Future Technology
Open Access Journal
ISSN 2832-0379

August 2023| Volume 02 | Issue 03 | Pages 12-16

Journal homepage: https://fupubco.com/futech

https://doi.org/10.55670/fpll.futech.2.3.3

Future Publishing LLC

Review

The range of hydropower projects and their effects on the environment

Mohamed Abdikadir Mohamoud, Gözen Elkiran*

Department of Civil Engineering, Faculty of Civil and Environmental Engineering, Near East University, Cyprus

ARTICLE INFO

Article history:
Received 12 December 2022
Received in revised form
11 January 2023
Accepted 15 January 2023

Keywords:
Hydropower, Reservoir, Downstream

*Corresponding author
Email address:
gozen.elkiran@neu.edu.tr

DOI: 10.55670/fpll.futech.2.3.3

ABSTRACT

The peak load capacity of hydropower facilities has become more necessary as electricity grids have expanded. The ratio of power demands during peak times to those during off-peak times has increased in several power plant systems. One way to meet the rising need for affordable peak power is by using reversible pump turbines. Depending on the sorts of facilities used to generate hydropower, there are several types of hydropower plants. We'll talk about the most efficient and reliable hydropower sources, as well as various hydropower plant types based on the varied hydropower generation facilities, which will be the subject of this review investigation.

1. Introduction

There are still many hydroelectric facilities in operation today that were constructed during the turn of the 20th century. The turbines that were installed at that time are still working with an efficiency of between 80 and 90 percent. Hydropower actually uses an easy procedure that makes take advantage of the kinetic energy provided by falling water. Each hydroelectric facility plant uses a turbine to transform the velocity of the rushing water into mechanical and electrical energy. It is the most effective, dependable, and flexible source of electricity because of this straightforward method [1]. There are several ways that this technology is applied in practice, depending on the electrical services needed and the specific site circumstances. As a result, there exist many hydroelectric projects, each of which provides a variety of services and has an impact on society and the environment that is unique in both type and extent. The brief review that follows highlights the necessity of evaluating each hydroelectric project is evaluated in the context of the solutions it offers and energy-contrasting supply strategies based on the same socially useful services. The essay begins by outlining how hydropower helps produce electricity. Then, a number of hydropower project types are covered, along with the particular electrical services they provide and how the various environmental effects of each project type differ [2].

2. Hydropower and electricity supply

Electricity cannot be stored, despite the fact that demand for it varies significantly from day to unlike forms of energy like wood, solar energy is available every day of the year, such as gasoline or gas, which can. Any shift in the demand for electricity must be quickly matched by a corresponding shift in the supply. The electric current's "pressure" or voltage decreases when demand increases, but supply cannot keep up, which could strain the ultimate electrical systems, resulting in "brownouts" and creating power outages. This might have significant implications on economic activity as well as basic services like security, health, and education; utilities integrate a number of power plants to meet the highly wide variety of power demands. With extremely demanding levels of service continuity. Some power plants are better suited for base-plant operation, whereas others are better suited for peaking-plant operation. For instance, nuclear power facilities work best in stable environments [3]. Because of their output, they actually serve as base-load power plants. However, based on how they are constructed, hydropower plants can produce electricity for base load, peak load, or both. Hydropower's versatility in the way it delivers electricity is one of its special technological advantages. Hydropower can therefore offer a range of electrical services.

A. Production of base and peak loads in various locations with a substantial supply, hydropower can be used to meet peak as well as base loads. The primary load is generated by large or numerous energy-storage projects, such as reservoirs. And multiple seasons. Run-of-river plants may also be combined with these initiatives to provide the base load if they are available (hydro plants that don't have a reservoir but use river water flows). In order to generate the additional electricity needed to accommodate peak load, some power plants build more water turbines. Several hundred to a thousand hours a year at most is consumed from this reserve capacity, but it enables additional power when necessary.

B. Producing peak loads in regions with a diminished hydropower supply, hydroelectric plants are typically employed to meet peak demand, maximizing the use of other, less adaptable energy sources, such as nuclear energy sources based on coal or oil. Due to the water scarcity in the majority of the world, this second method is much more prevalent than the first. This tactic also highlights another inherent technological benefit of hydropower, which is its ability to begin producing electricity almost immediately, within a minute or less of receiving the go-ahead to begin operations. From a technological standpoint, hydroelectricity, which generates power as needed, successfully complements other main energy sources. Hydropower plants are easy to maintain and have good reliability thanks to their simple design (no radiation protection, steam cycle, or combustion) [4].

3. Types of hydroelectric projects

There are several non-exclusive categories into which hydropower projects might be placed:

- In accordance with available space (projects involving rivers or reservoirs) purpose.
- Size (big, tiny, or micro), purpose (single or dual), and other factors.
- By head, which refers to the height difference between the water levels above and (below) the dam, the hydraulic turbine's design is chosen.

The following sections' goals are to give a brief overview of sources of environmental protection and energy services effects caused by various project types. Storage capacity is therefore given a lot of weight in the proposed classification system, as indicated in Table 1, which significantly influences the extent of environmental effects. As a result, we advise grouping hydroelectric projects into the following categories:

3.1 Types of hydroelectric projects

- Pumped-storage initiatives.
- Projects that divert rivers, run-of-river initiatives with minimal to no storage,
- River diversion projects
- Projects similar to reservoirs with large storage capacities, small, mini, and micro projects. This subject is also explored because modernizing current hydropower plans might have an effect on the environment and alter the type of energy service the plant provides.

Finally, projects that use water to develop and fulfill many purposes are also highlighted.

3.2 Reservoir type projects

The majority of reservoir-based hydropower projects are known as "conventional hydropower" or "dam-toe," where a dam is constructed across a river (often out of concrete, earth, rock fill, or wood) and prevents all downstream water flow except through turbines, via a spillway, or over the top of the dam (for lower head structures with run-of-river operation). Behind the dam is a water-storage reservoir, lake, or pond, often known as an impoundment. To turn the turbines and generators within the powerhouse, water must pass through a gate with a garbage rack (a screen that captures solids) and into the penstock. From there, electricity travels through a transformer and out to transmission lines.

Table 1. types of hydropower projects and their services

Project type	supplied services	main factors
Type of reservoir	Power and Energy	Consequences of reservoir on social issues and habitat changes alterations to river flows
Run-of-river	Limited flexibility base load	Small flooding River flow is unaffected.
Pumped-storage	Power alone is a net energy user.	Effects on the upper storage pool
Cross-watershed diversion	Project life is extended by energy alone, and sometimes output is increased.	Flow reduction after the diversion Increase in incoming stream flow Decrease in downstream stream flow
In-stream diversion	Hydropower and other uses of water	Minimal extra effects
Upgrading	Energy and Power	Effects primarily caused by reservoir Evaluation of the combined effects of various water usage is necessary
Multipurpose	Limited flexibility base load	Consequences of reservoir on social issues and habitat changes alterations to river flows

Baseload grid demand can be satisfied by reservoir-based hydropower through predictable and manageable water discharges. Additionally, it may "load-follow" (offer intermediate generation) and adjust the amount of water released based on variations in demand above the baseload (Figure 1). Additionally, it can deliver "peak" power, temporarily releasing enormous amounts of water to satisfy peak energy needs while depleting the reservoir. Compared to the creation of energy, this has less impact on society and the environment. The area of reservoirs Size variations of several orders of magnitude is possible depending on the height of the dam. The local topography and anticipated energy requirements. Some reservoirs have an area of a few, 5000 or even more square kilometers [5]. However, they also typically have the greatest environmental implications and undoubtedly spark the most debate. These later ones have the maximum storage capacity and, therefore, the best level of energy security. The best-documented environmental effects of reservoir-type developments come as a result of:

- The construction of dikes, embankments, the dam, and the power station.
- The availability of infrastructure (access roads, power lines, substations, etc.)
- The building of the dam, the power plant, and the dikes and embankments.
- The project's dimensions and the site's specifics will determine how severe the impact is. These specific components are examined in other journal articles.

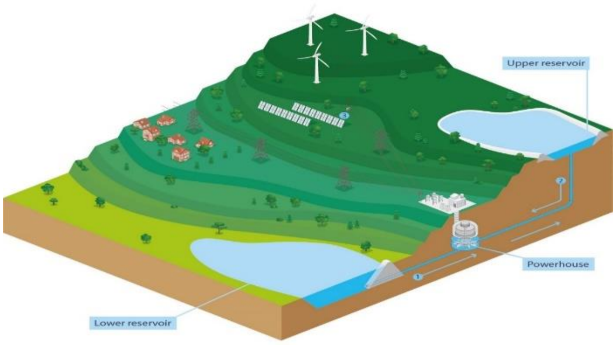

Figure 1. Pumped storage hydropower

3.3 River run-of-projects

The river's regular water flow is used to generate hydropower in this way. Therefore, there is minimal to no impoundment of a reservoir. Typically, on large rivers with mild grades or small rivers with severe gradients, they can be constructed with either a low or a high head. Run-of-river projects may utilize all or a portion of the river flow. In the first instance, changes in plant inputs are brought about by seasonal fluctuations in river flow. These run-of-river facilities provide varying amounts of power throughout the year because they are reliant on river discharge, as Figure 2 shows. But increasing unless the time of maximum demand, plant capacity is typically not reasonably priced. Also happens to be the time of greater flows. In order to produce the same amount of electricity for the base demand throughout the year, most run-of-river power facilities are built to use just a tiny fraction of the total river flow. Constructing a significant storage facility in the upper catchment to regulate flows for a number of downstream. The most typical method for increasing the energy production of hydroelectric facilities on rivers is to build run-of-river or smaller reservoir plants. Any run-of-river projects have significantly fewer negative social and environmental repercussions when there isn't a substantial reservoir because the river isn't turned into a lake. Because the river's flow pattern is basically unaltered, so the project's downstream consequences are mitigated [6].

3.4 Storage-pump projects

Pumped capacity facilities use excess electricity produced by baseload power plants during off-peak hours to push water into an upper storage basin. They then change the flow in order to generate electricity during the daily peak load period.

Figure 2. River run-of-projects

Due to the energy requirements, water is pumped up to the upper reservoir, using more energy than the plant produces as it rushes down to the lower reservoir. These facilities use energy in a negative. The reason for this is that the top reservoir was designed to hold water that would be pushed back during off-peak times. The energy needed for pumping is typically recovered at a rate of between 65% and 75% during the generation stage. When existing grid facilities, Nuclear or coal-fired power plants, for example, provide largely base energy with little flexibility. Construction of pumped-storage facilities is economical. It is possible for peak electricity prices to double over off-peak prices in some circumstances. A little upper pool drains quickly on short travels (typically only a few square kilometers in size) [7]. Pumped storage plants function in intervals, once or twice per week. Consequently, there has been a noticeable reduction in the upper reservoir. These ponds seldom transform into a stable aquatic environment since they are frequently man-made. For pumped-storage systems, the lower reservoir occasionally functions as a lake, river, or active reservoir. Other times, it will be necessary to build a new lower reservoir, and the size and drawdown of the new reservoir will depend on the local topography and hydraulics. The upper pool's location, the type of powerhouse (either below or above the ground), and the habitat at the bottom of the reservoir's ecology are three key environmental concerns with pumped storage systems. These problems can be resolved at the project's design stage because they are site-specific by nature [6].

3.5 River diversion projects

Initiatives for diverting rivers include:

A. In-stream diversion, which involves damming a river and channeling it via tunnels dug into a slope so that it empties further downstream and returns to its original riverbed.

B. Diversion over a watershed: This strategy involves increasing river flow upstream while decreasing river flow near the power station. A power plant's head is raised via in-stream diversions, which increases the quantity of electricity and energy that is accessible. Cross-watershed diversions generate energy by boosting the receiving stream's flow where the power plant is located. A significant or complete reduction of flow immediately downstream initiatives that involve diversion have a distinct environmental impact. This might have an impact on water temperature, water quality, and coastal erosion further downstream. The extent of these effects depends on the length of the river section with lower flow and the ecosystems that are affected, particularly in terms of aquatic biology. Cross-watershed diversions are more strongly influenced by the increased flow in the receiving river. There is also a chance that invasive fish and plant species will move between catchments. Ultimately, a new ecological equilibrium is attained, with terrestrial animals, plants, and shrubs inhabiting the river margin in rivers with the decreased flow and aquatic habitats expanding in rivers with increased flow. In order to protect a river's ecosystem and the area's current land use, the optimal mitigation strategy- which is currently frequently used is to ensure a minimum ecological flow after a diversion. Keep in mind that seasonal variations in river flow affect the majority of naturally occurring rivers and that seasonal variations in river flow can cause some rivers to dry up totally. Every river's ecosystem has evolved to suit how it flows. To lessen the loss of breeding grounds, the design of an ecological flow in a diverted river, for instance, may be based on the habitats of the most valuable aquatic species in the river. On rivers with less flow, small weirs can be constructed to maintain water levels similar to those before the diversion [8].

3.6 Mini, micro, and small projects

According to the circumstances in each nation, tiny, mini, and micro hydropower projects have different classifications. There are no definitions that are accepted as valid by everyone. Here, small, mini, and micro hydropower are denoted by outputs of 10, 1, and 0.1 MW, respectively. Smaller projects are simpler to finish than larger ones because they take less time to plan and build, cost less money, and involve the purchase of fewer pieces of property. An established and used generalization states that the area flooded is roughly inversely connected to the environmental consequences. Due to the modest scale of the projects and the relatively small water bodies they affect, tiny, mini, or micro-hydro projects are often regarded to have little environmental effects. Other benefits include fewer safety risks and issues with population flow or land usage. For instance, as a result of this, the states of Maine and New Jersey now designate large hydro as a non-renewable energy source and define small hydro as facilities with a capacity of 30 and fewer megawatts (MW), respectively. There is continuing debate regarding the relative merits of large and small dams. In addition to having substantial implications for energy policy, as already mentioned, this issue may have a huge impact on future hydropower advancements. The distinction between small, renewable dams and large, non-renewable dams is mostly arbitrary from an environmental perspective. The project's distinctive characteristics and geographical setting- not its size—determine whether it is renewable and sustainable. Additionally, when they are compared on the basis of identical electrical output, the environmental benefit of small hydropower over large hydropower is noticeably less obvious. Which is more hazardous to the environment: a 2000 MW power station built on a single river or 400 5 MW hydropower facilities dispersed across 100 rivers? Is it possible that the overall impact of a single 2000 MW project would be less than the sum of 400 5 MW small hydropower projects, given the number of rivers and tributaries that would be impacted? The volume multiplies by eight when the cube's sides are doubled, but the surface area only increases by two, showing that the surface area of a small object is greater in relation to its volume than that of a large object [9]. This implies that in order to accomplish the same quantity of water storage, the land mass flooded by 400 tiny hydropower plants of 5 MW would need to expand in size. Much larger than the region that would be flooded by a 2000 MW plant alone. This suggests that multiple additional habitat effects are necessary to generate the same storage as a single, significant reservoir. The amount of land that is flooded per unit of hydroelectric plant output, as sampled internationally Therefore, hydropower projects should be compared based on the amount of energy and power generated or the service they provide to society, even though it is obvious that a small degree of human engagement in a certain habitat has fewer consequences than a very large intervention in the same environment. The cumulative consequences of numerous tiny hydro projects could be negative due to the variety of habitats that could be harmed and the substantially greater cumulative surface area that would need to be submerged for an equivalent storage volume with small projects. From this perspective, be greater than those of a single project. Beyond the debate between "small" and "big" dams, site-specific factors and energy supply needs influence effects on the environment, including their type and scope [10]. The average size of the hydro reservoir per unit of capacity is listed in Table 2.

3.7 Improvement projects

Because they offer a supply of reasonably priced, adaptable, and frequently environmentally friendly power, power companies have a significant interest in preserving the hydroelectric plants' earlier hydropower outputs. This is due to the comparatively long life spans that hydropower plants are designed for. Indeed, upgrading uses the infrastructure that has already been created more effectively and more affordably than from scratch. Additionally, options for extending plant life include several stages of upgrading, such as renovation, modernization, or uprating [11]. These choices consist of continual upkeep.

- Refurbishing: a plant is a common practice to return to its previous state and functionality in an effort to cut maintenance expenses and increase plant lifespan by a set amount of time, usually 25 to 50 years.
- Modernization: also aims to increase plant availability by utilizing more advanced technologies and materials. This can result in improved operational effectiveness and hence better productivity.
- Upgrading: making an effort to increase the plant's installed megawatts (MW) of nominal power as well as its hydraulic capacity. Because the infrastructure is already in place and available, expanding the capacity of existing facilities has a less detrimental effect on the environment than starting a new project. Therefore, there is a significant financial motive to minimize any planned downtime. Environmental effects of upgrading activities often have a place- and time-specific focus. When the circumstance calls for a significant increase, upgrading initiatives may be paired with constructing a river diversion to increase electricity output. Environmentally speaking, this approach might be preferable to creating a brand-new hydroelectric facility somewhere else.

3.8 Multipurpose projects

Due to the fact that the water needed to drive the turbines is not consumed during the process, hydropower is a renewable resource that may be used for a number of other essential human survival needs. In reality, a large number of hydropower projects are built with a variety of goals in mind. Approximately one-third of all hydropower projects, according to Lecornu [12], do more than only generate electricity. They can make it easier to engage in leisure activities like fishing, travel, and navigation. They can help minimize or stop droughts and floods. Additionally, they can be utilized to supply irrigation and water for domestic, public, and industrial purposes. Due to the conflicting demands these several water applications have on water utilization, trade-offs are necessary. The other article in this publication discusses these trade-offs. One aspect that comes up when discussing hydropower and the numerous uses of water is frequently overlooked is that the hydropower plant, as an income producer, pays for the infrastructure necessary to develop alternative water uses in some circumstances. The necessity to take into account not only the hydropower project's environmental consequences but also the total of all other anticipated water users is one of the main environmental aspects of projects with multiple uses. Multipurpose projects need a sustainable allocation of water resources and effective coordination with the different user groups, which makes hydropower planning and operation more difficult. In actuality, better planning could aid in averting many of the problems that uncontrolled water consumption will likely cause in the future. Therefore, a thorough watershed-wide integrated water resource management strategy must be taken into account whenever multiple purposes projects are expected [13].

Table 2. The average size of the hydro reservoir per unit of capacity

Size of plants (MW)	Number of plants in category	Average size of reservoir per unit of power (ha/MW)
3000-18,200	19	32
2000-2999	16	40
1000-1999	36	36
500-999	25	80
250-499	37	69
100-249	33	96
2-99	33	249

4. Conclusion

This brief assessment serves as an illustration of the necessity of evaluating and comparing energy supply projects based on the same socially advantageous services each hydropower project provides in the context of the services it provides. The term "hydropower" refers to a wide range of undertakings with varied scopes, objectives, and architectural styles. The social and ecological settings are impacted in a number of ways and are benefited from this. The main sources of influence are clearly a reservoir and an impoundment. A reservoir is the most practical way to store enormous A reservoir, however, also provides the best level of electricity supply services. In addition to being used for energy storage, a reservoir also makes it possible to cost-effectively and with minimal negative environmental effects develop run-of-river plants downstream.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] Egré, D., & Milewski, J. C. (2002). The diversity of hydropower projects. Energy policy, 30(14), 1225-1230.

[2] Klein, S. J. W., & Fox, E. L. B. (2022). A review of small hydropower performance and cost. Renewable and Sustainable Energy Reviews, 169, 112898.

[3] Goodland, R., 1995. How to distinguish better hydros from worse: the environmental sustainability challenge for the hydro industry, The World Bank. Google Scholar

[4] Oladosu, G. A., Werble, J., Tingen, W., Witt, A., Mobley, M., & O'Connor, P. (2021). Costs of mitigating the environmental impacts of hydropower projects in the United States. Renewable and Sustainable Energy Reviews, 135, 110121.

[5] Rosenberg, D., McCully, P., & Pringle, C. (2000). Environmental effects of hydrological alteration. BioScience, 50(90), 746-751.

[6] Vaca-Jiménez, S., Gerbens-Leenes, P. W., & Nonhebel, S. (2020). The monthly dynamics of blue water footprints and electricity generation of four types of hydropower plants in Ecuador. Science of The Total Environment, 713, 136579.

[7] Johnsen, B. O., Arnekleiv, J. V., Asplin, L., Barlaup, B. T., Næsje, T. F., Rosseland, B. O., ... & Tvede, A. (2011). Hydropower development–Ecological effects. Atlantic Salmon Ecology, 351-386.

[8] Mattmann, M., Logar, I., & Brouwer, R. (2016). Hydropower externalities: A meta-analysis. Energy Economics, 57, 66-77.

[9] Rochman, S., & Hermawan, A. (2022). Design and Construction of Screw Type Micro Hydro Power Plant. BEST: Journal of Applied Electrical, Science, & Technology, 4(1), 21-26.

[10] Brookshier, P. (2004). Hydropower technology. Encyclopedia of energy, 3, 333-341.

[11] Tammaruckwattana, S., Reangkittakarn, S., & Rerkratn, A. (2018, April). Hydropower plant generator system. In 2018 3rd International Conference on Control and Robotics Engineering (ICCRE) (pp. 160-164). IEEE.

[12] Lecornu, J., 1998. Dams and water management paper presented to the Conférence Internationale Eau et Développement Durable, Paris. http://genepi.louis-jean.com/cigb/article-barrages-an.html. Google Scholar

[13] Breeze, P. (2018). Pumped storage hydropower. Power system energy storage technologies, 13-22.