CHAPTER 5

KEY ISSUES FOR SEA IN THE HYDROPOWER SUB-SECTOR

Why is SEA important to the hydropower sub-sector

An overall rational for why it is important to use SEA to support the energy transition is provided in the preliminary sections of 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 socio-economic risks not only at the individual project level but across the 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 country 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; and
- Across all catchments in a country (critical for national energy and hydropower planning).

The SEA process will:

- Identify and focus on key environmental and socio-economic issues and the concerns of likely affected stakeholders, including local communities, marginalised groups, and indigenous peoples. Major issues are discussed in detail in section 5.4 and are summarised 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.

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

- Engage stakeholders (along a river course, in a single or all catchments) – including communities, marginalised groups and indigenous peoples which can be particularly affected by hydropower developments. Stakeholders should to be informed of proposed or possible policy options or plans and they should be given opportunities to provide their perspectives and present their concerns. This will enable key issues to be identified and verified at a basin level and to help build understanding and support for hydropower development and avoid future misunderstanding and possible conflicts.

Section 5.5 discusses the benefits of SEA to the development and implementation of hydropower PPPs.

The steps and methodologies available for use 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 3 and are therefore not repeated in this chapter.

5.1 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 whilst there are numerous guidelines for conducting environmental impact assessments (EIA) for hydropower projects[1].

The report of the World Commission on Dams (WCD 2000) 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 such as social impacts and risks[2,] environment and climate[3], tools[4], indigenous people[5,] health and safety[6], developers and investors[7], affected peoples and livelihoods[8] and infrastructure safety[9.] In 2010, the International Hydropower Association (IHA) published the Hydropower Sustainability Assessment Protocol (HSAP)[10] (updated 2020) which offered 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, labour 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, labour 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.

[1] e.g. REMA 2008; UKEA 2009, IHA 2021c
[2] e.g. Cernea (2004); EIB (2019)
[3] EIB (2019)
[4] e.g. HSC (2020)
[5] e.g. HSC (2022); IHA (2022), IHA (2022b)
[6] e.g. IFC (2018)
[7] e.g. IFC 2015b
[8] e.g. IHA 2020)
[9] e.g. IHA (2021)
[10] Hydropower Sustainability Assessment Protocol

5.2 HYDROPOWER INSTALLED CAPACITY

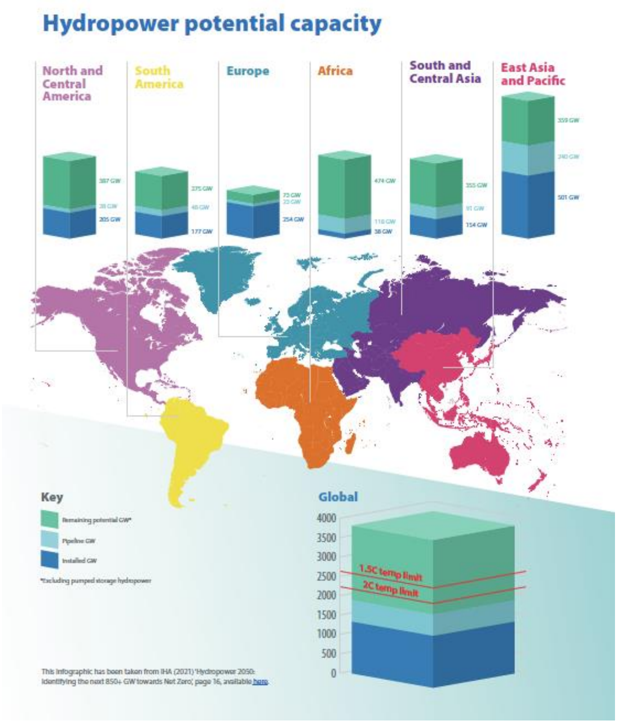
Since 1995, the hydropower sub-sector has more than doubled in size from 625 GW to over 1,300 GW, with China having, by far, the greatest installed capacity (see Table 5.1 and Figure 5.1).

Table 5.1: Hydropower installed capacity in 2021
Source: IHA (2022c)

Country	Installed Capacity (GW)	Country	Installed Capacity (GW)
China	391	Spain	20.4
Brazil	109.4	Vietnam	17.3
USA	101.9	Switzerland	16.8
Canada	82.3	Sweden	16.5
Russia	55.7	Venezuela	15.4
India	51.4	Austria	14.7
Japan	49.6	Mexico	12.6
Norway	33.4	Iran	12.2
Turkey	31.5	Colombia	11.9
France	25.5	Rest of World	268.1
Italy	22.6		
Total			***1360***

According to the International Hydropower Association[11], hydropower generated around 4,300 terawatt hours (TWh) of clean electricity worldwide in 2021; 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 (Figure 5.2). Global hydropower potential is shown in Figure 5.1.

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



11 IHA (2022c)

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 decarbonising the power system and improving system flexibility as other renewable sources are brought on-stream[12].

5.2.1 Application of SEAs in the hydropower sub-sector

A recent international inventory identified 34 SEAs conducted for the hydropower sub-sector during the period 1995 – 2019[13] (Table 5.2). Sixteen (43%) of these were specifically focused on hydropower PPPs, whilst 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.

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.

5.3 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) are renewable energy sources that are not dispatchable due to their fluctuating nature, such as wind power and solar power).

Large-scale hydropower projects can generate and supply large amounts of dispatchable electricity in a consistent manner. Currently. they generate around 16% of the world's electricity[14]. Pumped storage hydropower schemes can also be used as a "battery" by moving water to higher elevations during times of surplus electricity and releasing it through turbines to generate electricity at times of

[12] https://www.iea.org/energy-system/renewables/hydroelectricity
[13] Kolhoff and Slootweg (2021)
[14] IHA (2022c)

high demand. In this manner, pumped storage can support wind and solar projects which have more intermittent generation.

Hydropower projects that include a reservoir can act as a source of flood mitigation in some circumstances, as the reservoir can store peak flows and control the release of water to the downstream river course. However, hydropower projects can have many environmental and social impacts that vary in scale and significance depending on the location, size, and project design.

In addition, hydropeaking (the discontinuous release of turbined water due to peaks of energy demand) causes artificial flow fluctuations downstream of reservoirs. This can result in a series of environmental and social impacts due to flow modifications[15].

5.3.1 Installation types

Hydropower projects come in many different sizes, 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:[16]

- ***Run-of-river hydropower***: a facility that channels flowing water from a river through a canal or penstock to spin a turbine. Typically, a run-of-river project will have little or no storage facility. Run-of-river provides a continuous supply of electricity (base load), with some flexibility of operation for daily fluctuations in demand through water flow that is regulated by the facility.

- ***Storage hydropower*****:** typically, a large system that uses a dam to store water in a reservoir. Electricity is produced by releasing water from the reservoir through a turbine, which activates a generator. Storage hydropower provides base load as well as the ability to be shut down and started up at short notice according the demands of the system (peak load). It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks or even months.

- ***Pumped storage hydropower***: provides peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps which use surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity.

- ***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 only used 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, e.g.[17]:

- Very Large: 5,000 – 10,000 MW, feeding into a large grid;
- Large: exceeding 100Mw, and usually feeding into a large grid;
- Medium: 15 v- 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, and
- Pico: from a few hundred Watts up to 5 kW.

[15] Greimel *et al.* (2018)
[16] https://www.hydropower.org/iha/discover-types-of-hydropower
[17] Classification of Hydroelectric Power Plants (engineeringenotes.com)

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).

5.3.2 Hydropower installation components

The most important components of a hydropower project: dams, spillways, power stations and water ways.

Dams

Dams are the most recognizable features of hydropower facilities. They are constructed to create water storage or diversion that provide a continuous supply of water to turn the turbines. The type of dam depends on a range of factors including:

- Height (or head) of water to be stored;
- Shape and size of the valley at the proposed construction site;
- Geology and geotechnical conditions of the valley walls and floor;
- Availability, quality and cost of construction materials, and
- Availability and cost of labour and machinery.

The ability of a dam to withstand the pressure of water built up behind it depends on its weight and/or shape. The dam also needs to be made of or contain material that prevents water flowing through it.

Spillways

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 over the top. These are not normally appropriate for embankment dams because of the damage that floodwater can cause to loose rock on the downstream side. Spillways on embankment dams take the water around the side of the dam and away from the downstream face. Alternatively, a dam may rely on gates to release water during floods.

Power stations

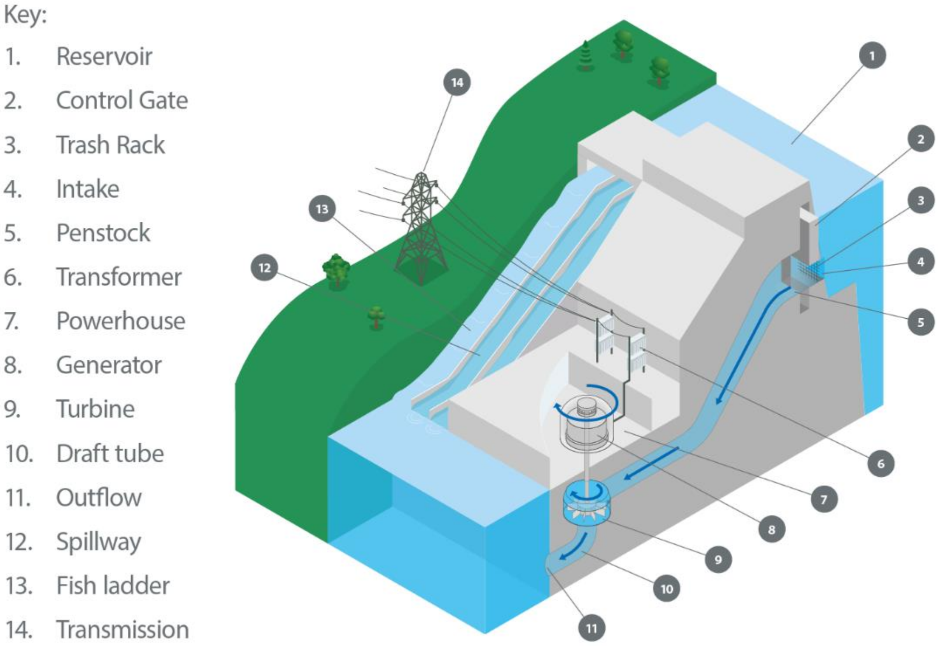
Power stations (or power houses) (see Figures 5.2 and 5.3) contain the turbines and generators that generate electricity from moving water. They may be located near the water storage or up to several kilometres away. Their location is determined by the topography and foundation conditions. The lower part of the power station houses the turbines. Water enters the station on one side, spins the turbines, and flows out the other side. The choice of turbine type will depend on the water quantity and head that it needs to accommodate. Above the turbines are the generators. They are securely fastened to solid concrete foundations. Some power stations are built underground—the decision to do so may be based on a lack of suitable surface sites, or benefits gained by creating extra height (or head) through which the water can fall, or for social or environmental reasons to minimize the impact an above-ground power station would cause.

The downstream placement of the powerhouse can also affect how much of a stretch of river is dewatered below the dam. This can be countered by having an “ecological” flow maintained from the dam to the powerhouse. This involves the flow of the river being returned after passing through and an additional powerhouse placed directly below the dam. Small amounts of electricity may also be generated by this ecological flow to supplant energy generated from the main powerhouse.

Figure 5.2: Inside a hydro powerhouse
(*Sou*rce [Inside a hydropower plant / Hydropower (alley600.eu)])

Image redacted pending securing copyright permission to use. If you have an image showing the components in a hydroelectric plant that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

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



Waterways

Water is conveyed to power stations situated near storages through intakes and down vertical shafts and inclined tunnels (penstocks). Power tunnels are often lined with concrete or steel to maximize integrity and prevent leakage of high-pressure water into the surrounding rock. A 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. Where reservoirs are situated some distance from the power station, channels need to be constructed to carry the water overland. If the topography is relatively flat, open channels are used. In rugged topography, it is cheaper to channel the water through tunnels and pipelines. Above the power station, the overland channels feed water into vertical shafts, power tunnels or high-pressure steel pipes (penstocks). Large towers (surge towers) are often built near the top of these structures and are used as a pressure neutralizer in a hydropower water systems to prevent excess pressure rise and pressure drop conditions during operations[18].

Reservoirs

The configuration of a reservoir is dependent upon the topography where the dam is situated. Reservoirs can vary from large and shallow impoundments covering thousands of square kilometers (e.g., Three Gorges, China; and Itapau, Brazil) to narrow and deep reservoirs that can be up to several hundres of meters in depth (e.g., Lianghekou hydropower station, China). The filling of a reservoir can also destabilize slopes due to the pressure of water in the impoundment, and it may take several years for the reservoir slopes to stabilize.

5.3.3 Grid stability and flexibility

Hydropower production can be adjusted instantly. This enables hydropower to act as a load frequency compensator for irregular solar and wind power, in order to balance electricity supply and demand. Pumped storage HPP systems provide additional flexibility, in particular to absorb surplus of production from renewable sources (provided the generation capacity of the facility is higher than the demand).

5.4 IMPACTS OF HYDROPOWER DEVELOPMENT

During scoping for a 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 3, section). The subsequent assessment phase predicts how achieving the ESQOs will either be impeded or enhanced as a result 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.), 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[19].

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 that might be likely to arise. Implementing a policy, plan or programme (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. A SEA should be focus on the potential for such cumulative impacts to occur and to 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.

[18] https://theconstructor.org/water-resources/surge-tank-types-function/12946/

[19] see International Commission on Large Dams (ICOLD https://www.icold-cigb.org/) and International Hydropower Association (www.iha.org).

Table 5.3 summarises the key environmental and socio-economic concerns, issues, risks, impacts and benefits often associated with individual hydropower project development. In section 5.5, the benefits of SEA for managing impacts of multiple hydroelectric projects are discussed such as:

- Integrated river basin management/coordination
- Cumulative impact mitigation and management.
- Opportunities for cascade management and optimizing hydropower generation across multiple projects and reducing cumulative E&S impacts;
- Data sharing;
- Optimizing environmental flows and opportunities for coordinated flow management, and
- Climate change mitigation and management e.g. GLOFs.

Table 5.3: List of key environmental and socio-economic issues often associated with hydropower projects

ISSUE	COMMENT
Environmental	
Loss of habitats and biodiversity (terrestrial)	• Inundation by dams and reservoirs and loss of important terrestrial habitats • Deforestation (for hydropower sites, dams, roads and transmission lines, and release of stored carbon • Fragmentation of habitats and creation of barriers to wildlife movements • Clearing for access roads and transmission lines and consequent disturbance to migration and increased road kills • Increased poaching and hunting due to increased access to areas • Disturbance to fauna from noise, vibration, and dust from blasting and other construction • Drowning of species during reservoir impoundment • Introduction of invasive species • Changes in diversity or make up of the plant and animal communities due to changes in ecosystems • Impacts on ecosystem services such as trees used for fuel • Submersion of caves used by bats • Impacts on terrestrial fauna from changes to aquatic ecosystem (e.g., loss or reduction of food sources) • Loss of riparian habitat due to erosion • Collision of birds and bats with overhead power lines leading to electrocution
Loss of habitats and biodiversity (aquatic)	• Loss of riparian habitats through inundation or changes to river flow regime • Change from lentic (fresh water) to lotic (moving water) habitat in new reservoir • Dam walls prevent migration of fish to breeding areas • Organic matter decomposition in the base of the dams over time can deplete water oxygen and kill fish and aquatic organisms • Fish killed by powerhouse turbines and/or by tail races/spillways • 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 • Blockage of fish movements • Fragmentation of aquatic systems • Change in sediment and nutrient flows due to river flow changes can affect biodiversity, and can decrease sediment loads downstream

ISSUE	COMMENT
	• Change in riparian habitats due to hydropeaking[20] and aggressive river effects in the event of releases: loss of interface between land and the river due to riverbank erosion • 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 • 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 • 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 • Reservoirs may also be used for irrigation, fishing, supply of water, and for recreational purposes • Changes in nutrient flows and sediment transport leading to indirect loss of agricultural land downstream • Changes in river flow regime leading to less productive agricultural land downstream (e.g., river no longer flooding crops when required) • 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 and sediment runoff into the river • Landslides: ground movements such as mudflows and debris flows that occur due to project construction • Erosion and instability of riverbank or bed (and adjacent areas, e.g., following changes in river flow and geomorphology) • Erosion of rim or boundary of reservoir and increased sedimentation in reservoir • Intense rainfall on cleared land may lead to gullying and increased runoff, erosion, and sedimentation (during construction and in a reservoir catchment) • Changes in the geomorphology of river channels and increased erosional forces downstream due to sediment retention • Increased sediment runoff into rivers or streams at vehicle crossing points during construction • Sediment retention and accumulation over time (e.g., in dam bottom—reducing dam capacity, or locally in riverbeds): • Release of sediment-laden water can cause issues downstream
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

[20] 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
	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.) • Dust from land clearing and construction, vehicles on dirt roads • Dust from exposed areas of dam margin following drawdown operations
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 • Oil or chemical spills during construction or operation • Pollution from the catchment can collect in reservoirs • Release of heavy metals from sediments • Reservoir stratification: separation of reservoir water into oxygenated and deoxygenated zones (due to organic decomposition) and unseasonal temperature water released to downstream • 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 • Organic decomposition: decomposing of organic material during the early years of operation leading to the consumption of oxygen • Decreased air quality during drawdown operations and exposure of reservoir areas • 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 • Contamination of surface and groundwater—particularly during construction • Impacts of degraded water quality downstream • 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 • Reduced water for downstream use (e.g., irrigation, consumption). But sometimes dams/reservoirs are used to supply irrigation water. • Changes downstream: significantly reduce or alter patterns of flow between the intake and the powerhouse • Altered flow regime and sediment flows downstream of the powerhouse • Reservoirs offer opportunity to control floods and manage drought (climate adaptation and disaster-risk reduction).
Greenhouse gases	• Hydropower can reduce GHG emissions where it displaces coal as a fuel source • GHG emissions (carbon dioxide, methane, nitrous oxide) from reservoirs (particularly from decomposition of submerged vegetation) and from vehicles and fuels used in machinery and camps during construction

ISSUE	COMMENT
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 tunneling and excavation activities
Flooding	• Inundation of new areas to create impounded reservoir • Flash floods downstream (due to breaches, overtopping, emergency releases) • Dam break resulting in loss of life, communities, infrastructure and biodiversity, erosion • 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 • Loss of economic and livelihood activities, such as agriculture, animal grazing, fishing • 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. • Opportunities for fishing • Recreational opportunities • 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 and access roads
Employment and labour conditions	• Job opportunities with hydropower companies and their contractors • Loss of jobs with existing enterprises and public administration when people are relocated • Forced labour and child labour on hydropower projects
Health and safety	• Pollution of downstream and upstream areas • Insufficient and poor-quality water quality for worker camps—due to the water source being affected • 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 • Impacts on fish and human health from methyl mercury releases from sediment into the water column and food chain • Increased road traffic accident and fatalities, particularly during construction • Accidental drowning in reservoirs • Risks of dam failure and natural disasters, land slides • Impacts on communities due to rock blasting • Electrical safety incidents

ISSUE	COMMENT
	• Fatalities at the construction site and substandard accommodation of workers. • Pressure on health services (e.g. high demand on essential drugs) during construction • Potential for increase in vectors for human transmissible disease e.g. malaria and schistosomiasis (particularly due to dams)
Migration	• Influx of people looking for work during construction • Tension between immigrants and workers • 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 • Increased domestic and gender-based-violence due to relocation and in-migration of workers to remote areas. • Gender equity and employment opportunities on new projects • Opportunities for vulnerable groups to acquire new skills and learn new technologies • 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 • Pressure on local pre-existing health services and infrastructure, equipment, human resources. due to projects, immigration, accidents during construction, etc. • Increased pressure on the host communities' public services when displaced people relocate • Improvement (investment) to infrastructure (e.g., roads and bridges, schools, health centers, and administrative buildings) • Heavy vehicles and transportation damage existing roads and bridges
Community cohesion and engagement	• Weakened community cohesion resulting from self-relocation and community relocation • Risk of internal conflict due to increased stress as result of lost income • Opportunities for communities to engage in the decision-making processes about hydropower development • Increased tension between the communities, NGOs, activists, and hydropower companies
Conflicts	• Conflicts over: o Lack of perceived project benefits accruing to local communities(e.g. access to power and water services): o Environmental degradation (e.g. from the reduced water quality o Loss of land or access to resources/areas used for livelihoods or cultural activities o Working conditions amongst those employed in construction or operation • Tensions between immigrants and local workers/communities • Transboundary conflict between states (e.g. over dams restricting water flow).

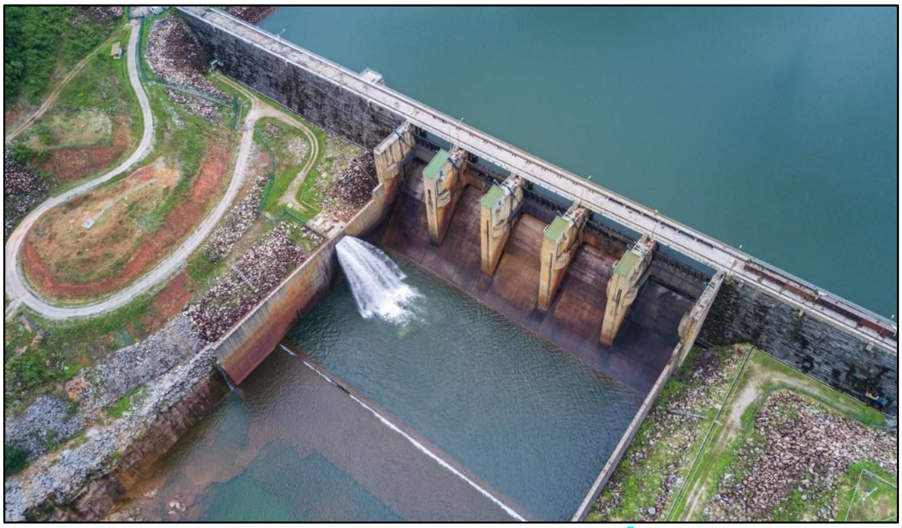
5.4.1 Environmental Issues and Impacts

Hydrology

A hydropower project will normally change the hydrological flow regime of a river. Depending on project design, this may be a significantly reduced or altered pattern of flow between the intake and the powerhouse (typical for run-of-river projects), or it may be an altered flow regime downstream of the powerhouse (typical for reservoir projects). Rivers that are already regulated by either hydropower or irrigation projects can be less sensitive to new hydrological impacts, so it is better to develop projects on rivers or tributaries that are already impacted by flow regulation[21], although 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. So, maintaining low flows at their natural timing and level can maintain the abundance and survival rate of native species (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[22].

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



(Photo credit: A. Javellana/ADB)]

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 reduce disaster-risk. Large reservoirs can provide storage capacity to attenuate water flow during high rainfall events, reducing downstream

[21] Opperman *et al*. (2015)
[22] World Bank (2018).

floods. However, in the unlikely event of a dam break and inappropriate timing of a large release of water can cause downstream flooding, loss of human life and biodiversity, and damage to communities and infrastructure.

Dams/reservoirs also provide opportunities to release water to downstream areas in the event of drought as a climate adaptation response. However, this will also depend upon the availability of upstream flows to maintain reservoir integrity. [need a reference here. Can anyone suggest one?]

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 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 typically cleared of vegetation. This can result in soil erosion and sedimentation of the river, reducing water quality. As a reservoir fills, pollutants in the surrounding soil (e.g., fuels, chemicals, and other substances from previous human activities in the area), can be washed into the reservoir and then the river system. Water quality in the reservoir can be further compromised from upstream contamination sources from industrial and human activity.

When the reservoir is full, the decomposition of dead vegetation is likely to cause an increase in biological and chemical oxygen demand and deplete dissolved oxygen in the water (and may lead to anaerobic conditions), which will reduce water quality, both in the reservoir and in the downstream river. It can also result in releases of methane. 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 humans consuming 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 and methane and can generate 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 the first 5–10 years of operation when most organic decomposition occurs, and a new equilibrium is found.

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[23]. This can improve short-term and long-term water quality in the reservoir and downstream. It can support faster stabilization of the reservoir ecosystem and improve aquatic habitat. Removing large trees improves navigation by local people and removes a risk for net fishing and development of fisheries. However, the benefits

[23] Strengthening Environment Management-Phase II. 2010. Environmental Guidelines for Biomass Removal from Hydropower Reservoirs in Lao PDR. Vientiane. http://monre.myqnapcloud.com/2017/emsp/images/doc/c2/biomassremovalfinal_6.pdf

need to be assessed on a case-by-case basis—it may not always be desirable or effective (Box 5.3)[24].

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–benefits balance of systematic vegetation clearance was an unfavourable 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 many contexts' removal of trees over a certain size is selected as the best compromise.

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

Photo credit: Peter-John Meynell

Source: Salignat, O., Descloux, S., Chanudt, V. To clear or not to clear vegetation prior to impoundment? Feedback experience on the Nam Theun II Reservoir (Lao PDR). Conference paper. https://www.researchgate.net/publication/259640331_To_clear_or_not_to_clear_vegetation_prior_to_impoundment_Feed-back_experience_on_the_on_the_Nam_Theun_II_reservoir_Lao_PDR.

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 upstream.

[24] HSC (2020)

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 on aquatic species, as can the flushing of sediment (see next 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 impact on 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 quality access roads are built.

In the operation 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.

As the dam captures sediment, the sediment load in the river downstream of the reservoir is 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 (armouring), 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 armour layer, whereas in sand bed rivers the erosion will be more dynamic (IHA 2019).

Increased sediment load in the river 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).

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.

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

(Photo credit: G. Joren/ADB)

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, 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 may 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.[25] 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.

In the operational phase, 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.

[25] IFC (2015b)

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). Run-of-river projects will often divert water around a stretch of river many kilometres long. Such a by-passed 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 up 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 passes (ladders) can mitigate the impact, but these may not be possible in high elevation dams.

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 pressure being placed on 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.[26] [27].

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 a 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.

Such impacts will usually lead to demand for and need for land and ecosystem restoration (see Box 3.9). 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.

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.

[26] IFC (2018)
[27] EBRD (2017)

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 the USA, currently underway in the state of Washington's Olympic National Park, 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.

Figure **: Elwha and Glines Canyon hydroelectric dams map

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Construction on 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 built 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 in to 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 21st-century, fewer than 4,000 adult salmon returned each year.

The Elwha Restoration Act of 1992 authorised 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 metres 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 is 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 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 revitalise tribal culture, traditions and previously sum and old traditions age-old traditions and previously submerged sacred sites.

Source: World's biggest dam removal and restoration project (water-technology.net)

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 sufficients 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 waste 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 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.

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 Company. 2015. Environmental and Social Management Plan. Lahore. https://epaajk.gok.pk/uploadfiles/downloads/Updated%20ESIA_Karot%20HPP_%20Report2-compressed.pdf

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 such that it no longer provides flood water to crops when required. Flood water sediment is important for agriculture because it often 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.[28]

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.

Greenhouse gases

Some reservoirs can be a source of methane and carbon dioxide, which are greenhouse gases (GHG). It 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 about 25 times more effect on climate 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.[29]

Hydropower projects do emit GHGs. However, the many myths around GHG emissions and hydropower projects have been addressed by IHA including tropical reservoirs emit more GHGs and 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[30].

[28] IFC (2018)
[29] IHA https://www.hydropower.org/blog/carbon-emissions-from-hydropower-reservoirs-facts-and-myths
[30] https://www.hydropower.org/blog/carbon-emissions-from-hydropower-reservoirs-facts-and-myths

Climate vulnerability, and dam and community safety

Hydropower is considered highly vulnerable to climate change[31] as it is directly related to precipitation patterns, behaviour of snow-caps and glaciers, and resulting changes in (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.

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) 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 climate change 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)[32].

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

In the preparation 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.

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

During the operational stage, there will be continuing risks of electric shock, accidental drowning, and road accidents.

[31] Sixth Assessment Report — IPCC

[32] https://www.scientificamerican.com/article/glacial-lakes-threaten-himalayan-dams/

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 and Cambodia's Stung Treng province, which lies downstream of the dam. 49 people died and 22 were missing 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.

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

Image redacted pending securing copyright permission to use. If you have an image showing the components in a hydroelectric plant that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Source: International Rivers. The Xe Pian-Xe Namnoy Dam Disaster: Situation Update Two Years On. https://www.internationalrivers.org/wp-content/uploads/sites/86/2020/08/ir-factsheet-2_year_xe_pian_dam_collapse_1_0.pdf.

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.[33]

Transboundary impacts associated with hydropower projects

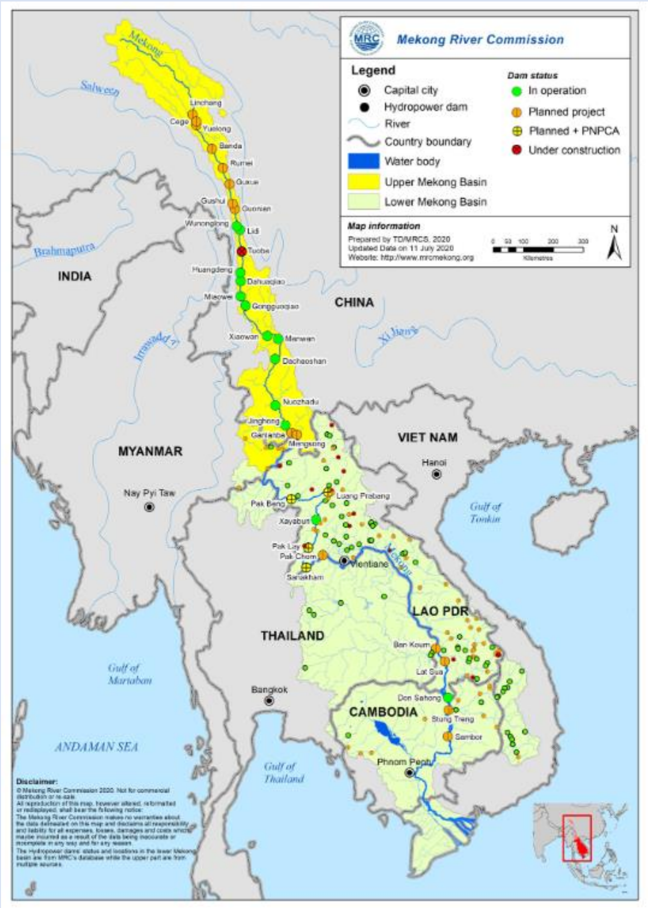
Hydropower projects can have impacts beyond national boundaries if they change the flow regime of a river that runs from one country to another. It is important that potential impacts are considered on a broad spatial and temporal scale. These can include changes to: a river's hydrological regime, its 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 a hydropower project are irrigation schemes, water supply projects, wetlands, and fisheries. This issue is particularly relevant when a river runs through several countries, e.g., the Mekong River in Southeast Asia (Box 5.8).

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[34] [35].

[33] IFC (2018)
[34] IFC (2015b)
[35] Young and Ear (2021).

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 5.8.



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 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 gor Sustainable Development. Hydropower. https://www.mrcmekong.org/our-work/topics/hydropower/.

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

Mini-hydropower dams are often “invisible” for EIA/ESIA (i.e.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 environmental flows (E-flows), concentrating cascade hydropower projects in one area of the watershed, conducting basin wide monitoring during project operations, and providing for the continuation of intact drainages in the watershed, free of any hydropower intervention (aquatic offsets)[37] [38].

5.4.2 Socioeconomic Issues and Impacts

Physical and economic displacement

Some hydropower projects cause economic and physical displacement of riparian communities and settlements[39]. Economic displacement is defined as the loss of assets, access to assets, or income sources or 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.[40] 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[41].

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 5.9) 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[42].

Box 5.9 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 (Figure 5.9), was completed in 2006 – at the time, it was the largest dam structure in the world. The dam and accompanying hydroelectric plant were built in phases and over the course of

[36] Slootweg (2023)
[37] Managing Environmental and Social Impacts of Hydropower in Bhutan
[38] World Bank (2016c)
[39] Cernea, M. M. (2004).
[40] IHA (2020)
[41] WCD (2000)
[42] WCD (2000)

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 (possible 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 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[43]. This created problems for many as the cities and towns they had to move to were more expensive, driving many people deeper into poverty (Yardley 2007), landlessness, joblessness, marginalization, and food insecurity[44]. The displaced were often farmers with little formal education, if any. Many opted to return to the Yangtze region.

Figure 5.9: Three Gorges Dam, China
Source: The New Scientist

Image redacted pending securing copyright permission to use. If you have an image showing the components in a hydroelectric plant that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Flooding the reservoir has forced those farmers still in the region to migrate northwards up the mountain slopes, adding to erosion through over utilization 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:
https://www.britannica.com/place/China
Environmental and Social Issues of the Three Gorges Dam in China (mandalaprojects.com)
Gleick (2009)
Hvinstendahl (2008)

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.[45]

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.[46] 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

[43] Hvinstendahl (2008)
[44] Gleick (2009)
[45] Cernea (2004)
[46] Young and Earl (2021).

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 socio-economic 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.

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, SHARE[47] concept was developed as a framework to address such potential conflicts[48] It 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 amongst all users and uses[49].

Indigenous communities

The development of a hydropower project may cause both positive and negative impacts on indigenous communities and people. The IFC’s Performance Standard 7 and the ADB’s SPS (2009) on Indigenous Peoples 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 [50], a major negative impact can often be loss of land under traditional use. This could be land for which their jurisdiction and management may have been previously removed by national governments. Impacts on IPs 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 loss of cemeteries, or reduction of their territory, and
- 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 5.10 provides examples of cases in which indigenous peoples have been displaced and affected by hydropower projects.

Box 5.10: Indigenous peoples affected by hydropower projects: some examples

Many indigenous groups protest against hydropower projects and denounce 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

[47] S: Sustainability approach for all users, H: Higher efficiency and equity among sectors, A: Adaptability for all solutions, R: River basin perspectives for all, and E: Engaging all stakeholders.
[48] Branche (2017)
[49] Branche (2017)
[50] IHA (2022)

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]

In Indonesia, displacement of indigenous people due to hydropower development projects are 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, and alleviating the work burden on women as well as providing other community benefits. Groups like ‘Grupo Yansa’ provide support to indigenous communities interested in developing the renewable energy potential of their land.[51] [52] In Canada, some indigenous peoples’ groups are partnering with the private sector to develop and operate large energy projects [53] [54].

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 [55]:

- Increased safety by having flood control and regulated flows;
- Support 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, and
- 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[56] . 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.

[51] Shah and Bloomer (2018)
[52] UNDESA (2021)
[53] CHA (2018)
[54] https://www.amazon.ca/Aboriginal-power-energy-Canadas-peoples/dp/1927506190
[55] IHA (2022b)
[56] Muskrat Falls jobs. Nalcor Energy. Accessed October 2013.

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 neighbour policy, and to provide a competitive advantage to meet consumer demand for ethically produced products[57]. 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 fairly negotiated benefit-sharing agreement is an important step forward that will help reconciliation efforts and shared hydropower project benefits with indigenous peoples.

Health and safety

Community health and safety issues are associated with hydropower development during both the construction and operational phases.[58] The IHA's guide [59] 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.

During the construction phase, the large amounts of heavy vehicle movements can also increase road traffic, affect road, and bridge conditions, and cause accidents. A major issue is the excavation of large quantities of soil and rock, drilling and creation of tunnels. Such 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.[60] These risks are exacerbated in low-income countries in Southeast Asia where water quality regulatory enforcement remains limited. In addition to health risks, 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[61].

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), increased drug and alcohol use and the potential for increased 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 5.11).

Hydropower projects usually involve the use of heavy goods vehicle fleets to transport materials and staff on-site. In many cases, hydropower projects require 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,

[57] Woodward & Company (undated)
[58] Acakpovi and Dzamikumah (2016)
[59] IHA (2021)
[60] NCEA (2018)
[61] https://en.wikipedia.org/Dhauliganga_Dam

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, a hydropower project can cause traffic related congestion, accidents, and fatalities.

Box 5.11: Karot Hydropower Project in Pakistan

Karot Hydropower Project is located on the Jhelum river in Pakistan and is nearing completion. 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 International Finance Corporation ([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.

Figure 5.10: Karot Hydropower Project, Pakistan
Source: CPEC https://cpec.gov.pk/project-details/16

Source: Business and Human Rights Resource Center (2021)

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); and
- Intangible forms of culture, such as cultural knowledge, innovations, and practices of communities embodying traditional lifestyles[62].

The Hydro Sustainability Secretariat[63], 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,

[62] IFC (2021)
[63] HSC (undated)

and groundwater and river flow changes. Construction activities may also be perceived to disturb spirits associated with special sites[64].

During project operation, impacts on cultural heritage may include the loss of sites inundated by a reservoir (Box 5.12). downstream damage to cultural sites (e.g., through riverbank erosion or flooding)

Box 5.12: 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.

Figure 5.11: Bujagali Hydropower Project

Image redacted pending securing copyright permission to use. If you have an image showing the components in a hydroelectric plant that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Source: Kabanda Umar and Francis Mwesigye. 2021. Cultural Heritage and Renewable Energy: How Bujagali Hydro-Electricity Generation Project sparked a latent conflict. https://blogs.prio.org/2021/06/cultural-heritage-and-renewable-energy-how-bujagali-hydro-electricity-generation-project-sparked-a-latent-conflict/

and interruption of ability to continue cultural traditions (e.g., in particular locations) or access specific sites due to changes arising from the project)[65].

Hydropower projects tend to be in remote areas where land is often claimed or occupied by vulnerable indigenous communities. The acquisition of land for the project can displace these communities and their cultural practices, such as sacred sites on land, in forests or in water.

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.[66]

The IFC's Performance Standard on Cultural Heritage (PS8)[67] 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. 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 [68].

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

[64] HSC (undated)
[65] HSC (undated)
[66] UNESCO (2021)
[67] www.ifc.org
[68] IHA Website notification September 2021. International Hydropower Association announces new commitment to World Heritage sites and protected areas - UNESCO World Heritage Centre.

tourists find them acceptable and desirable[69]. 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

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 shows that[70] 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, fodder, and must then deal with increasing workloads.

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 labour influx.[71] It identifies violent and risky behaviour 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 behaviours (greater alcohol and substance misuse), a heightened risk of sexual exploitation and abuse or sexual harassment[72], and long-lasting physical and mental health impacts for the community [73].

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[74], 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 [75].

Employment and labour 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) [76] [77]. 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)[78], providing significant employment. The development of a hydropower project can create job opportunities for local people

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[69] Saeporsottir and Hall (2018)

[70] Shrestha *et al.* (2019)

[71] World Bank (2016)

[72] 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)]

[73] See World Health Organisation (2021) https://www.who.int/news/item/25-11-2021-gender-based-violence-is-a-public-health-issue-using-a-health-systems-approach [Accessed 22/03/2022]

[74] IFC (2020)

[75] IFC. Bringing Gender Equity into Hydropower Development from the Start. https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/bringing+gender+equity+into+hydropower+development+from+the+start

[76] IRENA (2021a)

[77] OECD (2017)

[78] IHA (2021b)

(Box 5.13), as well an opportunity for vulnerable groups and indigenous communities to acquire new skills through working on the project[79]. Often, there are gender gaps with women significantly underrepresented (Box 5.14).

Box 5.13: 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[80], the large and small hydropower sector employed close to 53,600 workers in 2021, and this number continues to rise.

Source: Rivera (2021)

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) [81]. 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 underrepresentation 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.

While labour conditions may vary from one hydropower project to another, there is also a possibility that such projects can breach labour 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, 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, labour inspectors may not be able to regularly monitor projects. Some of the ILO Indicators of Forced Labour[82] 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.

[79] HSC (2022)
[80] INFRACOASIA (2021)
[81] 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.
[82] Rivera (2021)

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[83], 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. 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 harrassment.

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

- Larger projects lead to a greater impact of in-migration; small 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;
- High concentration leads to a greater impact; low concentration 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 centres lead to a greater impact of in-migration; projects close to urban centres lead to a lesser impact of in-migration, and
- 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.

Public services and infrastructure

Hydropower projects often fund improvements to and new local infrastructure and facilities, not least to support their own workforces (Box 5.15). 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 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).

Box 5.15: 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 kilometres, 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.

[83] IFC (2009).

> 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 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. By comparison, other types of renewable energy (in particular, wind and energy) tend to have smaller operational workforces and construct much less housing, and more of it is temporary.

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 people/communities affected by hydropower projects[84] notes that such projects can cause permanent or temporary closures of local infrastructure and services if inundation is required. This may include schools, health centres, 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 [85].

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[86]:

- 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 behaviour, and
- Conflicts within the local population. These can arise for a range of reasons, often relating to issues of inequity, including, for example: 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; and access to and extent of project benefits.

While the introduction of outsider culture 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).

Conflicts

Conflicts can arise over a number of issues, e.g.:\.:

- o Environmental degradation (e.g. from reduced water quality

[84] IHA (2020)
[85] Chandy *et al.* (2012)
[86] IHA (2020)

- 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 amongst those employed in construction or operation;
- Downstream impacts due to hydropower activities – changes in environmental flows, impacts to fisheries, water quality impacts;
- Loss of access to important spiritual or cultural sites;
- Tensions may arise between immigrants and local workers/communities, and
- There can be transboundary conflict between states (e.g. over dams restricting water flow).

Reviewers: Can you provide any case example boxes on conflicts?

5.5 HOW SEA CAN BENEFIT THE HYDROPOWER SECTOR

Section 5.4 focuses on the environmental and socio-economic 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 summarises how SEA can address the issues and benefit three different stages in the preparation and implementation of hydropower PPPs - planning, assessment, and management.

5.5.1 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, in reality, 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 very early on in hydropower PPP preparation process, SEA offers the following benefits:

- Considers alternatives (within hydropower) and 'to' hydropower development – through broadscale and inclusive stakeholder consultations that allows that the most desirable alternative basin / energy development pathways to be selected, Thus, SEA helps to identify alternative water driven development pathways for socio-economic development and energy demand planning at basin level.
- Identifies locations suitable 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;
- Supporting 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.
- 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);
  Supporting cascade development planning for siting optimization;
- Improving hydropower and energy policies pertinent to hydropower development;
- Increasing the efficiency of multi-level institutional review and coordination of sector development;
- Directing spatial planning for the optimal coordination of other land uses, and
- Identifying specific issues for stakeholder engagement planning and strategies for effective consultation and communication for the sub-sector.

5.5.2 Assessment

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

- Optimises 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, nature conservation, recreation as well as other hydropower plants, including transboundary aspects). SEA defines and priorities water uses (including for the environment) during times of water shortages. It elaborates different water use scenarios to maximise water use outcomes that will benefit assist decisions on specific investments[87].
- Integrates consideration of climate change and sensitive areas - important factors in assessing 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.

5.5.3 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;
- Identifies where institutional capacity needs to be developed for the effective implementation of SEA and SEMP recommendations;
- 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, and
- Improves private sector involvement in addressing environmental and socio-economic concerns by providing a higher level strategic approach to managing relevant environmental and social risks beyond the project level.

[87] Slootweg (2023).