce air pollution and to mitigate GHG emissions. Unfortunately, global climate change could also affect the renewable energy RE sources.

Given the fact that mountain areas are the source of numerous watercourses, the negative effects of climate change are not limited to these areas and their hydrology, but extend to downstream areas, whose hydrology can also be, affected and, consequently, the corresponding ecosystems.

4. THE ENVIRONMENTAL IMPACT OF HYDROPOWER PLANTS ON MOUNTAIN ECOSYSTEMS

First of all, hydropower plants offers a large series of benefits, besides the electricity necessary for economic development. Hydropower plants harness the energy of running water, which is a source of clean and renewable energy. They thus help to reduce consumption of fossil fuels and, consequently, to reduce air pollution. At the same time, water is an internal source of energy, much more accessible and reliable source than fossil fuels.

The formation of accumulation lakes offers the opportunity for complex uses of water. In addition to the main purpose, that of producing electricity, they make it possible to supply drinking water to the region and irrigate local agricultural land. They can also be used for

recreational purposes, such as fishing, water sports and light boating, the storage lakes being genuine tourist attractions.

During periods of heavy rainfall and floods, hydropower facilities, dams, made on rivers, can be used to control floods by regularizing their flows, preventing in this way damages to flora and fauna along the riverbanks. During periods of drought, increased water flow protects aquatic habitats.

In the same time, in the upper part of the dams of the reservoirs of the hydropower plants, communication paths can be built to cross the water courses.

From a technical point of view, the energy generated by hydropower plants can be injected faster into the energy system than from other types of powerplants, allowing the power to be restored quickly after interruptions and maintaining the voltage levels of the system.

In the mountain regions, although hydropower plants offer a wide range of benefits compared to thermal power plants, in terms of impact on the environment, significantly reducing air pollution, they are still not without an impact on the environment. While at the macroecological level it has advantages over other forms of electricity production, at the local and regional levels negative effects on the environment can be highlighted.

Therefore, several forms of impact on the environment of both large power plants and micro-hydropower plants can be identified during the construction phase (noise, waste, negative impacts on soil), but also during operation: in hydrological regime and water quality, effects on soil, flora, fauna (isolation, extinction or emergence of plant or animal species), damage to shores.

Uscătescu et al. [3] classified the forms of the environmental impact of the hydroelectric facilities based on various criteria (*Figure 2*).

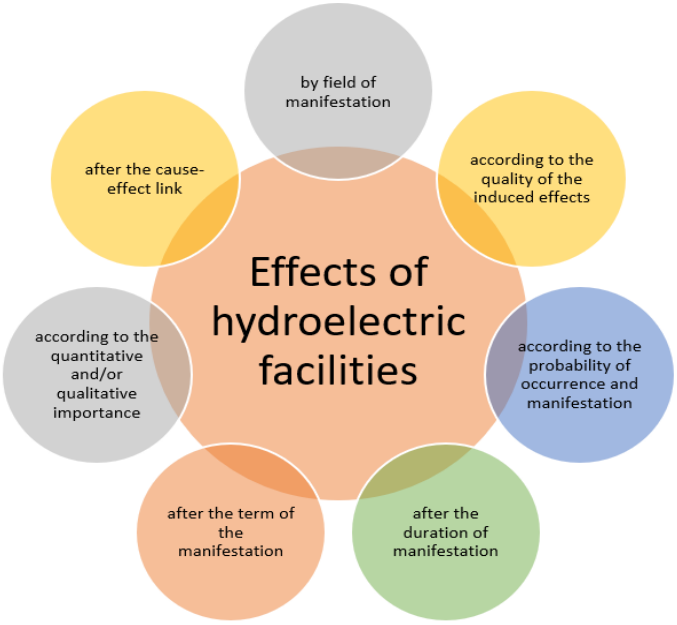

Figure 2. Schematic classification of the effects of hydroelectric facilities on mountain ecosystems (Processed and based on [3])

4.1. Impact on the atmosphere of the hydropower plants

Although in the case of electricity production in hydroelectric power plants we are talking about a renewable source of energy, water, it is not completely free of effects on the air, on the atmosphere.

Thus, different types of noxious substances (NOx, CO, SOx, heavy metals), COV and greenhouse gas emissions can be highlighted during the construction period, through the transport of materials and the operation of equipment and installations. Also, dust emissions are present during the execution of hydroelectric power plants. These emissions are temporary, so their impact on the environment is for a short time.

Flooding the land leads to the appearance of methane, another greenhouse gas, due to the organic materials, covered by water, through the decomposition of vegetation and soil. The amount of emissions depends on the site-specific characteristics, type of the soil, vegetation, temperature of air and water, reservoir management practice, season, the level of water. Also, greenhouse gas emissions depend on the type of hydropower plant HPP, the highest emissions being generated by storage (reservoir) HPP, followed by Run-of-river (RoR) and pumped storage plants [4]. During the operation phase, different activities of maintenance, the operation of cooling and heating systems could generate emissions of greenhouse gases. In the final stage, that of decommissioning of the power plant, the activities performed are also associated with such emissions.

Due to the excess of atmospheric humidity in the area, due to the presence of a large amount of stored water in the case of storage (reservoir) HPP, climatic disturbances occur: the decrease of the average temperature and frequent fog.

4.2. Impact on soil and subsoil

During the construction period, numerous cases of soil degradation are highlighted. The organization of the construction site requires the use of large areas of land. The works carried out to build the dykes change the configuration of the land.

In the case of hydroelectric plants that involve the construction of a dam, especially for the commissioning of large hydroelectric plants, it is necessary to clear forests or flood large areas of land, sometimes even fertile soils. Deforestation, clearing of vegetation can affect soil layers. Changes in texture, cohesion, state of loosening, temperature, etc. can be identified.

There is a risk of waste oil or waste, including hazardous waste, accidental leakage of fuels or lubricants, emissions of pollutants (NOx, SO, SO2, CO), sedimentable powders, heavy metals, which may settle on the ground.

During operation, the banks of the reservoir can be eroded, a phenomenon that also depends on the way the plant is operated.

The existence of a reservoir influences the soil and the subsoil due to the high pressure exerted on the earth's crust by the volume of accumulated water in reservoir and the infiltration of water from the lake into the earth's crust, with inherent intensifications of the action of the groundwater table on the structure of the crust [5].

4.3. Impact on water

Hydroelectric power plants have effects on river ecology through changes in hydro morphological characteristics: hydrological regime, continuity of the river, as well as the morphological conditions.

The changes that can be highlighted are chemical, physical (water temperature), and biological. There can be identified changes of the concentration of nutrients in water. Changes in the characteristics of aquatic and coastal ecosystems are also identifiable. The deviation of certain portions of the watercourses leads to changes of a physical-geographical nature with effects on the biocenoses.

During the construction period, solid particles, accidental leaks of fuels, oils, other chemicals or waste can enter the water. Changes in the movement and accumulation of sediments cause changes in the hydraulic balance and in the morphology of the riverbed, with a negative impact on some habitats.

Below the dams, the oxygen level is low, which has a negative impact on aquatic life. Reducing the flow of water courses causes changes in their thermal level and a decrease in the amount of dissolved oxygen, with long-term influences on the abundance and diversity of species [6]. To reduce this negative impact, aeration turbines can be used, or oxygen injected.

In the case of the construction of micro hydropower plants MHPP, an important problem for both the aquatic ecosystem and the local community is the reduction of water flow. There are also changes in the speed of the water, but also in the turbidity, transparency and chemical composition.

The servitude flow must be maintained at values that do not produce significant changes in the self-purification capacity and thermal regime of the river.

4.4. Impact of hydropower plants on biodiversity

The forms of impact on biodiversity can manifest both directly and indirectly, at the site of the construction of the hydropower plant or at a certain distance from it, immediately or even a few years after the construction or commissioning.

The construction of hydropower plants can lead to the alteration or loss of habitats not only for fish, but also for all other categories of biotic components: plants, terrestrial and aquatic invertebrates, amphibians, reptiles, birds, aquatic and terrestrial mammals. In the case of fish,

invertebrates, reptiles, amphibians and aquatic mammals, habitat fragmentation, disruption or even mortality of species even hundreds of meters from the noise source can occur [6].

Excavation works for the construction of power stations, of intakes and penstocks can have negative effects on riparian phytocenoses. The works of construction of adductions, of the catchment have an impact on the herpetofauna in the area. The negative barrier effect that hydropower plants can have on some mammal species can be highlighted. To reduce the negative impact, the solution of building crossings that have a more natural character, made of rocks, earth and vegetation specific to the respective area, can be practiced.

The flooding of land for the formation of reservoirs leads to the destruction of natural areas that bring together various plant species, but also to the loss of wildlife habitats. Changes in flows can significantly affect the ichthyofauna in the area, but also upstream and downstream.

The construction and operation of small hydropower plants can generate significant impacts on biodiversity when their location and design do not start from compliance with the ecological requirements of habitats and species. The effects of their construction are similar to large dams: modification of hydro-geomorphological parameters of riverbeds [7], interruption of habitat continuity, acceleration of ecosystem succession, rapid eutrophication [6].

The discharge of some sediments into the water course during the construction period of the intake and catchment can affect benthic invertebrates, which are a food source for some fish species, such as trout. For this reason, it is necessary to avoid their discharge into the riverbed.

During the period of operation of the small-hydropower plants, the negative impact on fish and some invertebrates can be highlighted also, determined by the release of sediments and organic matter into the river during the washing of the de-sanding devices of the small hydropower plants.

The diversion of river courses, the blocking of their natural course causes the obstruction of the natural migration routes of fish. Disruption of watercourse connectivity causes the decline of upstream species populations. The solution of building ladders for fish movement is suitable for large fish species, but not useful for small fish species. In the same time, the situation of accidental clogging of the slots of these scales may occur, interrupting the connectivity of the habitats of various species of aquatic life.

According to Romanian legislation, the construction of passageways for migrating aquatic fauna is required only for thresholds higher than 40 cm [8], respectively 50 cm [9], heights that prevent the migration of fish species small and some protected fish species, such as the benthic fish Cottus gobio.

It is therefore necessary to comply with the height, flow and velocity requirements of the water for the protected fish species. Moreover, the study carried out by Utzinger et al. [10] reveal that obstacles larger than 20 cm can stop their upstream movement. In addition to the size of the specimens Ovidio et al. [11] highlights other influencing factors in jump

performances: the type of obstacle, the age of the specimens and the abiotic conditions: depth, temperature and water speed.

The movement of fish and other aquatic organisms in the dam area is determined by the type and size of the hydropower facility. These organisms are vulnerable and can be injured. In order to identify the effects on them at the passing through the turbine the researchers use sensors and acoustic telemetric systems [12]. The ways in which they can be injured are multiple, as Coutant and Whitney [13] point out: blade impact, cavitation, grinding, rapid pressure decreasing, shear stress and turbulence (Table 2).

Table 2. Injuries of fish and aquatic organisms in the dam zone

Type of exposure	Injuries associated with the type of exposure	Source
Shear forces	• bruising, • eye and gill/opercular damage • descaling	Deng et al., 2005 [14]
Fast decreases in pressure	• rupture of the swim bladder, • exopthalmia, • emboli in the fins and gills, • hemorrhaging	Brown et al., 2012 [15]
Cavitation / Elevated total dissolved gas	• gas bubble disease: emboli in the fins, gills, and eyes	Deng et al., 2015 [16]

The rapid decrease in water pressure leads to an increase in the total volume of dissolved gases TDG, which can lead to injury or mortality of fish. Water supersaturated with dissolved nitrogen causes gas bubble trauma (GBT) in fish, a phenomenon that occurs when they pass through the turbine area.

The survival of fish passing through the turbine area is influenced by the speed of the turbine blades, the degree of inclination and the body part of the fish they hit [17], [18]. Depending on how the turbines are built, they can be more or less dangerous. In their report, Franke et al. [19] present the results of a study on reducing the impact on the environment through the design of environmentally hydro turbine systems. Also, Cada [20], Cada et al. [21] present turbines designed to improve fish survival rates.

In the case of large dams Deng et al. [16] identified three main possibilities for their movement downstream: through the turbines, over the spillway or using the bypass facility for juvenile fish. They also add as alternative options to avoid injury to fish such as fish screens to guide fish away from turbines and into bypass or transport facilities, as well as catching and transporting them downstream by water or land transport, using trap-and-haul facilities to collect and move fish. For large dams, also, the accumulation lake could be populated with fish specific to that area. However, the solutions used do not allow massive migrations.

A common solution for ensuring the migration of fish is, especially for small dams, the construction of ladders or windows in the dams that allow the passage of fish. These passages are practiced not only for migratory species, but also to the other species. Their design depends on the configuration of the hydropower, the characteristics of the river and on the fish species in the river [16].

4.5. Other forms of impact

Noise pollution is another form of pollution encountered during the construction period due to the machinery, means of transport used in the construction of dams and other construction and installation elements. Added to this are the vibrations caused by them, as well as the use of explosives, with effects on the population and fauna of the area.

Hazards related to damage to hydrotechnical constructions can affect embankments and dams of water accumulations. Technological accidents such as dam breakages, which can be initiated by natural causes (floods, earthquakes), can cause catastrophic effects both for the flora and fauna, as well as for the population and the surrounding constructions.

But sources of noise and vibrations can also be identified during the exploitation period, caused by turbines and generators, which can cause disturbances of the species in the respective area. There are studies in this regard that reveal that an increase in the noise level compared to the natural background of 3-10 dB can cause a 30-90% reduction in the alerting distances of wild animals [22], in while values higher than 48 dB for birds living in meadows and 42 dB for those living in forests can cause a decline in their numbers [23]. Noise can affect interspecific, intraspecific communications, reproduction, nesting and feeding of various species [16]. Vibration dampers and sound-absorbing panels can be used to limit noise and vibrations.

In addition to the different forms of pollution, visual pollution is also added by changing the visual characteristics of the landscape: constructions and electrical installations, changes in the watercourse bed, changes in the riparian vegetation.

During the construction period, the activities involved in realization of a small hydropower plant has negative effects on the landscape in the area selected for construction due to the specific construction works, the location of the construction site organizations and the intense traffic of machinery. More, a series of waste results, quantities of excavated soil, whose improper management can have effects on the environment.

In Romania, of the more than 430 micro hydropower plants in various stages of planning, authorization and construction, more than a quarter are in protected natural areas [24]. During their exploitation, reductions in the flow rates of water courses have been reported with effects on biodiversity, flora, fauna and landscape being affected [25]. Also, the roads of some localities where these micro hydropower plants were built during their construction were also affected. The negative effects are also felt on the local economy, whose development is based on the agritourism network.

5. CONCLUSIONS

In addition to the many benefits that hydropower plants bring, from economic, social and environmental points of view, there are also some forms of negative impact on the environment associated with them.

Thus, we can speak of a microclimatic impact on the atmosphere associated with the construction of large hydropower plants with storage lakes, to which is added a reduced amount of greenhouse gases, depending on the type of hydropower plant. Added to this is the impact on water courses, through changes in hydro morphological characteristics. Depending on their location, large installations can raise concerns about land degradation, loss of some fertile soils and forests.

Through works for the arrangement of large accumulations that involve deforestation and flooding of land, ecosystem imbalances can occur by modifying the habitats of some animal and fish species. The presence of the dam has influences both on the upstream area, causing the submergence of extensive areas, but also on the downstream areas, destroying the valley forests and pastures. If it is necessary to flood some areas with a special natural, artistic, cultural, historical potential, to the already very high costs of the initial investment will be added substantial additional costs for the displacement of the respective values.

In order to reduce the environmental impact of the hydro power plants a series of solutions have been developed and implemented during the time. Above all. environmental impact assessment is required for each hydropower plant, whether it is new plant projects or existing hydropower plants in operation.

A solution already used in many places around the world is dam removal, in the case of the old dams which need rehabilitation or for the small dams that are no longer used or recorded significant decreases in their reservoir capacity [26].

There are studies that highlight the possibility of reducing the volume of greenhouse gas emissions, the degradation of banks, the phenomenon of erosion, as well as the impact on aquatic and littoral habitats by optimizing the way of managing water from the reservoir in the operation of the hydropower plant.

To ensure the hydrological continuity of the river and not to significantly affect the natural habitat of the various aquatic and coastal species, it is necessary to regulate the minimum flow that must be ensured in the areas where the hydroelectric power station operates.

Petrescu [24] proposes the ecological reconstruction of the affected areas according to European legislation for nature conservation, believing that a solution would consist in renovating the old small hydropower plants, instead of building new ones, which could considerably reduce the impact on the environment.

In this direction, a series of measures can be used: the construction of ladders in the dam, motorized lifts or the implementation of the trap-an-haul solution, for hydropower plants that were not equipped from the beginning with technical solutions to ensure fish migration, removing pollutants from the reservoir, sediment management, design and construction of environmentally friendly turbines, installation of fish screens, implementation of technical solutions for water aeration in the reservoir to ensure water quality, temperature control, design of buildings in a way to integrate into the landscape.

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