IMPROVING DECISION-MAKING FOR THE ENERGY TRANSITION

# Guidance for using Strategic Environmental Assessment

CHAPTER 5

# HYDROPOWER

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*Links to the complete guidance document and to individual chapters are also available.*

# CHAPTER 5

# HYDROPOWER

## WHY IS SEA IMPORTANT TO HYDROPOWER?

An overall rationale for why it is important to use Strategic Environmental Assessment (SEA) to support the energy transition is provided in the preface to the guidance.

It is becoming increasingly clear that hydropower projects should be managed at a watershed or basin level. In this context, SEA can provide critical information to support better decision-making for hydropower planning and development, including identifying where there might be significant environmental and/or socioeconomic risks not only at the individual project level, but across the entire watershed. This information can be particularly important to identify and assess the scale and significance of possible cumulative impacts of multiple hydropower schemes/developments. These impacts can arise:

- Along individual rivers within a country (critical to understand the impacts of multiple often uncoordinated schemes/projects).
- Along transboundary rivers that flow across boundaries between countries (critical to anticipate potential disputes between countries).
- Along multiple rivers in a particular catchment (critical for catchment planning).
- Along multiple rivers in several catchments where inter-basin transfers are taking place.
- Across all catchments in a country (critical for national energy and hydropower planning).

The SEA process will:

- Identify and focus on ***key environmental and socioeconomic issues*** and the concerns of likely affected stakeholders, including local communities, marginalized groups, and Indigenous peoples. This could be on a national scale (for a national-level PPP [policies, plans, and programs]), or for an individual catchment/river scale (if the SEA is catchment-based). Issues associated with hydropower development are discussed in detail in Section 5.5 and are summarized in Table 5.3.

- Identify/recommend if there are ***areas that should be avoided*** for hydropower development ("no go" areas) because of particularly high risk to the environment and/or people and local communities, or preferred areas where the risks are lower.

- Inform where hydropower projects could best be sited (e.g., in particular watersheds or locations).

- Inform project design (e.g., preferred type of dam given constraints in a watershed or along a river).

- Make subsequent project-level ***EIAs/ESIAs*** *(environmental impact assessments/ environmental and social impact assessments)* ***more efficient and cheaper*** by addressing the big picture upstream and downstream across the watershed, and by addressing potential cumulative impacts and identifying the broader issues that individual project EIAs/ESIAs should focus on in more (site-specific) detail.

- ***Engage stakeholders*** (along a river course, in a single or all catchments—both upstream and downstream)—including communities, marginalized groups and Indigenous peoples which can be particularly affected by hydropower developments. Stakeholders should be informed early of proposed or possible policy options or plans, and they should be given opportunities to provide their perspectives and present their concerns as early as possible. This will enable key issues to be identified and verified at a basin level. It will also help build understanding and support for hydropower development and avoid future misunderstanding and possible conflicts. Such misunderstanding and conflicts are in many cases, and increasingly, the root causes for early project termination.

Section 5.1 discusses the benefits of SEA to the development and implementation of hydropower PPPs.

The stages and tasks in SEA are common to all SEAs, whatever they are focused on, and reflect internationally accepted standards of good practice. They are discussed in detail in Chapters 1 and 2 and are therefore not repeated in this chapter.

## 5.1 HOW SEA CAN BENEFIT THE HYDROPOWER SECTOR

Section 5.5 focuses on the environmental and socioeconomic issues and impacts associated with hydropower development, drawing mainly from global experience of implementing individual hydropower projects and comments on how such impacts can effectively be managed. In addition, recommendations are made regarding higher level planning mechanisms for sustainable hydropower development at a basin level. This Section summarizes how SEA can address the issues and benefit three different stages in the preparation and implementation of hydropower PPPs—planning, assessment, and management.

### 5.1.1 Planning

SEA can have the greatest benefit at the planning phase, when PPPs for renewable energy (or specifically for hydropower) are being prepared, updated, or revised, and prior to individual hydropower projects being proposed/developed. However, such synchronization is rare. Energy transition requires strategic planning, and SEA can assist to make well-informed decisions accepted by the public, decision-makers and hydropower developers. This will be particularly important where hydropower will either supplant or support baseload generation provided by fossil fuels.

If initiated sufficiently early in the hydropower PPP preparation process, SEA offers the following benefits:

- ***Considers alternatives*** within hydropower and “to” hydropower development—through broadscale and inclusive stakeholder consultations that allow the most desirable alternative basin/energy development pathways to be selected, Thus, SEA helps to identify alternative water-driven development pathways for socioeconomic development and supports energy demand planning at basin level.

- ***Identifies locations*** suitable and preferred for hydropower development (e.g., particular catchments/basins) as well ***areas to be avoided*** (“no go” zones) in terms of risks and potential impacts), aiding subsequent selection of sites for individual hydropower projects at a basin level.

- Identifies watershed catchment areas important for the ***sustainable functioning of existing or planned hydropower facilities***, along with legal and on-the-ground measures needed for the protection or improved management of these catchments.

- ***Supports basin/catchment planning and integrated water resource management*** (IWRM). In countries with hydropower potential, SEA can support river basin planning to identify the most suitable sites in terms of economic benefits and social and environmental acceptability. This is particularly important where multiple cascade hydropower developments are proposed within a single basin. This will allow for identification of key ecosystems (aquatic and terrestrial) within the river basin that need to be adequately conserved, and the range of natural or managed river flows that would sustain these ecosystems.

- ***Supports planning for energy integration*** whereby opportunities for hydropower and other forms of energy generation are identified and assessed (e.g., pump storage in combination with solar/wind).

- ***Supports cascade development planning*** for siting optimization.
- ***Improves hydropower and energy policies*** pertinent to hydropower development.
- ***Increases the efficiency*** of multi-level institutional review and coordination of sector development.
- Directs spatial planning for the ***optimal coordination of other land and water uses*** (including conservation areas).
- Identifies specific issues for ***stakeholder engagement*** planning and strategies for effective consultation and communication for the sub-sector.

### 5.1.2 Assessment

SEA can help inform PPP development and guide hydropower schemes/projects by assessing their environmental and social risks and impacts as follows:

- ***Optimizes strategic assessment of hydropower PPPs and hydroelectric development schemes*** (e.g., multiple hydropower projects in a particular catchment) to understand higher level environmental and social impacts and risks and their policy and planning consequences.
- ***Addresses cumulative effects*** of and impacts on other water users and uses (such as irrigation, water supply, riverine and coastal fisheries, navigation, biodiversity conservation, and recreation as well as other hydropower plants, including transboundary aspects). SEA ***defines and prioritizes water uses*** (including for the environment) during times of water shortages. It ***elaborates different water use scenarios*** to maximize water use outcomes that will assist decisions on specific investments.[1]
- ***Identifies key sensitive areas*** which could include protected areas, world heritage sites, key biodiversity areas, populated areas, and important cultural heritage sites.
- ***Integrates consideration of climate change*** to assess the suitability and future viability of the proposed hydropower developments.
- Addresses ***how to balance or achieve trade-offs*** between adverse impacts and identifies ***opportunities to enhance synergies*** (win-win outcomes) between environmental, social, economic, and other concerns.
- Provides direction and ***streamlining of project level ESIA*** and approvals in the sub-sector.

### 5.1.3 Management

The timely and early (*ex ante*) application of SEA can offer early solutions to the management of potential risks and impacts of hydropower PPPs (and subsequent projects/scheme):

- Contributes to ***basin wide strategic management plans***, identifying opportunities for ***cascade management*** and optimizing hydropower generation across multiple projects and reducing cumulative environmental and social impacts, and ***optimizing environmental flows*** and opportunities for ***coordinated flow management***.
- Identifies where ***institutional capacity*** needs to be developed for the effective implementation of SEA and Strategic Environmental and Social Management Plan (SESMP) recommendations.

[1] Slootweg (2023).

- Identifies ***opportunities for trade-offs*** (between environmental, social and economic considerations) for the hydropower sub-sector.
- Identifies where revised or new ***legislation, policies, and regulations*** for the hydropower sub-sector may be required.
- Promotes ***regional cooperation mechanisms*** to help enhance the modalities and benefits of SEA, particularly where transboundary and regional economic considerations need to be addressed.
- Improves ***data collection/sharing and monitoring*** requirements for the sub-sector.
- Helps identify ***efficiency measures/options for power generation*** in the sub-sector.
- Develops a specific ***environmental and social management plan*** (SESMP) for the sub-sector at a national, regional, or catchment level (addressing, e.g., sediment management, fisheries, navigation, biodiversity, relocation of people/communities, compensation, conflict management, etc.).
- ***Integrates climate change adaptation and resilience*** into hydropower planning and development.
- Coordinates the management of ***cumulative and transboundary impacts*** between multiple proponents, agencies, and interested parties.
- Enhances the ***credibility of hydropower development*** and review in the eyes of affected stakeholders, leading to smoother implementation and reduced conflict.
- Provides for ***easier access to funding*** from international development banks by examining higher level transactional and reputational risks.
- Improves ***private sector involvement*** in addressing environmental and socioeconomic concerns by providing a higher-level strategic approach to managing relevant environmental and social risks beyond the project level. This contributes to selecting the best alternatives in terms of type of renewable energy and helps to better justify selection of hydropower projects as the best option compared to other renewable sources.

## 5.2 EXISTING SEA GUIDANCE/GUIDELINES FOR THE HYDROPOWER SUB-SECTOR

An international survey of existing SEA guidelines conducted for the IAIA identified only one guideline specifically focused on the hydropower sub-sector,[2] while there are numerous guidelines for conducting environmental impact assessments (EIA) for hydropower projects.[3]

The report of the World Commission on Dams (2000)[4] set out comprehensive guidelines for dam building. It describes an innovative framework for planning water and energy projects that is intended to protect dam-affected people and the environment and to ensure that the benefits from hydropower are more equitably distributed.

Subsequently, a broad and extensive literature has become available on hydropower development. Some selected examples include general guidelines (but not concerned with SEA) covering issues

[2] Annandale, D. and Hagler Bailly Pakistan (Pvt) Ltd. (2014)
[3] e.g., REMA (2008), UKEA (2009), IHA (2021c)
[4] WCD (2000)

such as social impacts and risks,[5] environment and climate,[6] tools,[7] Indigenous people,[8] health and safety,[9] developers and investors,[10] affected peoples and livelihoods,[11] and infrastructure safety.[12] The International Hydropower Association (IHA) does not use or promote the use of SEA, but, in 2010, it published the Hydropower Sustainability Assessment Protocol (HSAP)[13] (updated 2020) which offers a way to assess the performance of a hydropower project across more than 20 sustainability topics. Subsequently the IHA launched its Hydropower Sustainability Standard which covers topics relevant to SEA in the hydropower sub-sector (Box 5.1).

**Box 5.1: IHA Hydropower Sustainability Standard**

The IHA Hydropower Sustainability Standard is a global certification scheme (the first of its kind for renewables), outlining sustainability expectations for hydropower projects around the world. It aims to help ensure that hydropower projects provide net benefits to the local communities and environments they interact with. The standard covers 12 environmental, social, and governance (ESG) topics, including biodiversity and invasive species, water quality, hydrological resource, cultural heritage, governance, labor and working conditions, climate change mitigation and resilience, and more.

In support of the Standard, IHA has published a suite of “how-to-guides” offering a deep dive into specific sustainability topics such as resettlement, labor and working conditions, biodiversity and benefit sharing. Embedded in the standard are four key project-based tools: guidelines of good industry practice, the hydropower sustainability assessment protocol (HSAP), the GRES (GHG Reservoir) tool, and the hydropower sustainability ESG gap analysis tool (HESG).

All documents are available at www.hydropower.org.

## 5.3 HYDROPOWER INSTALLED CAPACITY

Since 1995, the hydropower sub-sector has more than doubled in size from 625 GW to almost 14001,300 GW, with China having, by far, the greatest installed capacity (see Table 5.1 and Figure 5.1).

**Table 5.1: Hydropower installed capacity in 2022**
*Source: IHA (2023)*

| Country | Installed Capacity (GW) | Country | Installed Capacity (GW) |
|---|---|---|---|
| China | 415 | Spain | 20 |
| Brazil | 110 | Switzerland | 18 |
| USA | 102 | Vietnam | 17 |
| Canada | 83 | Venezuela | 17 |
| Russia | 56 | Sweden | 16 |
| India | 52 | Austria | 15 |
| Japan | 50 | Mexico | 13 |
| Norway | 34 | Iran | 13 |
| Turkey | 32 | Colombia | 13 |
| France | 26 | Rest of World | 275 |

[5] e.g., Cernea (2004), EIB (2019)
[6] EIB (2019)
[7] e.g., HSC (2020)
[8] e.g., IHA (2021c), IHA (2022), IHA (2022b)
[9] e.g., IFC (2018)
[10] e.g., IFC (2015b)
[11] e.g., IHA (2020)
[12] e.g., IHA (2021)
[13] For more information, see “Hydropower Sustainability Assessment Protocol” (https://www.hydropower.org/publications/hydropower-sustainability-assessment-protocol)

| | | | |
|---|---|---|---|
| Italy | 23 | | |
| | | | |
| ***Total*** | | | ***1397*** |

According to the International Hydropower Association,[14] hydropower generated around 4,400 terawatt hours (TWh) of clean electricity worldwide in 2022 (c.15% of the world's electricity), and Paraguay and Costa Rica achieved a 100% renewable electricity supply, with hydropower as the backbone. In some countries, almost all electricity generation comes from hydropower, e.g., Norway and Nepal. Global hydropower potential is shown in Figure 5.1.

**Figure 5.1: Global Hydropower Potential Capacity 2022**
*Source: IHA (2022)*

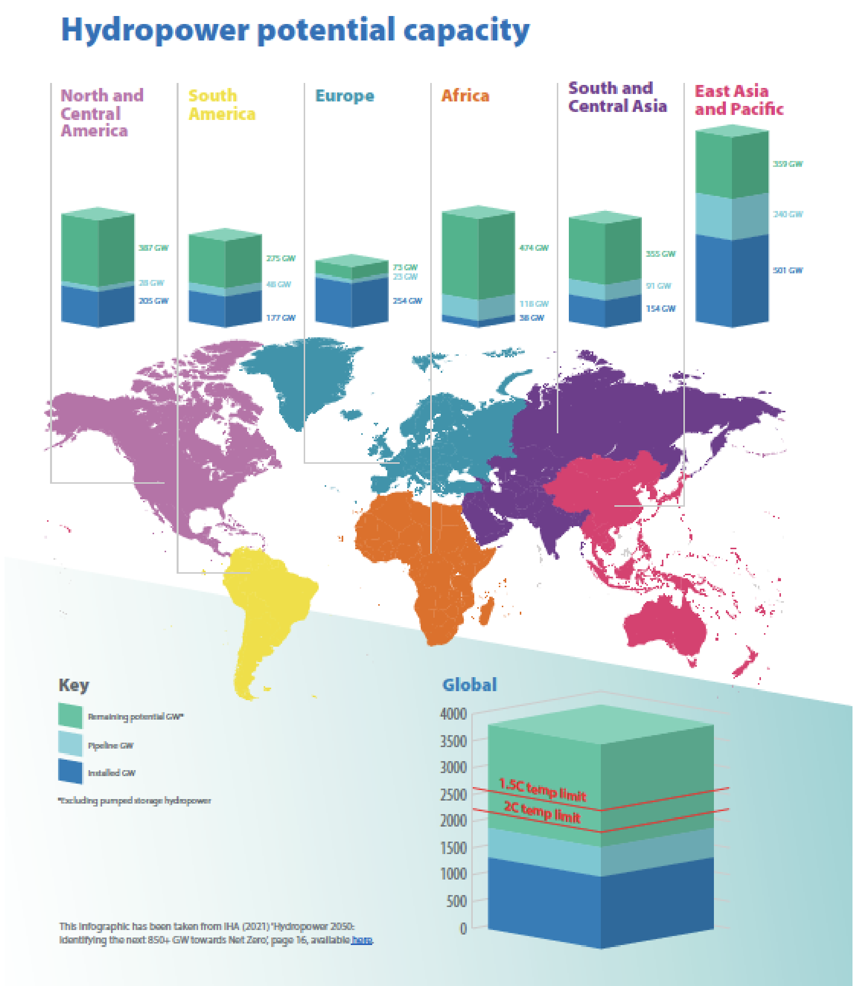


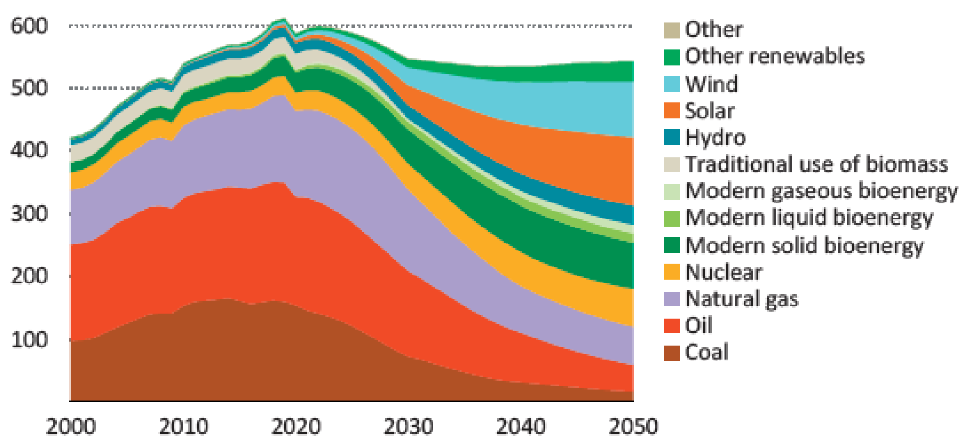

Figure 5.1 shows that the highest hydropower potential lies in Asia, South America, and Africa, and this is where SEA is much needed in future. According to the International Energy Agency and the International Renewable Energy Agency, at least 850 GW of new hydropower is needed to keep global warming below 2°C cost-effectively. However, to meet the more ambitious Net Zero target to

[14] IHA (2023)

limit temperature rise at below 1.5°C, hydropower development must double to at least 2,500 GW based on today's capacity.[15]

The importance of hydropower in the future global energy mix cannot be underestimated. Hydropower currently generates more electricity than all other renewable technologies combined and is expected to remain the world's largest source of renewable electricity generation into the 2030s. Thereafter, it will continue to play a critical role in decarbonizing the power system and improving system flexibility as other renewable sources are brought on-stream.[16] Figure 5.2 shows the importance of hydropower in the global energy mix to 2050.[17]

**Figure 5.2: Global Energy Mix to 2050**
*Source: IHA (Undated)*




### 5.3.1 Application of SEAs in the hydropower sub-sector

A recent international inventory identified 37 SEAs conducted for the hydropower sub-sector during the period 1995 – 2019[18] (Table 5.2). Sixteen (43%) of these were specifically focused on hydropower PPPs, while another sixteen (43%) addressed hydropower as part of broader PPPs for the overall energy sector. A few (5, 13%) dealt with hydropower as part of multiple PPPs covering multiple sectors.

[15] For more information, see "Hydropower 2050: Identifying the next 850+ GW towards Net Zero" (https://www.hydropower.org/publications/hydropower-2050-identifying-the-next-850-gw-towards-2050)
[16] International Energy Agency (Undated)
[17] For more information, see "Hydropower 2050: Identifying the next 850+ GW towards Net Zero" (https://www.hydropower.org/publications/hydropower-2050-identifying-the-next-850-gw-towards-2050)
[18] Kolhoff and Slootweg (2021)

**Table 5.2: SEAs for energy sector, multi-sector and hydropower sub-sector, for regions (columns) and type of PPPs (rows) for the period 1995-2019**
*Source: Kolhoff and Slootweg (2021)*

| Type of PPPs per sector* | Asia | Africa | Europe | Americas | Total |
|---|---|---|---|---|---|
| ***Energy sector, including hydropower*** | | | | | |
| International | 1 | 1 | | | 2 |
| National** | 5 | 4 | 4 | | 13 |
| State/provincial | | | | 1 | 1 |
| *Sub-total* | *6* | *5* | *4* | *1* | *16* |
| ***Hydropower sub-sector*** | | | | | |
| International river basin | 1 | | | | 1 |
| National** | 6 | | 1 | | 7 |
| State/provincial | 3 | | 1 | | 4 |
| River (sub-basin) | 3 | | 1 | | 4 |
| *Sub-total* | *13* | | *3* | | *16* |
| ***Multiple sectors, including hydropower*** | | | | | |
| International river basin | | 1 | | 1 | 2 |
| National river basins(s)** | 2 | 1 | | | 3 |
| *Sub-total* | *2* | *2* | | *1* | *5* |
| | | | | | |
| **Total** | **21** | **7** | **7** | **2** | **37** |

* Includes all SEAs applied for PPPs in the energy sector at international, national and state level have been included in the inventory. In two of these SEAs, hydropower is not included as an energy source. All SEAs applied for PPPs in multi-sectoral PPPs are included, in which hydropower is considered. All SEAs applied in the hydropower sector are included in the inventory.

** Selected cases: National energy plan Viet Nam, National hydropower plan Myanmar, State level hydropower plan India and Pakistan, Multi-sector River basin plan Rwanda.

## 5.4 BACKGROUND TO HYDROPOWER GENERATION

There are two types of renewable energy generation: ***dispatchable*** (sources of electricity that can be dispatched on demand at the request of power grid operators) and ***variable*** (intermittent renewable energy sources [IRES] that are not dispatchable due to their fluctuating nature, such as wind power and solar power).

Currently, hydroelectric power plants generate around 16% of the world's electricity.[19] "Storage" (both reservoir and pumped) hydropower plants (see below) generate dispatchable electricity[20] and can therefore be integrated with wind and solar projects which are characterized by variable (intermittent) generation.

In hydropower plants, electrical energy is produced by exploiting the potential energy of the water thanks to a difference in height ("head"). Water is taken at a certain height from a river or reservoir and conveyed through headrace works (e.g., canals, tunnels, penstocks), passed through hydraulic turbines connected to an electric generator, and finally discharged to the river (the same or another one) at a lower height.

### 5.4.1 Installation types

Hydropower projects come in many different sizes (e.g., high to medium head), designs, and configurations. The nature of their environmental and social impacts is determined by how they store and use water. Broadly there are four distinct types of hydropower schemes: run-of-river, reservoir, pumped storage, and offshore hydropower[21]:

[19] IHA (2022c)
[20] Dispatchable generation refers to sources of electricity that can be programmed on demand at the request of power grid operators, according to market needs.
[21] International Hydropower Association (2022)

- ***Run-of-river hydropower plant***: a hydropower plant with no (or very small) storage capacity that uses flowing water from a river to spin a turbine. It provides a non-dispatchable supply of electricity (base load) that fluctuates depending on the natural flow in the river.

- ***Storage hydropower plant***: a system that stores water in a reservoir. Storage hydropower plants typically provide peak loads, concentrating the production according to the demands of the system, thanks to the possibility to operate independently of the hydrological inflow for many weeks or even months.

- ***Pumped storage hydropower plant***: can store water both in an upper and a lower reservoir. Depending on the relation between the reservoir capacity and the natural water inflow to it, different "pumping" modes are possible:

  (a) When the natural flow in the river is zero or negligible, the plant operates in "pure pumping" mode and the cycle of the water is closed. When water is released from the upper reservoir to the lower one, the turbines provide energy to the generators.
  (b) Hydraulic pumps can lift water from the lower to the upper reservoir, using electric energy from the grid, when convenient or necessary for its stability.

  The pump storage hydropower plant acts as either a "generator" or as an "engine" in the two different operational modes. Some "reversible" hydraulic turbines can also carry out the pumping function; otherwise, two different, specific hydraulic systems need to be connected to the electrical turbines. As with storage hydropower plants, pumped plants also provide peak loads. Furthermore, they can absorb excess energy in the grid, acting as a "battery."

- ***Offshore hydropower***: a less-established but growing group of technologies that use tidal currents or the power of waves to generate electricity from seawater (usually referred to as tidal power (discussed in Chapter 10).

Facilities can be also classified as (a) single-purpose—which are used only for hydroelectricity generation, or (b) multipurpose—which are designed and used for other purposes such as water supply, irrigation, aquaculture, or flood control. Hydropower power plants can also be classified on the basis of installed capacity as follows[22]:

- Very Large: Exceeding 5,000 MW, feeding into a large grid
- Large: exceeding 100MW, and usually feeding into a large grid
- Medium: 15 – 100MW, usually feeding into a grid
- Small: 1 – 15 MW, usually feeding into a grid
- Mini: 100 kW – 1 MW, either isolated or feeding into a grid
- Micro: 5 kW – 100 kW, usually provides power for a small community or rural industry in remote areas away from the grid
- Pico: from a few hundred Watts up to 5 kW

However, classifications vary from country to country as there is currently no common consensus among countries and hydropower associations regarding the upper limit of small-scale hydropower plant capacity. For instance, some European Union countries like Portugal, Spain, Ireland, Greece, and Belgium accept 10 MW as the upper limit for small-scale hydropower installed capacity, while others place the maximum capacity from 3 to 1.5 MW. Outside the EU, this limit can be much higher, as in the USA (30 MW) and India (25 MW).[22]

### 5.4.2 Hydropower installation components

The typical components of a hydropower plant are reservoir (if present) with its dam and outlet works, intake works, head race, surge shaft or head pond, penstocks, power station and tail-race. In addition,

[22] See Classification of Hydroelectric Power plants (https://www.engineeringenotes.com/power-plants-2/hydroelectric-power-plant/classification-of-hydroelectric-power-plants/29422)

there will be associated infrastructure, including transmission lines and access roads (see Chapter 13).

***Reservoir***

The configuration of a reservoir is dependent upon the topography where the dam is situated and can vary from large and shallow impoundments covering thousands of square kilometers (e.g., Three Gorges, China, and Itaipu, Brazil) to narrow and deep reservoirs that can be up to several hundreds of meters in depth (e.g., Lianghekou hydropower station, China). A reservoir can mitigate floods in some circumstances, as the reservoir can store peak flows and control the release of water to the downstream river course, lowering the peak value and shifting it ahead in time.

In addition, due to its ability to concentrate water storage, a reservoir plant can produce hydropeaking (the discontinuous release of turbined water due to peaks of energy demand) causing artificial flow fluctuations in the river downstream. This can result in a series of environmental and social impacts due to flow modifications.[23]

***Dams***

Dams are the most recognizable features of hydropower facilities. They are constructed to create a reservoir (in storage plants) or to provide a fixed water level for the diversion of water (in run-of-river plants). They are structures designed to resist the "push pressure'' of contained water. Depending on the constituent materials and the static principles exploited, the main types of dams are:

- Gravity (concrete or masonry, resisting with its weight).
- Arch (concrete, resisting with arch effect, leading pushes to the sides of the valley).
- Embankment (earth fill or rockfill, with various schemes for water tightness).
- Buttress and multiple arches.
- Barrage (where the most part of the height is closed by mobile gates).

Often, more than one type is present in the same dam (composite dam).

The choice of the type depends on a range of factors including:

- The head—height difference between the upstream water level and downstream turbines.
- Shape and size of the valley.
- Geology and geotechnical characteristics of the valley.
- Availability, quality, and cost of construction materials.
- Availability and cost of labor and machinery.

***Outlet works***

Outlet works are necessary both for controlling floods and for emptying a reservoir. The first function is normally carried out by spillways; the second one by bottom outlets.

Dams must be designed to cope with floods. Spillways are built to provide a path for water to flow over or around the dam. On concrete dams, spillways are usually constructed to allow water to flow downstream in a safe way and respecting the maximum design levels in the reservoir. They can be an integral part of a dam or stand as autonomous works located at a different site on the reservoir. A spillway can either be equipped with gates (controlled spillway) or consist of a fixed, specially shaped edge (uncontrolled spillway).

***Waterways***

Water is conveyed to power stations through intakes and various hydraulic works (constituting the "head race") such as tunnels (pressurized or free surface), open channels, surge shafts (in pressure plants) or head ponds (in free surface plants), and/or penstocks, depending on the plant scheme. A

[23] Greimel *et al*. (2018)

typical intake is fitted with control gates and a steel mesh trash rack that prevents rubbish such as logs or floating trash being carried down into the turbines.

Surge towers (or surge shafts) are built between the headrace tunnel and the penstocks in a hydropower pressurized water scheme to prevent the rise back of pressure peaks into the tunnel (water hammer) after rapid flow variations.[24]

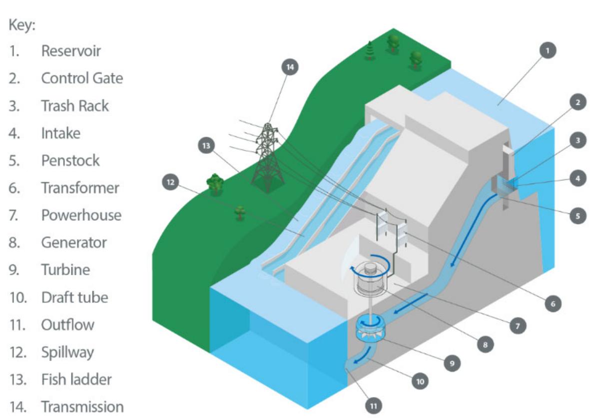
As well as in the “head race” works, tunnels and channels can also be present as “tail race” works, for conveying water from the powerhouse back to the river. The exit point location affects the length of river section “dried” because of the diversion. This can be counterbalanced by releasing an “ecological” flow just downstream of the dam.

***Power stations***

Power stations (or power houses) (see Figures 5.2 and 5.3) contain the turbines (and the pumps in case of a pumped plant), electric generators, transformers, all the mechanical and electrical auxiliary systems, and the automation and control devices. They may be located near the water storage or up to several kilometres away. Similarly, the point where the water is returned to the river can be close to or far from the power station. Their location, including even underground, is determined by the topography, the design targets, and many technical factors such as available room, geology, environmental issues, etc. The choice of turbine type will depend on the flow and head. Connected to the turbines are the electric generators.

**Figure 5.2: Inside a hydro power house**
*Source: Wikimedia Commons*

**Figure 5.3: Major components in a hydroelectric plant**
*Source: The International Hydropower Association Types of Hydropower*




24 The Constructor (2020)

## 5.5 ENVIRONMENTAL AND SOCIOECONOMIC ISSUES ASSOCIATED WITH HYDROPOWER DEVELOPMENT

During scoping for an SEA, key environmental and social issues should be identified together with stakeholders. They will be used to focus the SEA on the most important issues and to help develop environmental and social quality objectives (ESQOs) to be used in an “objectives-led approach” to SEA (see Chapter 2, Section 2.5.1). The subsequent assessment phase predicts how achieving the ESQOs will either be impeded or enhanced because of hydropower activities.

The key issues will be identified by reviewing relevant documents (e.g., EIAs of hydropower projects and special subject reports, environmental/social profiles, sector and inter-sector strategies, donor documents, academic papers, etc.), online databases such as IBAT (Integrated Biodiversity Assessment Tool),[25] interviews with key informants, and through multiple stakeholder consultations at national to local levels. Many of the issues will be well known because of knowledge gained from implementing a large number of hydropower development projects over the past 25-30 years.[26]

At the individual project level, these issues will be the primary focus of an EIA which should recommend how to manage or mitigate impacts of hydropower project activities (including constructing a transmission line and access road) that might be likely to arise.

Implementing a PPP for the hydropower sub-sector will involve multiple projects, schemes, and activities, some directly concerned with the construction and operation of sites and facilities; others linked to associated infrastructure (e.g., transmission lines, access roads, borrow pits/quarries, etc.). Thus, there is a risk that the combined impacts of individual developments/projects in a cascade development scheme may become highly significant as they become cumulative. An SEA should focus on the potential for such cumulative impacts to occur and make recommendations for addressing them. This may include recommending thresholds for particular factors that should not be breached by an individual project in combination with other projects (and which should be addressed firstly by a project-level EIA). Where the risks of cumulative impacts are extremely high, this might provide the basis for the SEA report to recommend an alternative to the PPP or components of it and the need for implementation of comprehensive management measures among multiple interests to mitigate cumulative impacts. Such measures could include designating selected river segments for permanent protection from dams or similar infrastructure.

Table 5.3 summarizes the range of environmental and socioeconomic issues associated with hydropower development. During scoping, a key task is to determine which issues the SEA should focus on.

[25] See Integrated Biodiversity Assessment Tool (IBAT) (https://www.ibat-alliance.org/)
[26] See International Commission on Large Dams (ICOLD) (https://www.icold-cigb.org/) and International Hydropower Association (https://www.hydropower.org/).

**Table 5.3: Environmental and socioeconomic issues associated with hydropower development**

| ISSUE | COMMENT |
| --- | --- |
| **Environmental** | |
| Loss of habitats and biodiversity (terrestrial) | • Inundation by dams and reservoirs and loss of important terrestrial habitats.<br>• Deforestation (for hydropower sites, dams, roads, and transmission lines, and release of stored carbon.<br>• Fragmentation of habitats and creation of barriers to wildlife movements.<br>• Clearing for access roads and transmission lines and consequent disturbance to migration and increased road kills.<br>• Increased poaching and hunting due to increased access to areas.<br>• Disturbance to fauna from noise, vibration, and dust from blasting and other construction.<br>• Drowning of species during reservoir impoundment.<br>• Introduction of invasive species.<br>• Changes in diversity or makeup of the plant and animal communities due to changes in ecosystems.<br>• Impacts on ecosystem services, such as trees used for fuel.<br>• Submersion of caves used by bats.<br>• Impacts on terrestrial fauna from changes to aquatic ecosystem (e.g., loss or reduction of food sources).<br>• Loss of riparian habitat due to inundation and erosion.<br>• Collision of flying birds and bats with overhead power lines leading to electrocution.<br>• Electrocution of birds and certain mammals that perch on power pole structures and touch electrified wires. |
| Loss of habitats and biodiversity (aquatic) | • Loss of riparian habitats (floodplain forests, seasonal wetlands, river islands, sandbars, rocky outcroppings, etc.) through permanent inundation or seasonal changes to river flow regime.<br>• Change from lotic (moving water) to lentic (relatively still water) habitat in new reservoir.<br>• Dam walls prevent migration of fish to vital breeding or feeding areas, upstream or downstream of the dam.<br>• Organic matter decomposition in the base of the dams over time can deplete water oxygen and kill fish and aquatic organisms.<br>• Fish killed or injured by powerhouse turbines and/or by tail races/spillways.<br>• Increased fishing (overexploitation) due to (a) increased access (e.g., to previously inaccessible areas) via access roads and transmission lines, or as result of workforce in the area; and (b) creation of popular fishing areas where fish concentrate.<br>• Blockage of fish movements.<br>• Fragmentation of aquatic systems, including populations of fish and other aquatic life.<br>• Change in sediment and nutrient flows due to river flow changes can affect biodiversity, and can decrease sediment loads downstream.<br>• Change in riparian habitats due to hydropeaking[27] and aggressive river effects in the event of releases: loss of interface between land and the river due to riverbank erosion.<br>• Fragmentation and loss of or changes to aquatic ecosystems and connectivity in river system: animal migration, fish movements, and plankton drift can be blocked both up and downstream by a dam.<br>• Loss of downstream floodplain habitat: regulation of a river by a dam and reservoir reduces the magnitude and duration of flood flows, which reduces downstream flooding and sediment transport. |

[27] Hydropeaking refers to frequent, rapid, and short-term fluctuations in water flow and water levels downstream and upstream of hydropower stations. Such fluctuations have far-reaching effects on riverine vegetation.

| ISSUE | COMMENT |
| --- | --- |
| | • Introduction of invasive alien plant and animal species leading to changes in ecosystem structure and composition. |
| Land-use changes | • Inundation of land (for reservoirs) leading to direct loss of productive land or loss of habitat.<br>• Reservoirs may also be used for irrigation, fishing, supply of water, and for recreational purposes.<br>• Changes in river flow regime, nutrient flows and sediment transport leading to indirect loss of agricultural land and less productive agricultural land downstream (e.g., river no longer flooding crops when required).<br>• A dam or hydropower infrastructure may alter access to an area, leading to indirect changes in land use such as loss of productive land. |
| Erosion and sedimentation | • Clearance and disturbance to vegetation and soil in areas surrounding dams and rivers, resulting in erosion (gullying and sheet erosion) and sediment runoff into the river, especially during intense rainfall (during construction and in a reservoir catchment).<br>• Landslides: ground movements such as mudflows and debris flows that occur due to project construction.<br>• Erosion and instability of riverbank or bed (and adjacent areas, e.g., following changes in river flow and geomorphology).<br>• Erosion of rim or boundary of reservoir and increased sedimentation in reservoir.<br>• Changes in the geomorphology of river channels and increased erosional forces downstream due to sediment retention.<br>• Increased sediment runoff into rivers or streams at vehicle crossing points during construction.<br>• Sediment retention and accumulation over time (e.g., in dam bottom—reducing dam capacity, or locally in riverbeds).<br>• Issues downstream due to release of sediment-laden water. |
| Land and ecosystem restoration | • Hydropower developers can maximize the adaptive benefits (regarding climate change) of watershed restoration by avoiding areas where the risks of destroying important wetlands are high, or avoiding forest clearing (e.g., around reservoirs for access roads and transmission lines) where the risks of soil erosion are highest, reducing unnecessary sediment flows and slowing runoff in order to protect and optimize reservoir storage. |
| Air quality | • Air pollution from machinery and vehicles (construction equipment, lorries, workers' buses, etc.).<br>• Dust from land clearing and construction, vehicles on dirt roads.<br>• Dust from exposed areas of dam margin following drawdown operations.<br>• Decreased air quality during drawdown operations and exposure of reservoir areas.<br>• Smoke from any burning of vegetation cleared for a hydropower project. |
| Water quality | • Sewage, solid waste, and polluted runoff into dams and rivers during construction (runoff from dumping of excavated materials) can contaminate surface and groundwater.<br>• Oil or chemical spills during construction or operation.<br>• Pollution from the catchment can collect in reservoirs.<br>• Pollution from any waste dumps submerged by the reservoir.<br>• Release of heavy metals from sediments.<br>• Organic decomposition: decomposing of organic material during the early years of operation leading to the consumption of oxygen.<br>• Reservoir stratification: separation of reservoir water into oxygenated and deoxygenated zones (due to organic decomposition) and unseasonal temperature water released to downstream.<br>• Change in water quality due to sedimentation during construction, and altered flows during operation with increased turbidity: increase in the cloudiness or haziness of water caused by individual particles.<br>• Changes in flow regime may increase the concentration of pollutants and result in the release of nutrient-laden water. There may also be inflows of sediment, and pollution or hazardous substances from construction and from the wider catchment, and dumping of excavated materials. |

| ISSUE | COMMENT |
|---|---|
| | • Contamination of surface and groundwater—particularly during construction.<br>• Impacts of degraded water quality downstream.<br>• Eutrophication due to fertilizer runoff in the catchment (nitrogen, phosphorus, and other nutrients) and enrichment in dams. |
| Hydrology | • Flow of rivers can be changed significantly due to presence of a dam or weir.<br>• Reduced water for downstream use (e.g., irrigation, consumption). But sometim.es dams/reservoirs are used to supply irrigation water.<br>• Changes downstream: significantly reduce or alter patterns of flow between the intake and the powerhouse.<br>• Altered flow regime and sediment flows downstream of the powerhouse.<br>• Reservoirs offer opportunity to control floods and manage drought (climate adaptation and disaster-risk reduction). |
| Greenhouse gases | • Hydropower can reduce GHG emissions where it replaces coal as a fuel source.<br>• GHG emissions (carbon dioxide, methane, nitrous oxide) from reservoirs (particularly from the burning of cleared vegetation before filling, or the decomposition of submerged vegetation after filling) and from vehicles and fuels used in machinery and camps during construction. |
| Noise and vibration | • Noise and vibration impacts during construction (from machinery, vehicles, blasting, drilling, machinery). |
| Spoil | • Significant amounts of spoil material may require disposal (where reuse is not an option) due to tunnelling and excavation activities. |
| Flooding | • Inundation of new areas to create impounded reservoir.<br>• Flash floods downstream (due to breaches, overtopping, emergency releases, or severe hydropeaking).<br>• Dam break resulting in loss of life (human and wildlife), danger to communities, damage to infrastructure, erosion.<br>• Reservoirs can be used to regulate water flow and control flooding. |
| **Socioeconomic** | |
| Physical and economic displacement | • Physical displacement and relocation of people and their structures due to reservoir impoundment and associated project facilities<br>• Loss of economic and livelihood activities, such as agriculture, animal grazing, fishing.<br>• Loss of income from small business and enterprise activities. |
| Benefits of reservoirs | • Storage of water for use in irrigation, both large- and small-scale (increasing yields, opportunities to grow range of crops), contributing to economic growth and livelihood opportunities.<br>• Opportunities for fishing.<br>• Recreational opportunities.<br>• Flood and drought management. |
| Cultural heritage | • Loss of (and loss of access to) religious, cultural, historical and archaeological sites, and properties submerged by dam and in downstream locations or destroyed or damaged due to transmission lines, access roads, or other associated project facilities (quarries, construction camps, equipment staging areas, disposal sites, etc.). |
| Employment and labor conditions | • Job opportunities with hydropower companies and their contractors.<br>• Loss of jobs with existing enterprises and public administration when people are displaced/resettled.<br>• Forced labor and child labor on hydropower projects. |
| Health and safety | • Pollution of downstream and upstream areas.<br>• Insufficient and poor water quality for worker camps due to the water source being affected.<br>• Influx of migrant workers may lead to an increase in communicable diseases (infectious diseases such as influenza, sexually transmitted infections (STIs), and HIV/AIDS), drug and alcohol use, gender-based violence, and conflict. |

| ISSUE | COMMENT |
| --- | --- |
| | • Impacts on fish and human health from methyl mercury releases from sediment into the water column and food chain.<br>• Increased road traffic accident and fatalities, particularly during construction.<br>• Accidental drowning in reservoirs.<br>• Risks of dam failure and natural disasters, landslides.<br>• Impacts on communities due to rock blasting.<br>• Electrical safety incidents.<br>• Fatalities at the construction site and substandard accommodation of workers.<br>• Pressure on health services (e.g., high demand on essential drugs) during construction.<br>• Potential for increase in vectors for human transmissible disease, e.g., malaria and schistosomiasis (particularly due to dams) in areas where these diseases are endemic. |
| Migration | • Influx of people looking for work during construction.<br>• Tension between immigrants and workers.<br>• Retrenchment of construction work forces. |
| Gender and vulnerability | • Vulnerable groups (e.g., the poor, women, persons with disabilities, children, the elderly, and Indigenous communities) may be disadvantaged and at particular risk.<br>• Increased domestic and gender-based violence due to relocation and in-migration of workers to remote areas.<br>• Gender equity and employment opportunities on new projects.<br>• Opportunities for vulnerable groups to acquire new skills and learn new technologies.<br>• Opportunities for vulnerable groups to engage in the decision-making processes and in inclusive dialogue about hydropower development. |
| Public services and infrastructure | • Loss and relocation of public services and infrastructure due to inundation by dams.<br>• Pressure on local pre-existing health services and infrastructure, equipment, human resources due to projects, immigration, accidents during construction, etc.<br>• Increased pressure on the host communities' public services when displaced people relocate.<br>• Improvement (investment) to infrastructure (e.g., roads and bridges, schools, health centers, and administrative buildings).<br>• Heavy vehicles and transportation damage existing roads and bridges. |
| Community cohesion and engagement | • Weakened community cohesion resulting from self-relocation and community relocation.<br>• Risk of internal conflict due to increased stress as result of lost income.<br>• Opportunities for communities to engage in the decision-making processes about hydropower development.<br>• Increased tension between the communities, NGOs, activists, and hydropower companies. |
| Conflicts | • Conflicts over:<br>o Lack of perceived project benefits accruing to local communities (e.g., access to power and water services).<br>o Environmental degradation (e.g., from the reduced water quality).<br>o Loss of land or access to resources/areas used for livelihoods or cultural activities.<br>o Working conditions among those employed in construction or operation.<br>o Tensions between immigrants and local workers/communities.<br>o Transboundary conflict between states (e.g., over dams restricting water flow). |

### 5.5.1 Environmental Issues

***Hydrology***

A hydropower project will normally change the hydrological flow regime of a river. Depending on design choices, this may be a significantly reduced or altered pattern of flow between the intake and the point where water is returned to the river. It may also mean an altered flow regime downstream of where water is returned to the river. Rivers that are already regulated by either hydropower or irrigation projects can be less sensitive to new hydrological impacts, so it may be environmentally preferable to develop projects on rivers or tributaries that are already impacted by flow regulation.[28] An SEA can identify where it is better to concentrate hydropower development along selected rivers (rather than on all rivers with hydropower potential) in order to reduce impacts at a larger spatial scale. However, multiple schemes on a river can also result in significant cumulative environmental and social impacts on habitats and species and downstream users.

Changes to a river's hydrological regime can negatively impact its aquatic ecosystem and can disrupt important environmental flows (E-flows) and associated ecological processes. The health and integrity of a river system will usually depend on a range of high, medium, and low flows. Most rivers experience natural annual low flows which reduce connectivity and limit species migration. This may be positive for native species which can often out-compete invasive species that have not adapted to low flows. Natural low flows also create seasonal habitats such as sandbars, rocky outcrops and temporary pools that are important to the breeding and survival of many species. So, maintaining low flows at their natural timing and level can maintain the abundance and survival rate of native species. For example, the Nam Theun 2 Dam in the Lao People's Democratic Republic provides for such downstream flow (Figure 5.4). Medium or base level flows will usually occur during most of the year. These flows maintain the hydro-geomorphology of a river which, in turn, maintains habitat, temperature, and dissolved oxygen levels to support aquatic species. Short high flow events are also important to prevent vegetation from encroaching on river channels and to move sediment and organic matter downstream. High flows can also reduce water temperature and increase dissolved oxygen, which can trigger ecological processes such as spawning and migration. Consequently, river flows altered by a hydropower project can lead to a reduction in health and integrity of the river system.[29]

**Figure 5.4: Dam at Nam Theun 2, Lao People's Democratic Republic, with downstream flow provision**

*Photo credit: A. Javellana/ADB*

[28] Opperman *et al*. (2015)
[29] World Bank (2018).

In some very large storage reservoirs, the filling of the reservoir may take more than one year, with a risk that downstream flows will not be adequately maintained, and this can lead to the degradation of downstream ecosystems and potential loss of habitats and biodiversity.

Dams can both contribute to and alleviate flooding and can reduce disaster risk. Large reservoirs can provide storage capacity to attenuate water flow during high rainfall events, reducing downstream floods. However, in the event of an inappropriate timing of a large release of water (or accidental release) or in the unlikely event of a dam break, this can cause downstream flooding, loss of human life and biodiversity, and damage to communities and infrastructure.

Reservoirs also provide opportunities to release water to downstream areas in the event of drought as a climate adaptation response.[30] However, this requires planning, depending upon the inflows of the previous season, the reservoir capacity, the seasonal energy production plan, the reservoir operational rules included in the concession/permission acts and/or possibly superimposed by the authorities for drought emergency purposes, the other co-present needs (e.g., electric system), etc.

***Water quality***

There can be a range of negative impacts on water quality throughout the construction and operation phases of a hydropower project.

During construction, the main impact on surface water quality is an increase in sediment load from construction site erosion/sedimentation or from spoil heaps. This erosion increases suspended solids and turbidity of river water, which may affect aquatic biodiversity and downstream water users. Poorly managed sewage and solid waste from the construction camp can pose a risk to drinking water. Accidental spills of oils and chemicals used during construction will contaminate soil and can also enter water courses. The spillage of wet concrete into a river can cause serious depletion of dissolved oxygen and negatively impact on aquatic species (even resulting in deaths).

Run-of-river projects tend to have minimal impact on water quality during the operational phase, although they may change the erosion and sediment dynamic of the river (see next sub-section).

Reservoir projects can have a significant impact on water quality in the operational phase. At the end of the construction phase, the reservoir area is often cleared of vegetation, although this specific measure is not always needed (see below). This can result in soil erosion and sedimentation of the river, reducing water quality. As a reservoir fills, pollutants in the submerged and surrounding soil (e.g., fuels, chemicals, and other substances from previous human activities in the area), can enter the reservoir and then the river system. Water quality in the reservoir can be further compromised from upstream contamination resulting from industrial and human activity.

When the reservoir is full, the decomposition of organic matter in submerged soil and of dead vegetation is likely to cause an increase in biological and chemical oxygen demand and—depending on water residence time—may deplete dissolved oxygen in the water. This sometimes results in anaerobic conditions which will reduce water quality, both in the reservoir and in the downstream river. It can also result in releases of methane (a greenhouse gas) into the atmosphere. The water in the reservoir is likely to be deeper and retained for a longer period than in the river, and this will cause changes in temperature at different depths, with potential for thermal stratification. The latter can also lead to deoxygenated water accumulating at the bottom of reservoir. If this is released to the downstream river via a low-level outlet, it will kill fish in that reach. In the reservoir, anaerobic conditions can liberate contaminants such as sulphides, selenium, ferrous and manganese ions, and organic mercury from the sediments. These can be directly toxic to fish and can bioaccumulate and subsequently be toxic to wildlife and to humans who consume such fish.

In some circumstances, during the first few years of operation after inundation, anaerobic conditions at lower levels (due to the breakdown of vegetation in the reservoir) can lead to the release of odorous hydrogen sulphide, thereby potentially generating grievances in the local community. Large amounts of hydrogen sulphide can be released if water is drawn from the lower levels in the reservoir and passed through the turbines. Water quality issues in reservoirs tend to be most problematic over

[30] Pannier (2021)

the first 5–10 years of operation—when most organic decomposition occurs—and a new equilibrium is reached.

In some situations, water quality can be maintained in the reservoir and downstream (both short- and long-term) by removing biomass from the reservoir area before it is flooded. This can improve water quality within reservoirs that have a relatively long water retention time, as well as downstream. Removing large trees can facilitate boat navigation and fishing with nets. However, pre-impoundment clearing of biomass in the reservoir inundation zone is not always necessary, nor even desirable. In reservoirs with a short water residence time (e.g., a week or less), decaying vegetation will not harm water quality due to the rapid flushing. Moreover, deforestation of slopes within and around the impoundment area will increase soil erosion and downstream sedimentation, particularly (i) during the inevitable time interval between forest clearing and reservoir filling, and (ii) in any areas that are deforested above the usual reservoir shoreline. Submerged trees create a useful habitat for many fish and other aquatic life below the water line, as well as for birds and other wildlife above the water line. In some areas, reservoir-area forest clearing may facilitate illegal logging elsewhere since it can be difficult to verify where the logs are coming from. Finally, pre-impoundment deforestation can be very expensive, since the felled trees often lack sufficient market value to cover the costs of their removal.

Accordingly, deciding how much (if any) vegetation to clear should be assessed on a case-by-case basis, considering factors such as water residence time, the volumes of biomass present (see Figure 5.5) , the need for boat navigation or other special use corridors, wood marketability and economic costs, and the fish and wildlife habitat that the submerged trees would create (Box 5.3).[31]

**Figure 5.5: Reservoir at Nam Theun 2, Lao PDR, showing trees remaining after filling**

*Photo credit: Peter-John Meynell*

[31] HSC (2020)

**Box 5.3: Cost–benefits of removing vegetation from Nam Theun 2 Hydropower**

A detailed study for the Nam Theun 2 project in the Lao People's Democratic Republic found that the cost–benefit balance of systematic vegetation clearance was an unfavorable option. The study identified several difficulties concerning the removal of vegetation:

- Only a small fraction of the rapidly degradable biomass is located in trees or bushes.
- Cutting the vegetation alone does not address the question of disposal of this biomass. Burning is the option most often considered, but it has significant impacts on air quality.
- Exportation of the biomass is not practically feasible.
- Clearance of large areas is technically challenging, particularly in steep terrain which is common for a hydropower project.
- The clearing operation itself has significant environmental and social impacts and poses a risk to worker safety.
- Residues from logging activity can impact operation of the powerhouse.

As such, in some situations, removal of trees over a certain size may be appropriate, especially if the large trees are commercially marketable.

*Source: Salignat (2011)*

Pollution from human activity in the catchment can accumulate in reservoirs. This can lead to eutrophication due to excess nutrients (especially nitrates) from fertilizer runoff or sewage, untreated industrial waste discharges, or the accumulation of solid waste from rubbish disposal on the inundated lands or upstream.

When water is released from a reservoir, the river downstream will be susceptible to any reduction in water quality generated in the reservoir. Variation in temperature and oxygen levels can negatively impact aquatic species, as can the flushing of sediment (see next sub-section).

Impacts on groundwater tend to be of a more minor nature than those affecting surface water. Groundwater may be affected by accidental spillages of construction materials and oils, or because of poorly designed solid waste disposal facilities. A reduction in groundwater quality can adversely affect communities that rely on groundwater for drinking or irrigation.

***Erosion and sedimentation***

The clearing of and disturbance to vegetation and soil in areas surrounding dams and rivers during the development of a hydropower project usually leads to an increase in soil erosion and sedimentation of the river, mainly through the construction phase. If the local geology is unstable, landslips, mudflows, and debris flows can all contribute to additional sedimentation loads of a river. During construction, earthmoving activities and road construction can increase erosion, particularly if there is inadequate attention to design and drainage. This often happens when temporary, lower cost, and lower quality access roads are built.

In the operational phase, there is less site erosion as vegetation cover becomes established. An operational reservoir project can significantly change the sediment dynamic of a river. Dams can trap sediment, reducing sediment in the downstream reach. However, large volumes of sediment can be released to a river over a short duration, for example, if the operator needs to remove the sediment from the reservoir (e.g., to maintain storage capacity). Erosion of a reservoir rim can also occur as the water level rises and falls due to peaking operations.

Changes to the erosion and sedimentation dynamic of a river are common issues for all hydropower projects. They affect water quality and can modify the riverbed composition and geomorphology and cause the degradation or loss of habitat for fish and other aquatic organisms.

If a dam captures sediment, the sediment load in the river downstream of the reservoir will be lower than it was before the dam was constructed. This means that, for an equal volume and turbulence of water, the downstream river will have greater capacity to move bed load and to pick up sediment as suspended load. In so doing, the river will erode the riverbed or banks. The water of the river may be referred to as sediment-hungry or aggressive, or the river may be said to have ***hungry-river syndrome***. The flow may erode the riverbed and banks, producing channel incision (downcutting), coarsen bed material (armoring), and remove spawning gravels used by fish. The mix of riverbed material will affect the pattern of downstream erosion: in sand-gravel mixtures (gravel bed rivers) downstream erosion will be controlled by the coarse surface armor layer, whereas in sand bed rivers the erosion will be more dynamic (IHA 2019).

Increased sediment load in the river (due to erosion or sediment flushing from a reservoir) can extend a long way downstream and can smother aquatic vegetation and habitats. This can be particularly problematic where gravel beds provide important habitat for downstream fisheries. More turbid water can also encourage fish to move to cleaner parts of the river. If sediment levels are very high, this can result in the smothering of aquatic invertebrates and can coat the gills of the fish causing death. Where significant erosion risks are likely, protection measures will be required (Figure 5.6).

**Figure 5.6: Erosion protection at Nam Theun 2, Lao People's Democratic Republic**

*Photo credit: G. Joren/ADB*

***Loss of habitats and biodiversity (terrestrial)***

Hydropower projects can have significant negative impacts on terrestrial ecosystems and their associated flora and fauna. The impacts are greater for reservoir projects due to the loss of inundated land. During the construction phase, vegetation must be cleared for dam sites, access roads, and transmission lines, which leads to the destruction or alteration of terrestrial habitats. Such clearance can fragment habitats by restricting the movement of fauna and potentially their access to important feeding and breeding grounds. In turn, the changes to ecosystems can lead to changes in the diversity or composition of plant and animal communities.

During construction, particularly through the displacement of soil, conditions are often created for the spread of alien species (some of which may be invasive), which can be brought in with construction equipment. Introduced invasive alien species are often able to colonize modified habitats and can out-compete and displace native species. Aquatic invasive species can also proliferate in the reservoir from upstream sources (e.g., water hyacinth).

Construction activities can cause disturbance to fauna from vibration, dust, light, and noise from blasting—particularly from quarrying activities. As access roads are developed in an area, there can be an increase in the number of animals killed by vehicles. Improved access can also facilitate increased poaching and hunting and overextraction of resources such as trees used for wood or fuel.

Inundation by a reservoir permanently changes the habitat. If biomass clearance is required, then trees and other vegetation will be cut down, and removed, if valuable. During impoundment, the rising water will slowly disperse fauna, but rescue may be required if animals become trapped and there is a risk that some animals will drown. Caves which provide habitat for bats can also be submerged with the habitat being permanently lost.

When a hydropower project is operational, the impacts on terrestrial fauna are much more limited. However, changes to the aquatic ecosystem may have a negative impact on terrestrial fauna when previous river food sources are lost. Similarly, riparian habitat can be lost or degraded by riverbank erosion upstream and downstream of a hydropower project. Downstream of a dam, changes to the flow regime can lead to the loss or change of floodplain habitat. Regulation of the river by the dam and reservoir reduces the magnitude and duration of flood flows which, in turn, reduces downstream inundation of floodplain habitats.[32] Wildlife movements can also be fragmented or restricted by the presence of a large reservoir (IHA 2021).

***Loss of habitats and biodiversity (aquatic)***

In the construction phase of a hydropower project, aquatic flora and fauna in the immediate proximity of the site (dam site and powerhouse) will be lost as habitat is removed. Increased sediment loads as a result of site erosion can have a negative impact on fish and aquatic invertebrates. Additionally, riparian habitats can be lost when a stretch of river is inundated by a new reservoir. Habitats which are important for fish breeding and spawning (e.g., deep pools, rapids, riffles, and in-channel wetland areas) can be submerged.

Changes to river flow regime can affect aquatic ecosystems and biodiversity by changing the daily or seasonal patterns of flow. This can be particularly severe if a peaking regime is used (i.e., a project only generates electricity for a few hours of the day). Some projects will divert water around a stretch of river many kilometers long. Such a bypassed stretch can be left dry or with insufficient flow to maintain the original aquatic habitats.

Dams fragment aquatic systems and prevent the migration of fish upstream and downstream. This loss of aquatic connectivity in a river system can also affect plankton drift and potentially remove important spawning grounds. To some extent, fish passage facilities—fish ladders, fish elevators, or trap-and-haul systems—can mitigate the impact, but they normally cannot maintain the natural upstream and downstream movements of fish and other aquatic life.

The creation of a reservoir can result in a range of water quality issues, as described above. Of particular concern at the start of the operational phase is the decomposition of organic matter which can deplete water oxygen, release methane, and kill fish and other aquatic organisms.

Opening up a previously undeveloped area with new access roads can lead to increased fishing. Fishing opportunities can be created by the creation of a reservoir, but dynamite fishing can be particularly damaging. Furthermore, exotic fish may be deliberately added to reservoirs by local people for fishing, and this can result in the decline or loss of native species. Over time, lentic species will also replace lotic species in newly created reservoirs where rivers would have originally flowed. New access roads can also enable an increase in fish poaching. This can be a particular problem where an access road is near to or passes through a protected or ecologically sensitive area.[33] [34]

***Land and ecosystem restoration***

As discussed above, there are significant risks associated with hydropower development with regard to potential environmental harm and degradation (e.g., unnecessary or excessive deforestation) and destruction of habitats and loss of biodiversity and ecosystem services as well as soil erosion and pollution. This will particularly arise where mitigation measures proposed by an SEA (and subsequent project-level EIAs) are inadequate, ineffective, or not undertaken. The significance and seriousness of such degradation can be compounded where the impacts are cumulative and extensive. Such cumulative impacts will be highly likely to occur where there are multiple hydropower developments along a river or along the different rivers of a catchment and compounded further across the entire river drainage system.

[32] IFC (2015b)
[33] IFC (2018)
[34] EBRD (2017)

Such impacts will usually lead to demand for and need for land and ecosystem restoration (see Box 2.12). This need will also arise at sites of projects that have come to the end of their useful life (e.g., when a reservoir has silted up and no longer serves its purpose). When a dam is removed (Box 5.4), restoration can involve:

- Revegetation, which can help to restore natural ecosystem processes and minimize the presence of invasive and exotic species.
- Fisheries restoration.
- Sediment and hydrology restoration.

**Box 5.4: Dam removal and ecosystem restoration:**
**The case of Elwha and Glines Canyon hydroelectric dams, USA**

The removal of the Elwha and Glines Canyon hydroelectric dams in Olympic National Park, Washington State, USA, is not only the world's largest-ever dam removal but is also the second largest ecosystem restoration project in the American National Park System.

Construction of the 105-foot Elwha Dam was completed in 1914 and led to the formation of the 267-square-mile Lake Aldwell reservoir. The 210-foot single-arch Glines Canyon Dam was completed in 1925, several miles upstream from the first dam, and flooded the surrounding land, creating the 415-acre Lake Mills reservoir. The dams generated a combined 28 MW of electricity and provided a major boost to expanding local communities and industrial development, in and around the nearby city of Port Angeles in the early 20th century. But they have long since ceased to play a major role in meeting power supply demands.

Construction of the two dams effectively split the Elwha River into three separate entities: the 4.9 miles of the Lower River below the Elwha Dam, the Middle River between the two dams, and the Upper River above the Glines Canyon Dam 8.7 miles further upstream. This had profound negative impacts on the Elwha River watershed, including sediment and silt blockage behind the dams. Construction also led to erosion of the riverbanks, impacts on protected areas, as well as adverse effects on Indigenous people, such as the Lower Elwha Klallam Tribe, who previously relied on native fish populations for sustenance.

Lacking passage for migrating salmon, Glines Canyon Dam blocked access by anadromous salmonids to the upper 38 miles (61 km) of mainstem habitat and more than 30 miles (48 km) of tributary habitat. The Elwha River watershed once supported salmon runs of more than 400,000 adult returns on more than 70 miles (110 km) of river habitat. By the early 21$^{st}$ century, fewer than 4,000 adult salmon returned each year.

The Elwha Restoration Act of 1992 authorized the US Federal Government to acquire the dams for decommissioning and demolition. Following the creation of a diversion channel to allow the continued flow of the river during deconstruction, the dam was fully removed by March 2012 (cost of US$26.9m) and the river was returned to its natural route. The two dams were removed in stages to prevent major disturbances caused by disrupting the many millions of cubic meters of sediment piled up above the dams, as this could potentially cause extensive damage to ecosystems further downstream. The larger Glines Canyon Dam presented greater difficulties, requiring a number of additional measures to deal with the relocation of water and sediment in Lake Mills. The first phase saw the reservoir's levels dropped gradually using an outlet pipe to transport water downstream.

Dismantling involved removing sections of the dam walls from the top down, with the concrete blocks being trucked offsite and recycled. The final stage comprised controlled blasts to clear what was left of the dam wall.

A number of other projects are helping to restore the Elwha River ecosystem, including the installation of facilities to treat water and remove sediment downstream of the dams. The area that was under Lake Mills is being revegetated and its banks are being secured to prevent erosion and to speed up ecological restoration.

The return of Pacific salmon to their spawning streams will be important to the region. Adult salmon bring with them marine-derived nutrients. Decomposing salmon carcasses provide nutrients that link the marine and terrestrial ecosystems. Salmon are known to benefit more than 100 other species. The return of salmon and the entire ecosystem will help to revitalize tribal culture, age-old traditions and previously submerged sacred sites.

*Source: Water Technology (2012)*

Hydropower developers can maximize the adaptive benefits (regarding climate change) of watershed restoration by: (a) avoiding areas where the risks of destroying important wetlands are high, or (b) avoiding forest clearing (e.g., around reservoirs, for access roads and transmission lines) where the risks of soil erosion are highest, reducing unnecessary sediment flows and slowing runoff in order to protect and optimize reservoir storage.

Restoration projects such as described above are a new occurrence with very few examples in place. However, as many of the world's hydropower project continue to age, dam decommissioning and restoration of affected terrestrial and aquatic ecosystems will become increasingly more common. This will require setting aside sufficient funds to cover large restoration costs.

***Waste and spoil***

The wastes generated by a hydropower project typically range from benign to potentially very harmful (e.g., toxic chemicals and hydrocarbons). Waste also includes excess spoil or waste rock from excavation, vegetation from clearing, and sewage and wastewater. Many jurisdictions have strict controls over the handling, transport, and storage of certain types of waste. A construction site should generally have dedicated areas that provide effective storage and transport points for wastes.

Human wastes, both solid and liquid, are a management issue at the implementation stage with respect to the large numbers of construction staff and their living quarters. Large construction camps are often developed to service the construction phase of a project. Appropriate refuse, sewage and wastewater disposal need to be planned for and managed and conform to regulatory requirements. Interactions of local fauna with refuse disposal sites (scavenging) can be an issue requiring management.

Spoil is excavated or dredged material that cannot be used in construction because it is either not of the required quality or specification, or because it is surplus to requirements. Significant amounts of spoil can be generated during the construction phase of a hydropower project, particularly if there is a tunnelling operation (Box 5.5). The spoil needs to be reused or stored near to the project site to avoid

**Box 5.5: Karot Hydropower Project, Pakistan**

One of the most significant impacts identified from the 720 MW Karot Hydropower Project in Pakistan was the generation of significant volumes of spoil from excavations and tunnelling activities. The main impacts identified were land loss due to the large amount of space required to accommodate spoil that could not be reused, and the resulting landscape and visual impacts created by the spoil heaps.

*Source:* Karot Hydropower Project, Pakistan - Power Technology (power-technology.com)

significant transport costs. It is typically used to make large, terraced piles on land which is not productive for agriculture or not important for conservation. In some cases, spoil can benefit a local community by filling in a steep area of land to make it usable. Key concerns are the gradient of slopes and suitable drainage to maintain stability and avoid erosion.

Earthmoving and quarrying activities can have an impact on soil quality in the project area. Soils can be contaminated as a result of spills of oil and fuel from vehicle operation and maintenance and fuel storage areas. Contaminated soil needs to be removed to special waste disposal sites to prevent contamination of both groundwater and soils.

***Agriculture***

The inundation of land by a reservoir can lead to direct loss of productive agricultural land. In addition, downstream agricultural land can be impacted by a reduction in nutrients carried in sediment by flood water. This occurs if the hydropower project changes the river flow regime to the extent that it no longer provides flood water to crops when required, such as for flood-recession agricultural systems. This type of agriculture can diminish, or even disappear, if water releases from an upstream dam do not sufficiently replicate seasonal flood flows. Flood water sediment may also be important for agriculture because it carries phosphorus (dissolved and total), nitrates, and ammonium downstream. Without these nutrients, crop yields will be lower. This problem can be countered by applying fertilizers, but this can lead to further environmental problems such as inappropriate use (with associated health hazards) and pollution from fertilizer runoff.[35] However, hydropower dams are sometimes used as reservoirs providing water for the downstream irrigation of crops and over a wider area benefitting more farmers.

***Air quality***

Hydropower projects do not normally have a significant impact on air quality. There is typical construction-related air pollution from materials extraction, machinery and vehicles (trucks, workers' buses, etc.) and dust from land clearing and from vehicles moving on dirt roads—mainly in the construction phase.

***Greenhouse gases***

Some reservoirs can be a source of methane and carbon dioxide (greenhouse gases [GHG]). Methane is released if the water in the bottom of a reservoir becomes anaerobic or there are low oxygen conditions, and bacteria decompose organic matter (dead vegetation left from clearing the reservoir site). One metric ton of methane in the atmosphere has a short-term effect on climate that is about 25 times greater than one metric ton of carbon dioxide. Many reservoirs will not be significant emitters of methane, but this risk needs to be carefully checked before a project is developed.

The potential for GHG emissions can be assessed through the IHA G-Res Tool. It uses a conceptual framework that integrates up-to-date science in an online interface to estimate the GHG emissions from reservoirs. Such tools help hydropower companies and researchers estimate and report the net GHG emissions of a reservoir without the need to conduct expensive field sampling campaigns. They are especially valuable in the prefeasibility stage as a screening tool to avoid high-emitting projects.[36]

Hydropower projects do emit GHGs. However, the many myths around GHG emissions and hydropower projects have been addressed by IHA. These myths include the erroneous claims that (i) tropical reservoirs emit more GHGs than temperate reservoirs and (ii) that clearing of vegetation lowers GHG emissions. Instead, GHG emissions in operating reservoirs can be reduced by implementation of operating practices such as changing operating levels, aeration, adding additional inlets above the thermocline, and using methane to generate electricity. The IHA Hydropower Sustainability Standard, as well as the Guidelines on Good International Industry Practice, state that a project with low emissions should have an emissions intensity less than 100 gCO2e/kWh. This emissions level can and should guide future new hydropower development.[37]

***Climate vulnerability, and dam and community safety***

[35] IFC (2018)
[36] See "Carbon emissions from hydropower reservoirs: facts and myths" (https://www.hydropower.org/blog/carbon-emissions-from-hydropower-reservoirs-facts-and-myths)
[37] Ibid.

Hydropower is considered highly vulnerable to climate change[38] as it is directly related to precipitation patterns, behavior of snow-caps and glaciers, and resulting changes in the quantity and timing of river flows. This affects both the capacity to produce electricity and the safety of dams, for example, when flood gates or spillways can no longer safely evacuate increasing river discharges.

The most obvious risk associated with a hydropower reservoir is dam wall failure, which can have catastrophic consequences for communities, livestock, and wildlife downstream (Box 5.6). Dam failure can be due to:

- Substandard construction materials and techniques.
- Spillway design error.
- Geological instability caused by changes to water levels during filling.
- Poor maintenance, especially of outlet pipes.
- Extreme inflow.
- Human, computer or design error.
- Earthquakes.

**Box 5.6: Dam failure: Saddle Dam D, Lao People's Democratic Republic**

On 23 July 2018, Saddle Dam D on the Xe Pian-XeNamnoy hydropower project in Champassak and Attapeu provinces collapsed following heavy rain. The Government of the Lao People's Democratic Republic (Lao PDR) immediately suspended new hydropower projects and initiated safety inspections of all existing dams. The dam failure caused devastating floods in both Lao PDR (Figure 5.7) and Cambodia's Stung Treng province, which lies downstream of the dam. 49 people died and 22 were missing and presumed dead. The collapse displaced thousands of people, flooding homes and villages. Over 7,000 people in 19 villages in Attapeu province experienced losses and long-term damage to houses, property, and farmlands. The floodwaters extended far downstream and across the border into Cambodia, affecting an estimated 15,000 people, damaging farms and destroying livestock and property.

*Source: International Rivers (2020)*

**Figure 5.7: Downstream flooding following the collapse of Saddle Dam D in Lao PDR.**

*Photo credit: Courtesy of the Lao Government*

[38] For more information, see "Sixth Assessment Report, IPCC (https://www.ipcc.ch/assessment-report/ar6/)

Dam break risk may be exacerbated by climate change. Depending on location, climate change may lead to changes to (i) annual and seasonal rainfall averages, (ii) the type and seasonal distribution of precipitation, (iii) the ranges of temperatures and precipitation, and (iv) the frequency and severity of extreme weather events. Changes in these conditions will have effects on hydrological and other conditions including, for example, runoff and seasonal patterns of runoff, glacial melt or timing of glacial melt, intensity of floods and droughts, frequency or magnitude of landslides, and sediment transport. Fortunately, dam break is relatively rare due to well-established design and maintenance standards. An emerging issue for hydroelectric projects and climate change in the Himalayas is the potential for dam breach associated with an upstream glacial lake outburst flood (GLOF) (Box 5.6).[39]

**Box 5.7: Effects of glacier loss in the Himalayas**

A study by NASA and Columbia University, based on an analysis of declassified spy satellite photos from the 1970s, showed that glaciers across the Himalayas have experienced significant ice loss over the past 40 years, with the average rate of ice loss twice as rapid in the 21st century compared to the end of the 20th century. The research team calculated that glaciers have been losing 20 vertical inches (c. 50 cm) of ice per year since 2000. Figure 5.8. shows the extent of glacial retreat on Kokthang Glacier in Sikkim, India.

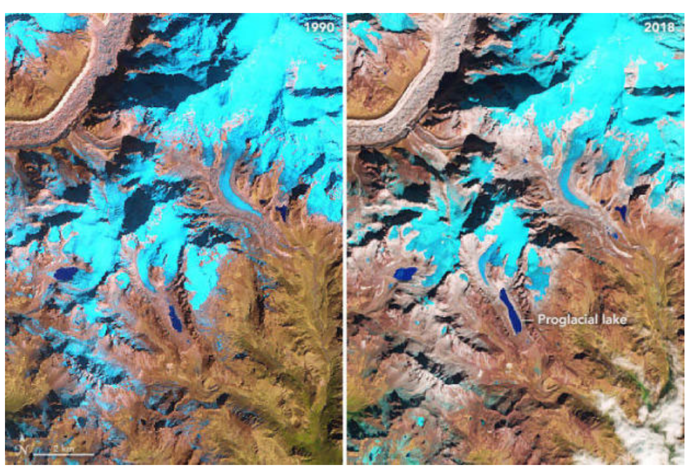
The rapid melting is leading to serious impacts, including increased water flowing down from the mountains which is increasing the potential for flooding. Meltwater lakes are swelling rapidly behind natural dams and are threatening downstream communities with potentially destructive glacial lake outburst floods (GLOF).

But with glacial melt, the volume of dry season release is diminishing with the likelihood of long-term fresh water shortages, It is estimated that around 800 million people depend on seasonal runoff from Himalayan glaciers for irrigation, hydropower, and drinking water. Some villages are reported to have already been forced to move because glacier retreat has reduced their supply of irrigation water to levels that are unviable, and many more are threatened.

Glacial retreat is predicated to lead to changes in regional weather patterns due to the immense size and influence of the Himalayan range.

*Sources: Maurer et al. (2019) and "Spy satellites reveal Himalayan glaciers losing ground to climate change* (https://www.cbsnews.com/news/spy-satellites-reveal-himalayan-glaciers-melting-climate-change/)

**Figure 5.8: Ice loss on the Kokthang glacier, Sikkim, India: 1990 (left) to 2018 (right)**
*Source: NASA*




[39] Qiu (2016)

A range of risks is associated with hydropower infrastructure such as electric shock, drowning, road accidents, and accidents arising from community interactions with project activities.

In the construction phase, there can be risk linked to structures used to support site investigations, e.g., access roads, buildings, test wells, helipads, etc. During project design, adherence with safety standards is an important consideration.

A significant safety risk during the construction period is the risk of flooding. Diversions are constructed to divert water from the river around the construction site. This diversion will have a capacity that can be exceeded during river flood events in which case water can inundate the construction site and the dam which is under construction can be put at risk of failure.

Both construction and operation of hydropower plants can involve structural failure and flooding. An example is the Dhauliganga hydroelectric station in India. In June 2013, there was an unprecedented flash flood, causing massive debris accumulation and the complete submergence of the powerhouse. Damage caused electrical equipment replacement and loss of total generation capacity for more than six months.[40]

Other implementation safety issues include those related to construction such as increase in traffic, heavy machinery on roads, and blasting activities.

***Noise and vibration***

Various activities during hydropower project construction generate noise and vibrations (truck movements, excavations, removal of vegetation, transport of workers to and from site, etc.). The use of explosives for blasting rock while preparing a dam site and in quarries will create excessive temporary noise and vibration and disturbance for nearby communities as well as wildlife. Quarries may be located at some distance from the dam site, so can increase the number of communities affected by noise. During operation, noise will be limited to generation from the power station and vehicle movements.[41]

***Transboundary issues associated with hydropower projects***

Hydropower projects can have impacts beyond national boundaries if they change the flow regime of a river that runs from one country to another. It is important that potential impacts are considered on a broad spatial and temporal scale. These can include changes to a river's hydrological regime, its sediment dynamic and water quality, all of which can affect aquatic ecosystems as well as associated fisheries and livelihoods. Key receptors to be considered in assessing the likely downstream impacts of hydropower projects are irrigation schemes, water supply projects, wetlands, fisheries, and biodiversity (aquatic and terrestrial). This issue is particularly relevant when a river runs through several countries, e.g., the Mekong River in Southeast Asia (Box 5.8).

**Box 5.8: Multiple hydropower dams on the Mekong River**

The Mekong River arises in the People's Republic of China (PRC) and flows through Myanmar, the Lao People's Democratic Republic (Lao PDR), Thailand, Cambodia, and Viet Nam. In the Upper Mekong River Basin, the PRC has constructed 11 hydropower dams (of which two are large storage dams). Another 11 dams, each with production capacity exceeding 100 MW, are being planned or constructed. There are a further 89 projects in the lower basin, of which two are in Cambodia, 65 in Lao PDR, 7 in Thailand and 14 in Viet Nam. Many more dams are planned over the next 10 years, as shown in Figure 5.9.

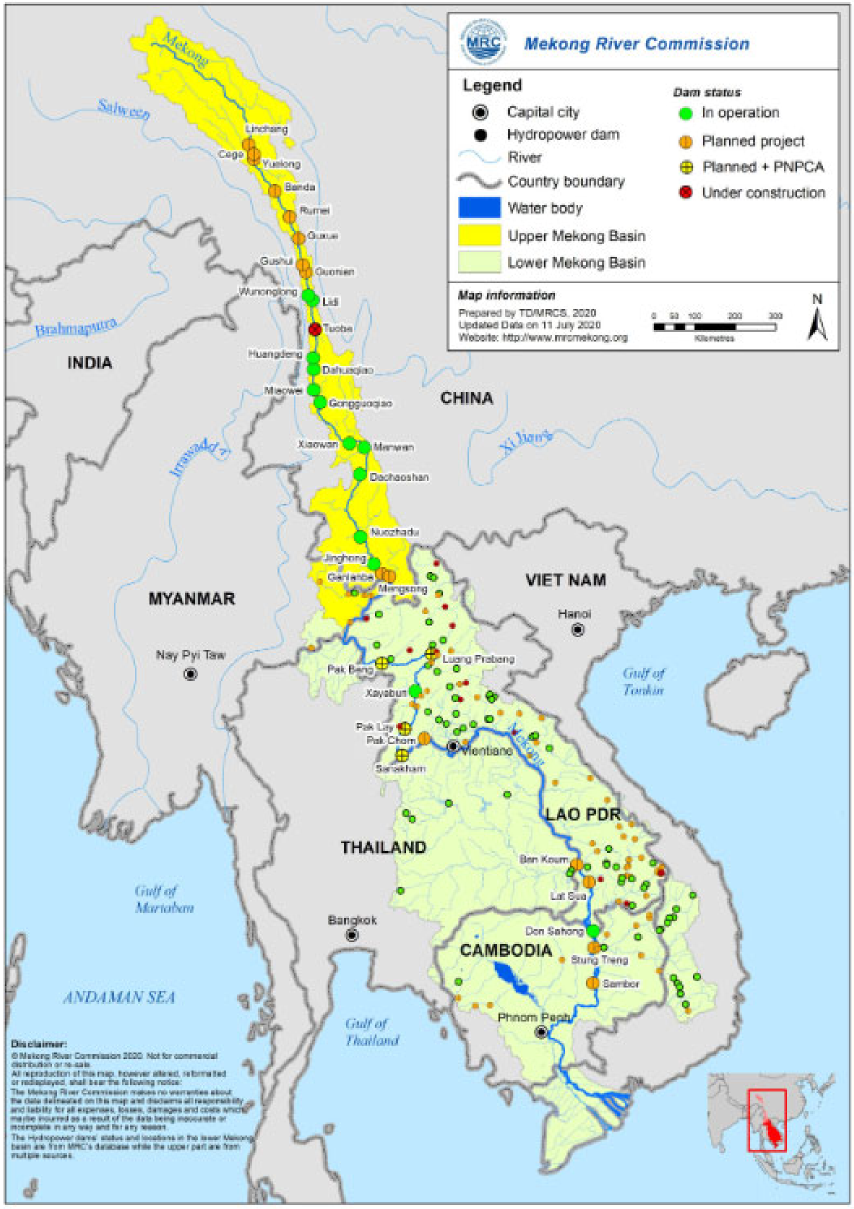
The Mekong River Commission has been established to manage the transboundary issues associated with these projects. It is an intergovernmental organization that works directly with the governments of Cambodia, Lao PDR, Thailand, and Viet Nam to jointly manage their shared water resources and the sustainable development of the Mekong River. Its aim is to promote and

[40] For more information, see https://en.wikipedia.org/wiki/Dhauliganga_Dam
[41] IFC (2018)

coordinate sustainable management and development of water and related resources for the countries' mutual benefit and the people's well-being.

*Source: Mekong River Commission for Sustainable Development (Undated)*

**Figure 5.9: Hydropower developments along the Mekong River**
*Source: Mekong River Commission for Sustainable Development (2020)*




Dams with potential transboundary impacts, such as Xayaburi run-of-river hydroelectric dam on the Lower Mekong River (around 30 km east of Sainyabuli [Xayaburi] town in northern Lao PDR), provide lessons about how dams can cause not only ecological and environmental impacts across an international national border, but also adverse effects on the socioeconomics of the downstream riparian states and communities.[42 43]

[42] IFC (2015b)
[43] Young and Ear (2021)

***Location issues and cumulative impacts***

Downstream dams in the main river channel are more damaging than dams in upstream river branches. Several dams located in different branches of the same river are far more damaging than a cascade of dams in one branch, if other branches remain untouched and free-flowing.[44] Studies undertaken by, for example, The Nature Conservancy (TNC) in Mexico show that good site selection at basin scale can significantly avoid riverine and terrestrial impacts due to fragmentation, while delivering similar levels of power generation (Box 5.9 and Figure 5.10).

**Box 5.9: Hydropower by Design: Helping the hydropower development in Mexico**

“Hydropower by Design” is an integral approach to the planning and management of hydropower development at a macro-basin scale and helps prevent negative environmental and social impacts. The Nature Conservancy has used this system-scale approach to help the government of Mexico to reduce investment risks in hydroelectric infrastructure projects in a major tributary of the Gulf of Mexico: the Coatzacoalcos River.

The systemic planning effort at the macro level permits the evaluation of impacts these projects can have on industry and agriculture, on the lives of towns and cities in Veracruz—one of the richest states in Mexico both culturally and naturally—and on the biodiversity that inhabits the river and gives it life,

*Source: The Nature Conservancy (Undated)*

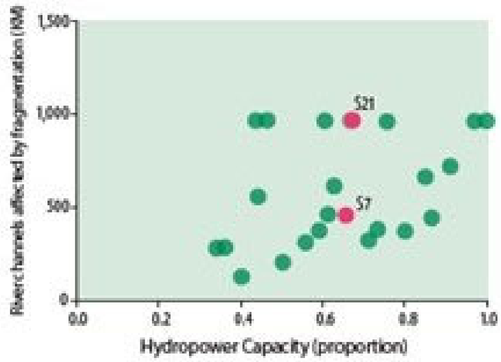
River basin-wide analysis should be applied to find optimal locations, preferably through SEA or cumulative impact assessment.

Mini-hydropower projects are often “invisible” for EIA/ESIA (i.e., they are below the threshold requiring such an assessment). However, potentially they can be very damaging, particularly when constructed in cascade. An EIA/ESIA for the entire cascade would be warranted, but this usually is effectively avoided by investors by taking a one-by-one approach. A river basin management plan and dialogue or a well-designed permit may avoid this, informed by a basin-wide assessment of all existing and planned interventions and water uses/users, through SEA or cumulative impact assessment.

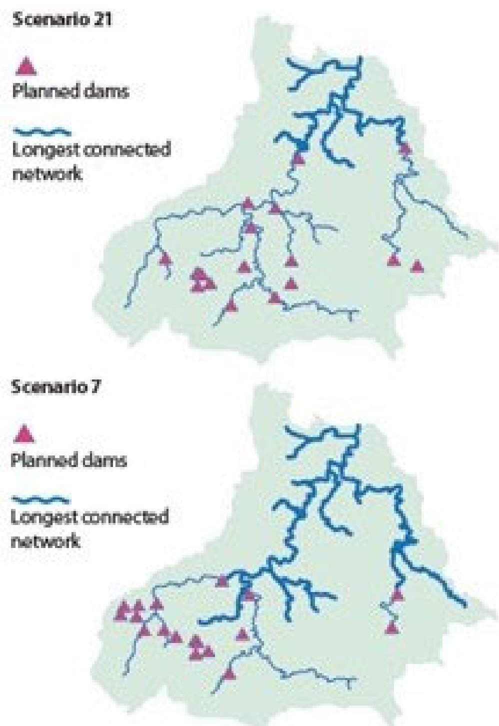
This can involve several innovative planning measures such as implementing a basin wide strategic roadmap for hydropower planning; addressing baseline data gaps in biodiversity, social, and cultural conditions; maintaining downstream E-flows; concentrating cascade hydropower projects in one area of the watershed; conducting basin-wide monitoring during project operations; and providing for the permanent legal protection of free-flowing river segments in the watershed, free from hydropower or other dams (aquatic offsets).[45] [46]

[44] Slootweg (2023)
[45] World Bank Group (2016)
[46] World Bank (2016c)

**Figure 5.10: Results from the Nature Conservancy study of Coatzacoalcos Basin in Mexico**
*Source: IHA (2021)*




Above: Hydropower capacity and river kilometers affected by fragmentation for alternative development scenarios in the Coatzacoalcos. The two scenarios compared in the maps below are highlighted in red.




Above: Two scenarios with similar hydropower capacity, but considerably different levels of connectivity. Scenario 7 has 452 km affected by fragmentation compared to Scenario 21 with 970 km.

### 5.5.2 Socioeconomic issues

***Physical and economic displacement***

Some hydropower projects cause economic and physical displacement of riparian and other communities and settlements.[47] Economic displacement is defined as the loss of assets, access to assets or income sources, or to means of livelihoods, which could be caused by land acquisition, changes in land use or access to land, restrictions on land use or access to natural resources, or changes in the environment leading to impacts on livelihoods.[48] Hydropower projects can also cause physical displacement from the loss of residential land and shelter. Physical displacement involves risks for both the displaced people and for the host communities receiving them when they relocate.[49]

The amount of displacement will often depend on the type of hydropower project. Run-of-river schemes may cause only limited displacement. But hydropower projects that include a reservoir tend to occupy a large area of land. The land acquisition for a reservoir can affect farmland and grazing lands that are located near the river. Farmers' and villagers' incomes from farming and livestock raising will be lost or reduced when the land is flooded. Large reservoirs can also inundate residential areas and displace an entire community to a new resettlement area (Box 5.10).

**Box 5.10: Displacement of people due to development of the Three Gorges project in China**

Construction of the Three Gorges Dam on the Yangtze River (Chang Jiang) in Hubei Province, China, was completed in 2006. At the time, it was the largest dam structure in the world (Figure 11). The dam and accompanying hydroelectric plant were built in phases and over the course of many years. It reached its full generating capacity in 2012. The dam allows the navigation of oceangoing freighters and generates hydroelectric power. It was also intended to provide protection from floods, but efficacy on this aim remains unclear.

While the construction of the Three Gorges Dam was an engineering feat, it has also been fraught with controversy: construction of the dam caused the displacement of about 1.4 million people. Hundreds (possibly thousands) of towns and villages were evacuated and later submerged. The area surrounding the Yangtze contains some of the densest clusters of human life in the world. Those forced to relocate were promised compensation for the value of their homes and land. But the majority of relocated citizens were either given far too little in compensation or their dues were allegedly slimmed through corruption and embezzlement; many claim they received only half the land compensation they were promised.[50] This created problems for many as the cities and towns they had to move to were more expensive, driving many people deeper into poverty,[51] landlessness, joblessness, marginalization, and food insecurity.[52] The displaced were often farmers with little formal education, if any. Many opted to return to the Yangtze region.

Flooding the reservoir has forced those farmers still in the region to migrate northward up the mountain slopes, adding to erosion through overutilization of topsoil.

The dam also resulted in the destruction of natural features and countless rare architectural, cultural, and archaeological sites. The dam's reservoir is blamed for an increase in the number of landslides and earthquakes in the region.

*Sources: Encyclopaedia Britannica (Undated)*
*Environmental and Social Issues of the Three Gorges Dam in China (mandalaprojects.com)*
*Gleick (2009)*
*Hvinstendahl (2008)*

[47] Cernea (2004).
[48] IHA (2020)
[49] WCD (2000)
[50] Hvinstendahl (2008)
[51] See "Chinese Dam Projects Criticized for Their Human Costs" (https://www.nytimes.com/2007/11/19/world/asia/19dam.html#:~:text=The%20Three%20Gorges%20Dam%20is%20projected%20as%20an%20anchor%20in)
[52] Gleick (2009)

**Figure 5.11: Three Gorges Dam, China**
*Source: Wikimedia Commons (2023)*

Business activities, whether small, medium, or large enterprises, can also be displaced, affecting their owners and workers. Furthermore, community public facilities such as schools, clinics, public meeting halls, and cultural and religious sites may also be lost or need to be relocated. Often, associated infrastructure such as access roads and transmissions line can also cause physical and economic displacement.[53]

Displacement can impoverish the resettled people, who are often from poor communities. Without adequate mitigation measures and compensation, the livelihoods of displaced peoples can be made significantly worse.[54]

The construction of dams and weirs for both run-of-river and reservoir hydropower schemes can disrupt fishing activities which are often important income-generation activities of the riparian communities. For example, large-scale and transboundary dams along the Mekong River in Southeast Asia have led to less fish migration and lower fishing yields both downstream and upstream of the dams.[55] Hydropower projects can also displace sand mining businesses and the collecting of sand or other aggregate materials from rivers by local people.

The relocation of affected people can create pressure on the public facilities and infrastructure in the host communities, giving rise to tensions between the two groups. The losses endured by the host community can lead to weakened community cohesion and an increase in domestic and gender-based violence.

***Benefits of reservoirs***

Although dams/reservoirs can have significant negative environmental impacts, they can also provide significant socioeconomic benefits. Sometimes they are used to supply water to downstream areas for the irrigation of crops, increasing agricultural yields and job opportunities and contributing to local and regional economies. Reservoirs generate the opportunity to establish new fishing opportunities and support local livelihoods. Reservoirs can also benefit local and more distant communities by providing a guaranteed source of fresh water to the public and industry. They are frequently used for recreational purposes (e.g., sport fishing, sailing, picnicking). Some large dams are even used for navigation and the use of locks can facilitate transport across the dam.

[53] WCD (2000)
[54] Cernea (2004)
[55] Young and Ear (2021)

However, achieving such benefits is often the result of intense negotiations with authorities and affected communities, sometimes with authorities putting multipurpose use as a requirement to in the design of a hydropower project.

A challenge is to minimize contradictions/competition among multipurpose water uses of hydropower reservoirs, and to set an appropriate governance to allow coordinated/integrated water uses management. Based on twelve worldwide case studies of multipurpose hydropower reservoirs, the SHARE concept was developed as a framework to address such potential conflicts.[56] SHARE refers to a **S**ustainability approach for all users, **Hi**gher efficiency and equity among sectors, **A**daptability for all solutions, **R**iver basin perspectives for all, and **E**ngaging all stakeholders. As a concept for multipurpose water uses of hydropower reservoirs, it aims to help make use of hydropower reservoirs more sustainable and equitable among all users and uses.[57]

***Indigenous communities***

The development of a hydropower project may cause both positive and negative impacts on Indigenous communities and people. The International Finance Corporation's (IFC) Performance Standard 7 and the Asian Development Bank's (ADB) Safeguard Policy Statement (SPS) on Indigenous Peoples (2009) recognize that Indigenous peoples can be marginalized due to their sometimes tenuous economic, social, and legal status and their limited capacity to defend their rights and interests. Indigenous peoples typically have strong spiritual, cultural, and economic relationships with their land and waterways. According to the International Hydropower Association's new guide on hydropower and Indigenous peoples,[58] a major negative impact can often be loss of land under Indigenous use. This could be land for which Indigenous peoples' jurisdiction and management may have been previously removed by national governments. Impacts on Indigenous people other than loss of communal lands include the following:

- Reduced or variable flows that could affect the safety, irrigation, water uses, and livelihoods of communities living downstream.
- Loss of ancestral land and cultural resources (cemeteries, tombs, sacred groves, temples, etc.), or reduction of their territory.
- Loss of access to or reduction of resources (e.g., water, fish and animal species, fertile land, and forested areas) and associated nutritional issues.

Box 5.11 provides examples of cases in which indigenous peoples have been displaced and affected by hydropower projects.

**Box 5.11: Indigenous peoples affected by hydropower projects: Some examples**

Many Indigenous groups have protested against hydropower projects and denounced government approvals for projects. For example, an Indigenous community on the border of Thailand and Myanmar organized a large protest against the Salween River hydropower project in 2017.[a] This unrest occurred, in part, because of inadequate engagement of and consultation with affected communities, and a lack of appreciation of their ties to the land.

In Cambodia, the construction of hydropower projects, such as Lower Sesan 2 Dam, have caused adverse impacts on Indigenous communities (nearly 5,000 people, mostly IPs and other ethnic minorities—Bunong, Brao, Kuoy, Lao, Jarai, Kreung, Kavet, Tampuan, and Kachok—who have lived in villages along the Sesan and Srepok Rivers for generations.[b] The latter were displaced which resulted in disagreements with project proponents.[c]

In Lao PDR, where ethnicity is diverse, a number of Indigenous people have been affected or displaced by hydropower projects, including the multilateral development bank-financed Nam Theun 2 project.[d]

[56] Branch (2017)
[57] Ibid.
[58] IHA (2022)

In Indonesia, displacement of Indigenous people due to hydropower development projects is often reported by media outlets. For example, a 480MW-hydropower project in South Sulawesi affected Pohoneang, Hoyyane and Amballong Indigenous communities. [e]

*Sources:*
*[a] Shah and Bloomer (2018)*
*[b] Human Rights Watch (2021)*
*[c] Young (2020)*
*[d] Nam Theun 2.com. NTPC Document Proforma (namtheun2.com)*
*[e] Rusdianto (2017)*

There are also examples from Southeast Asia of renewable energy initiatives that are being driven by Indigenous communities. Micro-hydro power developments in the Philippines and Malaysia are increasing access to clean energy, reducing harmful pollutants (e.g., from diesel generators, burning wood or charcoal indoors for cooking), and alleviating the work burden on women as well as providing other community benefits. Groups like “Grupo Yansa” (a not-for profit organization based in Mexico) provide support to Indigenous communities interested in developing the renewable energy potential of their land.[59] [60] In Canada, some Indigenous peoples’ groups are partnering with the private sector to develop and operate large energy projects.[61] [62]

There are many opportunities for hydropower development to bring benefits to the Indigenous communities. According to the IHA, these benefits include but are not limited to[63]:

- Increased safety by having flood control and regulated flows.
- Support (e.g., financial) to promote and enhance cultural traditions.
- Employment and business opportunities through the project life, including direct employment opportunities, subcontracting services during construction and maintenance, service provision such as food and transportation services, and indirect employment within local communities.
- Investment revenues from project partnerships with indigenous peoples’ communities.
- Training (pre-project and during construction and operation) and improved community governance capacity.

Jobs during the construction phase are varied depending on the type and size of hydropower project. The Muskrat Falls hydropower project in Canada advertised that the construction workforce would span more than 70 different types of occupations.[64] While some of the expertise may not be available in Indigenous peoples’ communities, the range of needs, especially in larger projects, is considerable, meaning the emphasis should be on matching available local skills to needs among the contracting tiers and service providers.

In some countries, companies choose (for business reasons) or are regulated to offer impact benefit-sharing agreements. One report from British Columbia in Canada identifies several reasons for entering into benefit-sharing agreements with Indigenous peoples including: to further social license to operate, as matter of good neighbor policy, and to provide a competitive advantage to meet consumer demand for ethically produced products.[65] The report indicates that such agreements are not a cure for all conflicts and uncertainties and will not resolve complex legal, political, cultural, and historical issues; nor should one company or project be expected to bear all of the burdens of history nor share current development responsibilities. But each negotiated benefit-sharing agreement is an important step forward that will help reconciliation efforts and shared hydropower project benefits with Indigenous peoples.

[59] Shah and Bloomer (2018)
[60] UNDESA (2021)
[61] CHA (2018)
[62] *Aboriginal Power: Clean Energy and the Future of Canada's First Peoples*. Available at https://www.amazon.ca/Aboriginal-power-energy-Canadas-peoples/dp/1927506190
[63] IHA (2021c)
[64] Muskrat Falls jobs. Nalcor Energy. Accessed October 2013.
[65] Woodward & Company (undated)

***Health and safety***

Community health and safety issues are associated with hydropower development during both the construction and operational phases.[66] The IHA's guide [67] on hydropower infrastructure (2021) identifies the following issues: road safety, safety around water bodies associated with the hydropower complex, blasting and other construction activities, electrical safety, natural hazards, underground geotechnical hazards, and pressurized conveyance hazards.

Hydropower projects usually involve the use of heavy goods vehicle fleets to transport materials and staff on-site. In many cases, projects increase road traffic, affect road and bridge conditions, and cause accidents. Often there is a need for new access roads or upgrades to existing roads and bridges to transport heavy equipment, but key risks can be neglected in policies, procedures, and monitoring programs: unsafe road design and conditions, unsafe vehicles, speeding, non-use of seatbelts and helmets, lack of driver training, driving under the influence of alcohol or drugs, inadequate post-accident care, and lack of enforcement of traffic rules. Without mitigation measures for these risks, hydropower projects can cause traffic related congestion, accidents, and fatalities.

A major issue is the excavation of large quantities of soil and rock for drilling and creation of tunnels. Construction work creates significant health and safety risks for both workers and local communities from dust, noise, and vibrations; eutrophication; waste disposal; and the potential spread of communicable diseases.

ESIA guidance for hydropower published by the Netherlands Commission for Environmental Assessment (NCEA) identifies numerous vector-borne and tropical diseases associated with the development of reservoirs.[68] These risks are exacerbated in low-income countries in Southeast Asia where water quality regulatory enforcement remains limited.

The IFC hydropower guidance notes that some infectious diseases can spread around hydroelectric reservoirs, particularly in warm climates and densely populated areas. Some diseases (such as malaria and schistosomiasis) are borne by water-dependent vectors (mosquitos and aquatic snails, respectively); others (such as dysentery, cholera, and hepatitis A) are spread by contaminated water, which is frequently present in stagnant reservoirs. Hydropower development projects can also increase other communicable diseases (infectious diseases such as influenza, STIs, COVID-19 and HIV/AIDS), increase drug and alcohol use, and have the potential to increase crime and domestic and gender-based violence due to the immigration and large-scale influx of workers.

As the COVID-19 pandemic has shown, the large workforces often required by hydropower projects need to be managed to avoid being a spreading point for diseases, but there can be challenges, as illustrated by the experience of Karot Hydropower Project in Pakistan (Box 5.12).

**Box 5.12: Karot Hydropower Project in Pakistan**

Karot Hydropower Project is located on the Jhelum River in Pakistan and is nearing completion (Figure 5.12). The power company faced challenges over managing the spread of COVID-19 early on when no vaccine was available. Trade unions filed a complaint to the IFC (project funder) that the project company undermined the rights of 3,000 workers by restricting their movement, curtailing their freedom of association and collective bargaining (particularly of workers dismissed during the COVID-19 pandemic) and violated the IFC's own performance standards on workplace safety and working conditions, terms of employment, grievance mechanisms, and retrenchment.

*Source: Business and Human Rights Resource Center (2021)*

[66] Acakpovi and Dzamikumah (2016)
[67] IHA (2021)
[68] NCEA (2018)

**Figure 5.12: Karot Hydropower Project, Pakistan**
*Source: CPEC (https://cpec.gov.pk/project-details/16)*

***Cultural heritage***

Cultural heritage includes:

- Tangible forms of culture such as movable or immovable objects, property, sites, structures, or groups of structures having archaeological (prehistoric), paleontological, historical, cultural, artistic, and religious values.
- Unique natural features or tangible objects that embody cultural values (sacred groves, rocks, lakes, and waterfalls.
- Intangible forms of culture, such as cultural knowledge, innovations, and practices of communities embodying traditional lifestyles.[69]

The Hydro Sustainability Secretariat[70] identifies that hydropower schemes can have impacts on cultural heritage at each stage of project development. The construction stage may cause direct and indirect damage to or loss of access to physical cultural resources as a result of excavation, soil compaction, blasting, vibrations, pollution, vandalism, theft, desecration of cultural objects and sites, and groundwater and river flow changes. Construction activities may also be perceived to disturb spirits associated with special sites.[71]

During project operation, impacts on cultural heritage may include the loss of sites inundated by reservoirs (Box 5.13). downstream damage to cultural sites (e.g., through riverbank erosion or flooding) and interruption of ability to continue cultural traditions (e.g., in particular locations) or access specific sites due to changes arising from the project).[72]

**Box 5.13: The Bujagali hydropower project and natural heritage in Uganda**

The Bujagali hydropower project in Uganda was commissioned in 2011 and is still being cited as a project that negatively impacted the culture of local people. The Bujagali Falls was a place of spiritual healing and traditional culture but was blocked and inundated by the hydropower project.

*Source: Umar (2021)*

[69] IFC (2021)
[70] HSC (undated)
[71] Ibid.
[72] Ibid.

From 2019 to 2021, a UNESCO World Heritage Centre initiative advocated for the protection of natural heritage in the context of renewable energy projects. Hydropower projects need to be effectively planned, evaluated, and implemented to safeguard world heritage properties.[73]

The IFC's Performance Standard on Cultural Heritage (PS8)[74] sets out good practice for addressing cultural heritage impacts. They require the protection of cultural heritage from adverse impacts, and support for preservation and equitable sharing of benefits from the use of cultural heritage. In September 2021, the International Hydropower Association announced that no new hydropower projects should be developed in World Heritage sites.[75] It proposed a "duty of care commitment" to implement high standards of performance and transparency when affecting protected areas as well as candidate protected areas and corridors between protected areas. [76] [77]

Hydropower projects can support local communities and their cultural heritage by helping to encourage tourism to their location. It is assumed that hydropower plants and accompanying infrastructure reduce the attractiveness of the areas in which they are located for tourism, but some tourists find them acceptable and desirable.[78] Around the world, hydropower projects organize tours and celebrate local culture, e.g., projects at Itaipu at the conjunction of Brazil, Argentina, and Paraguay, and at Niagara Falls on the border between Canada and the US.

***Gender and vulnerability***

Often, there are gender gaps with women significantly underrepresented in job opportunities in hydropower projects (Box 5.14).

**Box 5.14: Gender gaps in the hydropower sub-sector**

A recent study for the World Bank looked at gender gaps in the hydropower sector. It was carried out by the Energy Sector Management Assistance Program in partnership with the IHA and the Global Women's Network for the Energy Transition (GWENET).[79] The study reports that women remain underrepresented in the sub-sector, as they are in the overall energy sector in general. It was difficult to determine the degree of under-representation since sex-disaggregated data and gender statistics on employment in the sub-sector are scarce. The report notes that hydropower generates almost two-thirds of renewable energy electricity, and it employs over two million people globally. Hence, the sub-sector has the potential to make a significant contribution to improving diversity and gender equality across the energy workforce.

A hydropower project may affect women and vulnerable groups and impair their ability to access benefits, as they often lack ownership of and rights to property, which affects their access to compensation. A sector study from India[80] shows that women are especially vulnerable when gender sensitivities are ignored or overlooked in the project design and planning phases of hydropower development. These vulnerabilities range from losing their traditional means of livelihood when they lose access to their land, which in turn affects their food security and often their access to water and sanitation as well. Women lose access to and control over resources such as land, rivers, forests, and fodder, and must then deal with increasing workloads.

[73] UNESCO (2021)
[74] See www.ifc.org
[75] A landmark or area with legal protection by an international convention administered by the UNESCO. (UNESCO World Heritage Centre – World Heritage List)
[76] IHA Website notification September 2021. International Hydropower Association announces new commitment to World Heritage sites and protected areas - UNESCO World Heritage Centre.
[77] See San Jose Declaration on Sustainable Hydropower (San José Declaration on Sustainable Hydropower)
[78] Saeporsottir and Hall (2018)
[79] Energy Sector Management Assistance Program (2021) World Bank-ESMAP Launches Survey on Gender Gaps in Hydropower Sector - As Part of New Study to Support Women's Employment in the Sector. ESMAP. 19 July.
[80] Shrestha *et al*. (2019)

Many large hydropower projects have large workforces that are resident for several years with many construction camps located near to communities. Their presence (often predominantly male, although this is changing) can impact on women's safety and routine activities. World Bank guidance addresses the management of the risks of adverse impacts on communities from temporary project-induced labor influx.[81] It identifies violent and risky behavior resulting from an increase of predominantly male construction workers for large infrastructure projects such as hydropower. Non-local workers can be drawn to the affected area and local workers can have access to relatively high incomes. This can lead to anti-social behaviors (greater alcohol and substance misuse), a heightened risk of sexual exploitation and abuse or sexual harassment,[82] and long-lasting physical and mental health impacts for the community.[83]

Furthermore, a lack of gender diversity within the workforce can limit access for women workers to economic opportunities created by the transition to hydropower. According to the IFC's Powered by Women initiative, which surveyed 20 hydropower companies in Nepal,[84] women make up only 10% of the total number of employees, and only 5% hold technical jobs. Women are inhibited from taking up non-traditional roles in the industry due to various factors: gender stereotyping in the workplace; a lack of women taking up training in science, technology, engineering and mathematics (STEM); a lack of access to formal finance for women-headed businesses; and deprioritizing gender mainstreaming within hydropower companies.[85]

***Employment and labor conditions***

Globally, the numbers of workers employed in the renewable energy sector increased from 8.1 million (1.3 million in hydropower) in 2015 to 12 million in 2020 (2.2 million in hydropower). [86] [87] The Asia and Pacific region had the greatest new hydropower capacity in 2020 (almost 14,500 MW) followed by Europe (just over 3,000 MW) and South and Central Asia (just over 1,600 MW),[88] providing significant employment. The development of a hydropower project can create job opportunities for local people (Box 5.15), as well an opportunity for vulnerable groups and indigenous communities to acquire new skills through working on the project.[89]

**Box 5.15: Long-term employment opportunities in the hydropower sub-sector in the Philippines**

In 2021, a Japanese renewable energy developer invested in the development of a 17.4 MW hydropower project in Ifugao Province in northern Luzon, Philippines. After the completion of construction, the wider and extended portfolio of hydropower projects is expected to provide the region with clean energy and long-term employment opportunities for local communities. In the Philippines, the large and small hydropower sector employed close to 53,600 workers in 2021, and this number continues to rise.

*Source: Rivera (2021)*

[81] World Bank (2016)

[82] Such factors should be combined with an understanding of wider sociocultural risk factors within the country context (i.e., pervasive gender inequality, poverty and discrimination, restrictive social and gender norms) to determine the steps needed to safeguard women and girls from harm. For more guidance, see EBRD, IFC, CDC (2021)

[83] World Health Organization (2021)

[84] See "Powered by Women: Business Case for Gender Diversity and Equality in Nepal's Hydropower Sector" (https://www.ifc.org/content/dam/ifc/doc/mgrt/report-on-business-case-gender-nepal-2020.pdf)

[85] See "New IFC report urges companies to take action to boost women's contribution in the hydropower sector" (https://www.ifc.org/en/pressroom/2020/new-ifc-report-urges-companies-to-take-action-to-boost-womens-co#:~:text=Various%20constraints%20continue%20to%20impede%20women%E2%80%99s%20entrance%20into)

[86] IRENA (2021a)

[87] OECD (2017)

[88] IHA (2021b)

[89] IHA (2021c)

While labor conditions may vary from one hydropower project to another, there is also a possibility that such projects can breach labor rights. It is common for construction monitoring to identify excessive use of overtime, working successive days without required days of rest, and excessive use of temporary or contract workers. The latter can create a two-tier workforce with repercussions for staff morale and workers not being paid correctly or not being correctly signed up for safety net systems.

The need to engage large workforces in remote areas (where hydropower schemes are often located) can lead to companies providing poor working conditions. In such remote areas, labor inspectors may not be able to regularly monitor projects. Some of the International Labour Organization (ILO) Indicators of Forced Labour[90] were frequently breached by companies during the COVID pandemic, e.g., restriction of workers' movements, isolation, abusive working and living conditions, and excessive overtime. They can also be breached by remote, large-scale construction activities such as hydroelectric projects.

One of the key elements of ensuring just renewable energy transition is ensuring that the workforce includes people from marginalized groups.

***Migration***

A hydropower project may lead to an influx of migrants and skilled workers seeking business and employment opportunities. Incoming workers and followers, including job seekers and squatters, can lead to adverse socioeconomic impacts on local communities residing near hydropower projects. According to IFC guidance on project-induced in-migration,[91] this may have a wide range of positive and negative impacts. Positive impacts include, among others, business opportunities, improved range of accessibility to goods and services, higher skill base, and increased local tax revenue. However, these impacts can only happen when a hydropower project is well prepared. In many cases, hydropower companies bring in their own staff, do not train local people, and try not to rely on them because they are not qualified enough.

Negative impacts include, among others, pressure on services and land, demand for and shortfalls in products and services, boom and bust cycles related to the construction phase, tensions and disputes among different groups related to benefit distribution, alteration in existing levels of communicable disease, increased incidents of social vices, and increased potential for domestic and gender-based violence and sexual harassment.

According to the IFC's guidance, the amount of in-migration can be influenced by various factors:

- Larger scale projects lead to a greater impact of in-migration; smaller scale projects lead to a lesser impact of in-migration.
- Low capacity leads to a greater impact of in-migration, high capacity leads to a lesser impact of in-migration.
- A higher concentration of people leads to a greater impact of in-migration, while a lower concentration of people leads to a lesser impact of in-migration.
- Many opportunities for compensation and benefits speculation lead to a greater impact of in-migration; few opportunities lead to a lesser impact of in-migration.
- Projects far from urban centers lead to a greater impact of in-migration; projects close to urban centers lead to a lesser impact of in-migration.
- Migration can cause both socioeconomic and cultural tensions between the local community and migrant workers from other regions or countries, especially if there is displacement of local people, economic loss, and loss of sites and religious or cultural practice of significance due to project development.

[90] Rivera (2021)
[91] IFC (2009)

***Public services and infrastructure***

As indicated in the Section on physical and economic displacement, the resettlement of affected people (e.g., due to the construction of a hydropower reservoir) can increase pressure on the use of the host community's public facilities (schools, clinics, hospitals) and infrastructure.

The IHA guide on people/communities affected by hydropower projects[92] notes that such projects can cause permanent or temporary closures of local infrastructure and services if inundation is required. This may include schools, health centers, shops, roads, bridges, footpaths and tracks, and boat/ ferry transport, transmission and telephone lines, and pipelines. For example, in Sikkim, India, hydropower companies support local area development programs for affected areas through community development projects such as school repair, road and footpath construction, provision of electrification and water supply for villages, and livelihood skill development.[93]

Hydropower projects often fund improvements to, and new, local infrastructure and facilities, not least to support their own workforces (Box 5.16). They also require the construction of new access roads or upgrading of existing nearby roads to transport equipment and for the construction of transmission lines or substations as associated infrastructure. While local communities can benefit from new or upgraded roads, tensions can arise when transmission lines are built, particularly since the electricity generated is not distributed locally (hydropower projects are typically permitted as generating facilities and are not allowed to distribute electricity to local communities). This could be solved by planning early to adjoin to the project a rural electrification program, relying on the energy generated by the project or on rural decentralized systems.

**Box 5.16: Hydropower Project Nam Theun 2, Lao, People's Democratic Republic: Contribution to improved public infrastructure and facilities**

Before the Nam Theun 2 project began, basic infrastructure and public facilities in the remote Nakai District was lacking or inadequate. Even in the dry season, it took half a day or more to travel between the district and provincial capitals. During the wet season, the Nakai Plateau was virtually inaccessible. The average distance to the nearest health facility was 11 kilometers, usually travelled on foot. Initial health surveys reported poor health conditions for both adults and children, high mortality rates for children under five (120.5 per thousand), widespread stunting and malnutrition, and remarkably high prevalence of parasite infection (59%). 63% of the population on the Nakai plateau lacked access to education, a situation that was of even greater concern for women, most of whom were illiterate. Electricity and communication services were not available to most households.

With project support, basic infrastructure and public facilities have improved. Households have access to electricity and telecommunication services, and most households own at least one mobile telephone. Traders and brokers can now access the plateau and northern villages by road to buy fish. Pigs and ducks can now be sold to collectors or at the market. The project supported the construction of new kindergartens, 14 primary schools, and two secondary schools. 90% of the children are currently enrolled in primary school, compared to 37% before. Two new dispensaries provide improved and convenient access to primary health care. In five years, child mortality of those under five decreased from 120 to 59 per thousand.

*Source: Nam Theun 2 dam website. NTPC Document Proforma (namtheun2.com)*

Many hydropower projects will build permanent housing for their operational workforce. But hydropower companies could plan early on to redistribute the worker housing they build to local communities after conclusion of construction. By comparison, other types of renewable energy (in

[92] IHA (2020)
[93] Chandy *et al.* (2012)

particular, wind and solar energy) tend to have smaller operational workforces and construct much less housing, and more of it is temporary.

***Community cohesion and engagement***

Hydropower development projects can have both positive and negative impacts on community relations and engagement. The impacts on community cohesion can include, but are not limited to[94]:

- Impacts to or loss of community resources (e.g., roads, gardens, land, forest, fisheries) and community assets (e.g., community meeting areas, culturally significant features).
- Conflicts between the workforce and the local population and exposure to anti-social behavior.
- Conflicts within the local population. These can arise for a range of reasons, often relating to issues of inequity, including, for example:
  - Access to employment (especially differences in opportunities between ethnic groups – which requires careful management).
  - Compensation measures (which may arise from a lack of clarity on cut-off dates).
  - Eligibility criteria or entitlement provisions (e.g., duration).
  - Access to and extent of training and support.
  - Access to and extent of project benefits.

While the introduction of outsider culture[95] and relationship issues are often raised in hydropower development projects, there are opportunities that projects can improve social relations and engagement (see example in Box 5.17).

**Box 5.17: Conflict over the Grand Ethiopian Renaissance Dam**

The conflict over the construction of the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile River has dragged on for 12 years. Ethiopia has failed to find an amicable solution with Egypt and Sudan, its two neighboring downstream countries, which say the dam threatens to cut off their water supply. But Ethiopia sees the dam as a boon for economic development in a country where half the 120 million citizens live without power. There was a fresh outcry by Egypt in mid-September 2023 after Ethiopia announced that it had finished the fourth and final phase of filling the GERD reservoir.

*Source: Kaledzi (2023)*

***Conflicts and opposition to hydropower projects***

Conflicts can arise over a number of issues as follows:

- Environmental degradation (e.g. from reduced water quality).
- Lack of perceived project benefits accruing to local communities (e.g., access to power and water services).
- Loss of land or access to resources/areas used for livelihoods or cultural activities.
- Working conditions among those employed in construction or operation.
- Downstream impacts due to hydropower activities—changes in environmental flows, impacts on fisheries or water quality.
- Loss of access to important spiritual or cultural sites.
- Tensions between immigrants and local workers/communities.
- Transboundary conflict between states (e.g., over dams restricting water flow. See Box 5.17 and 5.18).

[94] IHA (2020)
[95] Cultural beliefs and practices of immigrant workers who come from outside of the project area.

**Box 5.18: Conflicts over the Portezuelo del Viento Dam, Argentina**

After intermittent starts that date back to the 1950s, Argentina's Mendoza province is preparing to make the Portezuelo del Viento mega-project a reality. The dam in the west of the country promises energy, tourism, and jobs. However, it is a source for conflict with other provinces and social organizations which fear they will run out of water. The dam will be located on the Rio Grande in the department of Malargüe, 300 kilometers from the border with Chile. Its projected height is 185 meters and its reservoir capacity 2,000 cubic hectometers. The project's generating capacity will be 210MW, sufficient to power 130,000 homes.

In addition to the hydroelectric plant, the project involves laying an electric power line, the construction of new sections of National Route 145 (which links Argentina and Chile) and Provincial Route 226, and the construction of a new Villa Las Loicas village, since the original will be flooded. Despite opposition from the government of neighboring La Pampa province, Mendoza is moving forward with the bidding process.

The Grande River is the main tributary of the Colorado River, an important watercourse that runs for 1000 kilometers from the Andes to the Atlantic and crosses five provinces: Mendoza, La Pampa, Neuquén, Río Negro, and Buenos Aires. La Pampa province is opposed to the project, fearing that the dam will reduce the flow of the Colorado River in its territory and affect the quantity and quality of water in the Colorado basin. The province has already initiated several legal actions against Mendoza province and is demanding an environmental assessment throughout the entire Colorado River basin. It claims that Mendoza is not complying with national laws on water management.

The conflict is not new. One hundred years ago, a series of works in Mendoza considerably reduced the volume of water in La Pampa. These included the construction in 1947 of the El Nihuil Dam, which led to the disappearance of the major branches of the Atuel River in La Pampa, forcefully impacting the nearby ecosystem and commercial activities. Nor has Argentina avoided conflicts over mega dams in more recent times. Social and environmental organizations have strongly opposed the construction of the La Barrancosa-Cóndor Cliff hydroelectric complex on the Santa Cruz River in its eponymous southern province.

*Source: Profeta (2021)*