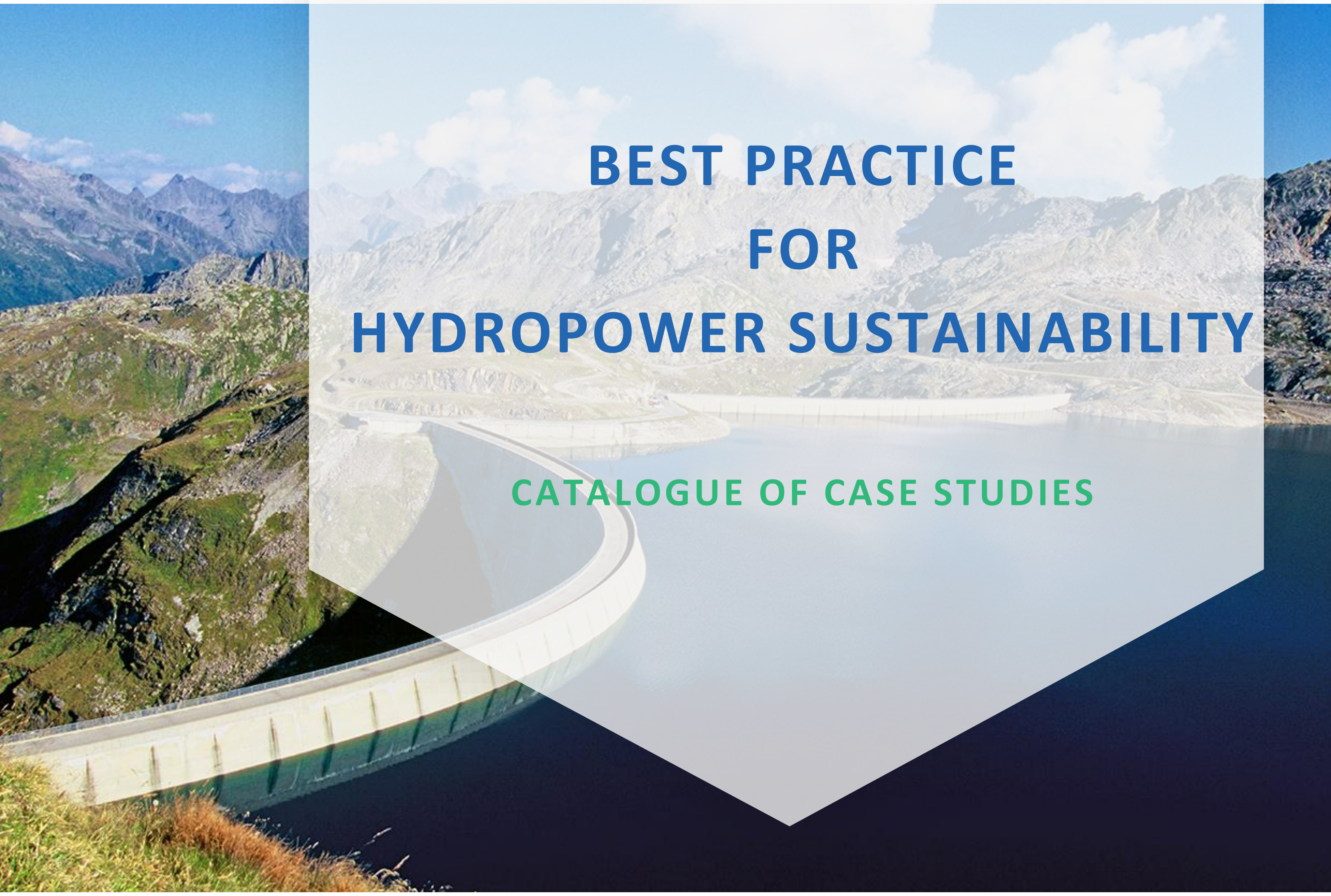
BEST PRACTICE FOR HYDROPOWER SUSTAINABILITY

CATALOGUE OF CASE STUDIES



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Summary

This report consists of identifying best practice for hydropower sustainability and providing a catalogue of examples.

In this document, best practice is practice which has enabled top environmental or/and social performance or has been successfully applied to solving conflicts of interest for environmental mitigation, and water management.

After reviewing the evolution of the relationship between hydropower and society, the role of ETIP HYDROPOWER in sustaining the Green Deal and Clean Energy Transition is introduced.

Sustainability was defined by the United Nations in 1987 as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. Corporate sustainability is a business approach that helps companies create long-term stakeholder value while ensuring accountability. To reach global sustainability in 2030, the United Nations adopted the 2030 Agenda for Sustainable Development in 2015, a shared blueprint for "peace and prosperity for people and the planet", thanks to the achievement of 17 world Sustainable Development Goals.

While sustainable hydropower is a driver for 7 of these Sustainable Development Goals and contributes to climate change mitigation, which benefits global biodiversity, it does so at the risk of local ecological cost unless implemented with stringent conservation measures and best practices. Several guides to address key local ecological impacts are reviewed: the Hydro Fit solutions, the Eurelectric guidebook, and the guide to monitor lakeshore.

To achieve consensus in decision making, a structured and inclusive process must ensure all participants are heard, differences are addressed, and the group agrees on shared objectives, even if not everyone fully prefers the solution, but all can accept it. Several pathways are reviewed: the Share concept, the ICOLD recommendations, the World Bank Water Resource Strategy, the Strategic Environmental and Social Assessment, and the Hydropower Sustainability Standard launched by the Hydropower Sustainability Alliance. The Hydropower Sustainability Standard defined 12 sustainability topics that cover the environmental, social, governance and climate change aspects detailed with their performance requirements.

The catalogue of best practice shows 18 examples of win-win situations between all stakeholders. These examples can improve public acceptance of hydropower and help allow the industry to reduce the risks of investment.

Acronyms

CBA	Cost-Benefit Analysis
CO2	Carbon Dioxide
CSO	Civil Society Organisation
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ENTSO-E	European Network of Transmission System Operators for Electricity
EQI	Environmental Quality Index
ESIA	Environmental and Social Impact Assessment
ETIP	European Technology and Innovation Platform
EU	European Union
EUR	Euro (currency)
GW	Giga Watt
HEP	Hrvatska Elektroprivreda
HSA	Hydropower Sustainability Alliance
HSAP	Hydropower Sustainability Assessment Protocol
HSS	Hydropower Sustainability Standard
IAIA	International Association for Impact Assessment
IHA	International Hydropower Association
ICOLD	International Commission on Large Dams
IPCC	International Panel on Climate Change
IUCN	International Union for Conservation of Nature
KXP	Kaunertal Expansion Project
NGO	Non-Governmental Organisation
NVE	Norwegian Water Resources and Energy Directorate
PSH	Pumped-Storage Hydropower
RIA	Research and Innovation Agenda

RoR	Run-of-River
SDG	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SESA	Strategic Environmental and Social Assessment
SET Plan	Strategic Energy Technology Plan
SIR	Strategic Industry Roadmap
SMHI	Swedish Meteorological and Hydrological Institute
TIWAG	Tiroler Wasserkraft AG
TNC	The Nature Conservancy
TWh	Terawatt
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCD	World Commission on Dams
WWF	World Wildlife Fund
WEFE Nexus	Water-Energy-Food-Ecosystem Nexus
ZAMG	Zentralanstalt für Meteorologie und Geodynamik

1 INTRODUCTION

1.1 Purpose

This report is a **deliverable of ETIP HYDROPOWER**. It consists of identifying best practice for hydropower sustainability and disseminating this in a catalogue.

In this document, **best practice** is practice which has enabled top environmental or/and social performance or has been successfully applied to solving conflicts of interest on environmental mitigation, and water management.

The idea came from the wider consultation of the HYDROPOWER EUROPE forum:

- "*Collect a Catalogue of Examples of Best Practice of Successful Multi-Purpose Projects Creating a Win-Win Situation Between All Stakeholders*" and "*develop Methodologies to Create Win-Win Situations Between All Stakeholders of Multi-Purpose Projects*" were considered by the stakeholders as very high priority actions to increase social awareness.
- *"Collect a Catalogue of Best Examples of Biotope Creation and Restoration through Uprating of Existing Hydropower or New Projects"* was considered by the stakeholders as a very high priority action to develop Environmental Mitigation Measures.

This idea was reinforced after a round table between NGOs and the HYDROPOWER EUROPE forum organized on the 19th of January 2021, where the issues raised by the NGOs concerned mainly small hydropower projects on not yet tapped rivers, especially in the Western Balkans which are still in a good natural state and have a vulnerable biodiversity. The witness of so-called hydropower "Bonanza", ongoing above all in the Balkan area, was alarming and very harmful to the overall image of the EU hydropower sector, especially small hydropower, not only in Europe but also worldwide. Many small hydropower projects presented during the roundtable obviously haven't been designed and built according to the high standards as used for hydropower in other European countries where plant owners have to comply with provisions of the Water Framework Directive to ensure that they are technically sound and safe, environmentally defendable and socio-economically beneficial. In many Balkan countries the political and legislation framework does not request and enforce the highest standards, and private investors are taking advantage of a kind of "Wild West" situation.

In essence, the purpose of this formalised catalogue of best practice is to:

- promote win-win situations between all stakeholders;
- improve public acceptance of hydropower; and
- allow the industry to reduce risks of investment.

1.2 Historical relationship between hydropower, society and nature

To understand the current situation of the management of hydropower externalities, it is useful to take a look at the four main periods of hydropower development.

1.2.1 1870-1980 Hydropower, the backbone of industrialization

At the end of the 19th century, and at the turn of century, in the early 1900s, hydropower closely linked with development. It was the most cost-effective, independent and reliable way to meet a growing electricity demand. The deployment of hydroelectric plants boosted the electrification of cities and the development of industry.

In the middle of the 20th century, after the Second World War, the industrial and economic recovery of Europe was based on massive dam and hydropower plant development. Hydropower was not only a unique renewable energy, but a large contribution to the social and economic development fostering regional growth, with irrigation and drinking water provision, flood and drought risk management, river navigation and recreation, roads and bridges constructions, and fisheries.

At that time, hydropower projects were viewed as emblems of progress. No major questions were being asked about their sustainability performance.

1.2.2 1980-2000 Critics and the World Commission of Dams

At the end of the twentieth century, hydroelectricity became a victim of its own success: several projects around the world were developed in an irrational, bureaucratic manner, without consultation or consideration for the environment. Many projects around the world were halted due to concerns about their potential negative impacts.

This extreme situation lead some financial organizations (for example World bank) to reassess the role of hydropower in development and to push for increased understanding of the environmental, social and governance impacts of the sector.

In 1996–1997, the World Bank's internal review of its dam portfolio along with growing criticism from NGOs and affected communities pushed the Bank to assess the global evidence base on large dams, rather than only examining individual case projects. Together with the International Union for Conservation of Nature (IUCN), it convened a multi-stakeholder workshop in Gland, Switzerland, where participants agreed that a commission on dams should be established to review the worldwide development performance of large dams, looking at their social, environmental, and economic costs and benefits, including how they affected displaced and downstream communities. A second task was to assess alternatives for meeting water and energy needs, including non-dam options and different ways of operating existing dams, in order to understand whether large dams were the most effective option in particular contexts and to highlight the numerous impacts of dams, including hydropower.

The final report (2000) recommended to study all other options and provided a set of strategic priorities if dams could not be avoided [25]. However, the climate change impact was underestimated, and one of the outcomes was that the World Bank gave advantage to finance thermal power stations rather than hydroelectric plants and their dams during the first years of the third millennium.

1.2.3 2000-2019 Making sustainable hydropower the norm

Since 2000, EU Directives in the European Union put a stop to excess and unsustainable abuses, while International organizations in the world provided recommendations.

a) 2000, The EU Water Framework Directive (WFD)

The **Water Framework Directive** (WFD) established a comprehensive legal framework aimed at protecting and restoring the ecological and chemical status of all water bodies across the EU. Its implementation has had significant implications for both the construction and management of dams. New hydropower projects must now comply with rigorous environmental requirements before being approved. This includes assessing their impact on river basins and aquatic ecosystems, and ensuring that they do not prevent the achievement of "good ecological status" for a river as mandated by the WFD. Article 4(7) of the WFD allows certain exceptions, but only under strict conditions, requiring clear demonstration that all practicable mitigation measures have been taken, and that the project's benefits outweigh environmental costs. Existing hydropower operations are subject to review and, where necessary, permit updates to align with ecological needs and WFD objectives leading sometimes to modifications such as installing fish passages, ensuring adequate compensation flows, and reversing changes that degrade water body health. The WFD introduced Holistic River Basin Management, which requires all activities (including dams) within a river basin to be assessed for their cumulative environmental impacts. Reservoirs must be managed so as to not prevent water bodies from reaching good status or potential. Measures must be adopted to address the fragmentation of rivers caused by dams and to reconnect ecosystems wherever possible. The WFD is legally binding and its requirements have been upheld by the Court of Justice of the EU, reinforcing the obligation of Member States to prevent any further deterioration of water bodies, and making it much more difficult to justify projects that would fragment rivers or disrupt aquatic life. The WFD has modified hydropower investments in the EU by embedding ecological considerations into permitting processes, promoting river basin management approaches, and necessitating environmental improvements in hydropower operations, leading to more environmentally responsible but potentially costlier and more complex investments.

b) 2001, the EU Strategic Environmental Assessment (SEA) Directive (2001/42/EC)

The **Strategic Environmental Assessment** (SEA) is a legislative framework that requires an environmental assessment to be carried out for certain public plans like hydropower deployment. Its main objective is to provide a high level of environmental protection and to ensure environmental considerations are integrated into policy-making at an early stage, promoting sustainable hydropower across the European Union. The main steps in the SEA process are:

1. **Screening**: Determines whether a plan or programme requires an SEA based on its potential environmental effects.
2. **Scoping**: Defines boundaries for the assessment and collects baseline environmental data.
3. **Preparation of the Environmental Report**: Identifies, describes, and evaluates the likely significant environmental effects and reasonable alternatives.
4. **Public consultation**: Engages the public and environmental authorities to gather feedback on the draft plan or programme and its environmental report.

5. **Decision making**: Considers findings from the environmental report and consultation before adopting the plan or programme.
6. **Monitoring**: Tracks the significant environmental effects of the implemented plan or programme and adjusts as necessary.

The SEA is for national strategic policies and plans, aiming to consider environmental factors early in broader decision-making. It requires that an Environmental and Social Impact Assessment (ESIA) focuses on any hydropower project, evaluating its environmental and social impacts in detail before implementation.

c) 2010 IHA launched the Hydropower Sustainability Assessment Protocol

The Hydropower Sustainability Assessment Forum launched by IHA published a sustainability assessment framework called the Hydropower **Sustainability Assessment Protocol**, that represents the views of all relevant hydropower stakeholders. The HSAP supports hydropower developers over the world to implement better practices and increase the sustainability performance of their projects. In 15 years, it has been used officially in over 25 countries.

d) 2015 the World Water Council SHARE concept

In 2015, the SHARE concept for hydropower project development is a framework aimed at achieving sustainable management of multipurpose hydropower reservoirs through principles of shared governance and cooperation among all stakeholders. The SHARE concept emphasizes participative, multi-stakeholder governance to balance competing water uses (energy, agriculture, environment, recreation, etc.) and to promote sustainability, efficiency, equity, and adaptability at the river basin scale. It is meant to guide all phases of reservoir development from early planning through operation, encouraging integrated water management and co-financing approaches. EDF actively applies SHARE to large-scale reservoir projects to foster collaboration and integrated outcomes benefiting energy production, ecosystem services, and local communities.

e) 2018 the IHA ESG gap analysis tool

In 2018, another supporting IHA resource was developed based on the good practice requirements defined in the assessment protocol: an **ESG gap analysis tool** associated with a set of good practice guidelines and aligned with the environmental and social standards of the World Bank Group.

f) 2019 the IPBES report

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an independent intergovernmental body comprising over 130 members Governments. Established by Governments in 2012, IPBES provides in May 2019 scientific assessments about the state of knowledge regarding the planet's biodiversity, ecosystems and the contributions they make to people, as well as options and actions to protect and sustainably use these vital natural assets [22].

IPBES provides policymakers with the following key messages:

A. Nature, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide.
B. Drivers of change have accelerated during the past 50 years.
C. Goals for conserving and sustainably using nature and achieving sustainability for 2030 and beyond may only be achieved through transformative changes across economic, social, political and technological factors.
D. Nature can be conserved, restored and used sustainably while other global societal goals are simultaneously met through urgent and concerted efforts fostering transformative change.

IPBES [22] illustrates approaches for sustainability and possible actions and pathways for improving freshwater management, protection and connectivity:

- Integrating water resource management and landscape planning, including through increased protection and connectivity of freshwater ecosystems, improving transboundary water cooperation and management, addressing the impacts of fragmentation caused by dams and diversions, and incorporating regional analyses of the water cycle.
- Supporting co-management regimes for collaborative water management and to foster equity between water users (while maintaining a minimum ecological flow for the aquatic ecosystems), and engaging stakeholders and using transparency to minimize environmental, economic and social conflicts.
- Increasing water storage by facilitating groundwater recharge, wetlands protection and restoration, alternative storage techniques and restrictions on groundwater abstraction.
- Promoting investment in water projects with clear sustainability criteria.

The expansions of roads, cities, hydroelectric dams and oil and gas pipelines can come with high environmental and social costs, including deforestation, habitat fragmentation, biodiversity loss, land grabbing, population displacement and social disruption, including for indigenous peoples and local communities (established but incomplete). Yet infrastructure can generate positive economic effects and even environmental gains, based on efficiency, innovation, migration, and urbanization, depending on where and how investment is implemented and governed (well established). Understanding this variation in impacts is critical.

1.2.4 2019-2050 Sustainable hydropower as a pilar of the Clean Energy Transition

a) 2019 - EU Green Deal Strategy

The EU Green Deal is the European Union's comprehensive climate and growth strategy aimed at making Europe the first climate-neutral continent by 2050.

Launched in 2019, the Green Deal consists of a package of policy initiatives, which set the EU on the path to a **green transition**, with the ultimate goal of reaching **climate neutrality by 2050**. It involves reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and decoupling economic growth from resource use while ensuring a just and inclusive transition that leaves no one behind (Figure 1.1).

The Green Deal Industrial Plan increases funding opportunities for decarbonization, innovation, renewable energy, and infrastructure through instruments such as the EU Innovation Fund, REPowerEU, and InvestEUPolicy. The most important policy initiatives of the Green Deal are introduced here under.

Figure 1.1 The main dimensions of the EU Green Deal

The main policy initiatives under the Green Deal umbrella involving hydropower are:

- **2021 - European Climate Law** legally binds the targets of climate neutrality by 2050 and a 55% emissions reduction by 2030.
- **2021 - Zero Pollution Action Plan** aims to achieve zero pollution for air, water, and soil by 2050, including stricter standards for chemicals and microplastics.
- **2023 - Fit for 55 Package** a legislative package, including the renewable energy directive, which aims to enable the EU to reduce its net greenhouse gas emissions by at least 55% by 2030 with 12 main proposals, covering all economic sectors. Includes measures to strengthen the EU Emissions Trading System (EU ETS), introduce a carbon border adjustment mechanism (carbon border tax) for certain imports, and boost carbon sinks such as through afforestation.

- **2023 - Renewable Energy Directive** raises the share of renewable energy in the EU's overall energy consumption to 42,5% by 2030.
- **2024 - Circular Economy** minimizes waste, promotes product recycling and sustainable production, and presents measures for sectors like textiles, electronics, and plastics.
- **2024 - Ecodesign for Sustainable Products Regulation** requires environmentally friendly materials and circular design for products, encouraging recycling and repairability.
- **2024 - Nature Restoration Law** preserves, restores, and enhances ecosystems, with objectives for forest preservation and restoration.
- **2024 - Net-Zero Industry Act** facilitates the conditions for investments in green technologies
- **2024 - Corporate Sustainability Due Diligence Directive** introduces corporate sustainability reporting for large companies working to protect environmental and human rights.
- **2025 - Green Taxonomy** criteria were updated to reflect sector best practice and align with other sustainable finance standards, enabling hydropower projects that meet them to demonstrate alignment with the EU Taxonomy and attract green investment.

The use and development of low carbon energy technologies is urgently driven by the mitigation of climate change: this is called the **Energy Transition**.

Wind and solar have become a priority. Their installed capacity in Europe has recently passed the 240 GW of Hydropower in Europe. **However, the main externality of wind and solar energies is their volatility**.

Fortunately, hydropower is the most mature solution to compensate the wind and solar volatility. As more wind and solar capacity are installed, so more hydropower support is needed. The energy crisis in 2022, the "Dunkelflaute" situations as experienced in November 2024, the blackout in the Iberian Peninsula in April 2025 have demonstrated that **hydropower**:

(i) strengthens the independence of the electricity system,
(ii) provides the grid with flexibility and storage and
(iii) restores the grid through its black-start capability.

Hydropower is the largest renewable energy source in the world and the second-largest renewable source in the EU and is proposed for inclusion as a "strategic net-zero technology" because of its unique contributions, like pumped storage, that provide essential grid services. Hydropower offers flexibility by storing energy during low demand and releasing it during peak demand, which is vital for grid stability as wind and solar generation fluctuates.

While hydropower has key benefits under the Green Deal, there is some opposition regarding hydropower environmental impacts, suggesting that its development must balance ecological considerations. The EU agenda calls for measures to improve the environmental performance of hydropower projects, ensuring sustainability in line with the Green Deal principles.

Overall, the EU Green Deal significantly supports hydropower in Europe, recognizing it as a crucial renewable energy source that can drive the continent's transition to carbon neutrality by 2050. Hydropower is considered a cornerstone technology under the EU Green Deal for enabling the full integration of renewables, ensuring a reliable and clean energy system, and supporting the EU's net-zero ambitions with a sustainable and flexible energy supply. Hydropower is valued for its flexibility, storage capacity, and ability to balance intermittent renewables such as wind and solar, making it a backbone for integrating higher shares of renewables into the electricity grid.

With 65% of Europe's economically feasible hydropower potential already tapped, the main hydropower challenge in Europe is not to increase its current level of 36% of all renewable electricity generation across the continent (which is the second highest share from renewable energy sources, after wind energy). Instead, **the main hydropower challenge is to reinforce the support it provides to the grid: independency, stability, affordability, and net zero emissions**.

The EU Green Deal encourages modernization and increased hydropower capacity, along with sustainability criteria to protect the environment and biodiversity. On the one hand hydropower has all the characteristics to serve as an excellent catalyst for a successful Energy Transition [24], whilst on the other hand it faces challenges in regulatory, environmental, and social acceptance spheres which the EU aims to address through targeted policies and innovation agendas.

b) 2020 - IHA Hydropower Sustainability Standard

The Hydropower Sustainability Tools were gathered into a global standard for sustainable hydropower. The Hydropower Sustainability Council had the vision of making sustainable hydropower the norm.

c) 2020 - "EU Biodiversity Strategy for 2030 – Bringing nature back into our lives"

On 20th May 2020, the Commission published the EU Biodiversity Strategy for 2030 containing specific actions to be delivered by 2030. Concerning the depletion of wetlands, as main reservoirs of ecological importance (down 64% worldwide since 1900), and the extinction of certain species highlighted by the International Union for Conservation of Nature (IUCN), the EU Environment Directorate considers that progress is too slow and emphasises ecological continuity in its 2030 biodiversity strategy: "Greater efforts are needed to restore freshwater ecosystems and the natural functions of rivers in order to achieve the objectives of the Water Framework Directive. This can be done by removing or adjusting barriers that prevent the passage of migratory fish and by improving the flow of water and sediments. To make this a reality, at least 25,000 km of rivers will be restored to free-flowing rivers by 2030 through the removal of largely obsolete barriers and the restoration of floodplains and wetlands." The EU Biodiversity Strategy 2030 calls for significant improvements in the conservation status of species and habitats protected under the EU Birds (Council Directive 2009/147/EC) and Habitats Directives (Council Directive 92/43/EEC). In 2012, the European Commission launched the Natura 2000 biogeographical process to help meet this target.

The EU directives include the Water Framework Directive (WFD), the Environmental Impact Assessment (EIA) Directive, the Renewable Energy Directive (RED), and the Environmental Liability Directive (ELD) have had a profound impact on the development, operation, and environmental regulation of hydropower within Member States through:

- long and costly comprehensive permitting and assessment before authorization of new plant

- increasing pressure on permit revision and public review
- increasing cost for mitigation and restoration of environmental impacts
- greater accountability for environmental damages
- increasing location restrictions
- increasing uncertainty in long-term investment.

The law's goal to restore 25,000 km of free-flowing rivers by 2030 explicitly includes removing obsolete dams and barriers, directly targeting some hydropower installations.

d) 2023 - Renewable Energy Directive III (RED III)

The Renewable Energy Directive III in the European Union significantly impacts hydropower development by raising renewable energy targets to at least 42.5% of the overall energy mix by 2030, which includes hydropower as a key renewable source. The directive emphasizes accelerating renewable energy deployment while ensuring environmental protection and sustainability. Hydropower is recognized within RED III as a vital, flexible, and renewable energy source contributing to EU climate and energy goals.

e) 2024 - Corporate Sustainability Reporting Directive (CSRD)

The Corporate Sustainability Reporting Directive is effective as of January 1st, 2024. The first companies subject to the Corporate Sustainability Reporting Directive (CSRD) have applied the new rules for the first time in the 2024 financial year, for reports published in 2025.

This EU law requires companies above a certain size to disclose information on what they see as the risks and opportunities arising from social and environmental issues, and on the impact of their activities on people and the environment. It aims to standardize extra-financial reporting of companies. This helps investors, civil society organisations, consumers and other stakeholders to evaluate the sustainability performance of companies, as part of the European Green Deal.

f) 2024 - IAIA Strategic Environmental Assessment (SEA) good practice guidance

The International Association for Impact Assessment (IAIA) published **Strategic Environmental Assessment (SEA) good practice guidance** supporting the energy transition and requiring a shift from a focus on project development towards a focus on strategic integrated planning in a river basin context. A development of hydropower-specific SEA guidelines by the IAIA SEA section working group on hydropower has proposed to IHA and ICOLD to further operationalize the guidance provide in Chapter 5 of the above-mentioned IAIA guidance.

g) 2024 - Nature Restoration Regulation Law

Europe’s nature is in alarming decline, with more than 80% of habitats in poor condition. The EU Nature Restoration Regulation, adopted in 2024, is the new key element of the EU Biodiversity Strategy, which sets binding targets to restore degraded ecosystems, in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters.

The EU Nature Restoration Law, is expected to significantly impact hydropower primarily by mandating the restoration of rivers and removal of obsolete hydropower dams, while generally leaving most existing hydropower facilities unaffected. Key impacts on hydropower include:

- **Removal of Obsolete Dams**: The law prioritizes restoring river connectivity, which leads to the removal of obsolete hydropower dams and other barriers to free river flow. This aims to enhance freshwater ecosystem health and biodiversity.
- **Pressure on Existing Facilities**: While most operational hydropower plants are exempt from direct intervention, there is increased scrutiny of those with major ecological impacts, especially if their permits are outdated or based on less stringent environmental standards. Hydropower facilities with limited or expired utility may be targeted for decommissioning as part of nature restoration efforts.
- **Permit Reviews and Stricter Conditions**: The broader environmental policy context, including the Water Framework Directive and Environmental Liability Directive, is being reinforced by the restoration law. This results in more frequent reviews and possible tightening of operating permits for hydropower plants to ensure compliance with restoration and biodiversity objectives.
- **Land Use Competition**: New hydropower developments may face increased challenges due to competition for land and river space, as restoration targets may restrict available areas for energy infrastructure.
- **Energy Policy Interactions**: The law allows for new energy infrastructure development including hydropower on protected sites only if there is an overriding public interest and environmental compensation measures are taken.

In summary, the EU Restoration Law is set to accelerate the removal of obsolete hydropower dams and increase regulatory scrutiny, particularly for facilities with legacy environmental impacts. However, it stops short of imposing blanket restrictions on operational hydropower plants, focusing instead on balancing renewable energy goals with ambitious river restoration and biodiversity objectives.

h) 2025 - Action Plan for Affordable Energy

As part of the Clean Industrial Deal, the Action Plan for Affordable Energy outlines measures for an affordable, secure, and climate-friendly energy supply in the EU and is a key element of the broader Clean Industrial Deal package aimed at industrial decarbonization and energy market reforms. Its commitment to accelerating renewable projects through shortened permitting timelines (targeting under 12 months for renewables in acceleration areas) could benefit hydropower development alongside other renewables.

The plan's neutrality toward technology means hydropower is supported at least indirectly by facilitating investment, reducing regulatory barriers, and integrating it into a flexible, renewable-heavy energy system. It includes measures to speed up permitting for renewable projects, facilitates long-term contracts like Power Purchase Agreements (PPAs) and Contracts-for-Differences (CfDs), and supports new investments through a pilot program with the European Investment Bank (EIB).

i) 2025 - Taxonomy Disclosures, Climate and Environmental Delegated Acts

The EU Green Taxonomy was recently updated on July 4, 2025, when the European Commission adopted a Delegated Act amending the Taxonomy Disclosures, Climate and Environmental Delegated Acts. This update aims to simplify the application of the taxonomy by reducing administrative burdens and enhancing competitiveness while preserving the core climate and environmental goals.

The EU Taxonomy includes electricity generation from hydropower as an eligible economic activity under its climate change mitigation goals. Hydropower can be considered taxonomy-eligible but specific criteria must be met for it to be recognized as a sustainable activity. Key requirements for hydropower to qualify include:

- The facility must be either a run-of-river plant without an artificial reservoir, or have a power density above 5 W/m². In such cases, a life-cycle greenhouse gas (GHG) emission assessment showing emissions below 100 gCO_2e/kWh is not mandatory.
- For plants with reservoirs and a power density below 5 W/m², a GHG life-cycle assessment must confirm emissions are below this threshold.
- The hydropower activity must comply with the EU Water Framework Directive and other environmental criteria to avoid significant harm, including requirements on biodiversity, pollution prevention, and climate adaptation.
- Pumped storage hydropower is explicitly recognized as contributing substantially to climate change mitigation in the taxonomy.

j) 2025 - Grids Package

On the 10 December 2025, the European Commission published the Grids Package, addressing critical bottlenecks in grid connections, permitting, and infrastructure planning. **The directive's permitting deadline is two years for Pumped Hydropower Storage, as projects benefiting from the overriding public interest presumption.**

k) Conclusion

In conclusion, EU policy initiatives have made hydropower in Europe subject to the world's most advanced environmental standards. This fosters greater environmental and social responsibility, but also imposes stricter limits and costs, increasing permitting time for projects in the pipeline, and affecting future expansion and operational models for the energy system.

The Energy crisis reveals the bottlenecks of this policy, and recent EU policy initiatives have been launched to boost overriding public interest projects like PSH. As hydropower remains crucial for renewable electricity supply, grid stability, and energy storage, contributing 36% of EU renewable generation, **The EU's policy challenge is to seek a balanced view, recognizing both the climate benefits and ecological risks of hydropower**.

1.3 ETIP HYDROPOWER, a platform for boosting the Energy Transition

1.3.1 The crucial necessity of the Energy Transition

Global warming is the major threat in the 21st century. 2024 was confirmed as the hottest year on record globally, according to multiple authoritative sources including the World Meteorological Organization (WMO), NASA, the European Copernicus Climate Change Service (C3S), and Berkeley Earth [9]. 2024 broke previous temperature records, surpassing 2023 as the warmest year since records began. The global average surface temperature in 2024 was about 1.55 degrees Celsius above preindustrial levels (1850-1900), marking the first calendar year to exceed the important 1.5°C warming threshold set by the Paris Agreement. The Paris Agreement's target of limiting global warming to below 1.5°C above pre-industrial levels is now out of reach.

Hydropower development should be driven by the need to limit global warming and achieve a reliable, affordable and independent energy transition, crucially highlighted by the triple health, energy and political crises of the 2020s.

Hydropower is currently a cornerstone of the energy sector in Europe. Hydropower is the key technology which can enable more renewable energy in Europe, storing energy in times when we have excess power from wind and solar power plants and providing more power when wind and solar can't. Hydropower can provide flexibility to the grid securing constant power and frequency - unlike batteries - and it can provide inertia that strengthens the stability of the power grid. This will change the operation pattern of hydropower to something it wasn't designed for. So, although hydropower is a mature technology, research, innovative solutions and industrial development are needed to utilize its potential in terms of energy production, capacity, storage, and flexibility.

Due to climate change, hydropower reservoirs increasingly provide adaptation functions such as securing the availability of water for agriculture, irrigation and domestic use, and flood mitigation. Extreme rainfall as well as droughts cause issues for reservoir management. Therefore, the design and function of new hydropower projects requires an integrated approach.

To fulfil the role of sustainable hydropower effectively, innovative and sustainable solutions development in accordance with environmental and social demands must be implemented to enhance production, flexibility, and storage capacity.

1.3.2 The 2018-2021 HYDROPOWER EUROPE project

Consequently, the European Union's Horizon 2020 Framework research and innovation program funded the HYDROPOWER EUROPE project (2018-2022), a Coordination and Support Action (CSA) to "bring all relevant stakeholders of the hydropower sector together in a forum in order to identify research and innovation needs and priorities." The HYDROPOWER EUROPE forum gathered 650 relevant stakeholders, representing all sectors of the value chain, who participated actively for 40 months (2018-2022) through an extensive program of review and consultation addressing needs of the whole hydropower sector. Half of the registrants came from Industry & Engineering and a quarter from Research as can be seen in Figure 1.2.

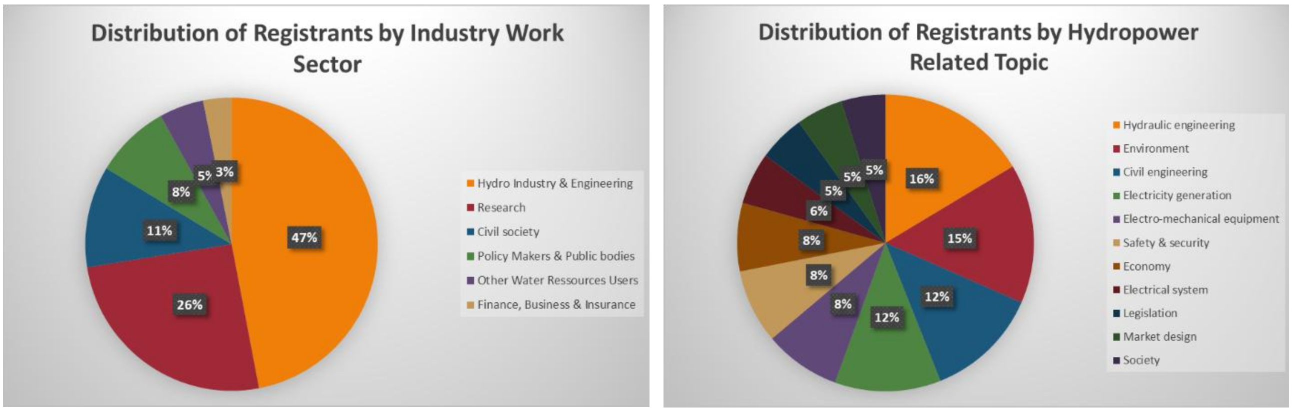

Figure 1.2 Breakdown of stakeholders in the Hydropower Europe forum

The forum produced a synthesis of expected research developments and research needs for the coming decade, the Research and Innovation Agenda (RIA), targeting an energy system with high flexibility and renewable share, and a Strategic Industry Roadmap (SIR), providing non-technical recommendations to overcome barriers for disseminating and scaling up the RIA outputs. The SIR highlights significant untapped hydropower potential, urging simplified approval processes, regulatory adaptation, and financial incentives to promote development.

1.3.3 The 2022-2025 ETIP HYDROPOWER project

To tackle environmental, societal, technological and market challenges pointed out by the SIR, the European Commission launched another CSA, the ETIP HYDROPOWER (2022-2025). A European Technology and Innovation Platforms (ETIP) is a key scientific and industrial community whose primary purpose is to focus the efforts of industry and scientific communities on the accelerated deployment of smart cleaner technology innovations that deliver on Europe’s energy security, technology development and manufacturing leadership, affordability and sustainability for the environment and society.

ETIP HYDROPOWER aimed to disseminate the Research and Innovation Agenda (RIA) drafted under the HYDROPOWER EUROPE project, taking into consideration the challenges identified (Figure 1.3), merging the R&I targets, the future needs of the sector, and EU policy priorities. This helped to ensure that hydropower could play the vital role of an enabler in the transition to a clean and safe energy system and the achievement of climate neutrality by mid-century.

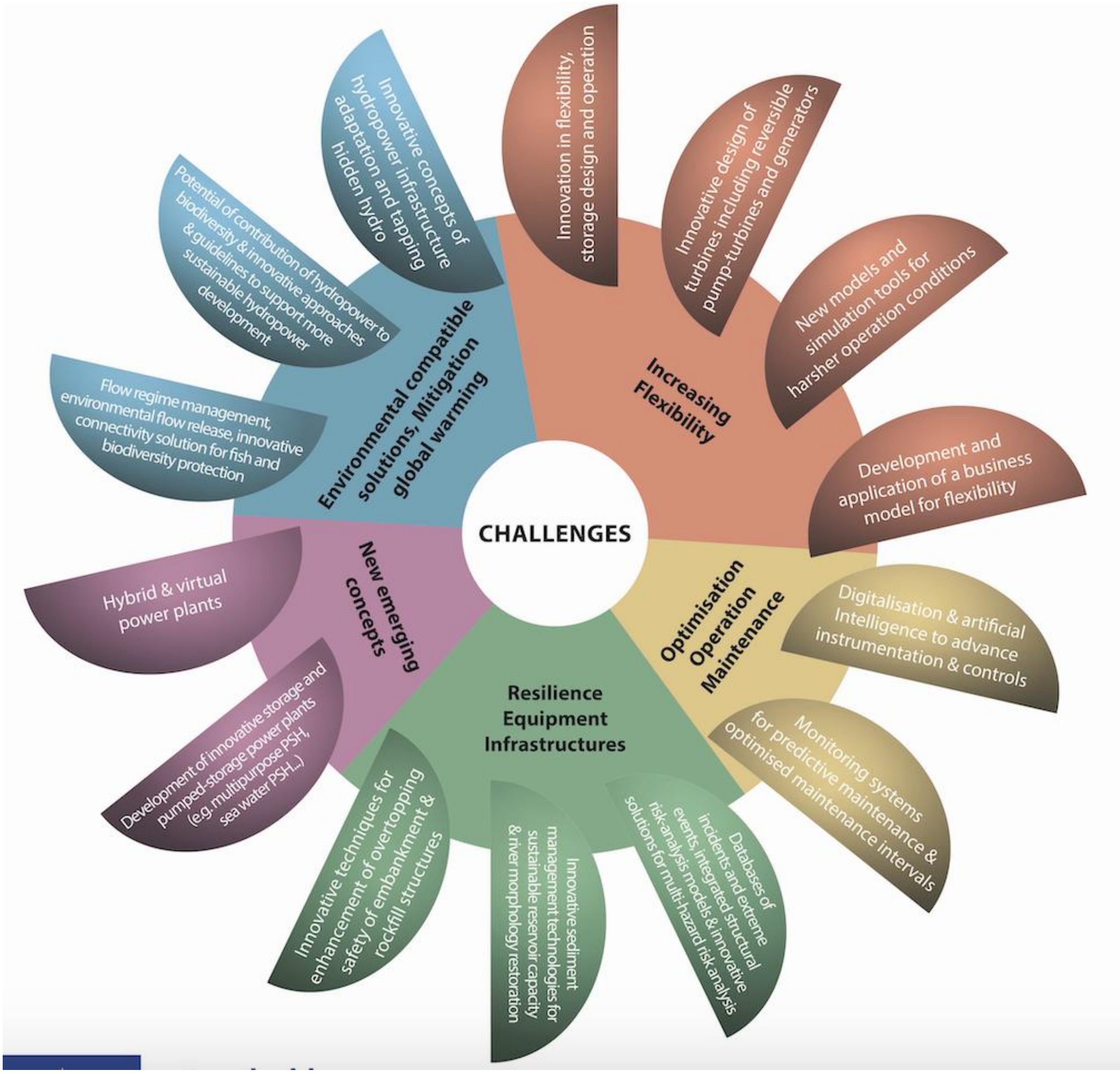

Figure 1.3 The challenges which hydropower must address

ETIP HYDROPOWER aimed to disseminate the Strategic Industry Roadmap (SIR) to provide consensus-based strategic advice for deploying hydropower in the Energy Transition covering (Figure 1.4):

(1) economic and legal support for storage and flexibility,
(2) raising public awareness and increasing social resilience and local employment,
(3) preserving biodiversity and improving ecosystems.

Providing economic and legal support for flexibility and storage	Raising public awareness, increasing societal resilience and local employment	Preserving biodiversity and improving river ecosystems
1. Improvement of flexibility markets 2. Best practice for investing under uncertainties 3. Development of a more pertinent regulation framework	1. Increase public awareness with communication and dissemination 2. Develop best practices for sustainability for successful projects and win-win situations 3. Increase security, decentralization and independence of the European energy system with PSH 4. Give a collaborative platform to the hydro sector	1. Collect best practice for sustainability and biodiversity protection 2. Increase the knowledge on environmental impacts 3. Develop innovative compensation measures for the protection of biodiversity 4. Develop comprehensive approaches allowing compromises

Figure 1.4 The 3 key strategic recommendation of the SIR for deploying hydropower in the Energy Transition

All hydropower projects must be developed and operated sustainably. Consequently, the second key action defined by the SIR for raising public awareness, increasing societal resilience and local employment was to develop best practice for sustainability for successful projects and win-win situations.

Compiling and disseminating in this catalogue lessons and methods from leading performers in all segments of the hydropower industry can drive improvements in hydropower performance. Identifying and disseminating best practice can help lead to successful energy, environment-related, and socio-economic outcomes of the hydropower regulatory process.

Sustainability is the key requirement for hydropower to be the corner stone of the Energy Transition in meeting EU climate and energy targets by providing renewable, affordable, and secure electricity.

1.4 References

The references from cases studies are included separately in each case study.

Main references of chapters 1 to 6 are hereunder.

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2 DEFINITIONS OF SUSTAINABILITY

2.1 The United Nations Brundtland Commission

In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [1].

It was developed as a concept that balances three pillars:

1. **Social Pillar** centres on promoting fairness, equity, community well-being, and human rights, ensuring a stable and healthy society with opportunities for all.
2. **Environmental Pillar** focuses on conserving natural resources, protecting ecosystems, and reducing pollution so that the planet remains healthy and viable for future generations.
3. **Economic Pillar** aims for economic development and profitability, but critically, in ways that do not undermine environmental health or social well-being

The environmental, social, and economic pillars—often called the "**triple bottom line**"—are deeply interconnected and interdependent in sustainability definitions. True sustainability requires the balanced integration of all three.

While sustainability is often thought of within an environmental framework, a **holistic approach** that encompasses its true impact across three essential categories has gained wide-spread acceptance.

Fittingly, these categories have become known as the **three pillars of sustainability**, encompassing **planet**, **people**, and **profit**.

2.2 Corporate sustainability

Corporate sustainability [2] is a business approach that helps companies create long-term stakeholder value while ensuring accountability. It's about understanding how business operations affect economic, social and environmental impacts, and managing them responsibly over time. The ultimate goal of corporate sustainability is to operate in a way that protects the future viability of the business and the communities it serves, while respecting and caring for the planet. By balancing economic success with social progress and environmental stewardship, companies can achieve true sustainable growth.

The 3 key components or responsibilities of corporate sustainability:

- **Economic responsibility.** Companies ensure their financial stability and growth, making decisions that drive profit, but not at the expense of the environment or society.
- **Social responsibility.** Companies act ethically and contribute positively to community wellbeing, including factors like employee rights, fair trade, and community development.
- **Environmental responsibility.** Companies minimize their negative impact on the environment by reducing waste and emissions, using resources efficiently, and adopting green technologies.

The three pillars of corporate sustainability are (Figure 2.1):

Figure 2.1 The three Ps of Corporate Sustainability, often referred as the triple bottom line

1) **The social pillar**, called "**People**", because it is about how businesses interact with people - their employees, customers, and the wider community. It emphasizes fair business practices for employees and the community. By fostering fairness in operations and embracing diversity, companies can contribute to a more equitable society, promoting social well-being and stability. Let's dive deeper into how businesses can achieve this.
   - **Diversity**. In the field of sustainability, diversity has taken centre stage as a critical ingredient for innovation and resilience. Different perspectives – from the local to the national level – foster creativity and collaborative problem-solving, ensuring the solutions we devise are holistic and effective in tackling the complex challenges of climate change.
   - **Human rights**. The bond between human rights and sustainability is irrefutable. Ensuring the rights to clean air, clean water, and a stable climate is paramount; these are prerequisites to a healthy life and serve as the cornerstones of any strategy focused on long-term, sustainable development.
   - **Equal opportunity**. In the process of devising long-term sustainability strategies, equal opportunity is both a destination and a journey. It's about levelling the playing field for everyone, ensuring fair access to resources and opportunities, while recognizing the existing inequalities that are a direct result of historical power structures. Lasting solutions to climate issues must not only be inclusive, but must also seek to rectify these existing inequalities.
   - **Civil society stakeholdership**. The role of civil society in sustainability can't be overstated. These groups play a vital part in pushing for change, holding governments and businesses accountable, and ensuring that the voices of the most vulnerable are heard in the discourse around climate change and sustainability.

2) **The ecological pillar**, called “**Planet**”, because it is about recognizing our dependence on Earth's diverse ecosystems and taking tangible steps to minimize our impact. By integrating environmentally-friendly practices into their operations, companies can contribute to climate change mitigation. Here are four key dimensions of the ecological pillar:
   - **Compliance**. Is not only about adhering to regulations; it's about proactively working towards net-zero. Voluntary reporting of CO2 emissions, for instance, signifies a step towards increased transparency and accountability, demonstrating a company's commitment to be part of the solution rather than the problem.
   - **Biodiversity management**. Is about recognizing our interconnectedness with all life forms and making a concerted effort to protect them. It is a prerequisite to life on our planet, maintaining the balance and health of ecosystems and, by extension, our own survival.
   - **Emissions**. Addressing emissions is a critical component of any environmental strategy. Cutting down greenhouse gas emissions is not just about meeting targets; it's about fulfilling our responsibilities to future generations.
   - **Material use & discharge**. Embracing a circular economy — where resources are used, reused, and recycled — can help minimize waste and the harmful discharge into our ecosystems. By shifting from a linear 'take-make-waste' approach to a more circular 'reduce-reuse-recycle' principle, companies and consumers alike can ensure the longevity of resources and the health of our planet.
3) **The economic pillar**, called "Profit", because it is about redefining success, not just in terms of financial gain, but in the broader context of sustainable development. Cultivating prosperity and progress responsibly, it underscores the role of businesses in fostering prosperity and progress, but not at any cost. The focus here is on achieving economic growth in a responsible manner, considering social welfare and environmental protection.
   - **Sustainable growth**. In the economic context of sustainability, growth must be synonymous with longevity. It's about ensuring that our progress today doesn't compromise the ability of future generations to meet their own needs. Sustainable growth is the intelligent fusion of environmental, social, and economic priorities to drive development that lasts.
   - **Inclusive growth**. Acknowledges that economic progress must be broad-based and equitable, benefiting all members of society. It is the concept that prosperity should serve the many rather than the few. By practicing inclusive growth, we ensure that local and global inequalities are internalized in future policy-making processes.
   - **Risk management**. In the pursuit of sustainability, risk management becomes a key economic principle. This involves identifying and mitigating not just financial risks, but environmental and social ones too. By doing so, we create resilient economies that are equipped to weather any storm, be it financial downturns or environmental crises.

2.3 Sustainable development

The main difference between sustainability and sustainable development [3] is that sustainability describes a condition or long-term goal—maintaining the health and viability of environmental, social, and economic systems—while sustainable development refers to the process and actions taken to achieve that goal.

2.4 The 17 Sustainable Development Goals

To reach global sustainability in 2030, all United Nations (UN) members in 2015 adopted the 2030 Agenda for Sustainable Development [4]. It is a shared blueprint for "peace and prosperity for people and the planet" while tackling climate change and working to preserve oceans and forests, now and into the future, thanks to the achievement of 17 world Sustainable Development Goals (SDGs).

The SDGs highlight the connections between the environmental, social and economic aspects of sustainable development (Figure 2.2 and Table 1).

Figure 2.2 The 17 objectives of the SDGs

Number	Purpose of the Sustainable Development Goals
SDG 1	No poverty
SDG 2	Zero hunger
SDG 3	Good health and well-being
SDG 4	Quality education
SDG 5	Gender equality
SDG 6	Clean water and sanitation
SDG 7	Affordable and clean energy
SDG 8	Decent work and economic growth
SDG 9	Industry, innovation and infrastructure
SDG 10	Reduced inequalities
SDG 11	Sustainable cities and communities
SDG 12	Responsible consumption and production
SDG 13	Climate action
SDG 14	Life below water
SDG 15	Life on land
SDG 16	Peace, justice, and strong institutions
SDG 17	Partnerships for the goals

Table 1 List of the SDGs

Today, there are almost 140 developing countries in the world seeking ways of meeting their development needs, but with the increasing threat of climate change, the most concrete efforts must be made to ensure development today does not negatively affect future generations. However, most, if not all, of the goals are unlikely to be met by 2030. Rising inequalities, climate change, and biodiversity loss are topics of concern threatening progress. The COVID-19 pandemic in 2020 to 2023, the wars in Europe and the Middle-East, made these challenges worse, and some regions, such as Ukraine, Palestine and Syria, have experienced significant setbacks during that time.

As the deadline draws nearer, monitoring progress is critical for identifying areas where hydropower has a role in achieving the United Nations Sustainable Development Goals (SDGs), especially in clean energy, water management, climate action, resilient infrastructure, and socio-economic development.

3 HYDROPOWER A DRIVER FOR SUSTAINABLE DEVELOPMENT GOALS

We have to remember that hydropower extends beyond renewable electricity generation to include climate adaptation and mitigation, sustainable water resource management, resilient infrastructure, economic opportunity, gender and social inclusion, and environmental stewardship and that it contributes significantly to 7 Sustainable Development Goals.

3.1 SDG 7 - Clean and Affordable Energy

3.1.1 Largest source of renewable electricity worldwide

Hydropower remains the largest and the most reliable source of renewable electricity worldwide and currently supplies about 14.3% of global electricity generation (4 578 TWh). Hydropower is the one of the world's largest and most reliable source of renewable energy. Hydropower installed capacity is currently at 1 443 GW [5] including 189 GW of Pumped Storage Hydropower [23].

3.1.2 Largest source of flexibility

Hydropower provides excellent flexibility. The contribution of hydropower increases with energy transition development. It becomes more important not only as it provides a base load compared to other variable sources such as wind and solar power, but as it is a dispatchable energy source, it ensures satisfactory level of adequacy, keeping power and frequency constant when wind and solar source are varying with its storage capacity to enable the time-shift of renewable energy production.

It facilitates the expansion of access to modern energy services, particularly in rural and underserved areas. Small and large hydropower projects enable both urban and remote communities to benefit from clean, affordable electricity.

3.1.3 Best energy gain and pay back factor

Hydropower offers the best EROI and the best EPBT, followed by wind and solar (although there is some difference between sources: see Table 2 compared to Figure 3.1.

Energy Source	EROI (Energy Gain Factor)	Typical EPBT Energy Payback Time (Years)
Wind	20 - 50	0.5- 1.5
Solar PV (monocrystalline)	8 - 34	1,1- 2,5
Nuclear	10 - 50	2 - 4
Coal	6 - 10	0.5- 1,5
Natural Gas	7 - 13	1 - 2
Biomass	2 -10	1 - 3

Table 2 Typical Energy Payback Gain and Times

Energy Return On Investment/EROI: The lifetime energy generated divided by energy invested in the system. Higher EROI means more net energy returned [6].

Energy Payback Time (EPBT): The time it takes for a power plant or technology to generate the amount of energy that was used to build, install, and maintain it [7].

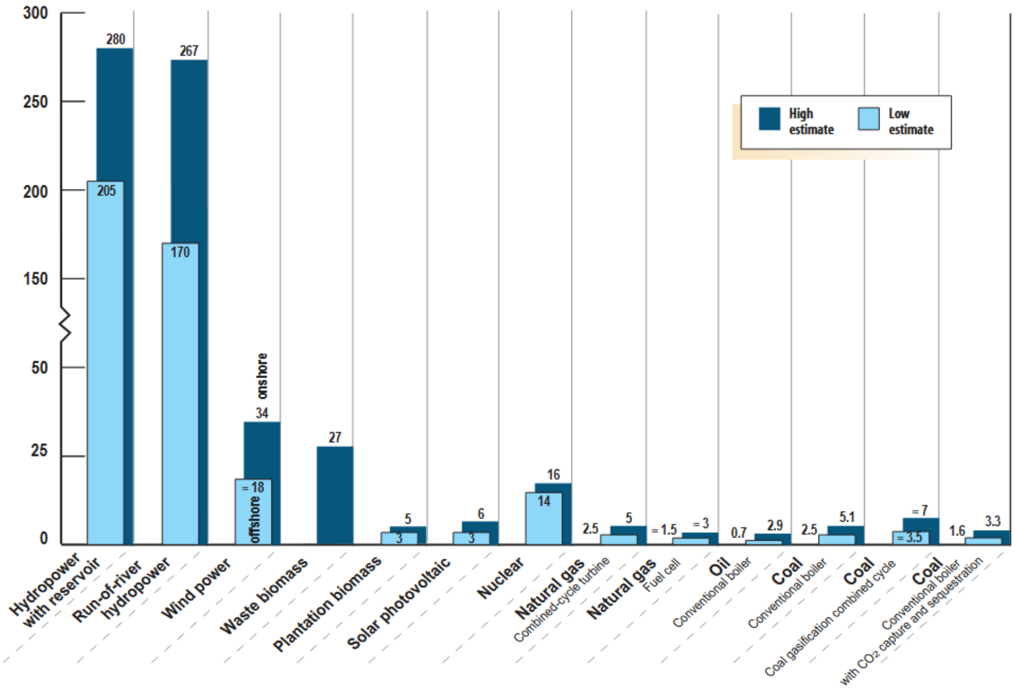


Figure 3.1 Energy Payback Ratio of Electricity Generation Options Based on Life-Cycle Assessment (Regie-energy)

3.1.4 Best efficiency in power generation

Hydropower is the most efficient technology, converting a very high percentage of water flow energy to electricity, often achieving efficiencies above 85%, with few losses during the energy conversion process (Table 3).

Technology	Efficiency Range (%)	Remarks
Hydropower	85 - 90 %	most efficient
Wind	35 - 47 %	theoretical max 59%
Solar PV	18 - 23 %	for most panels; up to 34% for advanced cells
Coal	32 - 45 %	modern plants up to 45%
Natural Gas	33 - 43 %	simple cycle, up to 60% (combined cycle)
Nuclear	33 - 50 %	depends on design; most around 33%
Oil	30%	

Table 3 Typical ranges of efficiency in power generation as of 2024–2025

3.1.5 Enhancing energy security and independence

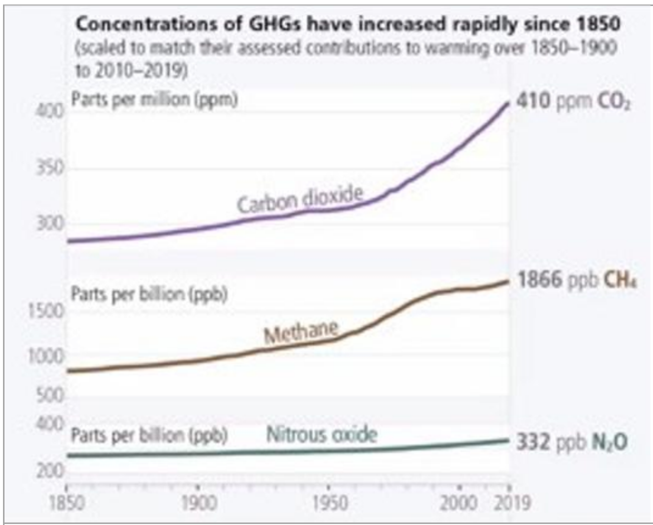
Hydropower enhances energy security, it is based on European domain technologies, it is not subject to fluctuating fuel prices, it reduces energy dependence on imports, it prevents black-outs.

3.2 SDG 13 - Climate Action

3.2.1 IPCC shared socioeconomic pathways driving the future life on the planet

The first volume of the sixth IPCC Assessment Report [8] presents the state of scientific knowledge on climate change, and communicates climate projections based in particular on GHG concentration assumptions. Concentration of greenhouse gases (GHG) have increased rapidly since 1950 (Figure

3.2). **GHG emissions are resulting from an increase in human activities** [8]. **2024 hits 1,5°C global warming** [9].



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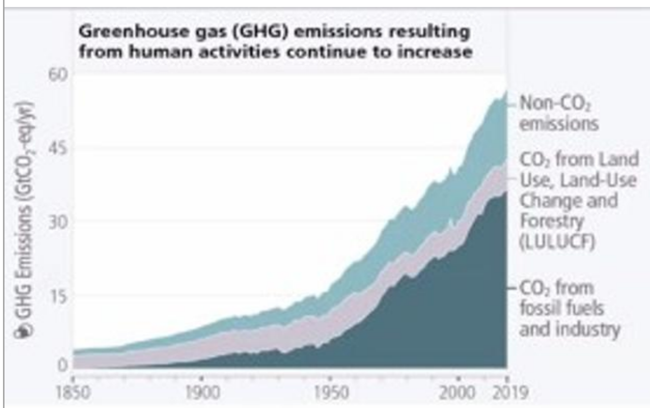

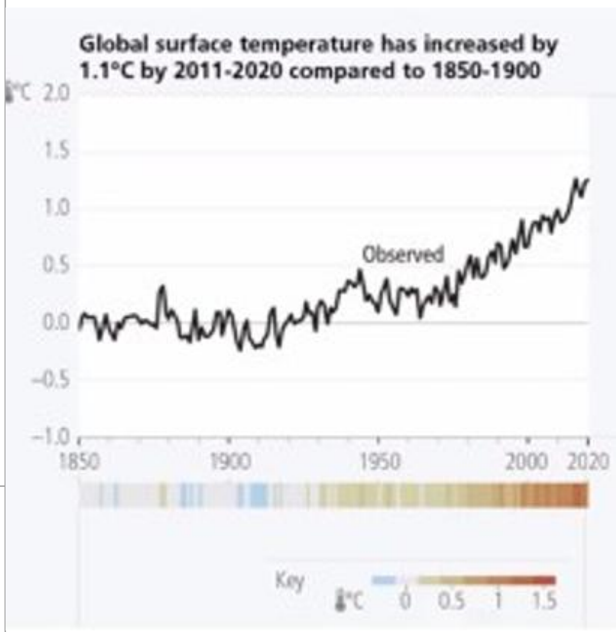

The 1.1°C global warming observed since 1950 is unequivocally caused by human activity. 2024 is the first calendar year that has reached more than 1.5°C above the pre-industrial level. **The year 2024 was the warmest year in the 175-year observational record, with a global mean near-surface temperature 1,55°C above the 1850-1900 average.**

Figure 3.2 GHG emissions and global warming increases

A set of five socio-economic scenarios (Shared Socioeconomic Pathways - SSP) is used in IPCC AR6 [8]. These scenarios correspond to possible evolutions towards different models of society, which are broken down into several GHG emission trajectories (Figure 3.3):

- SSP1-1.9 (radiative forcing level of 1.9 W/m^2) corresponds to an evolution toward sustainable development. It is being closest to the Paris Agreement target of 1.5°C, with CO_2 emissions cut to net zero around 2050, causing a 1.0 – 1.8°C very likely range of warming. Unfortunately, in 2025 we have seen: Trump and Putin develop a maximum of fossil fuel sources to fund economy and war respectively, and COP30 failed to set fuels 'end' under the petroleum lobby pressure.
- SSP1-2.6 corresponds to an evolution toward slower sustainable development (radiative forcing level of 1.9 W/m^2), assuming CO_2 emissions cut to net zero around 2075, causing a 1.3 – 2.4°C very likely range of warming.
- SSP2-4.5 considers a continuation of current socio-economic and technological trajectories (equivalent to a 4.5 W/m^2), assuming CO2 emissions around current levels until 2050, then falling but not reaching net zero by 2100, causing a 2.1 – 3.5°C very likely range of warming.

- SSP3-7.0 is high emissions scenarios of global warming with policies focus on national and regional security issues, assuming CO_2 doubles by 2100 causing a 2.8 – 4.6°C very likely range of warming.
- SSP4 corresponds to an exacerbation of global inequalities.
- SSP5-8.5 is very high emissions scenarios of global warming, it illustrates development based on fossil fuels, assuming CO_2 doubles by 2100 causing a 3.3 – 5.7°C very likely range of warming.

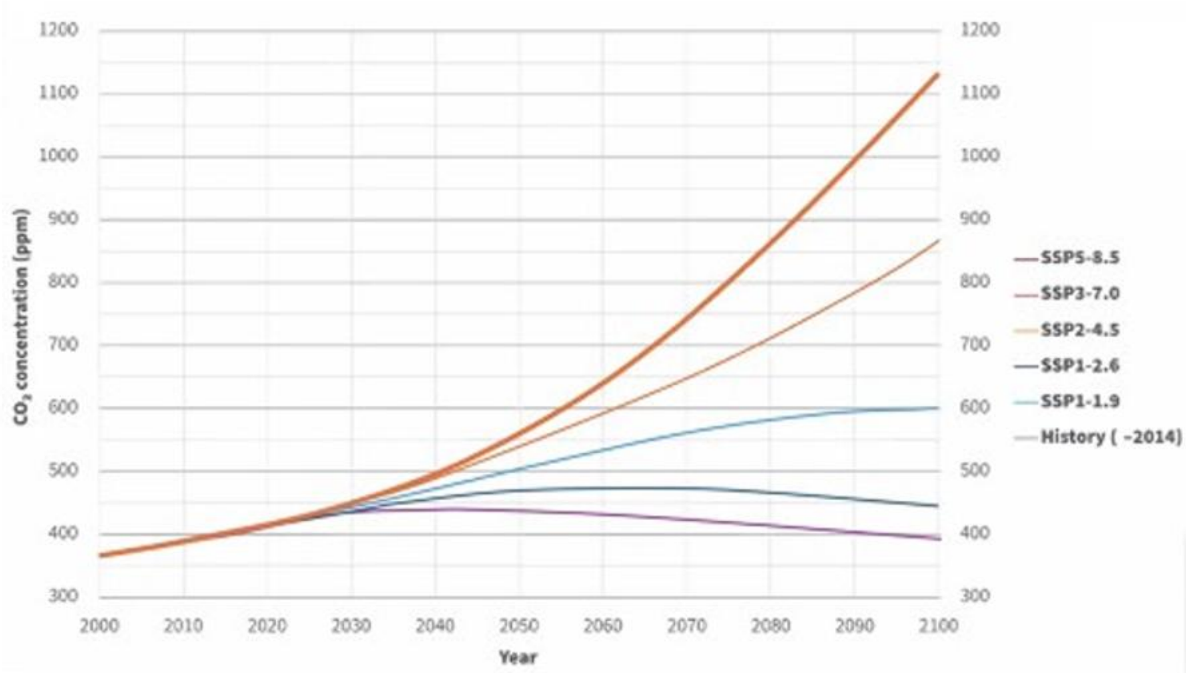

Figure 3.3 Different Shared Socioeconomic Pathways investigated by the IPCC

Shared Socioeconomic Pathway SSP1 should reach the Green Deal targets and provide:

- Policy focused on sustainable development
- Effective international cooperation
- Reduced inequality within and across countries
- Low consumption
- Low population growth.

On the other hand, Shared Socioeconomic pathways SSP3 and SSP4 should cause regional rivalry and inequality (Figure 3.4):

- Policy focused on security
- Barriers to international trade
- High inequality
- Slow economic growth
- Low population growth in rich countries and high in other countries.

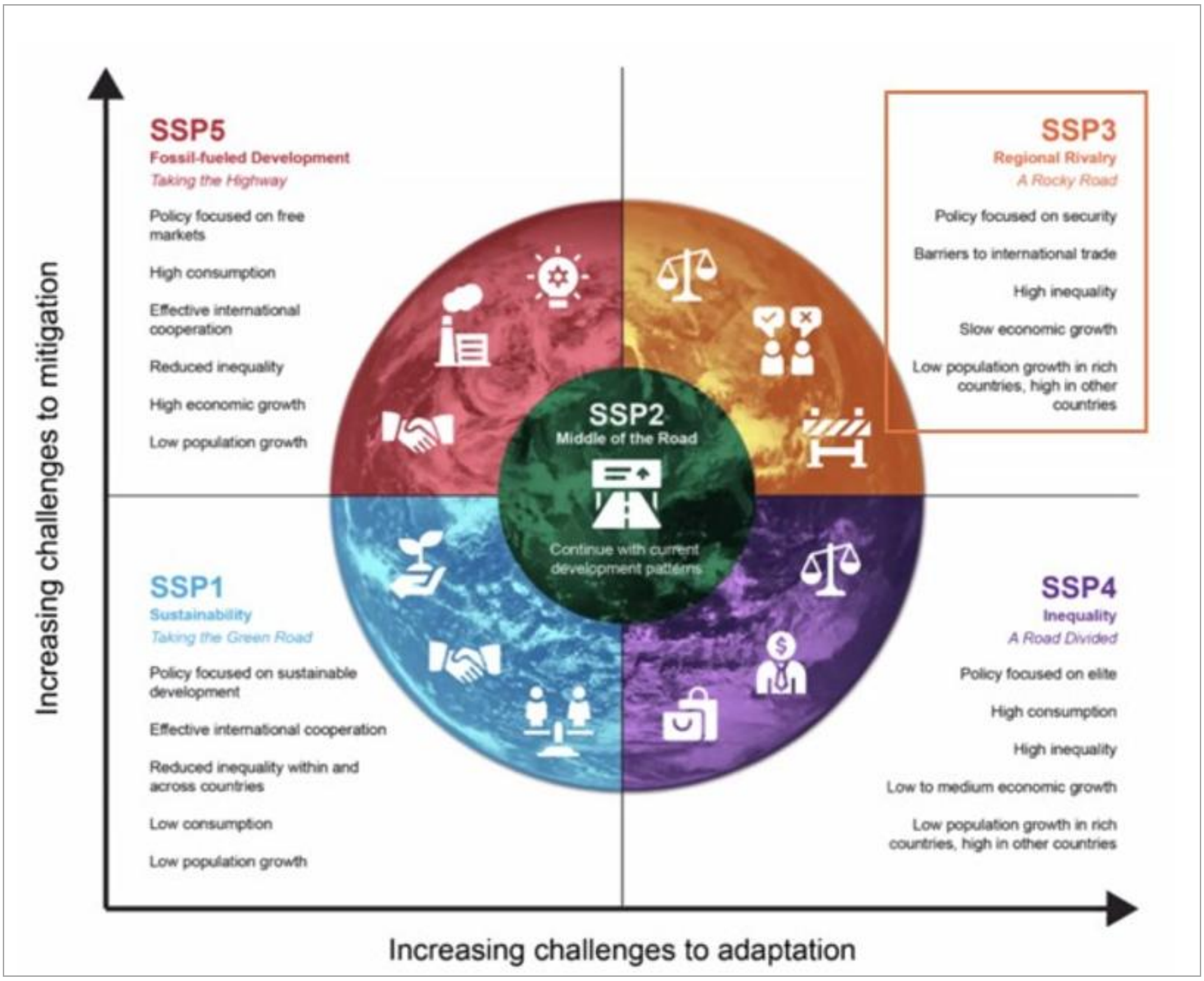

Figure 3.4 The different scenarios of the IPCC Report Six

3.2.2 Hydropower is the best climate-friendly energy

Hydropower is the form of energy to use as much as possible to sustain the Green Deal and the Energy Transition, threatened by energy overconsumption and mineral depletion. Hydropower helps reduce reliance on fossil fuels and contributes to climate change mitigation. By generating electricity without combustion, hydropower produces minimal greenhouse gas emissions in Europe, mitigating climate change and supporting the transition to low-carbon economies.

CIRAIG [10] concluded that hydropower plants have the lowest Climate Change indicator of generation technologies in countries in Europe or North of America (Figure 3.5). The Climate Change indicator is related to lifecycle greenhouse gas (GHG) emissions into the atmosphere per kWh. Estimating the total quantity of GHG emitted over the lifecycle can be compared between each type of generation technology.

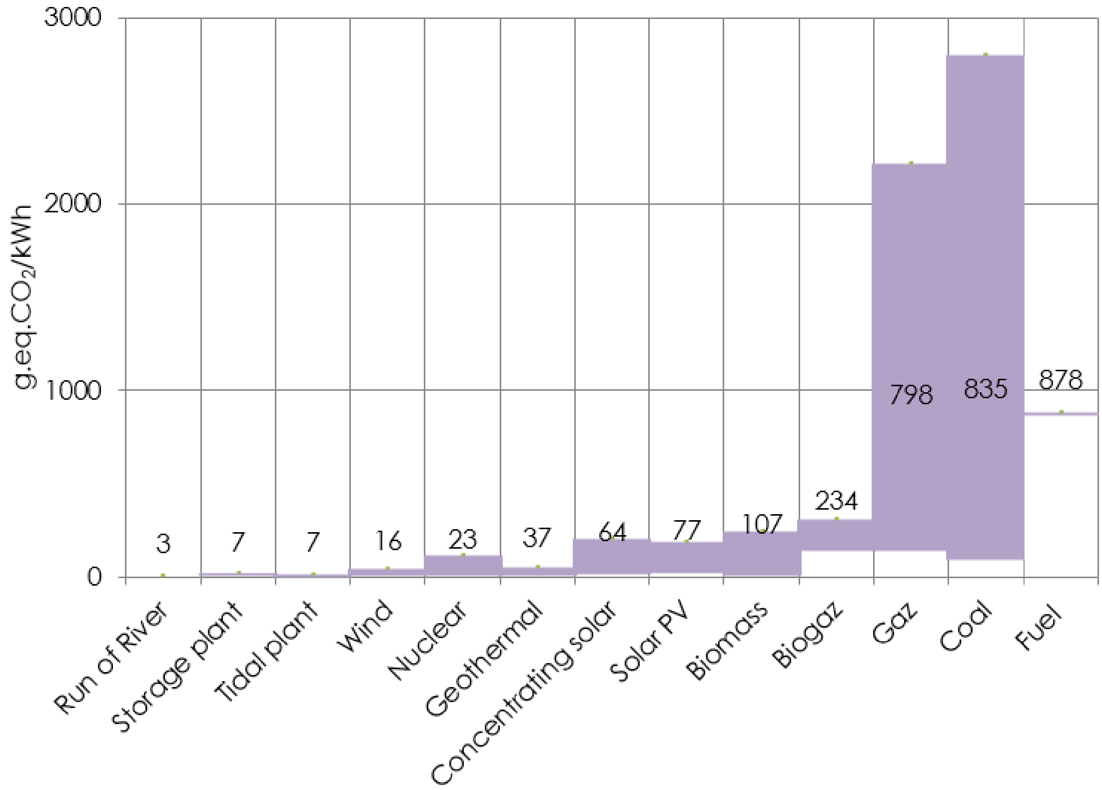

Figure 3.5 Comparison of the mean, min and max of the indicator "Climate Change" by technology (CIRAIG, 2014)

Hydropower is the resource which has the lowest impact on the stratospheric ozone layer (Figure 3.6).

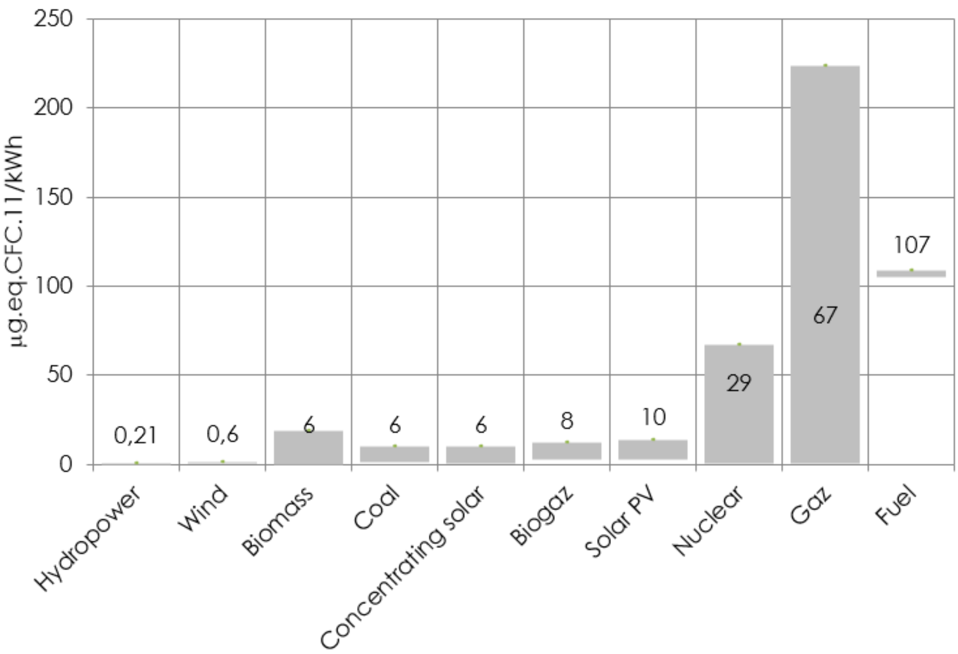

Figure 3.6 Comparison of the mean, min and max values of the indicator "Destruction of the ozone layer" by technology (CIRAIG, 2014)

The Ozone Layer Depletion indicator is related to the depletion of the stratospheric ozone layer, which results in an increase in ultraviolet (UV) radiation reaching the earth. The Ozone Depletion Potential (ODP) is measured in kilograms of trichlorofluoromethane equivalent (kg/kg CFC-11).

Reservoirs managed through hydropower projects can help societies adapt to the impacts of climate change by reducing the risks associated with floods and droughts.

3.3 SDG 6 - Sustainable Water Management.

Hydropower infrastructure is often integrated with water supply systems, benefiting irrigation, drinking water, and sanitation services. Reservoirs assist in regulating freshwater systems, supporting sustainable water use for both people and agriculture. Hydropower reservoirs can be used for a more reliable, predictable, and regular supply of water for irrigation [17].

3.4 SDG 8 - Economic Growth and Job Creation.

Hydropower is an economic sector providing a source of revenue for shareholders, water fees for public bodies and jobs for the local communities.

Hydropower projects play a significant role in accelerated GDP growth. A substantial share of generation revenues is transferred to the economy in the form of value added tax (VAT), local shareholder income, taxes and job employment.

Total revenues for governmental budgets amounted to more than 8 billion EUR for EU-28 or 14 billion EUR when also including Norway, Switzerland and Turkey. In other words, more than 32% and 37% of the gross value created by hydropower in the EU-28 and Europe respectively, are directly transferred to national or regional budgets (DNV GL, 2015).

Projects create employment during both the construction and operational phases, and can stimulate local economies through infrastructure development and increased investment. Hydropower development is linked to regional socio-economic benefits, including improved living standards and educational opportunities in rural and developing regions.

3.5 SDG 9 - Resilient Infrastructure and Innovation.

Hydropower fosters long-lasting energy infrastructure with low operating costs and high efficiency, helping to modernize energy systems.

Energy transition stimulates technological advancement and regional cooperation in water management, research, and renewable energy.

3.6 SDG 5 & SDG 10 - Gender Equality and Inclusive Development.

Community initiatives in small hydropower empower women and youth globally, increasing their participation in the energy sector and promoting inclusive industrialization.

3.7 SDG 15 - Ecosystem and Environmental Protection

3.7.1 Hydropower is the best renewable energy for limiting pollution from mineral extraction

The intensified competition for the resources to clean-energy technologies (achieving longer-range batteries and expanding renewable power) will demand vast amounts of nickel, copper, and other critical minerals. Meeting the goals of the 2016 Paris Agreement, which aims to limit global temperature rise by cutting emissions, would mean increasing mineral output to four times current levels. **How these resources are obtained will shape both the success of the energy transition and the planet's long-term health**.

"*I don't use the term green energy in my book because there's no such thing. Yes, solar power, wind power are renewables and have no carbon emissions, but they still create lots of environmental damage and human suffering due to all the mining that's involved."* wrote independent journalist Vince Beiser [11].

One solution is **extended producer responsibility**. Governments can force manufacturers to ensure that their products are recycled. **"***The European Union has good stringent rules around extended producer responsibility. China also has taken control by ensuring all the electric vehicle makers are required to make sure their vehicles get recycled at the end of their lives. In North America it barely happens at all, it is an unknown concept that has to change***."**

Another solution is to deploy hydropower the best renewable energy for reducing pressure on mineral resources (Figure 3.7). The Extraction of Mineral Resources indicator is measured in kilograms of antimony equivalent (kgeq.Sb) per kilogram extracted to take into account existing reserves, the rate of extraction and the "depletion" of each mineral substance [10].

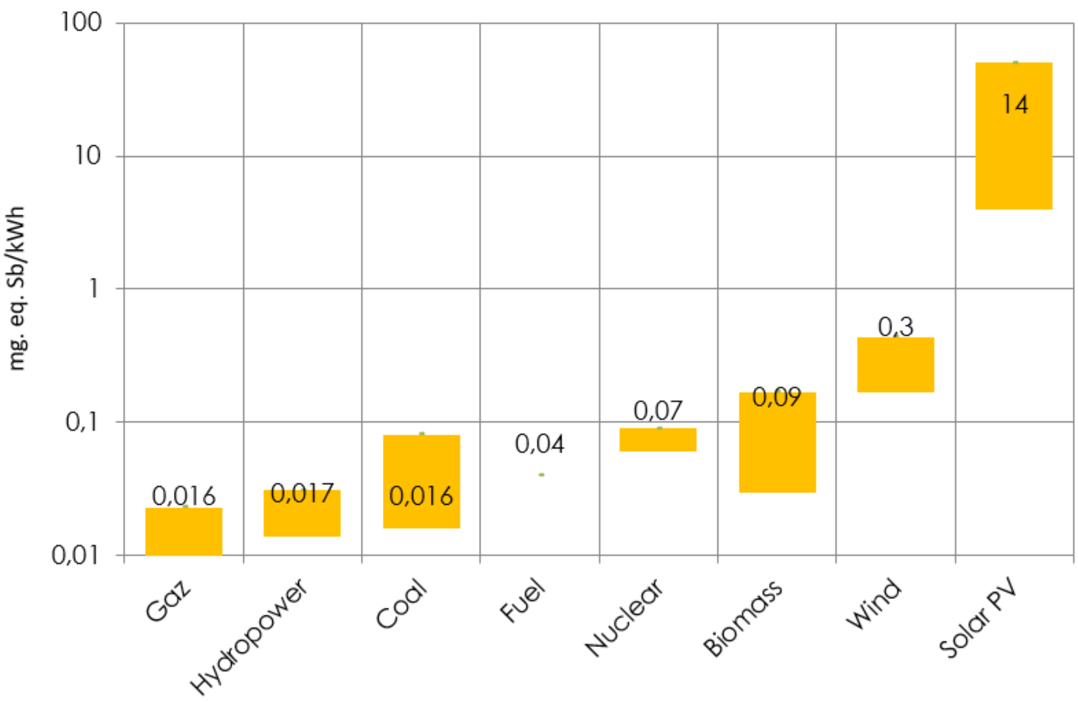

Figure 3.7 Comparison of mean, min and max values of the Mineral Resource Extraction indicator between generation technologies [10]

3.7.2 Hydropower reservoirs create new aquatic habitats for birds

Hydropower reservoirs can have positive impacts on birds by creating new aquatic habitats that attract various waterbird species which use them for breeding, feeding, and shelter, especially during migration and seasonal changes. These artificial reservoirs often provide resources that were not previously available in the landscape, such as open water and wetland-like environments, which can support diverse bird communities including waterfowl, shorebirds, and fish-eating birds. The attractiveness of reservoirs to birds sometimes prompts the use of bird deterrent systems to manage risks related to water quality, invasive species, or disease transmission. Thoughtful planning and adaptive management can maximize these benefits while minimizing negative impacts.

3.7.3 Protection of natural habitats during droughts and floods

It is not sufficiently recognised that sustainable hydropower can also help protect natural habitats particularly during droughts and floods when developed responsibly, for instance through certification and robust sustainability standards.

During the International Network on Basin Organization (ENBO) Conference [12] in Parma (2025) they “*called for immediate action at the sub-basin level, drawing on local knowledge, the reuse of treated wastewater, nature-based solutions (hedges, soil cover, wetlands) and i**nfrastructure combining storage and renewable energy**,… in high climate sensitivity area, with flow losses of 10% per decade since the 1970s and forecasts of up to 50% in summer by 2050*”. It was concluded that [12]: “*it is particularly effective to apply at basin scale a set of measures combining the control and the reduction of demand (which must remain a priority), **safeguarding the water availability through storage** (including a better soil management), and strengthening drought monitoring and forecasting tools*”.

3.7.4 More research and innovation to reduce impacts on biodiversity

It is well-known that hydropower has significant impacts on biodiversity, especially in rivers and surrounding terrestrial habitats, although most of its impacts can be reduced with careful planning and mitigation thanks to sustainable hydropower. Thus, more research and innovation are required to minimise, restore, and offset the most significant impacts [13].

3.8 Conclusions

In conclusion, hydropower is recognized as an essential driver for a wide range of SDGs. Hydropower is the only source of energy linked to such a wide range of SDGs.

Continued improvement and certification of hydropower projects will help ensure that their benefits are maximized, while their negative impacts are minimized, in alignment with the 2030 Sustainable Development Agenda.

Certification standards assess and reward hydropower projects for their environmental and social governance (ESG) performance, balancing development needs with biodiversity and Indigenous Peoples’ rights.

4 MANAGEMENT OF HYDROPOWER ENVIRONMENTAL IMPACT

4.1 Sustainable Hydropower Addressing Key Local Ecological Impacts

While renewable hydropower can contribute to climate change mitigation, which benefits global biodiversity, it does so at the risk of local ecological cost unless implemented with stringent conservation measures and best practices.

Key local ecological impacts include:

- Fragmentation of rivers, as dams act as barriers to the natural movement of fish and other aquatic species, limiting migration and gene flow needed for healthy populations.
- Habitat loss from flooding land for reservoirs, which reduces terrestrial ecosystems and transforms riverine habitats into still-water environments, often reducing species adapted to fast-flowing water.
- Disruption of natural flow, sediment, and temperature regimes, affecting water quality and altering cues vital for species' reproduction and survival.
- Altered aquatic biodiversity, particularly for freshwater fish, driven by changes in river discharge and water consumption, with specific impacts varying widely by location depending on local species richness and ecosystem sensitivity.

The first crucial step to address the global biodiversity loss is building new clean and renewable capacity including hydropower to mitigate climate change and decarbonise our economy. A renewables-based scenario could lower biodiversity losses by 75% compared to continuing with business-as-usual, according to WWF and BCG [14].

The second step to address the local biodiversity loss requires sustainable hydropower development based on the mitigation hierarchy, a sequential approach to avoid, minimise, restore, and offset negative biodiversity impacts including:

- Careful site selection to minimize biodiversity loss, as impacts are highly variable and some locations are much more sensitive than others.
- Mitigation measures such as improved fishways, sediment management, and adaptive flow releases to support ecosystem function.
- Balancing energy needs with conservation, employing systematic basin-scale planning and engaging stakeholders to ensure long-term ecosystem health.
- While hydropower helps mitigate climate change by providing low-carbon energy, its construction and operation can pose significant risks to biodiversity if not properly managed, highlighting the need for integrated approaches that seek both renewable energy and conservation goals.

4.2 The FIThydro Project Solutions

The EU FIThydro Project [15] proposes several solutions to ensure ecological continuity in hydropower development, primarily focusing on mitigating the negative environmental impacts of hydropower plants. Key solutions include:

- Implementing **fish-friendly technologies** such as fish ladders, bypass channels, and fish-friendly turbines to allow safe passage of migratory fish and reduce individual fish damage.
    - **Fish ladders and natural bypass channels:** These create alternative upstream and downstream migration routes around dams, mimicking natural river conditions and allowing fish to avoid turbines.
    - **Fish-friendly turbines:** These turbines are specially designed to reduce injury and mortality when fish pass through them. Examples include:
        - Modified conventional turbines with improved runner designs that minimize fish injury.
        - Turbines with thicker, curved blades that create a "stagnation zone" or cushion effect to reduce impact.
        - New runner designs tested to allow high survival rates of sensitive species like eels and salmon.
    - **Fish guidance systems:** Structures such as racks of curved bars create vortices that fish avoid, directing them away from turbine intakes. Also, induced drift application (IDA) uses subtle electric cues to direct fish safely through turbines.
    - **Screening and selective passage systems:** Screens at intakes can prevent fish from entering turbines, although they must be carefully designed to avoid harm or clogging.
    - **Adaptive operational strategies:** Using monitoring tools like 3D ultrasound tracking to detect fish swarms and temporarily shutting down turbines or opening spillways to let fish pass unharmed.
- Employing **adaptive flow releases** that mimic natural river flow variability to maintain the ecological integrity of aquatic habitats.
- Utilizing **environmental flow (E-flow) regulations** that enforce operational adjustments ensuring water flows support river ecosystems without compromising hydropower efficiency.
- Applying **retrofit and modernization strategies** to existing hydropower infrastructure to minimize new ecological disruptions while enhancing performance and biodiversity preservation.
- Integrating **digital monitoring and ecological modelling tools** [16] to optimize operational decisions that balance energy generation with ecosystem health.
- Promoting **cross-sectoral and transboundary watershed management**, ensuring cooperation between stakeholders to sustainably manage river basins and improve ecological outcomes.
- Combining **hydropower with multi-purpose approaches** (e.g., irrigation, flood control) relying on nature-based engineering that supports biodiversity and ecosystem services.

These approaches align with EU biodiversity goals, including the restoration of free-flowing rivers under the EU Biodiversity Strategy 2030. They also enable hydropower projects to be more environmentally sustainable and socially acceptable, supporting green investment and regulatory frameworks within the EU.

4.3 The Eurelectric Guidebook

Eurelectric commissioned a Guidebook [18] to support developers and system operators in scaling up nature-inclusive practices across the lifecycle of their projects. The guidebook introduces ‘biodiversity integration’ as a strategic approach for renewable energy and grid developers to make a positive impact on nature.

The guidebook consists of a set of twelve principles (Figure 4.1). The Mitigation Hierarchy has to be followed. The rest of the principles strengthen biodiversity integration and represent best practice. Project proponents should consider, demonstrate, and justify how each of the principles have been applied to deliver better outcomes for biodiversity, while ensuring the smooth functioning of the power plant project.

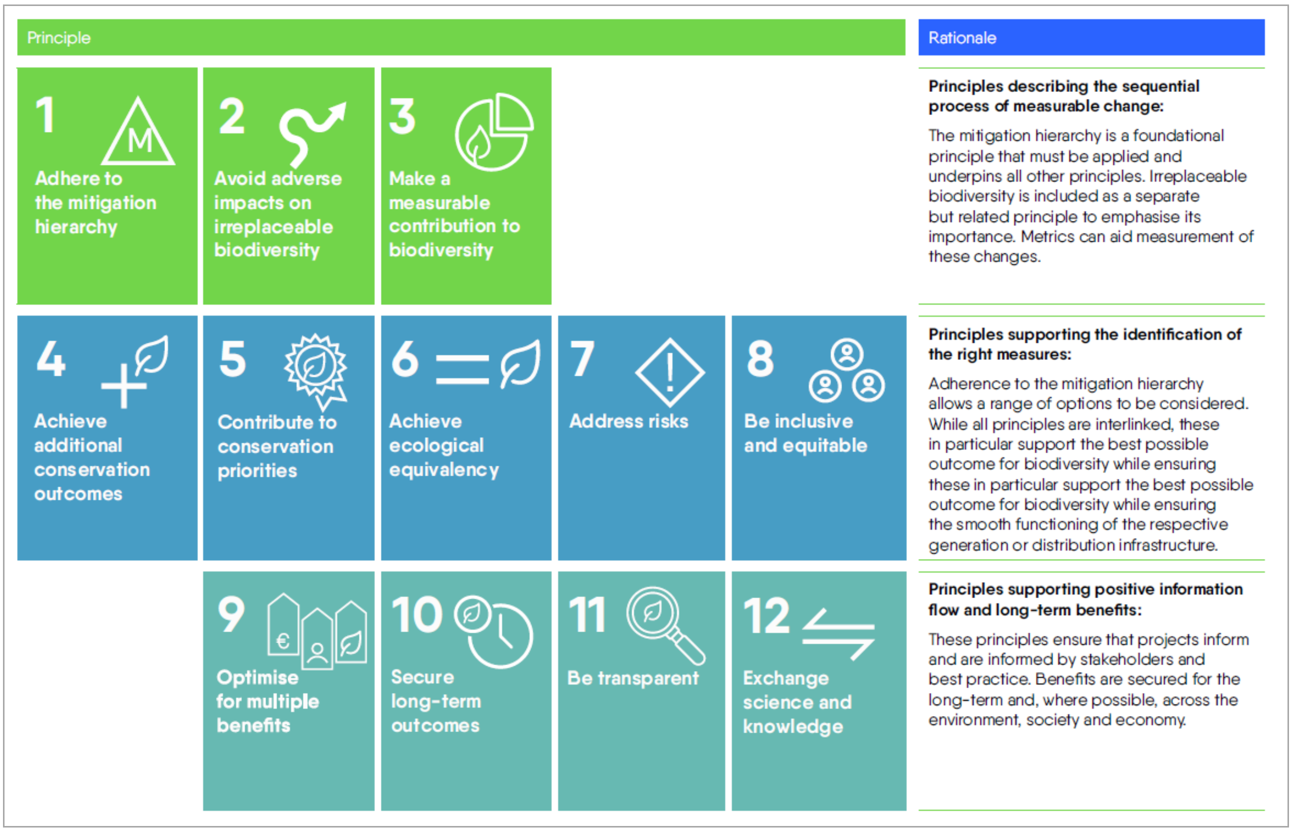

Figure 4.1 The 12 principles of the Eurelectric Guidebook

Some of these key actions for each project stage are outlined throughout the project lifecycle.

Site/route selection and screening

- Identify and preferentially avoid areas of key freshwater habitats or species. Prioritise sites on altered or impaired river stretches and consider powering/repowering/upgrading opportunities for existing structures;

- Align with regional water management strategies and explore synergies (e.g. flood and drought protection plans, water framework management plans);
- Consider restrictions in power generation (e.g. due to provision of ecological flows) in the economic analysis of the project.

Design, consenting and permitting

- Check possibilities to improve river morphology and connectivity of tributaries, wetlands, and floodplains;
- Manage sediment regimes to prevent up and downstream disruptions and habitat degradation;
- Ensure fish passage and migration routes by favouring nature-oriented bypass channels with diverse functions, structures, and habitats over technical fish ladders, if local conditions permit; and
- Seek use of low-impact equipment (e.g. fish friendly turbines) to minimise negative effects to aquatic life.

Construction

- Ensure that limit values for water quantity (e.g. minimum flows) and quality (e.g. suspended sediments) are not exceeded.

Operation

- Incorporate biodiversity enhancing measures into routine maintenance of dams and dikes;
- Establish operating rules that consider the natural flow conditions to facilitate fish migration;
- Maintain ecological flows that are vital to diverse aquatic ecosystems;
- Ensure water quality and habitat integrity when implementing sediment management measures;
- Manage the green areas around water bodies extensively, if possible, and avoid chemical pesticides.

Decommissioning

Consider potential loss of sensitive (secondary) habitats that have developed around and due to the plant over the years of operation.

4.4 The Guide and Protocols to Monitor Lakeshore

AFB-Irstea proposes a framework to harmonize monitoring of lakeshore improvement (restoration, mitigation, diversification of habitats) at the national scale in a guide [19]. It is intended to provide operational monitoring protocols for managers, design offices or other bodies aiming at assessing the impact of the actions undertaken.

Water bodies, and more specifically their shorelines, are subject to numerous anthropogenic pressures that alter their morphology and hydrology. Hydromorphological parameters are recognised under the WFD as factors that structure the ecological status of water bodies, which has encouraged the implementation of measures to restore the hydromorphological components of these ecosystems. Nevertheless, there is little well-documented and rigorous feedback available to decision-makers and management operators.

This situation led to the creation of the ‘Lake Ecosystems’ R&D centre in Aix-en-Provence, with the aim of developing a standardised method for monitoring hydromorphological restoration actions on the shores of lakes and reservoirs. The objectives are to obtain documented and informative feedback by implementing monitoring systems adapted to each type of restoration, enabling their effects on the ecosystem to be characterised; to evaluate the responses of biological communities to these actions over the long term; and to provide answers to questions about the effectiveness of these actions.

To this end, the project consists of three main stages:

1. developing a methodological guide,
2. testing the method and protocols in collaboration with managers across a network of pilot sites,
3. establishing a network of demonstration sites with the aim of comparing sites and improving knowledge of the trajectories followed following restoration work.

The proposed monitoring is based on a ‘BACI’ (Before-After-Control-Impact) design, at the restored site and at control sites. It proposes measuring the temporal evolution of the hydromorphological, physico-chemical and biological compartments of water bodies over a long period of time. The methodological guide details:

the definition of monitoring stations,

- the description of the hydromorphological, biological and physico-chemical elements to be included in the monitoring,
- operational and standardised protocols to be applied,
- a timeline for the application of these protocols from the pre-works phase (initial state) and to be continued post-works.
- a timeline for implementing these protocols from the pre-construction phase (initial state) and continuing post-construction phases.

The other deliverables related to this project are as follows:

- a report summarising the protocol trials carried out between 2016 and 2018 as part of the development of the method and monitoring protocols;
- a study report detailing the choice of methods and protocols proposed in the guide and the bibliographic synthesis work carried out as part of the project.

5 HOW TO GET A CONSENSUS IN DECISION MAKING?

To achieve consensus in decision making, you need a structured and inclusive process that ensures all participants are heard, differences are addressed, and the group eventually agrees on a shared solution, even if not everyone fully prefers it, but all can accept and support it.

5.1 Methodology

Essential steps to get consensus are:

- **Understand and involve all stakeholders**: Clearly identify who needs to be involved, and genuinely consider their perspectives and concerns. Encourage open dialogue so everyone's voice is included.
- **Clarify the problem**: Ensure everyone understands the issue or decision at hand. A clear statement of purpose or problem is foundational; confusion about what is being decided undermines consensus.
- **Open the discussion**: Allow time for everyone to share their needs, opinions, and any relevant information before attempting to reach a solution. This helps surface all viewpoints and builds mutual understanding.
- **Explore all options**: Brainstorm possible solutions and allow group members to evaluate pros and cons together. Combine good ideas to form an initial proposal.
- **Refine the proposal**: As discussions progress, adjust the proposal to address concerns and incorporate feedback. Amend as needed to maximize acceptance.
- **Test for agreement**: Clearly state the proposal and ask for explicit agreement. Check for any unresolved objections or reservations. In some processes, visible signals of agreement (e.g., hand signs) are used.
- **Address dissent**: If there is disagreement, identify what would be needed for holdouts to join in. Repeat dialogue and adjustment until everyone can accept the proposal or a fallback is triggered.
- **Confirm and record the decision**: Restate and document the final agreement to ensure everyone is clear on the decision and their roles in implementation.

5.2 Common Base for Best Practice

Key principles are:

- **Commitment to process**: Everyone must be willing to work through disagreements and stick with the process rather than default to a majority vote.
- **Trust and openness**: Honest disclosure of needs and reasons for positions is vital. Fostering an atmosphere of respect and trust is necessary for deep consent.
- **Skilled facilitation**: A neutral facilitator can help keep the process fair, productive, and on track, especially in diverse or larger groups.
- **Sufficient time**: Consensus takes longer than majority rule, particularly in larger or less cohesive groups. Budget enough time for genuine deliberation.

- **Alternate plans**: Sometimes consensus cannot be reached. Having a fallback (such as a designated decision-maker or pre-set deadline) ensures decisions still get made if impasse persists.

5.3 Social Acceptance

Social acceptance is the extent to which a project is welcomed, approved of, and valued by a broader group of stakeholders. It involves being included, respected, and given the opportunity to participate fully within that group, regardless of one's differences or unique characteristics.

Six dimensions for social acceptance are defined as follows:

1) **Environmental responsibility**: How hydropower plant developments affect local ecosystems, including water quality, habitats, and perceived environmental sustainability.
2) **Community involvement and trust**: The extent to which communities are engaged in planning and decision-making, and whether they trust developers and public authorities.
3) **Economic and employment effects**: Expectations regarding local job creation, economic benefits, and the project's contribution to regional development.
4) **Public perceptions and trade-offs**: How individuals evaluate the balance between benefits (e.g. energy storage, renewable integration) and potential disadvantages (e.g. landscape disruption, operational noise).
5) **Health and well-being**: Concerns related to perceived impacts on physical health, environmental quality, and general quality of life.
6) **Social licence to operate**: The overall level of ongoing support or acceptance granted by the community, which may evolve over the lifecycle of the project (Gunningham, Kagan and Thorton, 2004).

5.4 The SHARE Concept

Sustainable development requires attention to a wide range of economic, social and environmental objectives. Energy and water for sustainable development depend not only on supply choices, but also on how these choices are implemented.

A major challenge with multi-purpose reservoirs is sharing water amongst competing users. Although there are no universal solutions, there are principles that can be shared and adapted to local contexts. Indeed, the development and/or operation of such multipurpose hydropower reservoirs to reach sustainable water management should rely on the following principles: **shared vision, shared resource, shared responsibilities, shared rights and risks, shared costs and benefits**. These principles and acknowledgement of joint sharing among all the stakeholders are essential to the successful development and management of multipurpose hydropower reservoirs, and should frame all phases from early stage to operation.

The SHARE concept was developed as a solution of this challenge by the World Water Council with the support of EDF [20]. It is based on international case studies to find guidance on particular issues of multipurpose water reservoirs.

The SHARE concept gives guidance through an acronym for: **S**ustainability approach for all users, **H**igher efficiency and equity among sectors, **A**daptability for all solutions, **R**iver basin perspectives for all, and **E**ngaging all stakeholders.

Using this concept for multipurpose water uses of hydropower reservoirs both as an overarching principle and as a reminder of the five value propositions can help in making these reservoirs more sustainable and equitable. Figure 5.1 summarizes the SHARE concept.

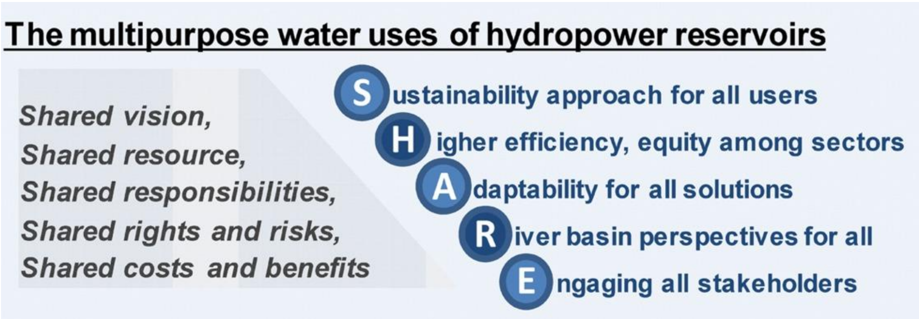

Figure 5.1 The Share concept

Addressing the sustainability of multipurpose hydropower reservoirs could be classified in the five following “shared” value propositions (SHARE concept).

5.4.1 Sustainability approach for all users

The degree to which multipurpose hydropower reservoirs can advance sustainable development objectives depends on careful planning, construction, operation, management, and governance. It is important to implement an adequate governance model that fosters equity across water reservoir users and ecosystems in line with agreed sustainability objectives. There are no one-size-fits-all solutions as each project is site specific and as, water governance, is place-based and context-dependent. It is therefore essential to customise the governance model to local conditions. The Hydropower Sustainability Assessment Protocol for these multipurpose reservoirs creates a common language among stakeholders and provides a measurement of the sustainable profile of the project and guidance for continuous improvement. In addition, governance mechanisms are vital tools for achieving equitable access to – and provision of – ecosystem services.

5.4.2 Higher efficiency and equity among sectors

Economic data and innovative financial mechanisms are crucial for equitable and efficient sharing of benefits among water users. A major challenge is that many of the additional benefits around hydropower reservoirs are currently not recognized or scaled in monetary unit. Putting a value for all benefits is necessary to allow discussions and negotiations between different water users, and to find optimal and efficient solutions. In addition, it is essential to have such values to bridge the gap between financial and economic viability. Many additional purposes of hydropower reservoirs may not be financially motivated in the short term, but would give more equitable long-term benefits that are not reflected in the financial analysis. Trying to assess the economic value of all services is important for investors; this is also a good way to bring stakeholders around the table to estimate collectively a value for water and for energy. Innovative financial mechanisms will be essential to address this gap between financial and economic feasibility, especially since hydropower reservoirs comprise such large up-front capital-intensive infrastructure. The challenge is to find ways of framing long-term strategies, securing long-term finance sources, and shielding them as effectively as possible from short-term constraints. In the developing world, funding and guarantees from bi-lateral or multilateral development banks are important financing instruments that can provide low-cost financing over long repayment periods, and act as a catalyst for other investors. Pension funds are another example of financing with long-time perspectives, which may unlock private sector capital to invest in long-term sustainable infrastructure, such as multipurpose hydropower dams.

5.4.3 Adaptability for all solutions

It is essential to provide greater flexibility and adaptability in the way water is allocated among users during the whole lifetime of the reservoir. History has clearly shown that multipurpose reservoir developments are long-term investments that can be of benefit to various generations: new purposes, demands or preferences may appear during this long lifetime due to the evolution of social and environmental values and requirements. In recognition of the significant uncertainty associated with future changes in climate, economies and demographics, there is a need for the physical design of hydro reservoirs and for the implementation of their governance systems to be able to respond to these changes. The multiple dimensions of projects as they emerge over time should be more explicitly addressed in the institutional management and operation arrangements. Hydropower as a renewable energy plays a key role in climate change mitigation. In addition, the water stored in the reservoir could help adapt to climate change; hydropower is climate-sensitive and it is also very important for the energy security and economic development of countries. River flows are vital for healthy ecosystems and their services. The mitigation of reservoir sedimentation should be addressed with a multi-stakeholder approach from the early stages of project planning through to operation.

5.4.4 River basin perspectives for all

An integrated approach is essential to reach a holistic view of the river basin. An important over-arching framework for sustainable hydropower reservoir development is Integrated Water Resource Management (IWRM) and basin development planning. Many hydropower projects are evaluated independently of an overall basin planning framework, and issues arise due to competing or conflicting needs and uses of the basin resources. The creation – and effective functioning – of trans-boundary river commissions (e.g., the Danube, Rhine, Mekong, Senegal Rivers, etc.) with the purpose of enabling information exchange and better transboundary cooperation with water infrastructure development and operation is essential for up-stream and downstream countries or for those having the same river as a national border. However, some river commissions are not operating as intended. River basin organizations need political commitment to address the very sensitive discussions around dam/reservoir projects, a broad representation of stakeholders and should also be equipped with capabilities related to staff, finance, expertise, skills, know-how, infrastructure etc., in order to carry out their duties effectively. Cross-sector coordination should be foreseen for greater policy coherence and consistency of multipurpose reservoirs uses. Water allocation in river-basin planning is a very important step forward to achieve sustainable use of stored water among users. In addition, stakeholder initiatives may also provide interesting opportunities for better integration of the different reservoir water users.

5.4.5 Engaging all stakeholders

Stakeholder engagement is critical for success in multipurpose reservoir management in terms of sustainability and efficiency. It is necessary to identify all stakeholders likely to influence or be impacted by decisions on the reservoirs, and engage them in the early stages to participate, on a voluntary basis, to the dialogue. It is important that the groups need to see there is a reason for them to engage, i.e. that they can influence decisions and outcomes that would be better than if they had not participated. It is crucial to understand early in the process stakeholder interests and power relations between these stakeholders. Most of them may not know or understand the perspective of the other stakeholders involved; it is therefore useful to raise awareness among them. Leadership within the community and across stakeholders is a key for success. Equity, transparency and accountability should drive the solutions. Different viewpoints generate alternative priorities and highlight different challenges among stakeholders. Coordination and potential improvements are required to manage multipurpose water use issues between different stakeholders. Policy makers should increase their engagement with all stakeholders to improve their understanding of issues and better communicate their impacts. Communication and diplomacy will be essential. Policy makers should also provide the enabling environment for result-oriented stakeholder engagement, and strive to include the inputs of engagement processes towards improved decision making. The quality of the data sources and the availability of information vary considerably at the local and state levels; making all this information accessible, timely, understandable, usable and useful is a real challenge. Strengthening partnerships and mobilizing resources remain essential to achieve effective multipurpose reservoir management.

5.5 International Recommendation and Certification for Hydropower

Much has been done for the sector on the topic of environmental and social sustainability. The recommendations of international associations are often the first and best practice to be applied.

5.5.1 ICOLD recommendations (1970-2025)

The **ICOLD recommendations** in technical bulletins 37, 50, 65, 66, 90, 96, 100, 115, 116, 128, 149, 159, 160, 162, 171, 182, 185, 193, 200, 201, and 208 prepared by the Technical Committee on the Environment related to environmental aspects, provide some useful insight and advice on preventing wildlife conflicts whilst building new dams and maintaining existing ones.

- Bulletin 37 – Dam projects and environmental success (1981).
- Bulletin 50 – Dams and the environment. Notes on Regional Influences (1985).
- Bulletin 65 – Dams and Environment. Case studies (1988).
- Bulletin 66 - Dams and Environment. The Zuiderzee damming (1989).

- Bulletin 90 - Dams and Environment. Geophysical impacts (1990).
- Bulletin 100 – Dams and Environment. Ridracoli: A model achievement (1995).
- Bulletin 115 – Dealing with reservoir sedimentation. Guidelines and case studies (1999).
- Bulletin 116 – Dams and fishes. Review and recommendations (1999).
- Bulletin 128 – Management of reservoir water quality (2004).
- Bulletin 147 – Sedimentation and sustainable Use of Reservoirs and River Systems (2009).
- Bulletin 149 – Role of dams on the Development and Management of River Basins. A general review (2014).
- Bulletin 159 - Supplement to the Position Paper on Dams and the Environment (2012).
- Bulletin 160 – ICOLD Dam Decommissioning Guidelines (2018).
- Bulletin 162 - The interaction of hydraulic processes and reservoirs. Management of the impacts through construction and operation. Downstream impacts of large dams (2022).
- Bulletin 169 - Global Climate Change, Dams, Reservoirs and Related Water Resources (2016).
- Bulletin 171 - Multipurpose Water Storage Essential Elements and Emerging Trends (2025).
- Bulletin 182 - Sediment management in reservoirs: National Regulations and Case Studies (2019).
- Bulletin 185 – Challenges and needs for dams in the 21st Century (2019).
- Bulletin 193 – Sediment Bypassing ad Transfer
- Bulletin 200 - Climate change, dams and reservoirs. Climate-induced water shortage and drought risk management. Climate resilience of water resources systems (2024).
- Bulletin 201- Climate change, dams and reservoirs. Role of Hydropower in climate change
- mitigation and new energy mix (2024).
- Bulletin 208 - Integrating dams with the environment. Case studies involving planning, construction and operation of dams demonstrating environmental and socio-economic benefits (2025).

The bulletins are guides developed by CIGB experts who sit on the Environment Committee for project owners and their consulting engineers. They are not mandatory, so they have not always been followed and are sometimes ignored.

5.5.2 World bank Water Resource Strategy (1993-2025)

The World Bank's Water Resources Sector Strategy, titled "Strategic Directions for World Bank Engagement," outlines a comprehensive approach to water management central to sustainable growth and poverty reduction [28]. Released following the 1993 Water Resources Management Policy Paper, it emphasizes integrated water resources management (IWRM), institutional reforms, and infrastructure development tailored to country needs. This strategy positions the Bank as a full-service partner, supporting both "soft" aspects like governance and "hard" investments like dams and storage where required.

Water resources development must address four key arenas: allocation, infrastructure, productivity in using sectors, and environmental sustainability, with Bank lending adapting to diverse country contexts. It calls for increased focus on water quality, conservation, groundwater, watershed management, and reforms to treat water as an economic good.

The Bank prioritizes predictable engagement in infrastructure for countries with investment options, enhancing its knowledge credibility for poorer nations. Recent emphases include climate resilience, such as early warning systems, dam safety, and green-grey storage, alongside subsidy repurposing and productivity gains via AI and remote sensing.

To reduce water-related risks and manage resources more sustainably, the World Bank Group focuses on three interconnected priorities: reducing the likelihood and impact of floods and droughts, managing and restoring rivers and aquifers, and strengthening ecological outcomes alongside economic productivity.

5.5.3 IHA Hydropower Sustainability Tools and Standard (2019)

The **Hydropower Sustainability Tools** are managed by IHA [27 - 29], and were developed by a governing council representing industry, government, financial institutions and social and environmental NGOs.

They include:

- HGIIP: the Hydropower Sustainability Guidelines on Good International Industry Practice,
- HSAP: the Hydropower Sustainability Assessment Protocol and,
- HESG: the Hydropower Sustainability ESG Gap Analysis Tool,
- HSS: the Hydropower Sustainability Standard.

5.5.4 IAIA Strategic Environmental and Social Assessment guidelines (2024)

A Strategic Environmental Assessment Directive has been applied in the European Union, while many hydropower projects were developed on other continents without assessment of their impacts on the river basin scale.

In the last 10 years IUCN, WWF and The Nature Conservancy have supported strategic integrated planning of the hydropower sector. There is increasing support for SESA because international lenders are requiring it. For example, the European Investment Bank has published that the World Bank has financed some SESAs in Africa, and the European Investment Bank now requires a basin plan as a condition for funding of hydropower projects. IFIs also promote Cumulative Impact Assessment (CIA) in hydropower, which has some overlap with SESAs.

Moreover, it is increasingly difficult to find suitable sites for hydropower that do not have significant environmental and social risks and impacts. This requires a shift from a focus on project development towards a focus on strategic integrated planning in a river basin context.

In the last 10 – 20 years, the hydropower sector and IFIs have developed guidance for hydropower, for example on Cumulative Impact Assessment and Management. The hydro sector has established the Hydropower Sustainability Standard, a range of How-to Guides on sustainability issues, and HydroSelect (an options assessment tool). However, the guidance remains largely project-focused and not towards government policies, plans and programs designed to guide sustainable hydropower development at a basin or country-level. SESA guidance would build on and be complementary to the above-mentioned guidance and tools, supporting strategic and integrated planning at a system or basin scale with the full involvement and support of governments.

Strategic Environmental and Social Assessment (SESA) case studies have shown that it can support strategic integrated planning and development of multi-purpose hydropower projects in a river basin context [30]. Good practice SESA facilitates inter-ministerial co-operation of government authorities; this type of co-operation is new to the sector. Moreover, SESA is a legal tool adopted by an increasing number of countries (N=135), and can be used alongside the development of a power sector plan, a national hydropower plan, and / or a river basin plan. Ideally, SESA development should be fully integrated into plan development for it to have a maximum benefit.

The International Association for Impact Assessment (IAIA – the community of impact assessment practitioners) actively engaged in promoting SEA supporting the energy transition and particularly the development of the hydropower sector has launched an initiative on developing an ICOLD Technical Bulletin on guidance to Strategic Environmental Assessment supporting planning of a more sustainable hydropower sector. Built upon the IAIA SEA Good practice guidance supporting the energy transition (2024) the hydropower-specific guidelines will further operationalize the guidance provide in Chapter 5 of the above-mentioned IAIA guidance. Objectives are as follows:

- Short term: Support for and development of hydropower-specific SESA guidelines.
- Medium term: Adoption of hydropower-specific SESA guidance by (i) the key players in the hydropower sector such as IHA and HS-Alliance, ICOLD and by (ii) donors and the international finance sector and iii) conservations organizations such as IUCN, The Nature Conservancy (TNC) and World Wildlife Fund (WWF) and iv) NGOs representing the people such as Oxfam International.
- Long term: To support the development of a more sustainable hydropower sector, resulting in multi-purpose projects that are economically feasible and socially, and environmentally acceptable. By capitalising on economic and financial trends, as well as improved technologies, hydropower can secure a brighter future for people and nature with power systems that are low carbon, low cost and low impact on rivers and other ecosystems.

5.6 IHA “Hydropower Sustainability Standard” (HSS)

Today hydropower is the only energy technology that can leverage on the benefits of an internal standard to review and certify the sustainability of new and existing projects.

5.6.1 IHA Hydropower Sustainability Assessment Protocol (HSAP)

The first major step in the preparation of an internationally recognised standard for the assessment of the environmental and social sustainability of hydropower projects was achieved with the publication of the Hydropower Sustainability Assessment Protocol (HSAP) in 2010.

The HSAP is a tool for assessing projects across several social, environmental, technical and economic criteria. Assessments are based on objective evidence and the results are presented in a standardised way, making it easy to see how existing facilities are performing and how well new projects are being developed. The Assessment Protocol covers all stages of a project's lifestyle: preparation, implementation and operation.

5.6.2 IHA Hydropower Sustainability Standard (HSS)

A second and final step was achieved in 2021 [27] with the publication of the Hydropower Sustainability Standard (HSS Figure 5.2). Under the HSS, hydropower projects around the world would be independently rated and certified for their sustainability performance.

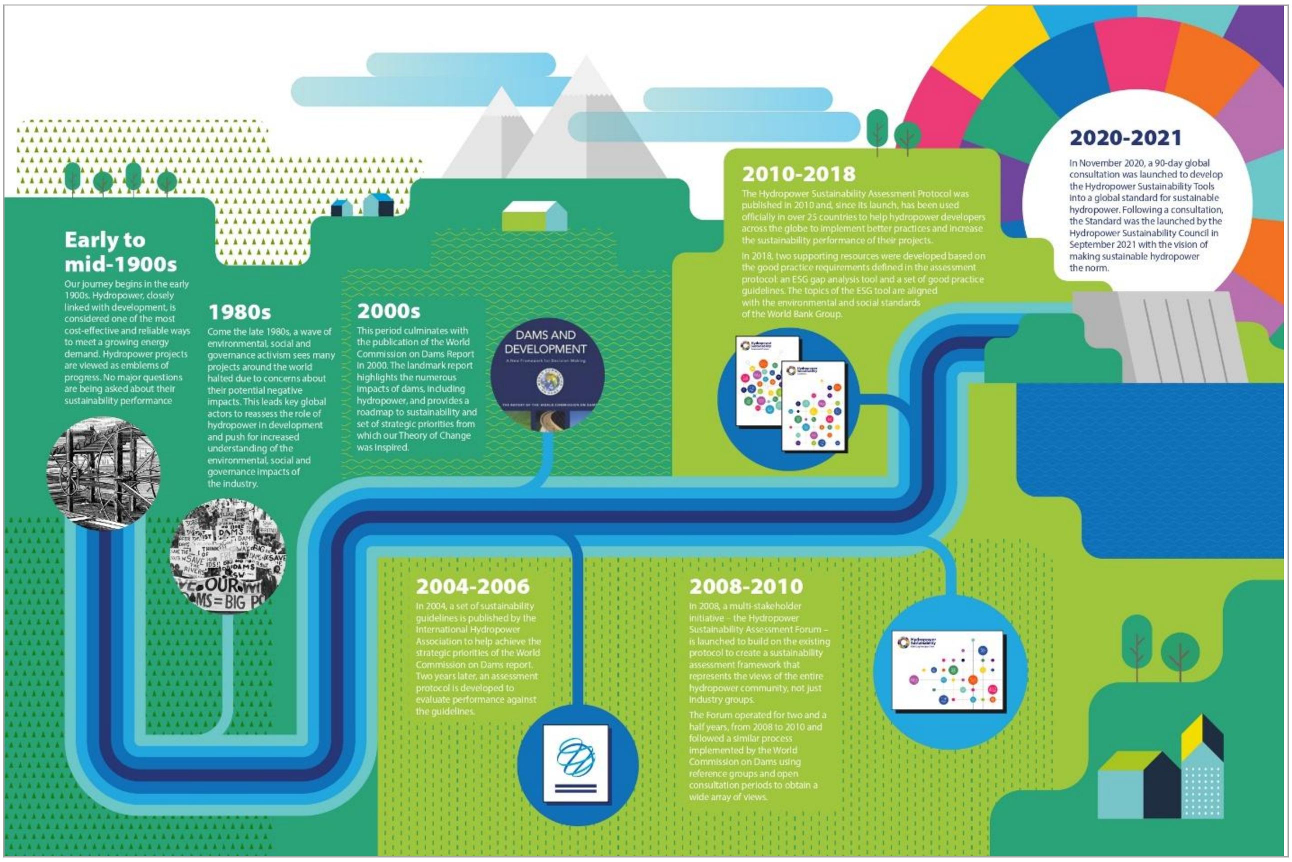

Figure 5.2 History of the Hydropower Sustainability Standard (IHA)

Developed by a multi-stakeholder group, including energy companies, government agencies, financial institutions and social and environmental NGOs, the HSS today represents the ultimate and most comprehensive framework designed to guide and assess the sustainability of hydropower projects worldwide.

This internationally recognised standard serves as a benchmark for industry stakeholders, ensuring that projects align with environmental, social, and governance considerations. The HSS encompasses three core pillars: environmental, social, and governance.

1. Under the environmental aspect, it addresses key concerns such as ecosystem preservation, water quality, and climate resilience.
2. Social aspects encompass community engagement, benefit sharing, and the protection of local cultures and livelihoods.
3. Lastly, the governance pillar underscores transparent decision-making, regulatory compliance, and ethical business practices. By adhering to this standard, hydropower projects demonstrate a commitment to responsible and sustainable development. The standard not only offers a credible assessment of a project's impact but also contributes to

building trust among stakeholders and, fostering a positive relationship with local communities, governments, and environmental organizations.

Furthermore, the HSS serves as a tool for continuous improvement. Its comprehensive nature encourages project developers and operators to adopt best practices, evolve their strategies, and address emerging challenges. As a result, the standard accompanies the industry's evolution towards greater sustainability, aligning with global efforts to ensure clean and responsible energy generation.

To summarise, the HSS serves as a guide for the hydropower industry, promoting sustainable practices, transparency, and positive engagement with the communities and environments that hydropower projects impact. In 2024, the Hydropower Sustainability Alliance promoting and using the HSS was the winner of the International Association for Impact Assessment’s 2024 Global Award.

The Assessment Protocol covers all stages of a project's lifestyle: preparation, implementation and operation.

5.6.3 Hydropower Project Lifecycle and Sustainability Assessment

The hydropower life cycle involves a sequence of stages, each playing a crucial role in shaping the overall sustainability assessment of a project. These stages collectively form the journey from conception to decommissioning, and are pivotal in evaluating how well a project aligns with sustainability objectives.

Preparation

Typically, this stage is subject to national regulatory procedures, including project-specific assessments like Environmental and Social Impact Assessment (ESIA) and adherence to project management protocols. An evaluation conducted at this point assesses whether all preparatory criteria have been met, management plans are established, and commitments are appropriate and legally binding.

Planning and Feasibility

This sub-stage involves evaluating the potential environmental and social impacts of the project. A sustainability assessment examines the project's alignment with local ecosystem health, community well-being, and regulatory frameworks.

Design and permitting

Assessing sustainability here involves evaluating how well the project design incorporates measures to minimize environmental impacts, including fish passage solutions, sediment management, and habitat preservation. Social aspects such as community engagement and benefit-sharing plans are also assessed.

Implementation

The implementation stage performance requirements revolve around the operational phase of a hydropower project. This stage encompasses construction, resettlement, and the implementation of management plans and commitments, including environmental considerations. Prior to the commissioning of any units, an evaluation is conducted to confirm the fulfilment of all commitments.

Construction

During construction, sustainability assessment focuses on minimising ecosystem disturbances, ensuring proper waste management, and assessing adherence to health and safety regulations. The assessment also examines social impacts such as local employment opportunities and community disruptions.

Operation

This ongoing stage evaluates the project's performance in terms of energy generation efficiency, environmental impact mitigation, and maintenance practices. It also involves assessing whether the project's benefits to the local community remain consistent.

Closure: Decommissioning and Removal

During this phase, the hydropower facility undergoes decommissioning, dismantling, and site restoration processes. Conducting a comprehensive sustainability assessment at this point is vital as it evaluates the project's adherence to ecological, social, and economic sustainability parameters. The assessment examines how well the closure activities align with environmental preservation, community well-being, and the efficient use of resources.

Overview

Throughout these stages, the sustainability assessment ensures that the hydropower project interacts well with its surroundings:

- By examining these ecological aspects, the assessment guarantees that the project's impact on the environment remains minimized and aligned with principles of environmental responsibility.
- By evaluating the project's effects on local communities, we can learn how the project engages with communities, whether it respects their rights, and contributes to the socioeconomic development.
- By exploring the economic dimension, we ensure that the project optimally employs resources, provides a reliable energy source, and bolsters the stability of the energy grid, also catering the long-term needs.

6 PERFORMANCE REQUIREMENTS

The assessment of good and best international industry practice presented here under comes from the experience gained with Hydropower Sustainability Tools of HSA [27].

Twelve sustainability topics that cover the environmental, social, governance and climate change aspects important to hydropower development and operation are defined with their performance requirements (Figure 6.1).

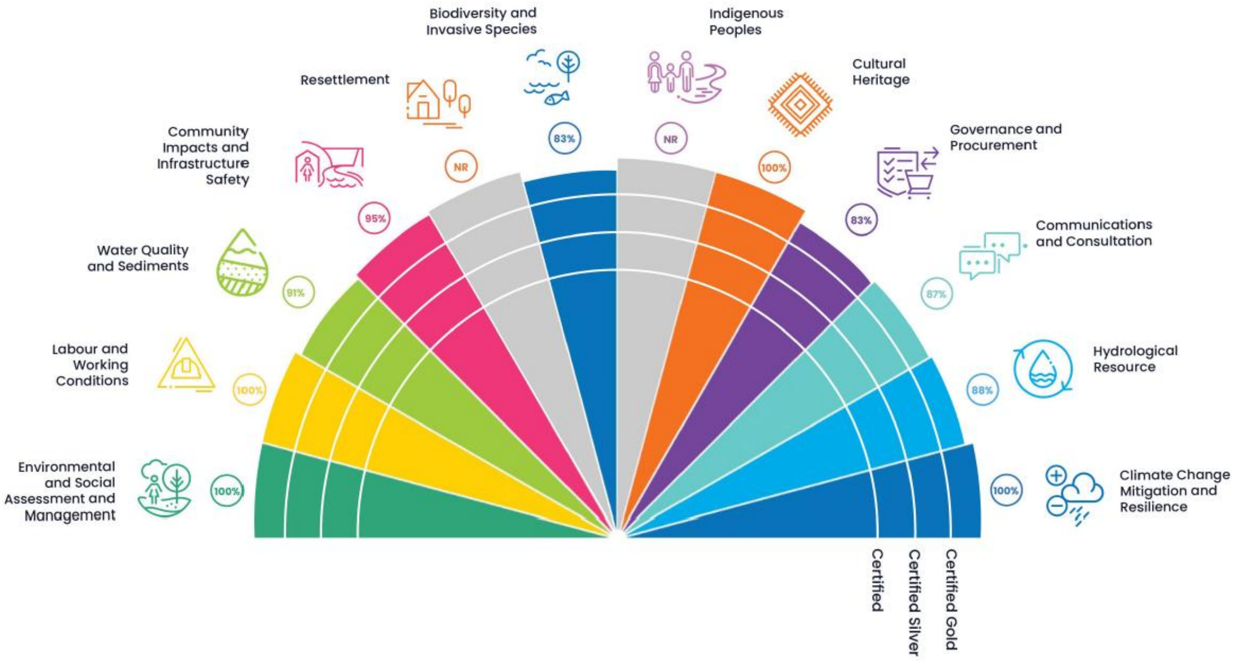

Figure 6.1 The 12 sustainability topics defined by HSA

6.1 The 12 Sustainability Topics from HSA

The twelve topics overseen by the Hydropower Sustainability Alliance are introduced in this section and the criteria are presented in the subsequent sections. For the formal and specific statements, the Hydropower Sustainability Alliance's website provides the most up-to-date and authoritative topic summary for Indigenous Peoples.

6.1.1 Environmental and social assessment and management

Environmental and social assessments play a pivotal role in ensuring that hydropower projects are developed responsibly and sustainably. These assessments are comprehensive evaluations of the potential impacts and benefits that a hydropower project might have on the surrounding environment and local communities.

Together, these assessments ensure that a hydropower project aligns with sustainable development goals and contributes positively to the environment and local communities. They inform decision-makers, project developers, and regulators about potential trade-offs and opportunities, helping to strike a balance between energy generation and environmental conservation while promoting social welfare. A well-conducted environmental and social assessment is a crucial step in the responsible development of hydropower projects, ensuring that their benefits are maximised while their negative impacts are minimised.

Depending on the jurisdiction (such as sub-national, national, regional or European), the terms used for the systematic and comprehensive process that evaluates the potential environmental and social effects of a hydropower project, before it is carried out, may vary; these include:

- Environmental Impact Assessment (EIA),
- Environmental and Social Impact Assessment (ESIA),
- Environmental Impact Statement (EIS),
- or other equivalents.

The purpose of an ESIA is to identify, predict, and assess the potential positive and negative impacts of the project on the environment, local communities, and societal well-being. Whether applied to new projects or existing operations, ESIAs play a crucial role in safeguarding ecological integrity, community well-being, and the overall sustainability of hydropower endeavours.

For new hydropower projects, an ESIA is a critical process conducted prior to taking significant decisions about implementation. The project lifecycle dimension involves engaging stakeholders in discussions about the proposed development's impacts and risks, culminating in a transparent and democratic decision-making process to determine whether the project should proceed and under what conditions. It involves a comprehensive evaluation of potential environmental and social impacts that the project might have during its construction and operation phases. This assessment helps identify and predict both positive and negative effects on ecosystems, local communities, and socio-economic aspects. By considering these impacts, stakeholders can make informed decisions about the project's feasibility, design, and mitigation measures. This process ensures that potential risks are mitigated, and benefits are maximized from the project's inception. An ESIA serves as a foundation for responsible decision-making and proactive management of potential impacts.

For hydropower projects that are already operational, an ESIA continues to be essential to maintain their sustainability and address any unforeseen impacts that may arise. Periodic reviews and assessments ensure that the project's ongoing activities are in alignment with environmental and social commitments. Operating projects might undergo assessments to verify that mitigation measures are effective, that the project remains compliant with regulatory standards, and that any evolving impacts are appropriately addressed. This helps ensure the project's continued positive contribution to the environment, communities, and the broader energy landscape.

The social assessment should include inclusive consultation with the population and stakeholders, including especially women and vulnerable groups, whilst also identifying and addressing distinct impacts on them. Existing ESIA reports often inadequately analyse the unique impacts these groups face due to the project's development [5]. Vulnerable groups encompass women-headed households, people with disabilities, ethnic and religious minorities, and those with distinct livelihoods. Tailored engagement and impact assessments are vital, requiring expertise in gender and social inclusion. Management plans, such as resettlement plans, must consider their needs to avoid unintended adverse effects.

Environmental assessment focuses on understanding and mitigating the potential environmental impacts of a hydropower project. It involves evaluating factors such as water quality, aquatic ecosystems, fish habitats, sediment transport, and the overall hydrological regime. The assessment identifies potential negative impacts, like alterations in river flow, disruption of fish migration routes, and changes in sediment dynamics. By identifying these impacts, measures can be devised to minimize or mitigate them. This might include incorporating fish-friendly turbine designs, creating fish passages to allow safe migration, and implementing sediment management strategies to prevent erosion and sedimentation downstream.

The ESIA process involves the following steps:

1. **Scoping:** defining the boundaries of the assessment, identifying potential impacts, and determining the scope of the assessment.
2. **Baseline Studies:** collecting data and information about the existing environmental and social conditions in the project area. This includes assessing aspects like air and water quality, biodiversity, ecosystems, cultural heritage, livelihoods, and community dynamics.
3. **Impact Assessment:** evaluating how the proposed project of hydropower facility might affect the environment and local communities. This involves identifying direct and indirect impacts, as well as short-term and long-term effects.
4. **Mitigation and Management:** developing measures to avoid, minimize, or offset negative impacts and enhance positive impacts. This may include meeting demonstrated needs for water and energy services, designing engineering solutions, adopting best practices, and establishing management plans.
5. **Public Consultation:** engaging with stakeholders, including local communities and relevant authorities, to gather input and feedback on the project's potential impacts and proposed mitigation measures.
6. **Reporting:** compiling all findings, assessments, and proposed measures into an ESIA report, which is submitted to regulatory authorities for review and approval.
7. **Decision-Making:** regulatory authorities use the ESIA report to make informed decisions about whether to approve the project, and if so, under what conditions.
8. **Monitoring and Follow-up:** implementing the approved avoidance, minimisation, mitigation, compensation and enhancement measures and monitoring their effectiveness during project implementation. Checking that environmental and social commitments are managed and fulfilled. If necessary, adjustments are made to ensure that impacts are managed as intended.

6.1.2 Labour and working conditions

This assessment checks that workers are treated fairly with equity and diversity and that their health and safety are protected. A comprehensive sustainability assessment considers the various dimensions of working conditions, from health and safety to fair labour practices, and assesses their impact on the project's overall sustainability. Key considerations in the assessment of labour and work conditions include:

- **Employment Opportunities**: Evaluating the potential for job creation, both during the construction phase and the operational lifespan of the project. Assessing the number of direct and indirect jobs that will be generated and their potential impact on local employment rates.
- **Workers' Rights**: Ensuring that workers involved are provided fair wages, safe working conditions, and adequate social protections, thus adhering to relevant labour laws and standards is essential.
- **Local Community Engagement**: Assessing how the project engages with the local workforce and whether efforts are made to hire from nearby communities. This can contribute to community development and reduce the project's social footprint.
- **Health and Safety**: Analysing the potential risks and hazards associated with the construction and operation of the hydropower project. Ensuring that adequate safety measures are in place to protect workers from accidents, injuries, and exposure to hazardous substances is crucial.
- **Skill Development**: Assessing whether the project provides training and skill development opportunities for local workers that enhances their employability beyond the project's lifespan and contributes to long-term community development.
- **Labour Displacement**: Evaluate whether the project may displace existing local livelihoods or industries and what mitigation measures can be designed to minimise negative impacts.
- **Gender and Diversity**: As mentioned before, considering the gender and diversity aspects of labour and work conditions, ensuring equal opportunities for all workers and addressing any potential discrimination.
- **Stakeholder Engagement**: Engaging with workers, labour unions, and relevant stakeholders to gather their input and concerns regarding labour and work conditions.

By thoroughly assessing these aspects, hydropower projects can ensure that labour and work conditions align with sustainability principles, contributes positively to local communities, and upholds ethical and responsible employment practices.

Throughout the entire hydropower lifecycle, addressing working conditions aligns with sustainability principles by ensuring ethical and responsible employment practices, minimizing social risks, and enhancing the project's positive contributions to local communities.

- **Preparation Phase.** Careful assessment of working conditions is essential to ensure that labour rights and safety standards are established from the outset. This includes evaluating the potential labour force required for various tasks during the project's construction and operation along with adequate planning for skilled labour and training. Potential job creation opportunities within local communities can positively impact the project's acceptance and long-term sustainability.
- **Implementation Phase.** Attention to working conditions is vital to guarantee the safety and well-being of the workforce. Adequate safety measures, access to protective equipment,

and proper training are crucial to prevent accidents and injuries. Properly managed working conditions contribute to efficient project execution and help prevent delays caused by workplace incidents. Stakeholder engagement with workers and labour unions during this phase can help address concerns and ensure that the labour force is treated fairly.

- **Operation Phase.** Regular monitoring of labour practices and conditions is necessary to ensure ongoing compliance with labour laws and standards. Properly managed work conditions can contribute to employee satisfaction and retention, reducing turnover rates. This phase also involves evaluating the long-term impact of the project on local employment and assessing whether the project has contributed positively to community development through job creation and skills enhancement.
- **Closure and Decommissioning Phase.** Properly managed decommissioning processes ensure the safe and fair treatment of workers involved in dismantling or repurposing project components. Adequate severance packages and support for re-employment opportunities can minimise negative impacts on the workforce.

6.1.3 Water quality and sediments

This assessment checks that water quality in the vicinity of the project is not adversely impacted by project activities, and that erosion and sedimentation caused by the project are managed responsibly and do not present problems with respect to other social, environmental and economic objectives. This involves implementing measures to mitigate erosion, sedimentation, and pollution, as well as ensuring proper sediment release strategies that mimic natural sediment transport patterns. Sustainable sediment and water quality management strategies contribute to the ecological integrity of rivers, the well-being of local communities, and the long-term viability of hydropower projects. An inclusive sustainability assessment evaluates these factors to ensure that hydropower projects are designed, implemented, and operated in a manner that harmonizes with both environmental and societal needs.

Water Quality

Hydropower projects can alter water quality by affecting flow regimes, temperature, dissolved oxygen levels, and nutrient concentrations. Disrupted water quality can harm aquatic habitats, affecting fish populations and other aquatic organisms. Ensuring that water quality remains within acceptable limits is vital for maintaining ecosystem health.

Poor water quality can negatively influence downstream communities that rely on the river for drinking water, irrigation, and livelihoods.

Altered water quality and sediment levels can impact fisheries, tourism, and recreational activities, which often depend on healthy aquatic ecosystems. Negative impacts on these activities can have socio-economic repercussions for local communities.

Water quality management refers to the comprehensive planning, implementation, and monitoring of strategies and measures aimed at maintaining, improving, or restoring the physical, chemical, and biological characteristics of water bodies. The goal of water quality management is to ensure that water resources meet specific standards and support the health of aquatic ecosystems, human consumption, and various uses while minimising negative environmental impacts and public health risks. It involves monitoring and addressing factors such as pollutant levels, temperature, dissolved oxygen content, pH, and nutrient concentrations to sustain the ecological balance of aquatic environments.

Sedimentation

Altered sediment transport due to dam construction and operation can lead to downstream erosion, sedimentation in riverbeds, and reduced water clarity. This disrupts habitats, impacts aquatic species, and affects overall ecosystem dynamics. Proper sediment management is essential to maintain natural sediment regimes and preserve downstream habitats.

Sediment accumulation in reservoirs can also reduce water storage capacity, necessitating costly dredging operations to maintain reservoir efficiency. Proper sediment management can extend the operational life of reservoirs and reduce maintenance expenses.

Sediment accumulation can lead to increased flooding risks and decreased water availability for agricultural use, impacting local economies and human well-being. It can affect the efficiency of hydropower generation, damaging turbines and other equipment, leading to decreased energy production and increased maintenance costs.

Sedimentation in European reservoirs is a pressing issue. A recent study "*Understanding the cost of soil erosion: An assessment of the sediment removal costs from the reservoirs of the European Union*" takes a first step in estimating the costs of sediment removal caused by soil erosion. By combining large-scale soil erosion assessments with local cost data from over 20 EU countries, it highlights major differences in costs depending on local conditions, sediment removal techniques, and reservoir characteristics. The study estimates that removing 135 million m³ of sediment caused by water erosion costs the EU and UK around EUR 2.3 billion annually. When considering all soil loss processes, this figure could rise to EUR 5–8 billion per year. While these numbers come with uncertainties, the findings underline the need for better data and effective mitigation strategies. Importantly, this work supports the goals of the European Green Deal by encouraging sustainable soil management, protecting biodiversity, and fostering a circular economy.

Sediments management refers to the control the movement, deposition, and accumulation of sediment particles within water bodies, particularly in the context of human activities such as construction, dam operation, and land development. The aim of sediment management is to prevent excessive sedimentation that can disrupt aquatic ecosystems, impact water quality, and cause adverse effects downstream. This involves measures to control erosion, sediment runoff, and sediment deposition in reservoirs, rivers, and other watercourses. This means to uptake strategies that incorporate erosion control practices, sediment trapping mechanisms, and the sustainable release of sediments from dams to mimic natural transport patterns.

6.1.4 Community impacts and infrastructure safety

Community impacts

This assessment checks that livelihoods including economic displacement, public health, rights and living standards impacted by the project are improved relative to pre-project conditions for project-affected communities.

The Hydropower Sustainability Tools (HST), managed by the Hydropower Sustainability Alliance, include explicit criteria statements, focusing on minimizing harm and maximizing benefits for communities affected by hydropower projects. While wording may vary slightly between the main tools—the Hydropower Sustainability Assessment Protocol, the ESG Gap Analysis Tool, and the Hydropower Sustainability Standard—the core criteria generally include:

- Projects must identify, evaluate, and manage the impacts (both positive and negative) on all directly affected communities and individuals over the project’s full lifecycle, including planning, construction, and operation.
- Developers must demonstrate that community engagement is ongoing, inclusive, culturally appropriate, and enables two-way communication. There should be clear evidence of information sharing, consultation, participation, and grievance mechanisms.
- Good practice requires that measures are implemented to avoid, minimize, and compensate for negative social impacts while maximizing project benefits for the community (such as improved infrastructure, employment, health, and education services) in a way that meets the communities’ priorities and needs.
- Criteria emphasize that project-affected communities' livelihoods and well-being are maintained or improved, and that risks—such as resettlement, loss of economic opportunity, or disruption to cultural heritage—are managed appropriately and transparently.
- There must be effective grievance management and transparent documentation to demonstrate that issues raised by communities are responded to and resolved appropriately throughout the project’s lifecycle.
- At the highest performance level, documentation must show ongoing benefit-sharing, proactive management of risks as they evolve, and measurable improvements in community well-being as a result of the project.

Infrastructure safety

This assessment checks also that life, property, community assets and resources are protected from the consequences of dam failure and other infrastructure safety risks. Ensuring the structural and functional integrity of hydropower assets is essential not only for public safety and environmental protection but also for the long-term reliability and economic viability of the facility.

Infrastructure safety in hydropower refers to the comprehensive management of risks related to the physical integrity and safe functioning of all infrastructure components throughout a project's life cycle. This includes the design, construction, operation, and, where relevant, decommissioning of elements such as dams, tunnels, spillways, transmission lines, roads, and associated facilities. The objective is to ensure the protection of workers, local communities, ecosystems, and downstream populations from hazards such as dam failure, structural collapse, extreme hydrological events, and associated accidents. Good international practice mandates that infrastructure safety must be embedded into every stage of hydropower development and operation. This includes proactive risk identification, robust technical assessments, adequate emergency preparedness and response mechanisms, and adaptive monitoring systems.

Infrastructure safety impacts a wide range of stakeholders and systems, including workers, local communities, environmental resources, and economic performance. Direct risks involve dam failure, landslides, sedimentation, and structural degradation, while indirect risks may arise from traffic accidents on access roads, electrical hazards from substations, or safety breaches at quarries and spoil areas. Safety failures can have far-reaching human, environmental, reputational, and financial consequences. The scope of safety planning must address dynamic risks, including those introduced by climate change (e.g., increased flood frequency), demographic shifts (e.g., urbanisation downstream), or evolving regulatory standards. Infrastructure safety measures must be regularly reviewed, updated, and effectively communicated across agencies and stakeholders.

Preparation Phase. A thorough and multidisciplinary assessment of potential safety risks must be carried out. This involves geological, hydrological, and seismic surveys, dam-break and flood-risk modelling, and the identification of public safety risks related to siting and project design. These assessments should be conducted with robust baseline data and in parallel with the environmental and social impact assessment (ESIA) process. The safety assessments should evaluate the full range of project conditions—including average, infrequent, and extreme scenarios—and be based on realistic simulations of dam performance under stress conditions. Cumulative impacts must also be addressed in river systems with multiple dams. Emergency preparedness and public communication strategies should be integrated early into project planning, with input from regulatory bodies and emergency services. Responsibilities must be clearly defined and agreed upon, including decision-making structures for risk response and thresholds for operational adjustments. The goal is to establish a foundation for risk prevention and effective crisis management.

Implementation Phase focuses on managing construction-related safety risks and setting the foundations for safe operation. This includes strict quality control in dam and infrastructure construction, public access restrictions, traffic safety measures, worker training, and slope and site stabilisation. Particular attention must be given to the reservoir filling process, which is recognised as a high-risk operation, requiring constant surveillance. All infrastructure works must be constructed following high safety standards, with clear responsibilities and well-documented safety procedures. Criteria for stopping operations must be in place in case of unexpected events like ground motion or seepage. Safety plans and emergency response mechanisms should be finalised and tested during this stage. These plans must be informed by the preparatory risk assessments and reviewed in consultation with relevant public authorities. The implementation phase also requires continuous information sharing with stakeholders to ensure transparency and build public trust.

Operation Phase. Infrastructure safety during the operation phase relies on ongoing monitoring, maintenance, and risk management. Dam behaviour, slope stability, flood risks, and performance indicators must be regularly assessed using real-time instrumentation and routine visual inspections.

Operational teams must be trained and prepared to respond swiftly to emerging risks or deviations from expected behaviour. Emergency preparedness must remain active throughout the facility's operational life, with regular simulations, public awareness initiatives, and inter-agency coordination. Adaptations to infrastructure or operational practices may be necessary in response to new scientific insights, regulatory changes, or extreme events such as landslides or floods. Asset maintenance and rehabilitation should be conducted systematically, with an emphasis on long-term infrastructure resilience. As hydropower facilities age, reassessments of dam safety and reinforcements or redesigns may be required to comply with updated standards or to address new hazards.

Decommissioning and Closure Phase demands careful safety considerations. This includes the controlled removal of physical structures, mitigation of residual risks (e.g., unstable slopes, contaminated sediments), and the restoration of affected ecosystems and land. A decommissioning plan must assess potential safety hazards associated with dismantling infrastructure or altering flow regimes. These plans should also account for long-term surveillance responsibilities, especially in regions where the removal of dams could reintroduce risks such as sediment flow or re-flooding of downstream areas. Coordination with regulators, emergency services, and communities is crucial to ensure a safe and socially responsible closure. Clear documentation of closure procedures, liability distribution, and post-decommissioning monitoring protocols is essential for effective risk management and to maintain public confidence.

6.1.5 Resettlement

Resettlement in hydropower projects refers to the process of managing the displacement of individuals, households, or communities resulting from land acquisition or environmental changes associated with project development. It involves both physical relocation and the restoration or improvement of livelihoods and living standards. The purpose of this topic is that physical displacement arises from the hydropower project development in a fair and equitable manner.

International good practice emphasises avoiding or minimising resettlement wherever possible. Where displacement is unavoidable, resettlement must uphold the principles of fairness—ensuring transparency and consistency—and equity—providing tailored support to vulnerable groups to ensure comparable outcomes for all.

The overarching objectives of resettlement activities are to achieve measurable improvements in the living standards and livelihoods of displaced persons. This goes beyond simply restoring pre-existing conditions; it requires that displaced communities are ultimately better off after resettlement interventions.

Attention to social dynamics, including gender roles and the specific needs of vulnerable groups, is critical throughout all stages of resettlement planning and execution. Without a strong, sustained focus on livelihood recovery and community development, displaced populations face significant risks of long-term impoverishment.

Hydropower projects typically require significant land acquisition for dams, reservoirs, power stations, transmission lines, access roads, quarries, and construction camps. Displacement can result directly from these infrastructure needs or indirectly through environmental changes such as inundation, erosion, sedimentation, and altered hydrology.

The areas of impact include:

- **Physical displacement**: The loss of homes and the need for resettlement.
- **Economic displacement**: The disruption of livelihoods based on agriculture, fishing, or other natural resource use.
- **Social disruption**: The fragmentation of communities, loss of social networks, and impacts on cultural identity.
- **Environmental impacts**: Changes to land and water resources that affect longer-term land use viability.

Hydrological changes can lead to secondary displacement even after project completion, such as gradual erosion, sediment build-up, or landslides affecting land usability. These secondary impacts can occur far from the immediate project site and may emerge months or years after the project becomes operational.

Construction activities also pose short- and medium-term displacement risks, particularly where temporary facilities like quarries, disposal sites, or campsites are poorly managed. Unplanned or incremental land needs during construction can significantly complicate resettlement efforts if not anticipated early.

Key consideration in the lifetime of hydropower project are the following:

Preparation phase

Preparation is the most critical phase for achieving successful resettlement outcomes. It begins with demonstrating avoidance—showing that all reasonable alternatives have been considered to minimise displacement. Project developers should assess design options that reduce land take, lower disruption to livelihoods, and minimise resettlement costs.

Key preparatory activities include:

- **Baseline studies**: Detailed socio-economic surveys and asset inventories to understand pre-project conditions.
- **Stakeholder engagement**: Transparent communication with affected populations, ensuring meaningful participation in decision-making.
- **Resettlement action plans (RAP)**: Comprehensive documents outlining entitlements, compensation mechanisms, relocation assistance, and livelihood restoration measures.
- **Cost and resource planning**: Realistic budgeting for all resettlement-related activities, including contingencies for unforeseen impacts.

Identification of vulnerable groups: Tailored strategies must be developed to ensure vulnerable individuals—based on age, gender, disability, ethnicity, or socio-economic status—receive adequate support.

Resettlement planning should not only focus on households immediately displaced but also anticipate wider impacts across communities and regions affected by changes to the environment and land use.

Gender mainstreaming must be integrated from the outset to ensure that women's needs, roles, and rights are explicitly addressed and that resettlement activities promote gender equality rather than reinforcing pre-existing disparities.

Implementation phase

Implementation involves the physical delivery of resettlement commitments as outlined in the RAP. Successful implementation depends on robust project management, accountability mechanisms, and continuous community engagement.

Key aspects include:

- **Compensation and land acquisition**: Payment of fair and timely compensation based on transparent valuation processes. Compensation should be sufficient not just to replace lost assets but also to enable improvement of livelihoods and living conditions.
- **Relocation support:** Assistance with physical moves, provision of replacement housing or land, and support services such as transport, schooling, and healthcare access.
- **Livelihood restoration programmes**: Practical, sustainable interventions that enable displaced persons to re-establish or improve their income-generating activities, for example through agricultural development, vocational training, or small business support.
- **Grievance redress mechanisms**: Accessible systems to allow displaced persons to raise concerns, seek remedies, and ensure accountability throughout the resettlement process.
- **Monitoring and evaluation**: Regular assessment of resettlement activities against predefined indicators, with adjustments made to ensure targets for living standards and livelihood improvements are met.

Attention must be given to the social fabric of resettled communities, supporting the rebuilding of social networks and institutions that sustain community cohesion and resilience.

Operation phase

Once the hydropower project becomes operational, resettlement responsibilities do not end. Ongoing support, monitoring, and potential remedial actions are necessary to ensure that the long-term objectives of improved livelihoods and living standards are achieved.

Operational-phase considerations include:

- **Post-resettlement monitoring**: Tracking socio-economic indicators to verify that displaced households experience tangible improvements over time. Monitoring should cover not only income but also health, education, housing quality, and social cohesion.
- **Addressing secondary impacts**: As environmental changes unfold—such as downstream sedimentation, altered water flows, or induced landslides—additional support or compensation may be required.

- **Sustaining livelihoods**: Continuous investment in livelihood support initiatives to ensure resilience against unforeseen challenges, market changes, or environmental degradation.
- **Institutional arrangements**: Ensuring that responsible agencies or organisations remain engaged and capable of managing post-resettlement issues, including grievance redress, additional compensation, or livelihood support.

Community engagement must be sustained through regular communication channels, ensuring that displaced persons feel heard, respected, and actively involved in decisions that affect their future.

Effective post-resettlement support helps to ensure that the project's broader development goals are achieved, fostering positive relations with host communities and contributing to the project's social sustainability.

6.1.6 Biodiversity and invasive species

This assessment aims to ensure that healthy, functional and viable aquatic and terrestrial ecosystems in the project-affected area are sustainable over the long-term, biodiversity impacts arising from project activities are managed responsibly; and that ongoing (fish passage in the catchment, reservoir and downstream areas) or emerging (invasive species) biodiversity issues are identified and addressed.

Biodiversity refers to the variety of life, including all living organisms, plants, animals, microorganisms, and the ecosystems they form. It encompasses the diversity of species, genetic diversity within those species, and the diversity of ecosystems and ecological processes.

Ensuring the respect of biodiversity in hydropower projects is crucial for maintaining the long-term health, functionality, and sustainability of both aquatic and terrestrial ecosystems within the project-affected region. Responsible management of biodiversity impacts stemming from project activities is imperative, encompassing the careful mitigation and monitoring of these effects. Additionally, fulfilling commitments to implement measures addressing biodiversity conservation and the control of invasive species is essential to uphold the integrity and sustainability of the natural environment.

Key considerations

Balancing the generation of renewable energy through hydropower with the preservation of biodiversity is a complex challenge. Sustainable hydropower development seeks to minimize these negative impacts through responsible project design, management, and mitigation measures while recognizing the importance of conserving biodiversity for the long-term health of ecosystems and the well-being of communities. Some of the aspects to be considered are:

- **Habitat Alteration**: The construction of dams and reservoirs for hydropower projects often involves significant alterations to natural river and aquatic habitats. These changes can disrupt or destroy critical habitats for various aquatic species.
- **Fish Migration**: Many fish species rely on river systems for migration, spawning, and feeding. Hydropower dams can block these migrations or cause physical harm to fish attempting to pass through turbines, affecting fish populations.

- **Water Flow**: Altering the natural flow of rivers and water bodies can impact the hydrology and ecology of aquatic ecosystems. Changes in water flow regimes can affect sediment transport, nutrient cycling, and the availability of habitat for aquatic organisms.
- **Invasive Species**: Hydropower projects can inadvertently facilitate the spread of invasive species. Altered flow regimes and the creation of reservoirs can provide new habitats for invasive species to thrive.
- **Ecosystem Fragmentation**: Dams can fragment river ecosystems, isolating populations of species and reducing genetic diversity. This can make species more vulnerable to extinction.

Depending on the type of hydropower project, the effects on biodiversity vary and thus the project needs to be assessed and managed on a case by case basis. However, we can identify some key areas where biodiversity impacts can arise, and should be taken into account in the performance of impact assessments: (1) The dam, spillway, and powerhouse sites; (2) the reservoir; (3) the streams flowing into the reservoir; (4) the immediate downstream river, which may be affected by diversions and hydropeaking up to 5–10 km; (5) the +10km downstream, that could be altered by changes to the the seasonal flow patterns or sediment transport, among others; and (6) infrastructure elements such as, quarries, roads, or transmission lines.

Another important thing to consider is the additional stress that cumulative impacts of more than one hydropower project in a single river can have for the sustainability. The sustainability assessment of these complex scenarios requires an additional layer of infrastructure planning and environmental assessment, that should consider the complete river basin as an ecosystem, instead of the hydropower project as an isolated entity.

Cumulative impacts can produce, among other complications, strain on local water resources, the alteration of natural flow patterns and blockages to sediment transport that could affect the quality of water and aquatic life further downstream. As the number of projects grow in European rivers, sustainability requirements grow also in complexity and a thorough understanding of the environmental and social dynamics becomes an essential part of the decision-making process.

Main mitigation measures

Mitigation measures are designed to minimise the negative impacts of hydropower projects on the natural environment and concerned communities. These measures, that can vary in effectiveness, comprise:

- **Fish Passages** are solutions designed to ensure the safe movement of fish past the barriers that hydropower infrastructures can present, thus fostering the conservation of the aquatic ecosystems and fish populations. Among the types of fish passages, we can find fish ladders, fish elevators, bypass channels/alternative routes or fish locks.

- **Flow Regime Management** refers to the manipulation and control of the river flow. Maintaining and monitoring natural flow patterns, including seasonal variations, can mitigate the disruption of aquatic ecosystems. Flow releases that mimic natural flow regimes help sustain habitats for aquatic species.

- **Habitat Restoration** refers to the efforts to rehabilitate and enhance the ecosystems that might have been disrupted by hydropower activities. Some of the measures that could be categorised here are restoration of riparian areas, wetland recovery or habitat enhancement.

- **Reservoir Management** involves the planning, operation and maintenance of the dam reservoir, which could include, among others, the control of the water level by the release or the storage of water, sediment control, quality monitoring, community engagement, etc.

- **Invasive Species Control** entails the identification and monitoring of species in the concerned area to prevent the introduction and spread of invasive species. Most of the methods are mechanical (physically removing the alien species), chemical (use of chemical products such as pesticides for control) and biological (the study of the hierarchy of the ecosystem in order to alter it for the benefit, for instance, by introducing a natural predator).

Research and Innovation are essential to stay ahead of the challenges and to develop more effective and sustainable mitigation approaches such as enabling further environmental and social understanding, improving the efficiency of the operation, upgrading biosecurity awareness, ensuring inclusivity and equality and improving regulatory measures.

To summarise, safeguarding biodiversity in hydropower projects is central to sustainability. Through research and innovation we could anticipate and mitigate potential impacts on hydropower ecosystems. This also entails transparency, ethical governance, and inclusive engagement with all stakeholders, especially vulnerable communities. As we push for sustainable hydropower, we should not lose the focus that our duty goes beyond energy generation; it also involves the protection of all life forms. The coexistence of renewable energy and biodiversity should not merely a vision but an imperative.

6.1.7 Indigenous peoples

The Hydropower Sustainability Tools (HST), set out explicit criteria statements for the Indigenous Peoples topic to ensure that hydropower projects respect the dignity, human rights, aspirations, culture, lands, knowledge, practices and natural resource-based livelihoods of Indigenous Peoples in an ongoing manner throughout the project life. The core criteria statements include:

- The project must respect the dignity, human rights, aspirations, culture, lands, knowledge, practices, and resource-based livelihoods of Indigenous Peoples.
- Projects are required to achieve Free, Prior and Informed Consent (FPIC) from affected Indigenous Peoples for good practice, with the extent of this engagement governed by the principle of proportionality—the level of consultation and consent required depends on the magnitude of potential impacts.
- Engagement must be conducted via Indigenous Peoples' own representative institutions, using culturally appropriate, two-way processes that allow for ongoing dialogue, issue-raising, and dispute management through mutually agreed procedures.

- The FPIC process must be adequately resourced, inclusive (accounting for gender and age diversity), and documented with verifiable, ongoing records agreed by all parties.
- Hydropower developers must demonstrate that the consent and engagement process addresses the full project lifecycle, especially for actions that affect Indigenous Peoples' land, livelihood, and cultural survival such as resettlement or hazardous waste storage.
- At the best practice level, documentation must show that for all directly affected Indigenous Peoples groups, FPIC is maintained throughout project planning and operation, with evidence of ongoing, good-faith negotiation and problem resolution.

These criteria are described in detail in the Hydropower Sustainability Assessment Protocol and the ESG Gap Analysis Tool and align with international frameworks such as the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).

6.1.8 Cultural heritage

This assessment checks that physical cultural resources are identified, their importance is understood, and measures are in place to address those identified to be of high importance and at risk of damage or loss by the hydropower project and associated infrastructure impacts.

Cultural heritage in the context of hydropower development encompasses both tangible and intangible attributes that represent the legacy of a community or society. This includes physical cultural resources such as archaeological sites, monuments, historic buildings, and culturally significant landscapes that may be at risk of damage or loss due to project activities. It also refers to the intangible cultural elements such as oral traditions, rituals, and social practices associated with these resources. The aim of good practice is to identify, assess, and manage cultural heritage in a way that preserves its value for future generations while accommodating the needs of the hydropower project.

Hydropower projects can have significant impacts on cultural heritage through direct physical alterations or indirect influences such as access restrictions, vibration, pollution, or landscape changes. Infrastructure developments like dams, reservoirs, transmission lines, and access roads may disturb or destroy physical cultural resources. Hydrological alterations may also affect sites downstream, causing erosion or flooding of areas of heritage significance. Additionally, construction activities and associated social changes, including the influx of workers, may result in the desecration or neglect of sacred sites and social traditions.

Preparation Phase

A comprehensive cultural heritage assessment should be integrated into the Environmental and Social Impact Assessment (ESIA). This assessment must identify, record, and evaluate the significance of all cultural heritage resources potentially affected by the project. Data should be gathered through both desk-based research and field surveys, complemented by input from local communities and heritage experts. Importantly, risks to these resources should be clearly documented and mitigation strategies defined. Stakeholder engagement is essential at this stage to ensure that culturally appropriate methods are used to understand and manage heritage concerns.

Where avoidance is not feasible, measures should be developed for documentation, conservation, or relocation of cultural items.

Implementation Phase

The focus shifts to executing the planned mitigation measures and ensuring compliance with heritage management commitments. Cultural heritage management should be embedded within the project's broader Environmental and Social Management Plan (ESMP). This includes applying a chance find procedure for unexpected discoveries and ensuring the presence of qualified experts on site. Monitoring programmes should be established to track the effectiveness of mitigation actions and respond to any emerging issues. Engagement with stakeholders must continue to validate actions and address concerns, ensuring that mitigation measures are accepted and understood by affected communities.

Operation Phase

The monitoring of cultural heritage should continue, particularly in areas vulnerable to long-term impacts such as reservoir inundation, riverbank erosion, or ongoing access limitations. Management systems must remain in place to address any emerging risks and to maintain the integrity of previously implemented mitigation measures. Regular inspections, engagement with local heritage stakeholders, and updates to management plans ensure that cultural heritage considerations remain active throughout the facility's lifespan. Operators should also remain informed about changes in legislation or policy that could affect their heritage responsibilities and adjust practices accordingly.

In all project phases, a commitment to transparency, cultural sensitivity, and stakeholder inclusion underpins effective cultural heritage management. Evidence-based approaches, clear documentation, and continuous monitoring are essential to preserving heritage values while advancing hydropower development.

6.1.9 Governance and procurement

The assessment topic aims to check that developer has sound corporate business structures, policies and practices; addresses transparency, integrity and accountability issues; can manage external governance issues (e.g. institutional capacity shortfalls, political risks including transboundary issues, public sector corruption risks); can ensure compliance; and all project-related procurement processes including works, goods and services are equitable, transparent and accountable.

Governance in the hydropower sector encompasses the frameworks, processes, and institutions through which decisions are made and implemented. It includes both internal corporate governance—relating to the organisation’s own structures, policies, and procedures—and external governance, which involves engagement with political, legal, and regulatory systems. Procurement refers to the processes by which hydropower developers and operators acquire works, goods, and services required for project preparation, implementation, and operation. Effective governance and procurement are essential to ensure transparency, accountability, ethical conduct, and efficiency throughout the project lifecycle.

Governance and procurement influence a wide range of outcomes in hydropower development. Sound governance ensures that projects are managed responsibly, risks are identified and mitigated, and compliance with regulatory and sustainability requirements is upheld. It also promotes stakeholder trust through ethical behaviour, fair treatment, and transparency. Procurement practices affect not only the cost and quality of project components but also contribute to ethical business conduct, local economic opportunities, and risk mitigation in supply chains. Together, governance and procurement underpin the social licence to operate and long-term sustainability of hydropower facilities.

Preparation Phase

Developers must conduct comprehensive assessments of the external governance environment, identifying relevant institutions, policies, and potential political, regulatory, and corruption risks. Understanding the broader legal and institutional context is critical to anticipate challenges such as inconsistent regulations, public sector capacity gaps, and transboundary or political issues. Internally, the project proponent should establish strong corporate governance structures, including clear roles for the Board of Directors, policies for risk management, compliance assurance, and stakeholder engagement.

Procurement planning begins with an assessment of the project's major supply needs, potential sources, and applicable legal frameworks. Developers must identify supply chain risks, including those related to corruption, delivery, and ethical labour practices. Early decisions on contracting approaches—such as unit pricing or EPC (Engineering, Procurement and Construction) models—must align with financial and risk management strategies. Procurement plans should outline objectives, itemise procurement requirements, define selection criteria, and set mechanisms for managing bidder engagement and grievances.

Implementation Phase

Effective governance involves the operationalisation of risk management systems, compliance tracking, ethical business conduct, and stakeholder engagement. Developers and contractors must demonstrate that corporate policies—such as codes of conduct, anti-corruption frameworks, and social and environmental responsibility plans—are being implemented and monitored. Transparent grievance mechanisms and communication channels should be in place to identify and resolve issues early.

Procurement activities are at their peak during implementation, requiring ongoing monitoring to ensure processes are followed and deliverables meet required specifications. Mechanisms must be in place to track contract performance, mitigate emerging risks, and verify compliance with environmental, labour, and quality standards. Procurement should be equitable, accountable, and inclusive, offering opportunities for local suppliers and workforce development where feasible. Independent audits and supplier performance evaluations support transparency and credibility throughout the supply chain.

Operation Phase

Governance responsibilities shift to maintaining compliance, adapting to changes in external governance, and ensuring sustained ethical and transparent conduct. Monitoring systems should identify emerging regulatory or institutional risks, while internal audits and reporting mechanisms support continuous improvement. Operators should maintain open communication with regulators and stakeholders, ensure timely updates to compliance registers, and uphold commitments to transparency.

Procurement in the operation phase is typically less extensive but still essential for maintenance and upgrades. It should follow established procedures and reflect lessons learned from earlier phases. Processes should continue to uphold principles of fairness, efficiency, and accountability, with ongoing opportunities for local engagement and continuous improvement of supplier performance. Ethical procurement, aligned with broader governance commitments, contributes to the overall sustainability and resilience of the hydropower facility.

6.1.10 Communications and consultation

Stakeholders (e.g. affected communities, governments, key institutions, partners, contractors, catchment residents, etc) are identified and engaged in the issues of interest to them, whilst communication and consultation processes establish a foundation for good stakeholder relations throughout the project life. The main requirements are:

- Stakeholders must be identified and appropriately engaged on issues that are relevant to them. This involves both internal company stakeholders and external parties such as affected communities, governments, and other institutions.
- Communication and consultation plans and processes covering all project stages (preparation, implementation, and operation) must be developed and implemented. These plans need to outline needs and approaches for various stakeholder groups and specific topics.
- A grievance mechanism must be in place to allow stakeholders to raise concerns and ensure responses are provided in a timely and effective manner.
- This mechanism should be accessible, transparent, and adaptable to both routine and significant issues raised by communities or individuals.
- Engagement should be ongoing, inclusive (including representation of marginalized groups), and support two-way communication, not just one-way provision of information.
- Evidence of application includes records of stakeholder engagement, documentation of issues raised and how they were addressed, and continual reassessment and adaptation of communication approaches as the project progresses.

At the certification (good practice) level, these requirements must be met throughout the full project lifecycle, while at the best practice level, communications and consultation processes must demonstrate strong outcomes—such as high levels of stakeholder satisfaction, proactive identification and resolution of issues, and clear improvements in stakeholder relationships and project legitimacy.

6.1.11 Hydrological resource Principle

This assessment checks that the project's planned power generation takes into account hydrological resource availability and reliability in the short and long-term, and that the reservoir and downstream flow regimes are planned and managed with an awareness of environmental, social and economic objectives.

Downstream flow regimes refer to the patterns, magnitude, and variability of water released from hydropower infrastructure into downstream river systems. These regimes are crucial for maintaining ecological integrity, social stability, and economic functionality in areas affected by flow alterations. In sustainable hydropower development, the objective is not only to maximise energy output but also to ensure that water released downstream supports the ecological functions of the river, meets community needs, and sustains other water users. Managing downstream flows requires careful attention to the volume, timing, and quality of water flows, considering both natural hydrological cycles and anthropogenic influences.

Changes in downstream flow regimes can significantly affect ecological processes, such as sediment transport, water temperature, aquatic biodiversity, and the integrity of floodplains and wetlands. Socially, communities dependent on consistent water flows for agriculture, fishing, transport or cultural activities may experience disruption. Economically, altered flow patterns can affect industries including agriculture, tourism, and fisheries, and may necessitate investments in mitigation infrastructure. Hydropower projects must thus adopt a holistic approach to downstream flow planning that balances energy generation with environmental and social objectives.

Preparation Phase

Downstream flow considerations begin with baseline assessments of hydrological, ecological, and social conditions. These include the documentation of existing flow regimes and how communities and ecosystems depend on them. Feasibility studies should evaluate all potentially affected river reaches, analysing possible changes in flow characteristics—including volume, seasonality, sediment load, and temperature—as a result of the proposed development.

Impact assessments must integrate multiple disciplines, often combining Environmental and Social Impact Assessments (ESIAs) with dedicated downstream flow studies. Hydrological and hydraulic modelling should be progressively refined throughout the preparation stage, using both site-specific data and regional trends, including those related to climate change. The goal is to define a flow regime that reflects a compromise between ecological requirements, community expectations, and energy production targets.

Stakeholder engagement is particularly critical at this stage. Regulators, local authorities, downstream communities, and sectoral agencies must be involved early in the planning process. Transparent dialogue can help align expectations, address potential conflicts, and inform design decisions such as dam location, outlet configuration, and the inclusion of adaptive management features.

Planning must also account for periods of operational extremes—such as droughts, floods, and reservoir filling—as these can pose risks to downstream values if not managed proactively. Where impacts are unavoidable, the preparation phase should outline mitigation strategies and clearly identify responsibilities and compliance mechanisms.

Implementation Phase

Downstream flow commitments transition from planning to practical application. Construction-related activities, especially reservoir filling and river diversion, can temporarily alter downstream flow conditions. While diversions typically have limited long-term impacts, the process of filling a reservoir can lead to significant flow reductions downstream, potentially for extended periods depending on reservoir size and inflow patterns.

Implementation should include detailed plans for controlled releases during reservoir filling to maintain minimum downstream flows. Infrastructure, such as bottom outlets or bypass systems, must be operational and tested prior to this phase to enable consistent flow management. Any temporary impacts—such as increased sedimentation or water quality changes—should be mitigated through measures like sediment retention ponds or temporary compensation flows.

This stage also offers opportunities to implement physical measures for future flow delivery, including the installation of monitoring equipment and adaptive infrastructure. Examples include flexible outlet systems, fish passages, and buffer storage areas for agricultural or ecological use. Adjustments based on emerging information, such as updated environmental data or stakeholder feedback, should be anticipated and integrated into revised management plans where necessary.

Operation Phase

Ongoing flow management, monitoring, and adjustment based on actual river and system performance are required. Operators must compare real-time data with predictive models to evaluate whether flow targets are being met. Monitoring should cover hydrology, water quality, ecological indicators, and socio-economic effects. Effective monitoring frameworks involve both the plant operator and external regulators, with clear roles for data collection, analysis, and public disclosure.

Operational decisions regarding flow releases are influenced by multiple factors, including energy demand, seasonal hydrology, licence obligations, and stakeholder expectations. A well-defined set of operational rules—such as reservoir rule curves and ramping rates—helps ensure consistency in flow management while allowing flexibility to respond to unforeseen conditions.

Adaptive management is central to good practice. Operational strategies should be responsive to threshold triggers, such as observed ecological stress or stakeholder grievances, allowing for modification of flow releases or mitigation strategies. Stakeholder consultation must continue throughout operations, particularly when changes in market or environmental conditions require significant adjustments to flow regimes.

Decommissioning and Closure Phase

Where hydropower infrastructure is removed or significantly altered, flow regimes may again change, potentially restoring more natural river conditions. It is essential to assess the ecological, social and economic implications of such changes, and to engage stakeholders in planning for the post-operation phase.

Monitoring should continue during and after decommissioning to assess whether the anticipated benefits—such as improved fish migration or sediment transport—are realised. Legacy infrastructure, such as weirs or channels, should be evaluated for potential removal or repurposing. Where facilities are maintained for non-hydropower purposes (e.g. flood control or irrigation), downstream flow responsibilities may need to be reassigned or renegotiated with new operators.

In conclusion, managing downstream flow regimes across all phases of the project life cycle is essential to ensuring the long-term sustainability and public acceptance of hydropower developments. A transparent, science-based, and participatory approach enables hydropower to meet both its energy goals and broader sustainability commitments.

6.1.12 Climate change mitigation and resilience

The topic aims to ensure that project's greenhouse gas (GHG) emissions are consistent with low carbon power generation, and the project is resilient to the effects of climate change, and contributes to wider adaptation to climate change. It provides guidelines for addressing climate change mitigation and resilience in hydropower projects, as outlined in the Hydropower Sustainability Tools (HST).

Climate change mitigation

Climate Change Mitigation is defined as human intervention to reduce greenhouse gas (GHG) emissions which may contribute or enhance their absorption. Reservoirs emit GHGs (CO2 and CH4) due to organic matter decomposition. Emissions depend on factors like reservoir design, water quality, temperature, and carbon stock. For hydropower schemes, climate change mitigation potential rests in the ability to provide clean energy with low lifetime GHG emissions, to displace fossil fuel generation, and support grid reliability. In the assessment, power density and net GHG emissions are calculated. GHG emission intensity is the grams of carbon dioxide equivalent per kilowatt-hour of electricity generated allocated to hydropower over the lifetime of the hydropower asset, assumed to be 100 years. Power density is the watts of capacity per square meter of flooded area. The recognised relationship between power density and emission intensity indicates that projects with a power density above 5 W/m^2 will exhibit emissions intensity below 100 gCO2e/kWh. A project with low emissions should have less than 100 gCO2e/kWh. Net GHG emissions in gCO2e per kWh per year should be estimated using a recognized tool such as the G-res Tool or through site specific calculations. (Net GHG footprint) = (Post-impoundment emissions) – (Pre-impoundment emissions) – (Unrelated anthropogenic sources emissions) + (Construction emissions). Management criterion are through design, construction, and operational measures which are implemented to reduce emissions. Projects with emissions above 100 gCO2e/kWh require site-specific assessments and design, construction, and operational measures to lower emissions below

this figure. Mitigation design measures consist of minimising water retention time, the extent of the shallow area or the flooded organic matter, and the amount of water takes from anoxic depths; increasing oxygen concentration, air injection or power density. Construction measures include biomass clearance, optimising vehicle use, minimising energy use, reducing CO2e footprint through procurement policies, managing and reducing water and waste, draining. Operational measures consist of release of oxygenated water at seasonally appropriate temperatures and managing water quality.
Outcomes: Projects must demonstrate consistency with low-carbon power generation and alignment with national/regional policies.

Climate change resilience

Climate Change Resilience is the capacity of hydropower projects to adapt to climate change impacts, such as altered precipitation, extreme weather, and runoff patterns. Assessment includes stress tests and risk assessments based on plausible climate change scenarios, focusing on dam safety, infrastructure resilience, environmental/social risks, and power generation availability. Measures to avoid or reduce identified climate risks which should be maintained during construction and operation are design/structural and non-engineering/functional measures. Examples of design/structural measures involve access roads and camps; river diversion works for higher inflows; increased spillway capacity, added sediment management facilities, raised dam crest, and provision for future storage capacity increases; enhanced flood defences for the powerhouse; installed variable speed turbines, corrosion-resistant turbine blades, and equipment adaptable to a wide range of discharges; environmental flow systems designed to accommodate varying discharge rates; reservoir rim stability assessed for slope stabilization in areas prone to landslides and transmission lines reassessed for greater stability. Examples of functional measures: revised reservoir level limits, operating rules, and monthly rule curves to provide increased flood storage buffers; restricted land development in flood-prone zones and protected vulnerable areas; modified legal agreements and operational rules to address changing water and energy demands; disaster preparedness and response plans developed, ensuring guaranteed downstream flows, and enhanced flood/drought management programs. These measures integrate climate science and hydropower engineering to build resilience into hydropower projects, ensuring their long-term sustainability and adaptability to climate change impacts. Management criterion include structural and operational measures that are planned to mitigate climate risks. Outcomes: Projects must demonstrate resilience under various climate scenarios and alignment with adaptation policies.

Stakeholder engagement plays a critical role in ensuring transparency, inclusivity, and accountability in addressing climate change mitigation and resilience in hydropower projects. Public disclosure of GHG emissions and climate risk management plans is essential. Stakeholders should be involved in discussions about dam safety, environmental/social risks, and adaptation services. Overall, stakeholder engagement ensures that hydropower projects align with community needs, address concerns effectively, and maintain trust and cooperation throughout their development and operation.

Conformance/Compliance: Projects must adhere to climate mitigation and resilience commitments, with evidence provided through monitoring, inspections, or independent reviews.

Outcomes: Projects should deliver low-carbon power generation and resilience to climate change, supported by evidence such as risk assessments, feasibility studies, and stakeholder engagement records.

The document emphasizes the importance of integrating climate science and engineering into hydropower planning, implementation, and operation to ensure long-term sustainability and adaptation to climate change.

6.2 Sustainability Assessment for Preparation Stage

The main requirements for each topic reflect two levels of performance requirements:

1. Minimum expectations to achieve good practice and
2. Advanced performance for best practice.

The performance requirements are specified by sustainability topic, with each topic showing the requirements criteria-by-criteria for each project life cycle stage.

6.2.1 Environmental and social assessment

Criteria	Good Practice	Best Practice
Assessment	*Impacts:* Assessed. *Demonstrated need and strategic fit:* water, energy, national & regional policies or plans being considered. *Siting and design:* done in preliminary project.	*Impacts*: Assessment takes broad considerations, risks and opportunities. *Demonstrated need and strategic fit:* Efficient dialogue with relevant stakeholders. *Siting and design:* For sustainable development of the river basin and integrated water resource management.
Management	*Impacts*: Plans and processes to address issues including construction issues have been developed and publicly disclosed *Siting and design:* An optimisation process has been undertaken.	*Impacts:* Processes in place to anticipate and respond to risks and opportunities Plans embedded within ISO 14001 Independent review mechanisms.
Compliance	On track to meet criteria with no major non-compliance or non-conformance.	No non-compliance or no non-conformance.
Outcomes	*Impacts:* Plans avoid, minimise and mitigate impacts and issues. *Demonstrated need and strategic fit* is relevant with policies and demand. *Siting and design:* Has responded to environmental and social demand. The project can pay for social and environmental plans and commitments.	*Impacts:* Plans provide for enhancements to pre-project conditions or contribute to addressing issues beyond those impacts caused by the project. *Demonstrated need and strategic fit:* the project is one of the priority options to address demonstrated needs.

		Siting and design: Is optimal with respect to sustainability considerations for siting and design.

6.2.2 Labour and working conditions

Criteria	Good Practice	Best Practice
Assessment	Done.	Assessment takes broad considerations, risks and opportunities.
Management	Plans and processes have been developed for implementation and operation that cover all labour management planning components, including those of contractors, subcontractors and intermediaries.	Processes in place to anticipate and respond to risks and opportunities.
Compliance		
Outcomes	There are no identified inconsistencies of labour management policies, plans and practices with internationally recognised labour rights.	Labour management policies, plans and practices are demonstrated to be consistent with internationally recognised labour rights.

6.2.3 Water quality and sediments

Criteria	Good Practice	Best Practice
Assessment	Done undertaking.	Assessment takes broad considerations, risks and opportunities.
Management	Plans and processes to address issues have been developed.	Processes in place to anticipate and respond to risks and opportunities.
Compliance	On track to meet criteria with no major non-compliance or non-conformance.	No non-compliance or no non-conformance.
Outcomes	Plans avoid, minimise and mitigate impacts and issues.	Plans provide for enhancements to pre-project conditions or contribute to addressing issues beyond those impacts caused by the project.

6.2.4 Community impacts and infrastructure safety

Criteria	Good Practice	Best Practice
Assessment	*Project-affected communities:* An assessment of issues has been undertaken, utilising local knowledge. *Project benefits:* An assessment of opportunities to increase the development contribution of the project has been undertaken and well-documented. *Infrastructure safety:* Thorough assessment of critical infrastructure safety risks during project preparation, construction and operation undertaken.	Assessment takes broad considerations, risks and opportunities.

	Public health: Public health issues and risks for different community groups assessed.	
Management	*Project-affected communities:* Dam and other infrastructure safety management plans and processes have been developed and independently reviewed for project implementation and operation in conjunction with relevant regulatory and local authorities and provide for communication of public safety measures; emergency response plans include awareness, training programs and on-site simulations.	*Project-affected communities, project benefits and public health:* Processes are in place to anticipate and respond to emerging risks and opportunities. *Infrastructure safety* – Processes to anticipate and respond to emerging risks and opportunities are in place, plans are widely communicated in a timely and accessible manner; and emergency response plans are independently reviewed.
Compliance		
Outcomes	*Project-affected communities:* Plans provide for livelihoods and living standards impacted by the project to be improved, and economic displacement fairly compensated, preferably through provision of comparable goods, property or services. *Project benefits* – Plans done. *Infrastructure safety* & *Public health:* Plans avoid, minimise and mitigate impacts and risks arising from project activities.	*Project-affected communities* – Plans done with the aim of self-sufficiency in the long-term; and the project contributes to addressing issues for project affected communities beyond impacts caused by the project itself. *Project benefits:* Plans deliver significant and sustained benefits for communities affected by the project. *Infrastructure safety:* Plans contribute to addressing safety issues beyond those risks caused by the project itself. *Public health:* – Plans avoid, minimise, mitigate and compensate negative public health impacts and provide for enhancements to pre-project public health conditions or contribute to addressing public health issues beyond those impacts caused by the project.

6.2.5 Resettlement

Criteria	Good Practice	Best Practice
Assessment	Assessment undertaken early in the project preparation stage to establish the socio-economic baseline for potential resettlement and host communities, and included cost for improvement in living standards.	Assessment takes broad considerations, risks and opportunities.
Management	A Resettlement Action Plan and associated processes have been developed in a timely manner for project implementation and operation, which includes an up-to-date socio- economic baseline, compensation framework, grievance mechanisms, and monitoring procedures; and formal agreements	Processes in place to anticipate and respond to risks and opportunities.

	with resettlement and host communities are publicly disclosed.	
Compliance		
Outcomes	Plans provide for resettlement to be treated in a fair and equitable manner, and resettlement and host communities to experience a timely improvement in livelihoods and living standards.	Plans provide for resettlement and host communities to experience a timely improvement in livelihoods and living standards with the aim of self-sufficiency in the long term.

6.2.6 Biodiversity and invasive species

Criteria	Good Practice	Best Practice
Assessment	An assessment of terrestrial biodiversity; aquatic biodiversity including passage of aquatic species and loss of connectivity to significant habitat; and risks of invasive species has been undertaken.	Assessment takes broad considerations, risks and opportunities.
Management	Plans and processes to address identified biodiversity issues have been developed for project implementation and operation.	Processes are in place to anticipate and respond to emerging risks and opportunities; and commitments in plans are public, formal and legally enforceable.
Compliance		
Outcomes	Plans avoid, minimise, mitigate and compensate negative biodiversity impacts arising from project activities with no significant gaps.	Plans avoid, minimise, mitigate and compensate negative biodiversity impacts arising from project activities with no identified gaps; and plans provide for enhancements to pre-project biodiversity conditions or contribute to addressing biodiversity issues beyond those impacts caused by the project.

6.2.7 Indigenous peoples

Criteria	Good Practice	Best Practice
Assessment	An assessment of the representation of Indigenous Peoples in the project-affected community has been undertaken, including identification of their rights at risk in relation to the project, utilising local knowledge and expertise.	Assessment takes broad considerations, risks and opportunities for Indigenous Peoples.
Management	Plans and processes have been developed for project implementation and operation to address the Indigenous Peoples' rights at risk in relation to the project; and formal commitments are publicly disclosed.	Processes in place to anticipate and respond to risks and opportunities.

Stakeholder engagement	Good-faith consultation with Indigenous Peoples' institutions of representation and decision-making, as determined by them, has been carried out through a process that was appropriately timed, culturally appropriate and two-way; ongoing processes are in place for Indigenous Peoples to raise issues and get feedback; and a mutually agreed disputes procedure is in place.	Feedback on how issues raised have been taken into consideration has been thorough and timely.
Stakeholder Support	Free, Prior and Informed Consent has been achieved with respect to the Indigenous Peoples' rights at risk following the principle of proportionality.	Free, Prior and Informed Consent of directly affected indigenous groups has been achieved for the entire project.
Outcomes	Plans provide for negative impacts of the project to Indigenous Peoples' rights to be avoided, minimised, mitigated or compensated, and some practicable opportunities for positive impacts to be achieved.	Opportunities for positive impacts have been thoroughly identified and maximised as far as practicable.

6.2.8 Cultural heritage

Criteria	Good Practice	Best Practice
Assessment	A cultural heritage assessment has been undertaken with no significant gaps; the assessment includes identification and recording of physical cultural resources, evaluation of the relative levels of importance, and identification of any risks arising from the project.	Assessment takes broad considerations, risks and opportunities.
Management	Plans and processes to address physical cultural resources have been developed for project implementation and operation; plans include arrangements for chance finds, and ensure that cultural heritage expertise will be on site and regularly liaised with by the project management team during construction.	Processes are in place to anticipate and respond to emerging risks and opportunities; and plans are supported by public, formal and legally enforceable commitments.
Compliance		
Outcomes	Plans avoid, minimise and mitigate negative impacts and issues on cultural heritage arising from project activities with no significant gaps.	Plans provide for enhancements to pre-project conditions or contribute to addressing issues beyond those impacts caused by the project.

6.2.9 Governance and procurement

Resettlement	Good Practice	Best Practice
Assessment	*Governance:* Assessments have been undertaken of political and public sector governance issues, and corporate governance requirements and issues, through the project development cycle. *Procurement:* An assessment of major supply needs, supply sources, relevant legislation and guidelines, supply chain risks and corruption risks has been undertaken.	There are no significant opportunities for improvement in the assessment of political and public sector governance issues and corporate governance requirements and issues; and the assessment includes opportunities for local suppliers and local capacity development.
Management	*Governance:* processes are in place to manage corporate, political and public sector risks, compliance, social and environmental responsibility, grievance mechanisms, ethical business practices, and transparency; policies and processes are communicated internally and externally as appropriate; and independent review mechanisms are utilised to address sustainability issues in cases of project capacity shortfalls, high sensitivity of particular issues, or the need for enhanced credibility. *Procurement:* procurement plans and processes have been developed for project implementation and operation.	*Governance:* processes are in place to anticipate and respond to emerging risks and opportunities; and contractors are required to meet or have consistent policies as the developer. *Procurement:* processes are in place to anticipate and respond to emerging risks and opportunities; sustainability and anti-corruption criteria are specified in the pre-qualification screening; and anti-corruption measures are strongly emphasised in procurement planning processes.
Compliance	No major non-compliance	No major non-compliance
Outcomes	*Governance:* there are no significant unresolved corporate and external governance issues identified. *Procurement:* procurement of works, goods and services across major project components is equitable, efficient, transparent, accountable, ethical and timely, and contracts are progressing or have been concluded within budget or that changes on contracts are clearly justifiable.	*Governance:* there are no unresolved corporate and external governance issues identified. *Procurement:* opportunities for local suppliers including initiatives for local capacity development have been delivered or are on track to be delivered.

6.2.10 Communication and consultation

Criteria	Good Practice	Best Practice
Assessment	Stakeholder mapping has been undertaken to identify and analyse stakeholders, to establish those that are directly affected, and to establish communication requirements and priorities.	The stakeholder mapping takes broad considerations into account.

Management	Communication and consultation plans and processes, including an appropriate grievance mechanism, have been developed at an early stage applicable to project preparation, implementation and operation that outline communication and consultation needs and approaches for various stakeholder groups and topics.	Communication and consultation plans and processes show a high level of sensitivity to communication and consultation needs and approaches for various stakeholder groups and topics; processes are in place to anticipate and respond to emerging risks and opportunities.
Stakeholder engagement	There has been some engagement directly with affected stakeholders appropriately timed, which has often been two way, and undertaken in good faith; there are ongoing processes in place for stakeholders to raise issues and to get feedback. Engagement with resettlees has been culturally appropriate; and resettlees and host communities have been involved in the decision-making around relevant options and issues. The business makes significant project reports publicly available and publicly reports on project performance in some sustainability areas; the results of the assessment of strategic fit are publicly disclosed; the power density calculations, estimated GHG emissions, and / or the results of a site-specific assessment have been publicly disclosed.	Engagement with directly affected stakeholders has been inclusive and participatory; negotiations were undertaken in good faith; feedback on how issues raised have been taken into consideration has been thorough and timely. The business publicly reports on project performance in sustainability areas of high interest to its stakeholders. The assessment of project resilience has been publicly disclosed.
Stakeholder support	Affected communities generally support or have no major ongoing opposition to the plans for the issues that specifically affect their community; resettlees and host communities generally support or have no major ongoing opposition to the Resettlement Action Plan; directly affected stakeholder groups generally support or have no major ongoing opposition to the cultural heritage assessment.	Formal agreements with nearly all the directly affected communities have been reached for the mitigation, management and compensation measures relating to their communities; there is consent with legally binding agreements by the resettlees and host communities for the Resettlement Action Plan; formal agreements with the directly affected stakeholder groups have been reached for cultural heritage management measures.
Compliance	Processes and objectives relating to communications and consultation have been and are on track to be met with no major non-conformances and non-compliances; any communications related commitments have been or are on track to be met.	No non-compliance or no non-conformance.

6.2.11 Hydrological resource

Resettlement	Good Practice	Best Practice
Assessment	*Hydrological resource* – Monitoring is being undertaken of hydrological resource availability and reliability, and ongoing or emerging issues have been identified; inputs include field measurements, appropriate statistical indicators, issues which may impact water availability or reliability, and a hydrological model. *Reservoir management* – Ongoing or emerging reservoir management issues have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective. *Downstream flows* – Ongoing or emerging issues relating to the operating hydropower facility's downstream flow regimes have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective.	*Hydrological resource* – Issues that may impact on water availability or reliability have been comprehensively identified; scenarios, uncertainties and risks are routinely and extensively evaluated over the short and long term. *Reservoir management* – Identification of ongoing or emerging reservoir management issues takes into account both risks and opportunities. *Downstream flows* – Issues identification takes into account both risks and opportunities; identification of the flow ranges and variability to achieve different environmental, social and economic objectives based on field studies as well as relevant scientific and other information.
Management	*Hydrological resource* – Measures are in place to guide generation operations that are based on analysis of the hydrological resource availability, a range of technical considerations, an understanding of power system opportunities and constraints, and social, environmental and economic considerations. *Reservoir management* – Measures are in place to manage identified issues. *Downstream flows* – Measures are in place to address identified downstream flow issues; where formal commitments have been made, these are publicly disclosed.	*Hydrological resource* – Generation operations planning has a long-term perspective; fully optimises and maximises efficiency of water use and has the flexibility to adapt to anticipate and adapt to future changes. *Reservoir management* – Processes are in place to anticipate and respond to emerging risks and opportunities. *Downstream flows* – Processes are in place to anticipate and respond to emerging risks and opportunities; commitments are made in relation to downstream flow regimes that include the flow objectives, the magnitude, range and variability of the flow regimes, the locations at which flows will be verified, and ongoing monitoring.
Compliance	*Reservoir management* – Processes and objectives in place for reservoir management have been and are on track to be met with no major non compliances or non-conformances, and reservoir management related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.

	Downstream flows – Processes and objectives in place to manage downstream flows have been and are on track to be met with no major non-compliances or non-conformances, and downstream flow related commitments have been or are on track to be met.	
Outcomes	Plans for downstream flows take into account environmental, social and economic objectives, and where relevant, agreed transboundary objectives.	Plans for downstream flow regimes represent an optimal fit amongst environmental, social and economic objectives.

6.2.12 Climate change mitigation and resilience

Criteria	Good Practice	Best Practice
Assessment	*Climate mitigation:* Power density has been calculated; if power density is below 5 W/m², net GHG emissions (gCO2e) of electricity generation have been estimated and independently-verified; if power density is below 5 W/m² and estimated emissions are above 100 gCO2e/kWh, a site-specific assessment of GHG emissions has been undertaken; an assessment of the project's fit with national and/or regional policies and plans on mitigation has been undertaken. *Climate resilience:* An assessment of the project's resilience to climate change has been undertaken, which incorporates an assessment of plausible climate change at the project site, identifies a range of resulting climatological and hydrological conditions at the project site, and applies these conditions in a documented risk assessment or stress test that encompasses dam safety, other infrastructural resilience, environmental and social risks, and power generation availability; and an assessment of the project's potential adaptation services and fit with national and/or regional policies and plans for adaptation has been undertaken.	*Climate mitigation:* If a site-specific assessment is required, it incorporates a broad range of scenarios, uncertainties and risks. *Climate resilience:* Assessment of resilience incorporates sensitivity analysis and project-specific hydrological modelling using recognised climate models.
Management	*Climate mitigation:* If GHG emissions estimates assume design and management measures, there are plans to put these measures in place. *Climate Resilience:* The project design is based on plausible climate change	*Climate mitigation:* Design and management measures have been developed for implementation and operation phases of the project to respond to risks and opportunities including offsetting emissions; plans

	scenarios and structural and operational measures are planned for design, implementation and operation phases to avoid or reduce the identified climate risks.	have been developed to monitor parameters used in GHG emissions estimates or to monitor GHG stocks. *Climate resilience:* Resilience measures take account of a broad range of risks and inter relationships, and processes are in place to respond to unanticipated climate change; plans have been developed to provide adaptation services if necessary.
Compliance	On track to meet criteria with no major non-compliance or non-conformance; any mitigation-related and resilience-related commitments have been or are on track to be met.	No non-compliance or no non-conformance
Outcomes	*Climate mitigation:* The project's GHG emissions are demonstrated to be consistent with low carbon power generation, and the fit of the project with national and regional policies and plans for mitigation can be demonstrated. *Climate resilience:* Plans will deliver a project that is resilient to climate change under a range of scenarios; the fit of the project with national and regional policies and plans for adaptation can be demonstrated.	*Climate mitigation:* Project net emissions are minimised or project operations facilitate system emissions reductions. *Climate resilience:* The project is resilient under a broad range of scenarios; the project will contribute to climate change adaptation at local, regional or national levels.

6.3 Sustainability Assessment for Implementation Stage

6.3.1 Environmental and social assessment

Criteria	Good Practice	Best Practice
Assessment	*Environmental and social issues & Waste, noise and air quality* – Monitoring is being undertaken during the project implementation stage appropriate to the identified issues.	*Environmental and social issues & Waste, noise and air quality* – Monitoring of issues during project implementation takes into account inter relationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	*Environmental and social issues & Waste, noise and air quality* – Processes are in place to ensure management of identified environmental and social issues utilising appropriate expertise (internal and external), and to meet any environmental and social commitments, relevant to the project implementation stage; plans are in place for the	*Environmental and social issues & Waste, noise and air quality* – Plans and processes are in place to anticipate and respond to risks and opportunities and are embedded within an environmental management system such as ISO 14001.

	operation stage for ongoing environmental and social issues management; the environmental and social impact assessment and key associated management plans are publicly disclosed.	
Compliance		
Outcomes	*Environmental and social issues* – Negative environmental and social impacts of the project are avoided, minimised and mitigated. *Waste, noise and air quality* – Negative noise and air quality impacts arising from project activities are avoided, minimised and mitigated with no significant gaps, and project wastes managed responsibly. The project or the corporate entity to which it belongs can pay for social and environmental plans and commitments.	*Environmental and social issues* – Negative environmental and social impacts are avoided, minimised, mitigated and compensated; enhancements to pre-project environmental or social conditions or contributions to addressing issues beyond those impacts caused by the project are achieved or are on track to be achieved. *Waste, noise and air quality* – Negative noise and air quality impacts arising from project activities are avoided, minimised, mitigated and compensated with no identified gaps; project wastes are avoided, minimised, mitigated and compensated with no identified gaps; the project contributes to addressing waste management issues beyond those impacts caused by the project.

6.3.2 Labour and working conditions

Criteria	Good practice	Best practice
Assessment	Human resources and labour management requirements have been identified through an assessment process, including occupational health and safety (OH&S) issues and risks; processes are in place to identify any emerging or ongoing issues, and to monitor if management measures are effective.	Assessment takes broad considerations, risks and opportunities.
Management	Human resource and labour management policies, plans and processes are in place that address all labour management planning components, including those of contractors, subcontractors and intermediaries.	Processes in place to anticipate and respond to risks and opportunities.
Compliance	Processes and objectives relating to human resource and labour management have been and are on track to be met with no major non compliances or non-conformances, and	There are no non-compliances or non-conformances.

	any labour related commitments have been or are on track to be met.	
Outcomes	There are no identified inconsistencies of labour management policies, plans and practices with internationally recognised labour rights.	Labour management policies, plans and practices are demonstrated to be consistent with internationally recognised labour rights.

6.3.3 Water quality and sediments

Criteria	Good Practice	Best Practice
Assessment	Water quality or erosion and sedimentation issues relevant to project implementation and operation have been identified through an assessment process utilising appropriate expertise; monitoring is being undertaken during the project implementation stage appropriate to the identified issues.	Monitoring of water quality or erosion and sedimentation issues during project implementation takes into account inter-relationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	Processes are in place to ensure management of identified water quality or erosion and sedimentation issues, and to meet commitments, relevant to the project implementation stage; plans are in place for the operation stage for ongoing water quality issues management.	Processes are in place to anticipate and respond to emerging risks and opportunities.
Compliance	Processes and objectives in place to manage water quality and erosion and sedimentation issues have been and are on track to be met with no major non-compliances or non-conformances, and water quality and erosion and sedimentation related commitments have been or are on track to be met.	No non-compliance or no non-conformance.
Outcomes	Negative water quality impacts arising from project implementation and erosion and sedimentation issues during project implementation are avoided, minimised and mitigated.	Negative water quality impacts arising from project implementation and erosion and sedimentation issues during project implementation are avoided, minimised, mitigated and compensated; enhancements to pre-project water quality or erosion and sedimentation conditions or contribution to addressing water quality or erosion and sedimentation issues beyond those impacts caused by the project are achieved or are on track to be achieved.

6.3.4 Community impacts and infrastructure safety

Criteria	Good Practice	Best Practice
Assessment	*Project-affected communities* – Monitoring of project impacts and effectiveness of management measures is being undertaken during project implementation appropriate to the identified issues. *Project benefits* – In the case that commitments to additional benefits or benefit sharing have been made, monitoring is being undertaken on delivery of these commitments. *Infrastructure safety* – Safety monitoring is being undertaken during the project implementation stage appropriate to the identified issues. *Public health* – Public health issues relevant to project implementation and operation have been identified through an assessment process utilising appropriate expertise; monitoring is being undertaken during the project implementation stage appropriate to the identified issues.	*Project-affected communities* – Monitoring of project-affected communities issues during project implementation takes into account inter-relationships amongst issues, and both risks and opportunities that become evident during implementation. *Project benefits* – The assessment of delivery of project benefits takes into consideration both risks and opportunities. *Infrastructure safety* – Consideration of safety issues takes into account a broad range of scenarios and both risks and opportunities. *Public health* – Monitoring of public health issues during project implementation takes into account interrelationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	*Project-affected communities* – Measures are in place to address identified issues that affect project affected communities, and to meet commitments made to address these issues; and if there are any formal agreements with project affected communities these are publicly disclosed. *Project benefits* – Measures are in place to deliver commitments by the project to additional benefits or benefit sharing; and commitments to project benefits are publicly disclosed. *Infrastructure safety* – Processes are in place to address identified dam and other infrastructure safety issues, and to meet any safety related commitments, relevant to the project implementation stage, including providing for communication of public safety measures; a formal quality control program is in place for construction; safety management plans for the operation stage have developed in conjunction with relevant regulatory and local authorities; and emergency	*Project-affected communities, project benefits and public health* – Processes are in place to anticipate and respond to emerging risks and opportunities. *Infrastructure safety* – Processes are in place to anticipate and respond to emerging risks and opportunities; and public safety measures are widely communicated in a timely and accessible manner.

	response plans include awareness and training programs and emergency response simulations. *Public health* – Processes are in place to ensure management of identified public health issues, and to meet commitments, relevant to the project implementation stage; plans are in place for the operation stage for ongoing public health issues management including hand-over to local authorities as appropriate.	
Compliance	Processes and objectives relating to project-affected communities issues, project benefits, infrastructure safety and public health issues have been and are on track to be met with no major non-compliances or non-conformances, and commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	*Project-affected communities* – Livelihoods and living standards impacted by the project have been or are on track to be improved, and economic displacement is fairly compensated, preferably through provision of comparable goods, property or services. *Project benefits* – Communities directly affected by the development of the hydropower project, and any other identified beneficiary of the facility have received or are on track to receive benefits. *Infrastructure safety* – Safety risks have been avoided, minimised and mitigated with no significant gaps. *Public health* – Negative public health impacts arising from project activities are avoided, minimised and mitigated.	*Project-affected communities* – The measures put in place to improve livelihoods and living standards are on track to promote self-sufficiency in the long- term. *Project benefits* – Benefits are significant and the project has delivered or is on track to deliver significant and sustained benefits for communities affected by the project. *Infrastructure safety* – Safety risks have been avoided, minimised and mitigated with no identified gaps; safety issues have been addressed beyond those risks caused by the project itself. *Public health* – Negative public health impacts arising from project implementation are avoided, minimised, mitigated and compensated; enhancements to pre-project public health conditions or contributions to addressing public health issues beyond those impacts caused by the project are achieved or are on track to be achieved.

6.3.5 Resettlement

Criteria	Good Practice	Best Practice
Assessment	An assessment of the resettlement implications of the project has been undertaken that establishes the pre-project socio-economic baseline for resettlees and host communities;	The assessment of delivery of commitments to resettlees and host communities takes into consideration both risks and opportunities.

	monitoring is being undertaken of implementation of the resettlement plans to see if commitments made to resettlees and host communities have been delivered and are effective and to identify any ongoing or emerging issues.	
Management	Measures to address resettlement are documented in a Resettlement Action Plan; measures are in place to deliver commitments to resettlees and host communities, and to manage any identified issues relating to resettlement, including provision of grievance mechanisms; formal agreements with resettlees and host communities are publicly disclosed.	Processes in place to anticipate and respond to risks and opportunities.
Compliance	Processes and objectives in the Resettlement Action Plan have been and are on track to be met with no major non-compliances or non-conformances, and any resettlement related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Resettlement has been and is being treated in a fair and equitable manner, and resettlees and host communities have experienced or are on track to experience a timely improvement in livelihoods and living standards relative to the pre-project baseline.	The measures put in place to improve livelihoods and living standards are on track to promote self-sufficiency in the long-term.

6.3.6 Biodiversity and invasive species

Criteria	Good Practice	Best Practice
Assessment	Biodiversity issues relevant to project implementation and operation have been identified through an assessment process utilising appropriate expertise; monitoring is being undertaken during the project implementation stage appropriate to the identified issues.	Monitoring of biodiversity issues during project implementation takes into account inter relationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	Processes are in place to ensure management of identified biodiversity issues, and to meet commitments, relevant to the project implementation stage; plans are in place for the operation stage for ongoing biodiversity issues management.	Processes are in place to anticipate and respond to emerging risks and opportunities.
Compliance	Processes and objectives in place to manage biodiversity issues have been and are on track to be met with no major non-compliances or non-conformances,	There are no non-compliances or non-conformances.

	and biodiversity related commitments have been or are on track to be met.	
Outcomes	Negative biodiversity impacts arising from project activities are avoided, minimised, mitigated and compensated with no significant gaps.	Negative biodiversity impacts arising from project implementation are avoided, minimised, mitigated and compensated with no identified gaps; enhancements to pre-project biodiversity conditions or contribution to addressing biodiversity issues beyond those impacts caused by the project are achieved or are on track to be achieved.

6.3.7 Indigenous peoples

Criteria	Good Practice	Best Practice
Assessment	Issues that may affect Indigenous Peoples' rights in relation to the project have been identified through an assessment process utilising local knowledge and expertise; monitoring of project impacts and effectiveness of management measures is being undertaken during project implementation appropriate to the identified rights at risk.	Monitoring during project implementation takes into account inter- relationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	Measures are in place to address the Indigenous Peoples' rights at risk in relation to the project, and formal commitments are publicly disclosed.	Processes in place to anticipate and respond to risks and opportunities.
Stakeholder engagement	Appropriately-timed, culturally appropriate and two-way channels of communication are maintained; ongoing processes are in place for Indigenous Peoples to raise issues and get feedback; a mutually-agreed disputes procedure is in place.	Feedback on how issues raised have been taken into consideration has been thorough and timely.
Stakeholder Support	Free, Prior and Informed Consent has been achieved with respect to the Indigenous Peoples' rights at risk following the principle of proportionality.	Free, Prior and Informed Consent of directly affected indigenous groups has been achieved for the entire project.
Conformance/ Compliance	Processes and objectives relating to Indigenous Peoples' rights at risk have been and are on track to be met with no major non-compliances or non-conformances, and any Indigenous Peoples related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Plans provide for negative impacts of the project to Indigenous Peoples' rights to be avoided, minimised, mitigated or compensated, and some practicable	Opportunities for positive impacts have been thoroughly identified and maximised as far as practicable.

	opportunities for positive impacts to be achieved.	

6.3.8 Cultural heritage

Criteria	Good Practice	Best Practice
Assessment	Cultural heritage issues, with respect to physical cultural resources, that are relevant to project implementation and operation have been identified through an assessment process utilising appropriate expertise; monitoring is being undertaken during the project implementation stage appropriate to the identified issues.	Monitoring of cultural heritage issues during project implementation takes into account inter-relationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	Processes are in place to ensure management of identified cultural heritage issues, and to meet commitments, relevant to the project implementation stage; plans are in place for the operation stage for ongoing cultural heritage issues management.	Processes are in place to anticipate and respond to emerging risks and opportunities.
Conformance / Compliance	Processes and objectives in place to manage cultural heritage issues have been and are on track to be met with no major non-compliances or non-conformances, and cultural heritage related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Negative cultural heritage impacts arising from project implementation are avoided, minimised, mitigated and compensated with no significant gaps.	Negative cultural heritage impacts arising from project implementation are avoided, minimised, mitigated and compensated with no identified gaps; contributions to addressing cultural heritage issues beyond those impacts caused by the project are achieved or are on track to be achieved.

6.3.9 Governance and procurement

Resettlement	Good Practice	Best Practice
Assessment	*Governance* – Processes are in place to identify any ongoing or emerging political and public sector governance issues, and corporate governance requirements and issues and to monitor if corporate governance measures are effective. *Procurement* – Major supply needs, supply sources, relevant legislation and guidelines, supply chain risks and corruption risks have been identified	There are no significant opportunities for improvement in the assessment of political and public sector governance issues and corporate governance requirements and issues; the assessment includes opportunities for local suppliers and local capacity development.

	through an assessment process; ongoing monitoring is being undertaken to monitor effectiveness of procurement plans and processes.	
Management	*Governance* - Processes are in place to manage corporate, political and public sector risks, compliance, social and environmental responsibility, grievance mechanisms, ethical business practices, and transparency; policies and processes are communicated internally and externally as appropriate and independent review mechanisms are utilised to address sustainability issues in cases of project capacity shortfalls, high sensitivity of particular issues, or the need for enhanced credibility. *Procurement* – Measures are in place to guide procurement of project goods, works and services and address identified issues or risks, and to meet procurement related commitments.	*Governance* – Processes are in place to anticipate and respond to emerging risks and opportunities; contractors are required to meet or have consistent policies to the developer; procurement processes include anti-corruption measures as well as sustainability and anti-corruption criteria specified in pre-qualification screening. *Procurement:* processes are in place to anticipate and respond to emerging risks and opportunities; sustainability and anti-corruption criteria are specified in the pre-qualification screening; anti-corruption measures are strongly emphasised in procurement planning processes.
Compliance	No major non-compliance and any procurement related commitments have been or are on track to be met.	No major non-compliance.
Outcomes	*Governance:* There are no significant unresolved corporate and external governance issues identified. *Procurement:* Procurement of works, goods and services across major project components is equitable, efficient, transparent, accountable, ethical and timely, and contracts are progressing or have been concluded within budget or that changes on contracts are clearly justifiable.	*Governance:* There are no unresolved corporate and external governance issues identified. *Procurement:* Opportunities for local suppliers including initiatives for local capacity development have been delivered or are on track to be delivered.

6.3.10 Communication and consultation

Criteria	Good Practice	Best Practice
Assessment	Communications and consultation requirements and approaches have been identified through an assessment process involving stakeholder mapping, supported by ongoing monitoring.	The stakeholder mapping takes broad considerations into account.
Management	Communications and consultation plans and processes, including an appropriate grievance mechanism, are in place to manage communications and engagement with stakeholders; these outline communication and consultation needs and approaches for various stakeholder groups and topics.	Communication and consultation plans and processes show a high level of sensitivity to communication and consultation needs and approaches for various stakeholder groups and topics; processes are in place to anticipate and respond to emerging risks and opportunities.

Stakeholder engagement	The project implementation stage involves engagement with directly affected stakeholders, and engagement is appropriately timed and scoped, often two-way, and undertaken in good faith. The business interacts with a range of directly affected stakeholders to understand issues of interest to them. Ongoing processes are in place for stakeholders to raise issues and get feedback. The business makes significant project reports publicly available, and publicly reports on project performance, in some sustainability areas; power density calculations, estimated GHG emissions, and / or the results of a site-specific assessment have been publicly disclosed.	Engagement with directly affected stakeholders has been inclusive and participatory; negotiations are undertaken in good faith and feedback on how issues raised have been taken into consideration has been thorough and timely. The business publicly reports on project performance in sustainability areas of high interest to its stakeholders. The assessment of project resilience has been publicly disclosed. Project-affected communities and resettlees have been involved in decision-making around relevant issues and options.
Stakeholder support	Affected communities generally support or have no major ongoing opposition to the plans for the issues that specifically affect their community; resettlees and host communities generally support or have no major ongoing opposition to the Resettlement Action Plan; directly affected stakeholder groups generally support or have no major ongoing opposition to the cultural heritage assessment.	Formal agreements with nearly all the directly affected communities have been reached for the mitigation, management and compensation measures relating to their communities; there is consent with legally binding agreements by the resettlees and host communities for the Resettlement Action Plan; formal agreements with the directly affected stakeholder groups have been reached for cultural heritage management measures.
Compliance	Processes and objectives relating to communications and consultation have been and are on track to be met with no major non-conformances and non-compliances; any communications related commitments have been or are on track to be met.	No non-compliance or no non-conformance.

6.3.11 Hydrological resource

Resettlement	Good Practice	Best Practice
Assessment	*Reservoir preparation and filling* – The important considerations prior to and during reservoir filling and during operations have been identified through an assessment process; monitoring of implementation activities is being undertaken appropriate to any identified issues. *Downstream flows* – Issues in relation to flow regimes downstream of project infrastructure during the project	*Reservoir preparation and filling* – Monitoring of reservoir preparation and filling activities takes into account inter-relationships amongst issues, and both risks and opportunities that become evident during implementation. *Downstream flows* – Monitoring of downstream flow issues takes into account inter- relationships amongst issues, and both risks and opportunities

	implementation stage have been identified and assessed; monitoring is undertaken to assess effectiveness of flow management measures or any emerging issues during project implementation.	that become evident during implementation.
Management	*Reservoir preparation and filling* – Measures are in place to address needs identified during reservoir preparation and filling; plans are in place to manage the reservoir and any associated issues for the operating hydropower facility. *Downstream flows* – Measures are in place to manage identified downstream flow issues; where formal commitments have been made, these are publicly disclosed.	*Reservoir preparation and filling & Downstream flows* - Processes are in place to anticipate and respond to emerging risks and opportunities.
Compliance	*Reservoir preparation and filling* – Processes and objectives in place for reservoir management have been and are on track to be met with no major non compliances or non-conformances, and reservoir management related commitments have been or are on track to be met. *Downstream flows* – Processes and objectives in place to manage downstream flows have been and are on track to be met with no major non-compliances or non-conformances, and downstream flow related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Downstream flow regimes take into account environmental, social and economic objectives and where relevant, they also take into account agreed transboundary objectives.	Downstream flow regimes represent an optimal fit amongst environmental, social and economic objectives within practical constraints of the present circumstances.

6.3.12 Climate change mitigation and resilience

Criteria	Good Practice	Best Practice
Assessment	*Climate mitigation* – Power density has been calculated; if power density is below 5 W/m², net GHG emissions (gCO2e) of electricity generation have been estimated and independently-verified; if power density is below 5 W/m² and estimated emissions are above 100 gCO2e/kWh, a site-specific assessment of GHG emissions has been undertaken. *Climate resilience* – An assessment of the project's resilience to climate change	*Climate mitigation* – If a site-specific assessment is required, it incorporates a broad range of scenarios, uncertainties and risks. *Climate resilience* – Assessment of resilience incorporates sensitivity analysis, and project-specific hydrological modelling using recognised climate models and an assessment of the project's potential adaptation services has been undertaken.

	has been undertaken, which incorporates an assessment of plausible climate change at the project site, identifies a range of resulting climatological and hydrological conditions at the project site, and applies these conditions in a documented risk assessment or stress test that encompasses dam safety, other infrastructural resilience, environmental and social risks, and power generation availability.	
Management	If GHG emissions estimates assume design and management measures relevant to the implementation stage, these measures are in place; measures relevant to the implementation stage are in place to avoid or reduce the identified climate risks.	*Climate mitigation* – Design and management measures relevant to the implementation stage are in place to respond to risks and opportunities including offsetting emissions; plans are in place to monitor parameters used in GHG emissions estimates or to monitor GHG stocks. *Climate resilience* – Resilience measures relevant to the implementation stage take account of a broad range of risks and inter-relationships and plans are in place to provide adaptation services if necessary.
Compliance	Processes and objectives relating to climate change mitigation and resilience have been and are on track to be met with no major non-compliances or non-conformances, and any mitigation-related and resilience-related commitments have been or are on track to be met.	No non-compliance or non-conformance
Outcomes	*Climate mitigation* – The project's GHG emissions are demonstrated to be consistent with low carbon power generation. *Climate resilience* – Plans will deliver a project that is resilient to climate change under a range of scenarios.	*Climate mitigation* – Project net emissions are minimised or project operations facilitate system emissions reductions. *Climate resilience* – The project is resilient under a broad range of scenarios and the project will contribute to climate change adaptation at local, regional or national levels.

6.4 Sustainability Assessment for Operation Phase

6.4.1 Environmental and social assessment

Criteria	Good Practice	Best Practice
Assessment	Systematic processes are in place to identify any ongoing or emerging environmental and social issues associated with the operating hydropower facility, utilising appropriate expertise; monitoring programmes are in place for identified issues.	Processes to identify ongoing and emerging environmental and social issues take broad considerations into account, including both risks and opportunities.
Management	An environmental and social management system is in place to manage measures to address identified environmental and social issues, and is implemented utilising appropriate expertise (internal and external).	Processes are in place to anticipate and respond to emerging risks and opportunities; plans and processes are embedded within an internationally recognised environmental management system which is third party verified, such as ISO 14001.
Compliance	Processes and objectives in environmental and social management plans have been and are on track to be met with no major non-compliances or non-conformances, and environmental and social commitments have been or are on track to be met. Environmental and social funding commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Negative environmental and social impacts associated with hydropower facility operations are avoided, minimised and mitigated; land disturbance associated with development of the hydropower project is rehabilitated or mitigated. The operating hydropower facility or the corporate entity to which it belongs can pay for social and environmental commitments.	Negative environmental and social impacts associated with hydropower facility operations are avoided, minimised, mitigated and compensated.

6.4.2 Labour and working conditions

Criteria	Good Practice	Best Practice
Assessment	A periodically updated assessment has been undertaken of human resource and labour management requirements for the operating facility, including occupational health and safety (OH&S) issues, risks, and management measures; monitoring is being undertaken to assess if management	Identification of ongoing or emerging labour management issues takes broad considerations into account, including both risks and opportunities.

	measures are effective; ongoing or emerging labour management issues have been identified.	
Management	Human resource and labour management policies, plans and processes are in place that address all labour management planning components, including those of contractors, subcontractors and intermediaries.	Processes in place to anticipate and respond to risks and opportunities.
Compliance	Processes and objectives relating to human resource and labour management have been and are on track to be met with no major non compliances or non-conformances, and any labour related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	There are no identified inconsistencies of labour management policies, plans and practices with internationally recognised labour rights.	Labour management policies, plans and practices are demonstrated to be consistent with internationally recognised labour rights.

6.4.3 Water quality and sediments

Criteria	Good Practice	Best Practice
Assessment	Ongoing or emerging water quality issues or erosion and sedimentation have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective.	Identification of ongoing or emerging issues takes into account both risks and opportunities.
Management	*Water quality* – Measures are in place to manage identified water quality or erosion and sedimentation issues.	Measures are in place to anticipate and respond to emerging risks and opportunities.
Compliance	Processes and objectives in place to manage water quality and erosion and sedimentation issues have been and are on track to be met with no major non-compliances or non-conformances, and water quality and erosion and sedimentation related commitments have been or are on track to be met.	No non-compliance or no non-conformance.
Outcomes	Negative water quality impacts arising from project implementation and erosion and sedimentation issues during project implementation are avoided, minimised and mitigated.	*Water quality* – Water quality in the area affected by the operating hydropower facility is of a high quality; the facility has contributed or is on track to contribute to addressing water quality issues beyond those impacts caused by the operating hydropower facility. *Sediments* – Erosion and sedimentation associated with operating facility do not

		present ongoing problems for environmental, social and economic objectives.

6.4.4 Community impacts and infrastructure safety

Criteria	Good Practice	Best Practice
Assessment	*Project-affected communities* – Monitoring is being undertaken to assess if commitments to project affected communities have been delivered and if management measures are effective; ongoing or emerging issues that affect project affected communities have been identified. *Project benefits* – Monitoring is being undertaken to assess if commitments to project benefits have been delivered and if management measures are effective; ongoing or emerging issues relating to delivery of project benefits have been identified. *Infrastructure safety* – Routine monitoring of dam and infrastructure safety is being undertaken to identify risks and assess the effectiveness of management measures; ongoing or emerging dam and other infrastructure safety issues have been identified. *Public health* – Ongoing or emerging public health issues associated with the operating hydropower facility have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective.	*Project-affected communities* – Identification of ongoing or emerging issues for project affected communities takes into consideration both risks and opportunities, and interrelationships amongst issues. *Project benefits* – Identification of ongoing or emerging issues relating to project benefits takes into account both risks and opportunities. *Infrastructure safety* – Identification of ongoing or emerging safety issues takes into account consideration of a broad range of scenarios and both risks and opportunities. *Public health* – Identification of ongoing or emerging public health issues takes into account public health system capacities, access to health services, and health needs, risks and opportunities for different community groups.
Management	*Project-affected communities and project benefits* – Measures are in place to deliver commitments to project affected communities, and to project benefits, and to manage any identified issues relating to these commitments; if there are any formal agreements with project affected communities, and commitments to project benefits, these are publicly disclosed. *Infrastructure safety* – Dam and other infrastructure safety management plans and processes have been developed in conjunction with relevant regulatory and local authorities, and provide for communication of public safety measures; emergency response plans	*Project-affected communities, project benefits and public health* – Processes are in place to anticipate and respond to emerging risks and opportunities. *Infrastructure safety* – Processes are in place to anticipate and respond to emerging risks and opportunities; public safety measures are widely communicated in a timely and accessible manner.

	and processes include awareness and training programs and emergency response simulations. *Public health* – Measures are in place to manage identified public health issues.	
Compliance	Processes and objectives relating to project-affected communities issues, project benefits, infrastructure safety and public health issues have been and are on track to be met with no major non-compliances or non-conformances, and commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	*Project-affected communities* – Livelihoods and living standards impacted by the project have been or are on track to be improved, and economic displacement is fairly compensated, preferably through provision of comparable goods, property or services. *Project benefits* – Communities directly affected by the development of the hydropower project, and any other identified beneficiary of the facility have received or are on track to receive benefits. *Infrastructure safety* – Safety risks have been avoided, minimised and mitigated with no significant gaps. *Public health* – Negative public health impacts arising from project activities are avoided, minimised and mitigated.	*Project-affected communities* – The measures put in place to improve livelihoods and living standards are on track to become self-sustaining in the long-term. *Project benefits* – Benefits are significant and sustained for communities affected by the project. *Infrastructure Safety* – Safety risks have been avoided, minimised and mitigated with no identified gaps; and safety issues have been addressed beyond those risks caused by the operating facility itself. *Public Health* – Where opportunities have been identified, measures to address public health issues beyond those impacts caused by the operating hydropower facility have been or are on track to be achieved.

6.4.5 Resettlement

Criteria	Good Practice	Best Practice
Assessment	Monitoring is being undertaken to assess if commitments made to resettlees and host communities have been delivered and if management measures are effective; ongoing or emerging issues relating to resettlement have been identified.	Identification of ongoing or emerging resettlement issues takes into account both risks and opportunities.
Management	Measures to address resettlement are documented in a Resettlement Action Plan; measures are in place to deliver commitments to resettlees and host communities, and to manage any identified issues relating to resettlement, including provision of grievance mechanisms; formal	Processes in place to anticipate and respond to risks and opportunities.

	agreements with resettlees and host communities are publicly disclosed.	
Conformance Compliance	Processes and objectives in the Resettlement Action Plan have been and are on track to be met with no major non-compliances or non-conformances, any resettlement related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Resettlement has been and is being treated in a fair and equitable manner, and resettlees and host communities have experienced or are on track to experience a timely improvement in livelihoods and living standards relative to the pre-project baseline.	The measures put in place to improve livelihoods and living standards are on track to promote self-sufficiency in the long-term.

6.4.6 Biodiversity and invasive species

Criteria	Good Practice	Best Practice
Assessment	Ongoing or emerging biodiversity issues have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective.	Identification of ongoing or emerging biodiversity issues takes into account both risks and opportunities
Management	Measures are in place to manage identified biodiversity issues.	Processes are in place to anticipate and respond to emerging risks and opportunities.
Compliance	Processes and objectives in place to manage biodiversity issues have been and are on track to be met with no major non-compliances or non-conformances, and biodiversity related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Negative biodiversity impacts arising from project activities are avoided, minimised, mitigated and compensated with no significant gaps.	There are healthy, functional and viable aquatic and terrestrial ecosystems in the area affected by the hydropower facility that are sustained over the long term; the facility has contributed or is on track to contribute to addressing biodiversity issues beyond those impacts caused by the operating hydropower facility.

6.4.7 Indigenous peoples

Criteria	Good Practice	Best Practice
Assessment	Ongoing or emerging issues relating to the operating hydropower facility that may affect Indigenous Peoples' rights have been identified, and if management measures are required	Identification of issues that may affect Indigenous Peoples' rights is undertaken with the free, prior and informed participation of Indigenous Peoples

	then monitoring is being undertaken to assess if management measures are effective.	taking into account both risks and opportunities.
Management	Measures are in place to address the Indigenous Peoples' rights at risk relating to the operating hydropower facility; formal agreements are publicly disclosed.	Measures to address ongoing or emerging issues that may affect Indigenous Peoples' rights at risk have been developed with the free, prior and informed participation of Indigenous Peoples and processes are in place to anticipate and respond to emerging risks and opportunities.
Conformance/ Compliance	Processes and objectives relating to Indigenous Peoples' rights at risk have been and are on track to be met with no major non-compliances or non-conformances, and any Indigenous Peoples related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Processes provide for negative impacts of the project on Indigenous Peoples' rights to be avoided, minimised, mitigated or compensated, and some practicable opportunities for positive impacts to be achieved.	Opportunities for positive impacts have been identified and maximised as far as practicable, and have been or are on track to be achieved.

6.4.8 Cultural heritage

Criteria	Good Practice	Best Practice
Assessment	Ongoing or emerging cultural heritage issues with respect to physical cultural resources have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective.	Identification of ongoing or emerging cultural heritage issues takes broad considerations into account, and both risks and opportunities.
Management	Measures are in place to manage identified cultural heritage issues.	Processes are in place to anticipate and respond to emerging risks and opportunities.
Conformance / Compliance	Processes and objectives in place to manage cultural heritage issues have been and are on track to be met with no major non-compliances or non-conformances, and cultural heritage related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Negative cultural heritage impacts arising from activities of the operating hydropower facility are avoided, minimised, mitigated and compensated with no significant gaps.	Where opportunities have been identified, measures to address cultural heritage issues beyond those impacts caused by the facility have been or are on track to be achieved.

6.4.9 Governance and procurement

Resettlement	Good Practice	Best Practice
Assessment	Ongoing or emerging political and public sector governance issues, and corporate governance requirements and issues have been identified, and monitoring is being undertaken to assess if corporate governance measures are effective.	There are no significant opportunities for improvement in the assessment of political and public sector governance issues and corporate governance requirements and issues.
Management	Processes are in place to manage corporate, political and public sector risks, compliance, social and environmental responsibility, procurement of goods and services, grievance mechanisms, ethical business practices, and transparency; policies and processes are communicated internally and externally as appropriate; in case of capacity shortfalls, appropriate external expertise is contracted for additional support.	Processes are in place to anticipate and respond to emerging risks and opportunities; contractors are required to meet or have consistent policies as the developer; procurement processes include anti-corruption measures as well as sustainability and anti-corruption criteria specified in pre-qualification screening.
Compliance	The project has no non-compliances.	The project has no non-compliances.
Outcomes	There are no significant unresolved corporate and external governance issues identified.	There are no unresolved corporate and external governance issues identified.

6.4.10 Communication and consultation

Criteria	Good Practice	Best Practice
Assessment	Ongoing or emerging issues relating to hydropower facility communications and consultation have been identified; requirements and approaches are determined through a periodically updated assessment process involving stakeholder mapping, and effectiveness is monitored.	The stakeholder mapping takes broad considerations into account.
Management	Communications and consultation plans and processes, including an appropriate grievance mechanism, are in place to manage communications and engagement with stakeholders. These outline communication and consultation needs and approaches for various stakeholder groups and topics.	Communication and consultation plans and processes show a high level of sensitivity to communication and consultation needs and approaches for various stakeholder groups and topics; processes are in place to anticipate and respond to emerging risks and opportunities.
Stakeholder engagement	The operation stage involves engagement with directly affected stakeholders, and engagement is appropriately timed and scoped, often two-way, and undertaken in good faith. The business interacts with a range of directly affected stakeholders to	Engagement with directly affected stakeholders has been inclusive and participatory; negotiations are undertaken in good faith; feedback on how issues raised have been taken into consideration has been thorough and timely. The business publicly reports on

	understand issues of interest to them. Ongoing processes are in place for stakeholders to raise issues and get feedback. Appropriately timed, culturally appropriate and two-way channels of communication with Indigenous Peoples are maintained and a mutually agreed disputes procedure is in place. The business makes significant project reports publicly available and publicly reports on project performance, in some sustainability areas. Power density calculations, estimated GHG emissions, and / or the results of a site-specific assessment have been publicly disclosed.	project performance in sustainability areas of high interest to its stakeholders. The assessment of project resilience has been publicly disclosed. Project affected communities, resettlees and directly affected Indigenous Peoples have been involved in decision-making around relevant issues and options. The assessment and management process for downstream flow regimes has involved appropriately timed and two-way engagement with directly affected stakeholders. Ongoing processes are in place for stakeholders to raise issues with downstream flow regimes and get feedback.
Compliance	Processes and objectives relating to communications and consultation have been and are on track to be met with no major non-conformances and non-compliances; any communications related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.

6.4.11 Hydrological resource

Resettlement	Good Practice	Best Practice
Assessment	*Reservoir preparation and filling* – The important considerations prior to and during reservoir filling and during operations have been identified through an assessment process; monitoring of implementation activities is being undertaken appropriate to any identified issues. *Downstream flows* – Issues in relation to flow regimes downstream of project infrastructure during the project implementation stage have been identified and assessed; monitoring is undertaken to assess effectiveness of flow management measures or any emerging issues during project implementation.	*Reservoir preparation and filling* – Monitoring of reservoir preparation and filling activities takes into account inter-relationships amongst issues, and both risks and opportunities that become evident during implementation. *Downstream flows* – Monitoring of downstream flow issues takes into account inter-relationships amongst issues, and both risks and opportunities that become evident during implementation.
Management	*Reservoir preparation and filling* – Measures are in place to address identified needs during reservoir preparation and filling; plans are in place to manage the reservoir and any associated issues for the operating hydropower facility. *Downstream flows* – Measures are in place to manage identified downstream	*Hydrological resource* – Generation operations planning has a long-term perspective which fully optimises and maximises efficiency of water use and has the flexibility to adapt to anticipate and adapt to future changes. *Reservoir management* – Processes are in place to anticipate and respond to emerging risks and opportunities.

	flow issues and where formal commitments have been made, these are publicly disclosed.	*Downstream #ows* – Processes are in place to anticipate and respond to emerging risks and opportunities and commitments are made in relation to downstream flow regimes that include the flow objectives, the magnitude, range and variability of the flow regimes, the locations at which flows will be verified and ongoing monitoring.
Compliance	*Reservoir preparation and filling* – Processes and objectives in place for reservoir management have been and are on track to be met with no major non compliances or non-conformances, and reservoir management related commitments have been or are on track to be met. *Downstream flows* – Processes and objectives in place to manage downstream flows have been and are on track to be met with no major non-compliances or non-conformances, and downstream flow related commitments have been or are on track to be met.	There are no non-compliances or non-conformances.
Outcomes	Downstream flow regimes take into account environmental, social and economic objectives and where relevant, they also take into account agreed transboundary objectives.	Downstream flow regimes represent an optimal fit amongst environmental, social and economic objectives within practical constraints of the present circumstances.

6.4.12 Climate change mitigation and resilience

Criteria	Good Practice	Best Practice
Assessment	*Climate mitigation* – Power density has been calculated; if power density is below 5 W/ m^2, estimates of net GHG emissions (gCO2e) of electricity generation are calculated and independently- verified, and periodically updated; if power density is below 5 W/m^2 and estimated emissions are above 100 gCO2e/kWh, a site-specific assessment of GHG emissions is undertaken and periodically updated. *Climate resilience* – An assessment of the project's resilience to climate change is undertaken and periodically updated; this assessment of project resilience incorporates an assessment of plausible climate change, identifies a range of resulting climatological and hydrological conditions at the project site, and applies these conditions in a	*Climate mitigation* – If a site-specific assessment is required, it incorporates a broad range of scenarios, uncertainties and risks. *Climate resilience* – Assessment of resilience incorporates sensitivity analysis, project- specific hydrological modelling using recognised climate models, and the project's opportunities to provide adaptation services are considered on an ongoing basis.

	documented risk assessment or stress test that encompasses dam safety, other infrastructural resilience, environmental and social risks, and power generation availability.	
Management	*Climate mitigation* – If GHG emissions estimates assume management measures, these measures are in place. *Climate resilience* – Measures are in place to avoid or reduce identified climate risks.	*Climate mitigation* – Management measures are in place to respond to risks and opportunities including offsetting emissions; plans are in place to monitor parameters used in GHG emissions estimates or to monitor GHG stocks. *For climate resilience* – Measures take account of a broad range of risks and inter- relationships, and processes are in place to respond to unanticipated climate change; plans are in place to provide adaptation services if necessary.
Compliance	Processes and objectives relating to climate change mitigation and resilience have been and are on track to be met with no major non-compliances or non-conformances, and any mitigation-related and resilience related commitments have been or are on track to be met.	No non-compliance or no non-conformance
Outcomes	*Climate mitigation* – The project's GHG emissions are demonstrated to be consistent with low carbon power generation. *Climate resilience* – Findings of the climate change assessment indicate that the project is resilient to climate change.	*Climate mitigation* – Project net emissions are minimised or project operations facilitate system emissions reductions. *Climate resilience* – The project is resilient under a broad range of scenarios; the project will contribute to climate change adaptation at local, regional or national levels.

7 CASE STUDIES FOR HYDROPOWER SUSTAINABILITY

7.1 1988 – Ridracoli Scheme Implementation

- Location: Ridracoli, Bagno di Romagna, Bidente River, Italy
- Project type: HPP and Multipurpose reservoir
- Project phase: Implementation
- Capacity: 7MW and annual generation 35 GWh.
- Key stakeholders:
  - owner: Romagna Acque S.p.A. Enel operating the hydropower plant.
  - All districts of Forlì-Cesena and Ravenna in the Romagna plain area, Ministry, ENEL, WWF.

Figure 7.1 Ridracoli scheme (© https://www.romagnacque.it/acqua-in-diretta/diga-di-ridracoli/)

7.1.1 Project details

There was a chronic shortage of water in Romagna plain. At the start of XX° century, water was pumped from underground. In the nineteen-fifties, groundwater abstractions became excessive causing ground subsidence and seawater to encroach into the water table. All politicians were unanimous in considering the possibility of building a mountain reservoir. In 1966, most of the districts in Romagna joined a joint stock public company, the Romagna Acque S.p.A.

Between 1975 and 1982, it was the site of one of the most innovative civil engineering projects carried out in Italy up to that time, which includes a 106 m arch gravity dam, located on the Bidente

River and the Rio Celluzze in Ridracoli, an area of Bagno di Romagna, a reservoir boasting a capacity of 33 hm^3, a 33 km high pressure pipe line, a water treatment Plant for 3,6 m^3/s and a 7 MW hydropower plant.

7.1.2 Objectives

Economic objectives

To provide drinking water to around a million people living in 43 municipalities in the provinces of Forlì-Cesena and Ravenna; and to provide electricity to the shareholders.

Social objectives

To develop an artificial lake as a popular tourist destination, where visitors can enjoy activities such as canoeing, motorboating and recreational fishing.

Environmental objectives

To create an unmatched blend of nature, engineering and environmental sustainability; to find a site with complete lack of buildings and roads, excellent water chemistry and temperature, and catchment area preventing erosion and siltation.

7.1.3 Main types of best practice implemented

- Environmental and Social assessment
- Water Quality and Sediments Management:
- Community impact and Infrastructure safety
- Cultural heritage
- Governance and Procurement
- Communication and consultation
- Hydrological resource.

7.1.4 Lessons learnt

Main Challenges

By 1975, when construction started, there was a reaction from conservationists who by then had become a political force. To this was added the reaction of the population living downstream of the dam. Argument focused on alleged dangers to the public. Protesters feared river depletion and geological and climate changes. They predicted certain disaster for the environment, declining population numbers and a deteriorating socio-economic situation over a vast area in the mountains and foothills. The local WWF office took the matter to the courts to try to stop construction on safety grounds.

Feedback

Romagna Acque managed to overcome the legal problem by submitting analyses from university specialists and providing safety monitoring and control systems for building the works.

Romagna Acque had a very positive attitude. It did not confine itself to justifying the projects alone, it expressed its will to look deeper and compare its own ideas with those of the local authorities, conservationists and residents on an on-going basis. It continually cross-checked its decisions and offered adequate changes to satisfy to satisfy its opponents.

Romagna Acque based its position on three sound principles:

1. Careful monitoring of the project and of its environmental impact.
2. Careful management of the dam, water resource, and land upstream and downstream.
3. Lively interest in social, cultural and economic development in the valley.

In this way, problems were overcome, and significant environmental and social benefits were procured by Romagna Acque:

- In order to release enough water downstream, water was not diverted from the Strabatenza River on the same catchment, but diverted from the Fiumicello River in the Rabbi River valley despite the loss of hm^3 inflow per year.
- All diversions from the river are stopped in summer, and an extra 200 L/s is released to increase the river flow downstream the dam by 30%.
- the landscape was improved around the dam by planting trees, repairing retaining walls, public footpaths, access and service roads, refurbishing old stone houses, river works and rim protection, near the Monte Falterona National Park.
- In order to promote frank and transparent relations with the local public and authorities, data on dam and reservoir performance, seismic intensity, water quality, temperature and rainfall precipitations, climate are continuously checked, collected and released on the website of Romagna Acque (Figure 7.2).

Figure 7.2 Information released on the website of Romagna Acque

- Economic development was promoted: the old village of Ridracoli was restored; drainage and roads were improved; water and gas were supplied; many public fountains, a new bridge, pipelines, car parks, tourist centre, foot paths, sport facilities, children's play area were built, tourist facilities for 200 persons were provided, with a view to attracting nature lovers.
- The lake was conceived as a centre of attraction teaching respect for the environment, capitalising on water, and providing recreational activities. A new museum, the Ridracoli Natural Science Museum, shows typical environments of vertebrates living in the Romagna Parks, and promotes knowledge and conservation of plant and animal wildlife. A teaching Centre, offering courses and international conferences that supplement those available in universities, is used throughout the year by students on ecology, public works, water engineering, water chemistry, computer and remote control. Guides are provided to let people see the environment around the reservoir. A short length of reservoir has been opened to sport fishing although fish conditions are monitored and the area is regularly inspected to protect the water in the reservoir. A ramblers' walk along the main aqueduct route, from the springs down to the coast attracts up to 80 000 persons annually, of which 20 00 are schoolchildren and students. The lake can be visited by boat with electric motor and large numbers use it to enjoy the natural beauty of the shores.
- The Rural Assessment and Accounting Institute of the University of Bologna and the National Research Council undertook a scientific study of the environmental impact of the dam. The experts examine negative and positive impacts of the project. They used an Environmental Quality Index (EQI) for comparison with the situation before the dam was built. They reached one very important conclusion: in terms of the general environmental situation, **the environmental quality index rose from 1000 before the project to 1219 after: a 22% improvement.**

Recommendations

Environmental considerations: It was recommended that good management must defeat the old way of seeing a man-made lake as just a place for storing water. Good management must actively seek to develop environmental and social values, which contribute to improving lifestyles.

Social considerations: Water is a source of wealth which must be carefully preserved and used rationally. If this means builder river development works, it is unjust to consider them blindly as causes of damage and disaster as requested by WB(2004) and IPBES (2019). Proper design careful construction, careful sensitive operation can have outcomes that improve environmental balance, beginning with the human sphere. In this way, there gradually emerged a "**solidarity Pact**" between man and the environment, between the population and institutions.

7.1.5 References

ICOLD (1988). Dams and Environment. Ridracoli: a model achievement. Technical Bulletin 100.

Grillanzoni M., Ragazzoni A., Marini P. (1994) Post6project multiple-criteria evaluation of the Ridracoli Dam. Pages 533-553. Q69. R33. XVIII° ICOLD Congress. Durban.

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7.2 2006 - Goldisthal PSH

7.2.1 Project details

- Location: Thuringia, Schwarza River, central Germany
- Project type: Pumped-storage hydropower facility
- Project phase: Implementation
- Capacity: 1,060 MW
- Key stakeholders:
    - owner: Vattenfall Europe Generation AG (now part of LEAG) was involved as the project developer and operator of Goldisthal PSH plant.
    - Local authorities and communities in the Thuringian Slate Mountains area: Goldisthal Municipality: The municipality served as an intermediary between the project developers (Vattenfall) and the local community, facilitating communication and addressing concerns. Due to the project's scale, the municipality played a role in decisions regarding land use and planning permissions. It also participated in discussions concerning the environmental impacts, particularly given the project's location on the Schwarza river.

Figure 7.3 Goldisthal Pumped-Storage Plant: More than Power Production (© Vattenfall)

The Goldisthal Pumped Storage Hydropower Plant, located in the Thuringian Forest, is one of the largest facilities of its kind in Europe, with an installed capacity of 1,060 MW. The plant consists of an upper and lower reservoir, connected by underground tunnels, enabling efficient water transfer during energy storage and generation. Advanced reversible pump turbines are used to alternately pump water to the upper reservoir during low energy demand periods and generate electricity during peak demand. The facility integrates modern control systems to optimise operations and grid stabilisation, making it a key asset in supporting Germany's renewable energy transition.

7.2.2 Objectives

Environmental objectives

The Goldisthal Pumped Storage Plant aims to support the integration of renewable energy sources, such as wind and solar, into Germany's power grid by acting as a reliable storage solution. By providing a clean energy buffer, it helps reduce reliance on fossil fuels, thereby contributing to a significant reduction in greenhouse gas emissions. The plant also seeks to maintain environmental integrity by managing water resources responsibly, minimising ecological disturbances during operations, and ensuring that the surrounding natural habitats remain protected.

Social objectives

Goldisthal contributes to regional development by providing employment opportunities during both its construction and operational phases. It fosters collaboration with local communities by promoting transparent communication and addressing any potential social impacts related to its activities. The plant also aims to enhance public acceptance of renewable energy systems by demonstrating the feasibility of sustainable energy storage solutions, thus contributing to public education and awareness about the energy transition.

Economic objectives

The plant plays a vital role in stabilising Germany's energy market by mitigating fluctuations from variable renewable energy sources. By storing excess energy during low-demand periods and generating electricity during peak demand, it ensures economic efficiency and energy security. Additionally, the facility reduces costs associated with energy imports and grid imbalances, while supporting long-term economic sustainability in the energy sector through the adoption of advanced technologies.

7.2.3 Main types of best practice implemented

- Environmental and Social assessment
- Water Quality and Sediments Management:
- Community impact and Infrastructure safety
- Biodiversity and invasive species
- Governance and Procurement

7.2.4 Lessons learnt

Main Challenges

The Goldisthal Pumped Storage Plant encountered several challenges during its development and operation:

- The complex geological conditions of the Thuringian Forest required advanced engineering solutions to stabilise the site and effectively manage groundwater inflows.
- Additionally, the plant's location in an ecologically sensitive area necessitated rigorous environmental safeguards to minimise impacts on local ecosystems while ensuring compliance with regulatory standards.
- On the operational side, integrating the plant's 1,060 MW capacity into the grid to support renewable energy sources demanded cutting-edge technology to enable rapid and efficient energy storage and release.
- Managing the water resources of the upper and lower reservoirs presented further difficulties, particularly during periods of low water availability.
- Building public trust also required ongoing engagement with local communities to address concerns related to noise, visual impacts, and land use.
- Finally, the substantial initial investment required meticulous economic planning to balance upfront costs with the long-term benefits of improved grid stability and renewable energy integration.

Feedback

The Goldisthal Pumped Storage Hydropower Plant implemented several best practices to ensure sustainability and efficiency:

- Environmental and social assessments were carried out during the planning and construction phases to minimise risks to local ecosystems and communities, particularly within the sensitive Thuringian Forest region.
- Biodiversity management was prioritised through habitat restoration initiatives and long-term monitoring to protect the area's flora and fauna.
- Hydrological resource management optimised water usage while reducing downstream impacts, supported by advanced water management technologies.
- Community impact and infrastructure safety were addressed through stakeholder engagement and the implementation of safety measures, helping to build trust and protect surrounding areas.

These measures reflect Goldisthal's commitment to sustainable energy production and environmental and community considerations.

Recommendations

<u>Environmental considerations:</u> To improve environmental sustainability at Goldisthal, ongoing monitoring of surrounding ecosystems should be prioritised, particularly to track the impacts of water usage and local biodiversity. Adaptive management strategies will help the plant respond effectively to environmental changes and ensure continued alignment with ecological preservation. Regular engagement with environmental bodies will support early identification and resolution of potential issues.

<u>Social considerations:</u> Socially, maintaining transparent communication with local communities is essential to sustain support for the plant. Providing clear information on how the plant supports

renewable energy integration and addressing concerns such as noise and visual impact will help maintain positive relationships.

Economic considerations: Economically, long-term infrastructure investments are necessary to enhance the plant's capacity, particularly in water management and storage. These upgrades will mitigate operational risks and ensure continued grid stability. Adopting advanced monitoring technologies will improve operational efficiency, optimise power generation, and help the plant meet growing energy demands.

7.2.5 References

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7.3 2013 - Jostedal Scheme Operation Assessment

7.3.1 Project details

- Location: Luster municipality in Vestland on Jostedalselva River, Norway.
- Project type: Hydroelectric power plant with storage.
- Project stage: Operation
- Project Capacity: 288 MW installed capacity (956.3 GWh annual production)
- Key stakeholders:
    - Owner: Statkraft Energi AS. The operator and primary decision-maker for the Jostedal Hydropower Plant, responsible for its daily management and compliance with regulations.
    - Regulatory and Environmental Management Authorities: Direktoratet for Naturforvaltning (Norwegian Directorate for Nature Management). Oversees nature management and biodiversity, ensuring the plant's operations align with environmental regulations, for example: ensuring protection of fish species and their habitats. Norsk Vassdrags och Energidirektorat (Norwegian Rivers and Energy Directorate). Ensures compliance with national water and energy policies, monitoring water quality and hydropower generation standards.
    - Hydrological and Ecological Research Institutions: Hydrologiska Byråns Vattenbalansavdelnings modell (Water-balance model of the Hydrological Bureau) provides models and data for water balance, critical for assessing the hydrological impact of the plant, for example monitoring river flow rates and reservoir regulation. Laboratorium for Ferskvannsøkologie og Inlandsfiske, Uni Miljø (Institute of Freshwater Ecology and Inland Fisheries, University of Bergen) focuses on freshwater ecology and fish populations, for example by studying fish passage and spawning in the Jostedøla River.
    - Energy Distributors and Infrastructure Operators: Power Generation, Midt Norge (Central Norway) Region. Handles electricity distribution in the region, benefiting from the Jostedal plant's power output. Coordinates grid connections and energy distribution in Central Norway.
    - Local Communities and Residents: those that live in the immediate vicinity and the surrounding areas of Jostedal Hydropower Plant influenced by the plant's operations, such as: Jostdalen Village residents concerned with the localised flooding caused by sedimentation, impacts on the fish population in the Jostedøla River, and safety risks associated with the quarry site near Styggevatn; Skjolden village near the outlet of the plant, where the water is channelled towards the fjord, concerned about the impact on the river flow, water quality and flood risks caused by sedimentation; Fjærland village, a very popular tourist destination known for its proximity to the Jostedalsbreen Glacier, concerned with touristic activities surrounding the plant; Brekke village's agricultural activities concerned with the changes in river flow or the flooding risks of the valley.
    - Tourism and Recreation Bodies. Organisations aiming to develop tourism around the plant's reservoir and surrounding areas, promoting activities such as hiking and

boating in the region: Sogn og Fjordane Tourist Board (Visit Sognefjord) as the official tourism organisation in the region promoting Sognefjord and sorrounding areas, including Jostedal valley; Friluftsliv – Norwegian Outdoor Recreation Association is a national association focused on promoting outdoor recreation activities such as hiking, fishing and canoeing across Norway, incuding the Sogn og Fjordane region; Norwegian Association for Fishing and Aquaculture (Norges Jeger- og Fiskerforbund, NJFF) advocates for the sustainable management of freshwater ecosystems;

- Government Agencies for Environmental Protection and Public Safety. These regulatory bodies oversee the enforcement of environmental laws and safety standards, playing a key role in assessing the impacts on biodiversity, ecosystems and local communities: the Norwegian Environment Agency (Miljødirektoratet) is responsible for ensuring compliance with Norway's environmental protection laws, including those related to biodiversity conservation and ecosystem management; Norwegian Directorate for Civil Protection (DSB) oversees public safety sandards, particularly concerning emergency preparedness, risk management, and infrastructure safety; The Norwegian Water Resources and Energy Directorate (NVE) is responsible for managing Norway’s water resources and ensuring that hydropower plants adhere to the necessary regulations for water quality, flow management, and energy production.

Figure 7.4 Reservoir of Jostedal scheme (Lars Petter Pettersen)

The Jostedal Hydropower Plant, commissioned in 1989, is a renewable energy facility located in Norway and fully owned by Statkraft. With an installed capacity of 290 MW and an annual production of around 956.3 GWh, it plays a notable role in supplying electricity to the region.

The plant utilises the height difference of 1,186 metres between Lake Styggevatnet and the Jostedalselva River to enhance energy generation. Lake Styggevatnet, the primary reservoir, is regulated between 1,200 and 1,110 metres above sea level, with a dam height of 55 m and a capacity of approximately 350 million m^3. Lake Kuppvannet, a secondary reservoir, is regulated between 1,263 and 1,190 metres above sea level. The facility also collects water from several stream intakes, which are then used in the turbines and channelled through an outlet tunnel to the Sognefjord, demonstrating an effective water management approach.

7.3.2 Objectives

An official assessment of the Jostedal Project was carried out using the Operation Stage tool of the Hydropower Sustainability Assessment Protocol.

Environmental objectives

- Biodiversity Management: the assessment aimed at identifying the efforts to manage biodiversity and understand why they had been primarily focused on salmonoid fish.
- Erosion and sedimentation mitigation: the geomorphological challenges of the Jostedøla River had caused localised flooding risks due to sedimentation. Addressing these risks was highlighted as an ongoing necessity.
- Reservoir Management: Safety concerns at the quarry site near Styggevatn and declining water levels in the Vivatjønni pond had not been fully addressed.
- Downstream flow management: reduced flows in tributary streams downstream of intakes were a topic of concern.
- Water Quality and Flood Protection: Monitoring of water quality and measures to prevent sedimentation from aggravating flood risks were seen as effective, but at the same time, opportunities for further enhancement were perceived.

Social objectives

- Community benefits: the project's potential to enhance tourism and recreation had already been identified since earlier stages, however, its full potential had not been explored. Styggevatn Lake, which acts as Jostedal HPP's reservoir, seemed to have the potential to bring additional cultural and economic benefits to the local communities.
- Public safety: Local stakeholders had several complaints about the safety of the quarry cliff near the tourist cabin at the shore of Styggevatn. Concerns had been raised about its vertical wall exposed above the reservoir surface, which may lead to falling into the water (or ice in winter) from a height of 20-25 metres when hiking or skiing on days of low visibility.

Economic objectives

- Increase financial viability: Since the beginning of its operations in 1989, Jostedal HPP has demonstrated financial sustainability and the revenues have contributed to local economic growth. However, the assessment aimed at seeking further optimisation measures to maximise benefits for the population in the area.
- Employment opportunities: linked to the previous, the project has provided direct and indirect employment opportunities and this assessment aimed to know what additional actions can be taken to contribute to local growth.
- Tourism: The value of the reservoir has been recognised as a tourism asset in the area, however, has not been fully leveraged.

7.3.3 Main types of best practice implemented

- Labour and working conditions
- Water quality and sedimentation
- Community impacts and infrastructure safety
- Cultural Heritage
- Governance and procurement

- Hydrological resources

7.3.4 Lessons learnt

Challenges

Environmental considerations: While the plant has limited environmental and social impacts, several concerns have been raised by local stakeholders. These include fish passage and spawning in the Jostedøla River, decreasing water levels in the Vivatjønni pond, reduced flows in tributary streams downstream of intakes, and sedimentation affecting local flood risks. Addressing these issues was important to ensure a balance between energy production and environmental sustainability. The project faced challenges in implementing a systematic approach to identify and manage broader environmental risks and opportunities, particularly those related to biodiversity. Notably, there was no structured process to anticipate or respond to risks to biodiversity, nor were additional measures in place to mitigate the impact of lowered water levels in Vivatjønni. These gaps limited the project's ability to fully address its environmental responsibilities.

Social Considerations: The assessment identified shortcomings in stakeholder engagement and communication. Specifically, there was a lack of comprehensive stakeholder mapping to identify issues of specific concern to different groups, as well as the absence of tailored communication strategies to address their unique needs. Furthermore, timely and thorough feedback on environmental and social issues was not consistently provided to stakeholders, which hindered effective dialogue and trust-building. Significant operational and safety issues remained unresolved. The security risks associated with access to the cabin near the Styggevatn dam were not adequately addressed. Additionally, persistent sedimentation in the valley continued to exacerbate flooding, adversely affecting local residents and their properties.

Feedback

The project provides significant social and economic benefits to the locality, especially flood protection and the generation of revenues that are used to provide benefits to the local population.

Jostedal meets Proven Best Practice on eleven out of seventeen topics assessed using the Protocol: Governance; Hydrological Resource; Asset Reliability and Efficiency; Infrastructure Safety; Financial Viability; Project Benefits; Project-Affected Communities and Livelihoods; Labour and Working Conditions; Cultural Heritage; Public Health; and Water Quality.

Jostedal meets or exceeds Basic Good Practice on all six remaining topics.

Recommendations

Environmental Recommendations. Efforts to support fish species were acknowledged, but it was recommended to broaden these initiatives to include a wider range of species and habitats. Opportunities to enhance biodiversity beyond fish species had been identified but were not systematically addressed; it was recommended a more comprehensive biodiversity management approach. Reduced water flows in tributary streams downstream of intakes were identified as a significant issue affecting aquatic ecosystems. It was recommended to adopt improved flow management practices to mitigate these adverse impacts and support the health of aquatic habitats. Safety concerns at the quarry site near Styggevatn, requiring urgent attention was recognised as priority to ensure environmental sustainability.

Social Recommendations. Stakeholder mapping and engagement processes were found to lack specificity, particularly in identifying and addressing the concerns of underrepresented groups. It was recommended to adopt a more inclusive and tailored consultation approach to ensure that diverse stakeholder interests were effectively represented and addressed. Feedback mechanisms on environmental and social issues were deemed insufficient, and establishing more comprehensive and timely updates for stakeholders was suggested to foster greater transparency and trust. Public safety, particularly concerning the quarry site near Styggevatn, along with the issue of declining water levels in the Vivatjønni pond, was highlighted as a significant concern for the local community. Ongoing discussions about potential solutions included relocating the cabin (not a priority for the community) or filling in the old quarry, which would substantially reduce reservoir capacity (not a priority for Statkraft). Resolving this issue was identified as critical to addressing the strong concerns of parts of the local population.

Economic Recommendations. The reservoir's untapped potential as a tourism asset was widely recognised but had yet to be fully leveraged. It was strongly recommended to develop the site into a destination for a range of recreational activities, such as hiking, boating, wildlife observation, and educational tours focusing on the region's natural and cultural heritage. These initiatives could not only attract visitors but also generate significant additional revenue for the region, stimulate local economic growth, and create meaningful employment opportunities for the community.

7.3.5 References

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- https://www.statkraft.com/about-statkraft/where-we-operate/norway/jostedal-hydropower-plant/
- https://en.sognefjord.no/fjord-villages/jostedal/get-inspired-in-jostedal/
- https://www.hs-alliance.org/published-assessments/jostedal

7.4 2014 - Program Sava Multipurpose Scheme Assessment

7.4.1 Project details

- Location: Sava River, Croatia
- Project type: Multipurpose scheme incorporating up to 7 hydropower plants
- Project phase: Preparation
- Installed Capacity: 151-156 MW
- Key stakeholders:
    - Owner: Program Sava Ltd;
    - Hydropower Sustainability Alliance: Program Sava team,
    - Expert Council members,
    - Ministries,
    - Croatian Waters,
    - Hrvatska Elektroprivreda (HEP),
    - the City of Zagreb administration,
    - IPF consultants, and
    - civil society.

Figure 7.5 Hydropower plant and its fish pass on the Sava River (Energetika.ba)

7.4.2 Objectives

Programme objectives include: flood protection and control; replenishment of groundwater aquifers; stabilisation of the riverbed and riverbanks; power generation; urban regeneration; transport; and irrigation and drainage. It is a high-profile programme, with significant implications for the long-term development of Croatia's capital city

Environmental objectives. The project aims to mitigate and manage negative environmental impacts, like fish migration, invasive species, and downstream flow regimes. The project was designed to support sustainable groundwater replenishment through options such as aquifer storage and recovery, riverbank filtration, and soil aquifer treatment, and to address inefficiencies in Croatia’s water supply system, where 46% of extracted water is lost. Improved water management is also a priority, with strengthened capacity to control water outflow into retention areas, allowing for more efficient handling of peak flow events and reducing risks to ecosystems and communities. Stabilisation of riverbed and riverbanks is another key priority.

Social benefits. The programme's multi-purpose objectives aim to minimise and effectively manage potential negative social impacts while providing net benefits to the affected communities, including enhanced flood protection, improved water supply, expanded tourism and recreational facilities, and urban regeneration. The project aims to support the urban regeneration of the Croatia’s capital city with alternative approaches including waterfront development, leisure facilities, green corridors, housing, commercial spaces, and recreational paths, similar to successful projects in cities like Vienna. The groundwater replenishment enhancing the recharge of the Zagreb aquifer ensures a reliable and sustainable water supply for both urban and agricultural use.

Economic benefits. The project aims to support transport, irrigation, drainage, upgrading transportation infrastructure, and improving river navigability. Design and siting adjustments may involve optimising port locations, connections to major transport corridors, and supporting infrastructure like bridges. The project presents several economic opportunities, including the creation of direct jobs and improved community health and safety due to enhanced flood protection. It also aims to implement hydro-technical solutions to manage flooding along the Sava River from the Slovenian border to Sisak and to harness the river's hydropower potential in this region. Additional benefits include securing a reliable long-term water supply for Zagreb and Velika Gorica by improving capacity and drinking water quality through groundwater replenishment. The project could also repurpose the Sava River urban corridor, currently reserved for high waters, enabling urban development through the "Zagreb on Sava" initiative. Furthermore, it supports river navigability to Prevlaka and beyond via the Sava-Sava drainage channel to Velika Gorica. Additional benefits include creating flood-free spaces with increased amenity value, expanding agricultural areas.

7.4.3 Main types of best practice implemented

- Water quality and sediments management
- Biodiversity management
- Hydrological resources
- Community impact and infrastructure safety
- Governance and procurement

By addressing these best practices, the programme creates opportunities for long-term environmental, social, and economic benefits.

7.4.4 Lessons learnt

Challenges

There were Gaps in data regarding erosion, sedimentation and biodiversity. Construction impacts concerning the environment involve habitat destruction, impacts on wildlife, and pollution from construction waste and emissions. Operational impacts include restricted access to land and resources affecting agriculture, changes to groundwater levels impacting buildings and irrigation, and potential groundwater contamination from rising levels meeting pollutants. Biodiversity risks involve habitat loss in Natura 2000 sites, disruption to migratory fish, spread of invasive species, and reduced ecosystem services. Downstream effects, such as erosion and sedimentation, may further alter the river ecosystem.

Resettlement of households and facilities was required, with relocations anticipated. Impacts include resettlement of households, relocation of public facilities, loss of agricultural land, and disruptions from increased dust, noise, and traffic.

Feedback

<u>Environmental Considerations:</u> The environmental assessment of the project was completed through the Strategic Environmental Assessment (SEA) process and technical analyses by IPF consultants. Gaps in data regarding erosion, sedimentation, biodiversity, and upstream hydropower impacts were addressed. Key strengths included aquifer protection, reforestation, habitat preservation, and improved flood management, while weaknesses focused on environmental awareness and infrastructure. Opportunities included water quality improvements, wetland rehabilitation, and habitat restoration, though challenges such as environmental pollution and limited cross-border cooperation remained.

<u>Social Considerations:</u> Land acquisition and resettlement were conducted in accordance with relevant legal frameworks and supported by a comprehensive Land Acquisition, Resettlement, and Compensation Plan. The programme offers substantial opportunities for sustainable development and enhanced climate resilience. It prioritises flood control, aiming to reduce the frequency and severity of flooding events and minimise the environmental pollution often caused by floods, such as contamination from waste and agricultural run-off.

<u>Economic Considerations:</u> The financial and economic risks were fully assessed, ensuring the project was financially viable. Early delineation of project components allowed for optimisation of financing and procurement plans. Costs for environmental and social mitigation measures were factored into the budget, and the economic valuation of benefits was incorporated into the Cost-Benefit Analysis (CBA). Independent third-party reviews and early involvement of potential financiers ensured financial sustainability and support for the project.

Recommendations

Such program supports adaptation to climate change by improving flood management systems, water supply infrastructure, and hydropower and irrigation capabilities. This integrated approach increases the region's capacity to cope with changing climatic conditions and enhances its resilience to future challenges.

7.4.5 References

- Smith D., Björklund P., Khalil A., Xiao E. (2017). Hydropower Sustainability Assessment Protocol. Official Assessment. Program Sava d.o.o. Program Sava Project. Croatia. Final. Assessment Date: 30/06/2014 to 04/07/2014. Report date : 25/09/2014.
- https://www.hs-alliance.org/published-assessments/program-sava
- https://energetika.ba/

7.5 2015 - Semla IV Rehabilitation Preparation Assessment

7.5.1 Project details

- Location: Kolbäcksån River, northwest of Fagersta Municipality, Sweden.
- Project type: Rehabilitation of existing small hydropower facilities.
- Project stage: Preparation
- Installed Capacity: 3.5 MW
- Key stakeholders:
  - Owner: E.ON. Owner, responsible for managing the development, financing, and operation of the Semla IV hydropower plant.
  - Primary Contractor: Voith was contracted for the upgrade of the Semla IV project, which included the supply and installation a complete horizontal bulb turbine unit, generator, and hydraulic governor.
  - Environmental and Hydrological Agencies: Swedish Meteorological and Hydrological Institute (SMHI) supplied hydrological and meteorological data critical to understanding water availability, river flow patterns, and potential impacts of climate change on the Kolbäcksån River. Swedish Environmental Protection Agency (Naturvårdsverket) ensured that the environmental assessment of Semla IV met national requirements, particularly regarding biodiversity, water quality, and ecosystem management, provided feedback during planning and assessment phases and monitored compliance with licensing conditions.
  - Local Communities and Municipal Stakeholders: Fagersta municipality is the primary administrative region affected by Semla IV plant operations; Virsbo village is located downstream the Kolbäcksån River and residents be affected by the effects related to the changes in the water flow; Surahammar Municipality further downstream includes several communities, that count on a few recreational points that might be affected by small direct impact.

Figure 7.6 Penstocks of the existing Semla plant to be replaced (HSA)

7.5.2 Objectives

The Semla IV project was assessed using the Preparation Stage tool of the Hydropower Sustainability Assessment Protocol.

The Semla IV project, located on the Kolbäcksån River in Fagersta Municipality, southern Sweden, involves a 3.5 MW hydropower facility that is nearing completion of its preparation phase. It forms part of a cascade of hydropower plants on the river, several of which are owned and operated by E.ON. The project focuses on the rehabilitation and modernisation of existing infrastructure that dates back to the early 20th century. While the primary aim is to enhance the efficiency of electricity production, the project also seeks to preserve the ecological health of the river and support local communities by meeting modern energy needs.

Environmental objectives: The environmental side of the assessment aimed to evaluate the potential impacts of rehabilitating and replacing existing hydropower facilities, particularly concerning biodiversity, water quality, and downstream flow regimes, including the ecological flow of 50L/s for the trout brook subsistence. The study sought to confirm that the project adhered to environmental best practices, focusing on preserving local ecosystems along the Kolbäcksån River and addressing concerns such as invasive species management and erosion control. Additionally, the assessment intended to ensure infrastructure safety and proper water management to minimise any adverse environmental effects.

Social objectives: Socially, the assessment examined the project's engagement with local communities and stakeholders. This included evaluating whether stakeholder concerns and expectations were being addressed through effective communication and consultation. The study also considered the potential impacts on public health, cultural heritage, and the livelihoods of those affected by the project, aiming to ensure compliance with recognised social standards and support positive outcomes for stakeholders.

Economic objectives: The assessment reviewed the financial viability of the Semla IV project and its ability to deliver sustainable energy benefits. It also examined procurement processes and the integration of the project within the cascade of hydropower facilities along the Kolbäcksån River. Additionally, the assessment aimed to identify potential economic opportunities, such as job creation and improved local infrastructure, to support regional development. The overall focus was to ensure a balanced and sustainable approach to hydropower development.

7.5.3 Main types of best practice implemented

- Biodiversity management
- Hydrological resources
- Community impact and infrastructure safety
- Water Quality
- Governance and procurement
- Cultural Heritage and Leisure facilities

The environmental assessment of the Semla IV project indicated minimal impacts on biodiversity, with a focus on the river’s hydrological resources. The project met basic good practices in areas like water quality and sediment management, though there was a need to address broader environmental risks and opportunities, particularly as the project advanced.

Socially, the project adhered to good practice standards regarding local communities, infrastructure safety, and labour conditions. However, improvements were noted in stakeholder engagement and community consultations. Economically, Semla IV was financially viable, but it did not explore additional economic opportunities beyond energy generation, which could be a potential area for future development.

7.5.4 Lessons learnt

Challenges

Penstocks of the existing Semla plant, were leaking badly and have to be replaced by one new penstock with the construction of Semla IV.

Even if Semla IV project is relatively small (3.5MW) and has limited impact, concerns include safety, access to recreational facilities, and impacts on livelihoods.

Feedback

The project meets or exceeds basic good practice in all but one (project benefits) topics, and in some meets proven best practice on four topics: Procurement, Water Quality, Reservoir Planning and Financial Viability.

The project did not evaluate its potential for local development or consider sustainable river basin management and alternative hydropower options. Additionally, the siting and design process did not incorporate environmental and social considerations alongside technical and financial aspects. Environmental risks, such as climate change, invasive species, and river restoration, and water availability were not comprehensively assessed.

The project also lacked a detailed economic viability assessment, missing a full evaluation of costs and benefits. Socio-economic risks to local communities were not reviewed, and there were no plans to address them. While stakeholder engagement was generally adequate, the project could have improved public information access and involvement of directly affected stakeholders. There were concerns about public safety, management of cultural heritage, and post-construction environmental rehabilitation.

Recommendations

<u>Environmental Considerations</u>**:** The Semla IV project assessment highlighted key environmental recommendations that suggested that the project expand its focus to include broader environmental risks and opportunities, such as mitigating existing environmental damage and addressing long-term climate change impacts. Comprehensive assessments of biodiversity, water availability, invasive species, and river restoration were recommended to better manage future ecosystem risks. Additionally, the project was advised to extend its hydrological study to cover the entire catchment and river cascade, considering long-term water availability and climate change

effects on flow patterns. Field studies on downstream flow impacts, particularly the proposed ecological flow of 50 L/s in the trout brook, were also recommended.

Social Considerations: The assessment recommended improving stakeholder engagement, particularly during the siting and design stages. It highlighted the lack of consultation with local communities directly affected by the project, urging the inclusion of opportunities for them to express concerns about potential impacts on livelihoods, recreation, and the local economy. A more transparent consultation process would ensure better representation of community interests. Regarding socio-economic impacts, the project's effects on local communities were expected to be minimal due to its small scale, but there were opportunities to enhance community benefits. Suggestions included creating local employment during the rehabilitation phase and supporting local businesses, such as those linked to the river ecosystem or eco-tourism. Additionally, the assessment recommended ensuring E.ON's human resources policies were consistently applied, particularly to contractors, to uphold worker safety and rights during the project. Lastly, improvements in public safety and access management were urged, with suggestions for restricted access or enhanced signage to minimise risks associated with public interaction with the infrastructure.

Economic Considerations: While the project was financially viable, there was no assessment of long-term costs related to biodiversity loss or sedimentation issues. It was recommended that these factors be included in the financial planning to ensure the project's sustainability both economically and environmentally. Additionally, the assessment found that local development opportunities beyond energy production were not fully explored. It suggested considering job creation during the rehabilitation phase or the development of leisure facilities around the reservoir to contribute to the local economy. Furthermore, a thorough assessment of economic risks and opportunities, such as fluctuations in energy prices, regulatory changes, and climate change impacts on water availability, was recommended to improve the project's long-term financial resilience.

7.5.5 References

- Smith D., Khalil A., Rydgren B., (2015). Hydropower Sustainability Assessment Protocol. Official Assessment. E.ON. Semla IV. Sweden. Project Stage: Preparation. Assessment Dates: 10/11/2014 to 14/11/2014. Final. Report date: 27/01/2015
- https://www.eonenergy.com/about-us/our-energy-portfolio.html
- https://www.hs-alliance.org/published-assessments/semla-iv
- https://fagersta.se/

7.6 2015 - The R2D2 2050 Project Operation Assessment

7.6.1 Project details

- Project name: Durance–Verdon river basin R2D2 2050
- Project location: Durance and Verdon Rivers, South-Eastern France
- Project type: Operation including water management at the whole scale of the river catchment area
- Assessment stage: Implementation in 2013
- Installed capacity: 2000 MW
- Project owner: Électricité de France SA (EDF)
- Project stakeholders: Funded under the French Environmental, Sustainable Development and Energy Ministry and the Rhone-Mediterranean and Corsica Water Agency, the R2D2 2050 project was implemented by six partners which were coordinated by IRSTEA: the National Research Institute of Science and Technology for Environment and Agriculture IRSTEA, two owners (EDF and Société du canal de Provence), two universities (Pierre-et-Marie-Curie" Paris, and Joseph Fourier LTHE Grenoble), and ACTeon.

Figure 7.7 Overview of the Durance–Verdon Rivers in France

7.6.2 Objectives

The 30 hydropower plants and 17 dams in the Durance–Verdon River basin contribute to the supply of water and renewable energy. The Serre-Ponçon reservoir holding 1.2 billion m^3 of water was designed to store and redistribute water resources to respond to various demands. These include renewable energy, drinking water supply, agricultural and industrial water supplies and providing for the tourist activities. Water resources are under a high level of pressure due to significant demands for irrigation, hydropower, drinking water, industrial use and recreational activities) and the need to maintain ecological services in Mediterranean climate change. A climate change adaptation strategy was required by the effects of climate stress and the evolution of demographic and socioeconomic territories on water resources and water demand. The hydropower reservoir should be managed to reconcile the needs resulting from all forms of water use and the safety of individuals and property. The R2D2 2050 project lasted three years (2012–2015), with the final report having been published in October 2015. EDF actively invests in coordinated efforts with all water stakeholders, to determine shared action programmes for the benefit of all water users, the river and its ecosystems. The adopted innovative strategy includes the value creation methodology, and water-saving agreements.

Environmental objectives:

Provide ecosystem with fresh water during droughts.

Social objectives:

Inform communities and public authorities about the measures required in order to adapt itself to one of the 21st century's greatest challenge: the climate change.

Economic objectives:

EDF is required to deliver 200 hm^3 of water to irrigators between 1 July and 30 September annually. To save water, EDF develop and sign successive Water Saving Conventions. The agreement requires EDF to pay back a part of the saving costs if the targeted objectives are reached by irrigators. EDF encourages farmers to save water by financing modern systems to reduce water consumption.

7.6.3 Main types of best practice implemented

- Environmental and social impacts
- Community impact and infrastructure safety
- Governance and procurement
- Communication and consultation
- Hydrological resources
- Climate change mitigation and resilience

7.6.4 Lessons learnt

Challenges

The main question was who can save water and who can pay the future water savings

Another issue was meeting multipurpose requirements requires a daily operation.

Feedback

Modelling of the climatic dependence of the Durance–Verdon system provides insights on availability of the natural resource, water requirement for non-energy uses and energy production:

- Increased air temperature results in reduced snowpack, early melting period and increased evapotranspiration, however changes in flood regime are uncertain,
- Hydropower generation undergoes a significant reduction of its flexible generation capacity,
- Water demand will decrease in Durance River and increase in Verdon River,
- Tourism management of the Verdon could be deeply impacted.,
- Spilling risk during flood events could be increased.

Water Saving Convention is a win–win solution for stakeholders. Through this, significant water savings were reached (30% reduction of water by the irrigators), and benefits achieved in several sectors:

- irrigators: attractive compensation and improved control of the Serre-Ponçon reservoir,
- energy: better seasonal use with the saved stored water volume (which could be generated during peak hours), but a limited energy gain (as those savings are located downstream the end of the chain; the valuation is recovered at 20% on the energy side and 80% regarding appropriate time generation),
- environment: water savings that were achieved by EDF means more water is released to the environment rather than being consumed,
- tourism: keep the reservoir water level of Serre-Ponçon.

Recommendations

Water saving is becoming an essential issue. Water stakeholders have to work together on incentive mechanisms to manage these water efficiencies in a sustainable way. For instance, owners and Water Agency have currently to work towards basin-level water savings. Future innovative mechanisms should address the question that a part of these water savings could be distributed back to the environment and to water deficit areas in the basin.

7.6.5 References

Branche E. (2017) The multipurpose water uses of hydropower reservoir: The SHARE concept. C. R. Physique 18 (2017) 469–478.

7.7 2015 – Cadarache Stilling Basin : A Migratory Bird Ecosystem

7.7.1 Project details

- Location: Durance River, Bouche du Rhône, France.
- Project Type: Hydroelectric Power Plant and reservoir
- Project stage: Operation
- Installed capacity: 78 MW
- Assessment Year: 2021
- Key Stakeholders:
  - Operator: EDF Hydro
  - Environmental association: LPO (Bird Protection Ligue)

Figure 7.8 Cadarache power station (© Camille Moirenc)

The Cadarache hydropower plant, built in 1959, is part of the Durance-Verdon hydropower cascade, a larger complex of 16 dams and 23 hydroelectric power plants with a total available capacity of 2,000 MW for the entire basin.

Downstream from the Cadarache dam, an 82.5-hectare flood control and desilting reservoir was commissioned in 1980.

The diversity of biotopes at the confluence of the Durance and Verdon rivers, and the waters rich in microfauna and aquatic flora in the basin, enable the Cadarache site to host a variety of birdlife. In addition, the vast open expanse of this basin is conducive to winter gatherings of water birds. Thanks to its low water level, the Cadarache reservoir developed aquatic vegetation and a beautiful reed bed. Therefore, the Cadarache basin welcomes a great diversity of ducks in exceptional numbers.

7.7.2 Objectives

Environmental objectives: The vast open area of this basin has become an ecosystem so favourable for winter gatherings of water birds that it has become necessary to study and protect this ecosystem.

Common coot (Fulica atra)

Great Crested Grebe (Podiceps Cristatus)

Ferruginous duck (Aythya nyroca)

Penduline tit (Remiz pendulinus)

Figure 7.9 Photos of birds observed on the Cadarache basin (© birding places)

7.7.3 Main types of best practice implemented

- Biodiversity Management

7.7.4 Lessons learnt

Main Challenges

Manage vegetation and other water use to protect the bird's ecosystem.

Feedback

Since 1976, surveys have been carried out as part of the Wetlands International (an organisation for the preservation of wetlands) inventories. For example, during winter monitoring carried out as part of the Wetland International census, between 1,000 and 4,500 individuals have been present each winter in Cadarache since 2007.

- 202 bird species recorded since 2012, including 94 waterbirds
- a breeding site for around 50 bird species
- 30 species of dragonflies counted
- 16 species of bats present, including 7 with high or very high conservation value
- 18 species of butterflies
- 7 plant species with conservation value

Recommendations

Environmental Considerations

Since 2015, an ecological management plan has been implemented in partnership with the LPO (League for the Protection of Birds). This has resulted in:

- Vegetation management methods that respect habitats and protected species and are more targeted at invasive species;
- Awareness-raising activities for EDF staff and contractors;
- Monitoring (birds) and inventories (dragonflies, semi-aquatic mammals, etc.) to improve knowledge of the species on the site;
- A reduction in night-time lighting on the site and work to identify the potential for hosting nocturnal species (bats, moths).

In order to address the challenges of preserving the entomofauna (dragonflies, butterflies, etc.), invertebrates and also the ocellated lizard (T. lepidus), a protected and endangered species present on the Cadarache site, late mowing is carried out from the end of October to March (mowing outside the ocellated lizard's period of activity). In addition, varying the cutting heights allows both open areas dominated by herbaceous plants, which are favourable for the ocellated lizard's diet, and taller areas composed of clematis and brambles, which provide refuge areas, to be preserved.

The creation of artificial shelters for the ocellated lizard, and the installation of brushwood fences along the access road to the dam to limit disturbance to birds.

With regard to invasive alien plant species, their spread is being monitored so that eradication campaigns can be launched if necessary (treatment of ailanthus is currently underway).

7.7.5 References

https://glossaire.eauetbiodiversite.fr/concept/zone-de-protection-speciale

https://www.birdingplaces.eu/fr/birdingplaces/france/bassin-de-decantation-de-cadarache

7.8 2015 - Rhine Ecological Flow at KEMBS

7.8.1 Project details

- Location: Rhine River downstream Basel
- Project type: restoration biodiversity of a run-of-river HPP with diverting dam
- Assessment stage: preparation and implementation
- Capacity: 155 MW
- Key stakeholders:
  - Owner: Électricité de France SA (EDF)
  - 17 State Representatives
  - 20 town representatives
  - 18 NGO
  - 3 Environmental companies

Figure 7.10 The Rhine River, the Kembs dam, Kembs island with the new HPP and river (©EDF)

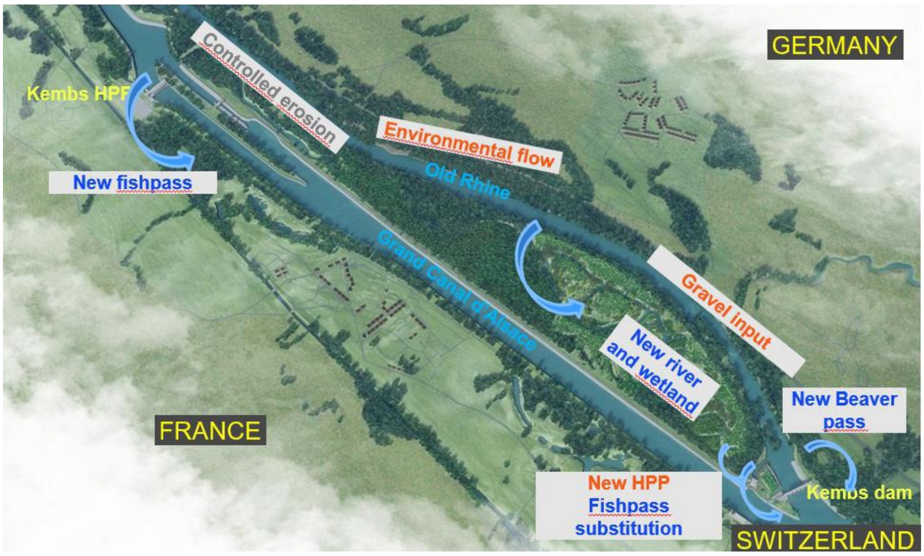

Figure 7.11 The new river, fish pass, beaver pass, and wetland in the Kembs Island

Figure 7.12 3D view of the new hydropower plant B with the fish pass and the upstream part of the new river, which is supplied in water through the fish pass and the plant.

7.8.2 Objectives

Rhine River biodiversity and geomorphology have been heavily modified since first embankment works in the 1830s and damming and by-passing in the 1930s.

The process of licensing renewal was the opportunity to restore biodiversity and geomorphological function: increase the ecological flow, build a power plant (8,5 MW, 28 GWh/y) providing part of the ecological flow (90 m^3/s), increase the sediments transport and renature the Kembs island.

Environmental objectives

Rhenian biodiversity restoration, via alluvial restoration, ecological flows, continuity improvement, and nature-based-solutions.

Social objectives

Acceptability of the Kembs scheme in a tri-national context, with cultural and practice differences.

Economic objectives

The increase of the ecological flow creates a great energy loss, through four plants along the Grand Canal d'Alsace. So EDF decided to build a new hydropower plant in order to possible to turbine part of the e-Flow and recover 20% of initial loss, manage daily variations of ecological flow, and feed out a recreated river for renaturing the Kembs Island and ensuring various functions thereby increasing the overall environmental gain.

7.8.3 Main types of best practice implemented

- Water Quality and Sediments Management
- Biodiversity Management
- Downstream flow regimes

- Communication and consultation
- Governance and Procurement

7.8.4 Lessons learnt

Challenges

Design a new ecological flow for “Old” Rhine River (natural riverbed), taking into account the objectives defined with NGOs and Authorities to improve biodiversity without excessive energy losses.

The complexity was in the ecosystem functions in multi-impacted and trans-boundaries rivers, like Rhine River impacted by the chemical industry, with a river bed deeply incised by Tulla’s works in the 19th century.

Feedback

Environmental and economic considerations

Ecological flow was assessed by considering:

1) objectives defined for fish, macrophytes, birds, insects, …, based on Hydraulic and Habitat models, observations and measures during in-situ tests and needs of progressive seasonal flow variations (Figure 7.13). The minimum flow has been increased, according to the season, and a daily variation component has been introduced from April to October (capped at a maximum summer value).

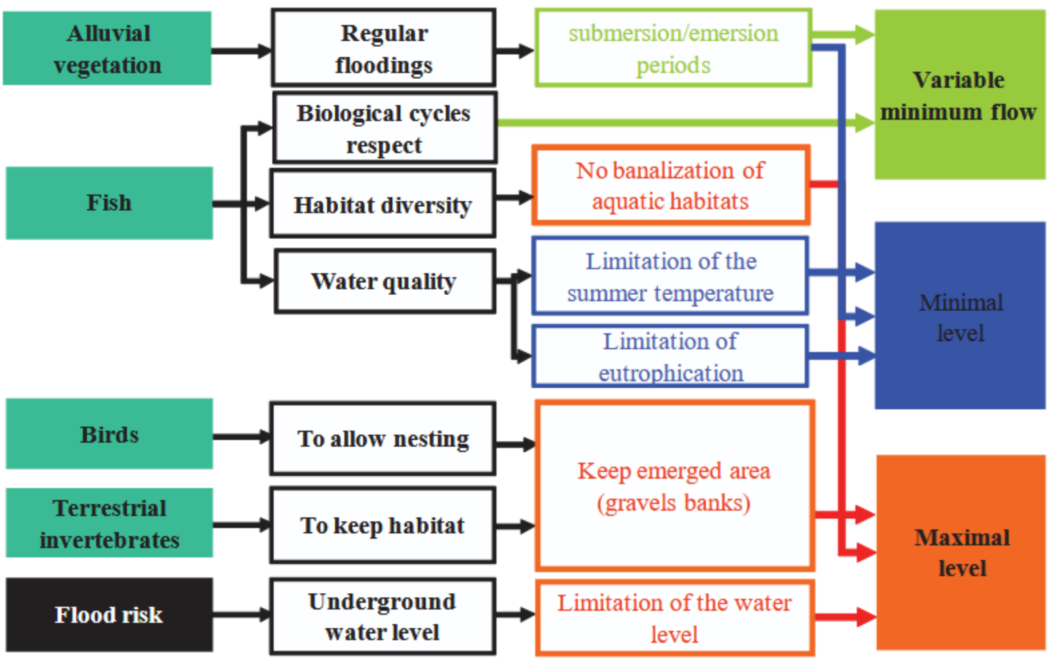

Figure 7.13 Main environmental constraints to define the ecological flow (EDF, 2006)

2) limitation of the energy losses, especially in winter.

Results

The innovative approach was to mimic the natural hydrological regime (according to the season, a daily variation component has been introduced from April to October, capped at a maximum summer value, Figure 7.14) combining different approaches (in situ observations and hydraulics and biological models) and involving stakeholders in working groups and during in situ tests to look at the habitats and water flows evolutions and were useful to reach consensus.

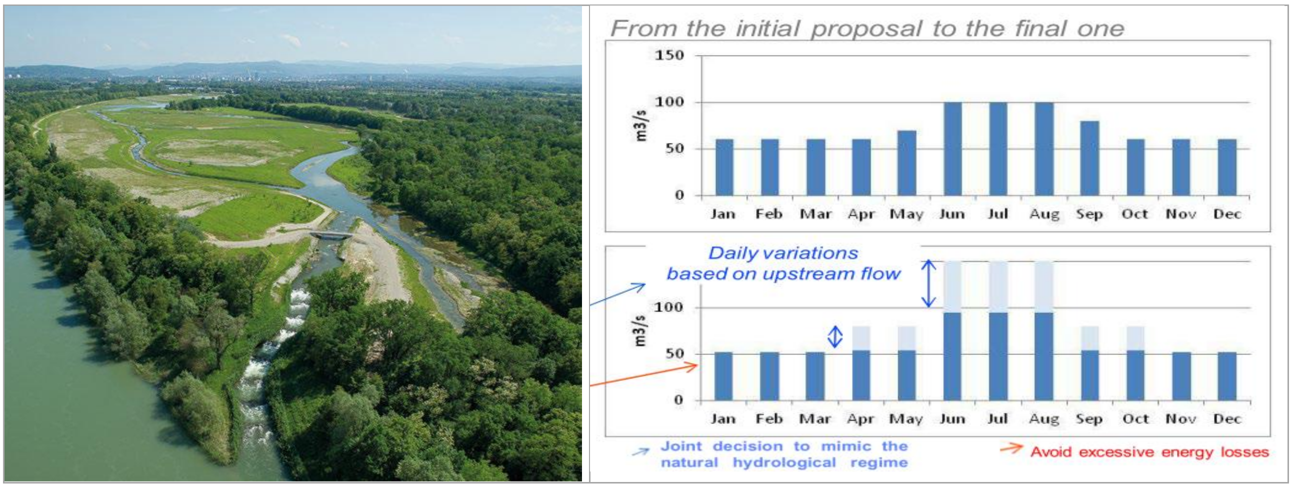

Figure 7.14 The fish path and the mimic environmental flow (© EDF)

The main outputs are restoration of alluvial dynamics (sediment recharge and controlled bank erosion) and connectivity for all aquatic mammals' species. Since commissioning, 45 000 m^3 of gravel were re-injected or eroded from banks, and more than 22 000 individuals of 19 fish species (including 3 long-distance migrators) used the fish pass in one year.

The level of ecological flows was designed considering the gravel improvement (with injection and controlled erosion of banks). The minimum of ecological flow has been increased, but was not sufficient alone to ensure good habitat for aquatic biocenoses, as Rhine River has been deeply incised by Tulla's works in the 19th. Despite all these efforts (millions of euros), aquatic biocenoses are below from what was expected, due to limiting factors that were not well identified (chemical issue) or not existing yet (some invasive species, like gobies which invaded the Rhine River after the e-Flow was implemented). However, aquatic biocenoses have benefited above all from the diversification of riverbank habitats through specific operations, and thanks to the new flows, which improves lateral connectivity.

Finding a compromise is a long process (several years) due to the complexity of ecosystem functions (everyone is not a specialist), and the three national regulations.

The project has drastically enhanced the environmental quality of the scheme; despite the energetic losses due to the increased ecological flow (partially recovered by the new plant), it perpetuates the legitimacy of the Kembs powerplant to sustainably produce a green energy over time.

Recommendations

Environmental flow is not necessarily a high flow; it is a flow that makes it possible to guarantee lateral and longitudinal continuity, favouring the functionality of refuge or special riparian or annexes habitats; it is possible to give nature a helping hand, especially in highly anthropized environments, by restoring the morphology of the reach, in addition to actions on flows.

Studies of the functioning of the ecosystem are required over several years in conjunction with stakeholders to anticipate the definition of ecological flows.

Future steps are proposed:

- Continuation of ecological monitoring to gain feedback, against a backdrop of climate change (trend towards changes in the hydrological regime and rising temperatures)
- Continuation of morphological restoration operations on the Old Rhine
- On going R&D to better assess functionality indicators.

7.8.5 References

GARNIER A., BARILLIER A. (2015) The Kembs project: environmental integration of a large existing hydropower scheme. La Houille Blanche, n° 4, 2015, p. 21-28. DOI 10.1051/lhb/20150041

EDF (2006) — Etude d'impact sur l'environnement de la concession hydroélectrique de Kembs. Rapport Ecotec. 500 pages + annexes.

7.9 2017 - Kaunertal Expansion (KXP) Assessment

7.9.1 Project details

- Location: Tyrol, Austria
- Project type: Power system expansion with a Pump Storage Hydropower
- Project phase: Preparation
- Capacity: Originally 392 MW and 1015 MW would be added
- Key stakeholders:
    - Owner: Tiroler Wasserkraft AG (“TIWAG”)
    - Affected communities in Ötztal, Kaunertal and Platzertal side valleys,
    - Regional and local institutions: Municipality Kauntertal, Provincial Government of the Tyrol; Gemeinderat Sölden; Gemeinderat Kaunertal; Gemeinderat Prutz;
    - National institutions: National Austrian Department of Environmental Protection; National Council; Österreichische Staubeckenkommission; Austrian Ministry for Agriculture, Forestry, Environment and Watermanagement; Environmental Ombudsman/ Kostenzer; ZAMG Zentralanstalt für Meteorologie und Geodynamik; Österreichs Energie; WISA; Verwaltungsge- richtshof;
    - European organisations: EU Commission/ National Council; European network of transmission system operators for electricity (ENTSO-E); Austrian Commission for UNESCO;
    - Quality and Standards organisations: Quality Austria; Austrian Standards Institute
    - NGO: WWF
    - Relevant Partners: Beratung Krismer; TALPA Gnbr; University of Innsbruck, Austrian Alpine Club; Tokyo University of Agriculture and Technology; Swiss Academies of Arts and Science; RISKConsult; University of British Columbia; Tiroler Raftingverband; ARGE Limnologie/ Institut für Ökologie OG; Österreichische Gesellschaft für Marketing; ETH Zürich;
    - Contractors: Österreichische Forschungsgesellschaft Straße; Verband der Elektrizitäts - werke Österreichs; Illwerke VKW

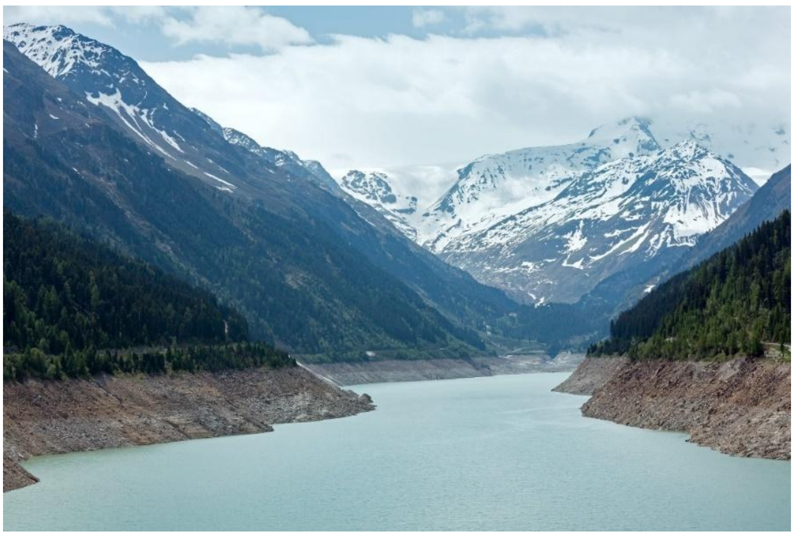

Figure 7.15 Kaunertal reservoir in West Tyrol, Austria. Hydropower Sustainability Alliance

The Kaunertal Expansion Project (KXP) is one of around ten power plant projects that TIWAG-Tiroler Wasserkraft AG, the in Tyrol, Austria, has at various stages of development. It involves the use of water from the Oetztal valley; a new upper stage reservoir for pump storage located in the Platzertal valley; the use of the Gepatsch reservoir as the lower stage reservoir for pump storage; a new pump storage hydropower plant the Versetz PSHP of 400 MW; a new second power station (Prutz 2) in Prutz of 500 MW; a new second power station (Imst 2) in Imst (92.5 MW) together with a new pressure tunnel between Runserau and Imst; addition of a third turbine at Haiming Power Station plus enlargement of the tailwater basin.

7.9.2 Objectives

An Official Assessment was carried out with the Preparation Tool of the Hydropower Sustainability Assessment Protocol. It is the first project to be evaluated using the official Hydropower Sustainability Assessment Protocol in Austria. The HSAP was carried out before the Environmental Impact Statement was completed and accepted. The assessment, which focused on sustainability, involved extensive stakeholder engagement and evidence collection.

Environmental objectives. The assessment tackles environmental aspects for construction and operation. The Upper Tyrol Water Management Framework Plan, along with its environmental assessment, comparable to a Strategic Environmental Assessment (SEA), outlines measures to address the cumulative impacts of large hydropower projects in the region. The Environmental Impact Statement (EIS) considers environmental aspects, including terrestrial and aquatic fauna, flora and habitats, landscape, soils, climate, and surface and groundwater quality. It also examines impacts associated with primary suppliers, such as the use of materials from quarries, landfills, and municipal wastewater treatment plants. Impacts related to aggregate suppliers, cement, and other materials have been addressed through the environmental management system complying with environmental specifications implemented by all major suppliers according to the procurement process established by TIWAG.

Social objectives. The social assessment considers impacts on leisure, recreation, tourism, agriculture, forestry, hunting, fishing, regional and inter-regional planning, transport, and human health. Similarly, it aims to develop and recommend measures to minimise impacts, such as restricting working hours, reducing land use areas, utilising low-noise construction equipment, creating buffer zones near residential areas, and elevating the Pontlatz bridge. Additionally, it seeks to establish a fair and transparent approach to land acquisition, including determining compensation based on current market rates.

Economic objectives. The economic objectives of the project focus on ensuring that it delivers a net benefit by balancing economic, social, and environmental costs and benefits. A key aim is to support regional economic development, particularly in sectors such as tourism and agriculture, which are vital to the Tyrol region. Additionally, the project seeks to optimise the use of hydrological resources while meeting social and environmental constraints, such as maintaining residual flows, enabling flood protection, and supporting biodiversity. The project also aims to enhance electricity generation capacity and flexibility by integrating renewable energy sources. It is expected to provide direct economic benefits, including increased communal tax revenues for affected municipalities during the construction phase. Furthermore, the analysis evaluates broader economic benefits through key indicators, including security of electricity supply, socio-economic welfare (e.g., reducing electricity costs through storage and supply optimisation), renewable energy integration, reduced system losses, lower CO2 emissions, enhanced technical resilience and safety, and improved management of power fluctuations, voltage, and frequency. These objectives align with the goal of promoting sustainable economic growth while meeting environmental and social commitments.

7.9.3 Main types of best practice implemented

- Labour and working conditions
- Water quality and sediments
- Community Impact and infrastructure safety
- Cultural Heritage
- Governance and procurement
- Environmental and Social assessment.

7.9.4 Lessons learnt

Challenges

The assessment highlighted several critical areas where evidence is lacking. These gaps raised concerns about the project's overall feasibility and effectiveness:

- The Kaunertal Expansion Project (KXP) as a priority option to meet all relevant needs.
- The ability of the KXP to avoid, minimise, mitigate, and compensate for all negative permanent social and environmental impacts:
    - There was no corporate policy addressing stakeholder engagement, transparency, and disclosure, nor are there processes to determine if stakeholder information needs and interests are being met.
    - Some stakeholder groups perceive that there are inadequate opportunities for informed dialogue regarding the need for and strategic fit of the Kaunertal Expansion Project (KXP).
- The KXP's capacity to manage financial issues under various future scenarios: economic analyses have not accounted for all costs and benefits, and consequently, a net benefit was demonstrated.
- The effectiveness of proposed biodiversity mitigation measures in fully compensating for permanent negative residual impacts.

Feedback

the HSAP findings showed very strong performance at the level of basic good practice, with only a few areas requiring further work.

The environmental and social assessment of the Kaunertal Expansion Project (KXP) was a crucial part of the evaluation. This involved a detailed analysis of potential impacts on local ecosystems and communities, ensuring measures were in place to mitigate any negative effects. Biodiversity management was particularly significant, with the project aiming to protect and enhance local wildlife habitats while compensating for any unavoidable impacts. Hydrological resources were another key focus, with the project designed to optimise water usage and maintain the health of local water systems. The impact on the community and infrastructure safety were also vital, ensuring the project disturbed the least as possible local populations and did not compromise their safety or well-being. Labour and working conditions were scrutinised to ensure fair treatment and safety for all workers involved in the project. Governance and procurement practices were equally evaluated to ensure transparency, accountability, and efficiency in the project's execution. Additionally, the preservation of cultural heritage and leisure areas was carefully considered, recognising their importance to the region's economy, which relies heavily on these sites. These comprehensive assessments aimed to ensure that the KXP not only met energy demands but also upheld high standards of environmental, social and economic responsibility.

Despite some significant gaps, the project generally scored highly due to TIWAG's substantial investment in its preparation and stakeholder feedback.

18 of the 21 topics assessed scored at levels at or above basic good practice. Topics scoring below Basic Good Practice were due to:

- strong opposition to the project amongst some Project-Affected Communities and Livelihoods,
- limitations to the analysis with respect to the Protocol requirements (in the case of the cost-benefit analysis, relevant to topic Economic Viability), and
- limitations to the forms of information provision to support effective stakeholder engagement relevant to topic Downstream Flow Regimes.

The project meets proven best practice on eight topics: Integrated Project Management, Infrastructure Safety, Procurement, Labour and Working Conditions, Cultural Heritage, Erosion and Sedimentation, Water Quality, and Reservoir Planning.

Recommendations

While the project adhered to basic good practice in most areas, certain aspects, particularly community engagement and economic viability, required further attention. The Environmental Impact Assessment (EIA) process was ongoing, with construction expected to commence in the late 2020s.

For land acquisition, compensation values were determined based on current market rates, using a comparative value method that considered potential yield or the assessment of an independent expert. TIWAG negotiated private agreements with affected landowners, and where agreements could not be reached, grievance mechanisms and redress procedures were in place to resolve disputes.

A range of impact minimisation measures were proposed. These included limiting working hours, reducing land take areas, employing low-noise construction vehicles and machinery, establishing buffer zones near residential areas, and raising the Pontlatz bridge. Additionally, the project aligned with the Tyrolean government's Energy Strategy 2020, Sustainability Strategy, and Energy Autonomy 2050, which aimed to reduce CO2 emissions, increase energy efficiency, and enhance renewable energy generation, system stability, and energy security.

7.9.5 References

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- https://www.hs-alliance.org/news/ihasandpamirenergy-2xn3z-s8ejp
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7.10 2017 - Kárahnjúkar or Fljótsdalsstöð Operation Assessment

7.10.1 Project details

- Location: Jökulsá á Fjöllum river basin, Iceland.
- Project type: Large-scale hydropower
- Project stage: Operation
- Capacity: 690 MW
- Assessment year: 2017
- Key stakeholders:
    - Owner: Landsvirkjun (Icelandic National Power Company). Responsible for the planning, development and operation of the Kárahnjúkar project.
    - National Government Bodies: Icelandic Government, as the owner of Landsvirkjun, was key in ensuring the Kárahnjúkar Hydropower Project aligned with national goals for energy production, economic growth, and environmental sustainability; Ministry for the Environment and Natural Resources focused on evaluating the project's environmental impacts, particularly concerning biodiversity and water quality, ensuring mitigation measures for land inundation and water flow changes; Ministry of Industry and Innovation: ensured the project contributed to Iceland's energy security and economic sustainability, aligning it with national energy policy and promoting renewable energy growth.
    - Regulatory and Industry Bodies: Icelandic Environment Agency. Ensure that the project complies with national environmental protection laws: Icelandic Water Resources Agency regulates water usage ensuring that the project does not deplete or harm water systems; Landsnet is responsible for the integration of the energy generated by Kárahnjúkar into the national grid.
    - Workers and Contractors: Alcoa (Fjardaál Aluminium Smelter) consumes much of the electricity produced by Kárahnjúkar, making it reliant on its smooth operation. It also plays an important role in the local economy providing numerous jobs and regional development.
    - Environmental NGOs: Icelandic Nature Conservation. Monitored the project's environmental footprint, focusing on the protection of wildlife, water quality, and ecosystems. Their involvement aimed to ensure that Kárahnjúkar minimises harm to wilderness areas and local water systems, acting as watchdogs to ensure compliance with environmental standards.
    - Academics and Researchers: University of Iceland's Institute of Life Sciences. Their research provided insights that guided decision-making on topics of environmental and social sustainability.
    - Local communities: these communities located mostly in the Fljótsdalur valley are integral stakeholders because they experience both the benefits and challenges of the project, including socio-economic impacts and environmental changes: Fáskrúðsfjörður: Historically, this community has been involved in fishing and small-scale industries, the hydropower project and the adjacent aluminium smelter (Fjardaál) have impacted the local economy by providing new employment

opportunities; Egilsstaðir the largest town in East Iceland,hosts various businesses, including those that benefit from the energy provided by Kárahnjúkar; Reyðarfjörður, a small community to the north, heavily influenced by the presence of the Fjardaál aluminium smelter, which is powered by electricity from the Kárahnjúkar plant; Höfn is another community that was indirectly affected by changes in local ecosystems, water flow, and tourism patterns due to the hydropower project.

Figure 7.16 Kárahnjúkar Dam (HSA)

The Kárahnjúkar Hydropower Project, situated in Iceland's eastern highlands, is one of the country’s largest energy infrastructure initiatives. The project involves the construction of several dams, tunnels, and powerhouses along the Jökulsá á Fjöllum river, with the Kárahnjúkar Dam being the largest in Iceland. With an installed capacity of 690 MW, it primarily provides power to an aluminium smelter, playing a significant role in the region's renewable energy supply. In addition to energy production, the project addresses important considerations such as water management, biodiversity, and the impact on local communities, representing a notable achievement in both engineering and sustainability.

7.10.2 Objectives

An assessment of the Kárahnjúkar project was carried out using the Operation Stage tool of the Hydropower Sustainability Assessment Protocol.

Environmental objectives

- The Kárahnjúkar project resulted in the inundation of wilderness areas through several reservoirs, leading to changes in the ecosystem, however efforts have been made to mitigate environmental impacts.
- The downstream flow in the Jökulsá í Fljótsdal river is significantly altered and work in mitigating the increased flow in certain areas was deemed necessary.

- Water Quality assessment: changes in river flows, particularly in the Jökulsá á Dal and Jökulsá í Fljótsdal rivers, affect the water quality and downstream ecosystems. The assessment the project emphasised monitoring potential pollution sources.
- Erosion and sedimentation: the environmental and social impacts from erosion are documented as a gap, with ongoing problems especially in the Kringilsáranni area and around Lagarfljót lake.

Social objectives

- Resettlement and Livelihoods: the livelihoods of affected communities, particularly in the highland areas, were impacted. This was originally rated as “Not Relevant”, but there were significant gaps in the equitable sharing of benefits.
- Public Health: the project has contributed to improvements in public health by providing power for communities, thus supporting health services and improving living conditions.

Economic objectives

- Ensure Financial Viability: explore and enhance the financial sustainability of the project by maintaining a stable revenue stream from energy exports and optimizing its contribution to Landsvirkjun’s operations and the broader Icelandic economy.
- Local and Regional growth: explore the economic impacts in terms of job creation and infrastructure development, as well as the equitable compensation provided to the communities affected.
- Infrastructure safety: ensure the ongoing safety and reliability of Kárahnjúkar’s infrastructure, including dams, tunnels, and powerhouses, by implementing best practices in monitoring and maintenance, not only for the population but for the workforce as well.

7.10.3 Main types of best practice implemented

- Environmental and social assessment
- Labour and Work Conditions
- Water Quality and Sediments Management
- Community Impact and infrastructure safety
- Biodiversity and invasive species
- Cultural Heritage preservation
- Governance and procurement
- Communication and consultation
- Hydrological resource.

The Kárahnjúkar project reflects several best practices critical for large-scale infrastructure developments. Among the most relevant are Labour and Work Conditions, Community Impact and Infrastructure Safety, and Hydrological Resources. Given its scale, the project places a strong emphasis on providing safe and fair working conditions, in compliance with international labour standards. Its location in a remote area further highlights the importance of considering the impact on local communities, through job creation and infrastructure development, while ensuring the safety of the project’s key components, such as the dams and powerhouses.

Additionally, the project demonstrates a commitment to the sustainable management of hydrological resources, ensuring water use is optimised in a way that preserves the surrounding environment. As climate change resilience becomes an increasingly important concern, the Kárahnjúkar project also contributes to renewable energy generation, while adapting to changing weather patterns. These practices together ensure the project's success, benefiting the local economy, safeguarding the environment, and offering a model for sustainable hydropower development.

7.10.4 Lessons learnt

Main Challenges

The Kárahnjúkar Hydropower Project encountered several significant challenges during its development and operation. A key issue was the lingering sense of inequity among affected communities regarding benefit-sharing and compensation, which stemmed from limitations in the regulatory framework. Additionally, erosion in areas such as Kringilsáranni and Lagarfljót lake caused persistent environmental and social problems.

Operational challenges included gaps in transmission capacity, which constrained the optimal use of water resources, and minor non-conformances with dam safety standards, such as incomplete instrumentation records and a lack of systematic data analysis. Landsvirkjun's support for tourism initiatives in the region was perceived as inconsistent, and feedback to individual landowners regarding bank erosion mitigation was neither thorough nor timely. These issues underscored the need for improved stakeholder engagement and operational management to enhance the project's long-term sustainability and community impact.

Feedback

Kárahnjúkar meets proven best practice on 11 out of 17 relevant topics: Communications and Consultation; Environmental and Social Issues Management; Asset Reliability and Efficiency; Financial Viability; Labour and Working Conditions; Cultural Heritage; Public Health; Biodiversity and Invasive Species; Water Quality; Reservoir Management; and Downstream Flow Regime.

Kárahnjúkar exceeds Basic Good Practice on all six remaining topics.

Recommendations

<u>Environmental Considerations</u>

The Kárahnjúkar Hydropower Project highlighted the need for a more robust approach to environmental management. Erosion in areas such as Kringilsáranni and Lagarfljót lake caused ongoing environmental issues, underscoring the importance of targeted erosion control strategies. Continuous biodiversity monitoring was essential to mitigate the project's impact on wilderness areas and ensure the protection of flora and fauna. Additionally, constraints in transmission capacity limited the efficient use of water resources, revealing a need for optimisation strategies to maximise hydropower generation while maintaining ecosystem health. Efforts to restore disrupted landscapes, including areas impacted by flooding or construction, would have reinforced the project's commitment to environmental sustainability.

Social Considerations

Social challenges from the Kárahnjúkar project emphasised the importance of equitable benefit-sharing frameworks to address frustrations among affected communities. Perceived imbalances in compensation and support highlighted the need for transparent mechanisms to distribute the project's advantages fairly. Furthermore, gaps in communication with landowners, particularly regarding erosion mitigation efforts, demonstrated the necessity for more effective stakeholder engagement. A more consistent strategy to support local communities, including the tourism sector, could have enhanced regional economic opportunities and fostered goodwill. Establishing reliable feedback mechanisms for communities to voice concerns would have contributed to stronger relationships and social cohesion.

Economic Considerations

Economic efficiency was another critical area for improvement in the Kárahnjúkar project. Limitations in transmission capacity impeded the optimal use of water resources, reducing the project's potential to maximise energy output. Addressing this would have required investments in upgrading infrastructure and improving system efficiency. While tourism was not significantly disrupted, the project's inconsistent contributions to regional tourism development highlighted opportunities to foster sustainable tourism initiatives that could complement local economic growth. Additionally, focusing on long-term economic planning that balanced regional and national priorities would have ensured the project's broader contributions to Iceland's economy. Finally, implementing advanced monitoring technologies and adhering to the highest safety standards would have further strengthened economic sustainability and operational reliability.

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7.11 2019 – Plobsheim Compensation Basin: An Exceptional Ecosystem

7.11.1 Project details

- Location: Rhine and Ill Rivers, France.
- Project Type: Strasbourg Power Plant.
- Project stage: Operation
- Installed capacity: 150 MW.
- Assessment Year: 2019.
- Key Stakeholders:
  - Operator: EDF SA
  - Environmental association: LPO
  - Fishing community

Figure 7.17 Plobsheim compensation basin (© peche67)

Covering 620 hectares, the Plobsheim compensation basin, linked to the Strasbourg hydroelectric power plant, was designed to regulate the levels of the Rhine and Ill rivers at the entrance to the Strasbourg metropolitan area, and commissioned in 1970 on the Rhine.

The Plobsheim lake is the largest body of water in the department. This clear, shallow artificial reservoir (3 metres deep on average) is home to lush flora. It is the basis of an exceptional ecosystem. Bream, tench thrive here, but it is the pike, in terms of their numbers and size, that make this place a unique destination.

Above all, however, the entire lake is used by nearly 10,000 birds, which find food and shelter there.

7.11.2 Objectives

Environmental objective. The Plobsheim compensation basin has been subject to a Biotope Protection Order due to its major ornithological interest. A series of measures have been implemented to preserve habitats, food sources and, more generally, all the protected species present on the site.

7.11.3 Main types of best practice implemented

- Biodiversity Management

7.11.4 Lessons learnt

Main Challenges

Pay particular attention to ensuring that projects to develop leisure activities, whether sporting or otherwise, are not carried out to the detriment of the site's environmental interests.

Pay particular attention to ensuring that mowing vegetation do not develop invasive species damaging fish population.

Feedback

In total, 234 bird species were recorded between 2011 and 2020. Among them, during Wetlands International's annual inventories, around 60 species of wintering waterbirds were observed on the lake in winter, such as the common pochard (A. ferina), the red-necked grebe (T. ruficollis), etc.

Figure 7.18 Colvert duck (left) and Foulque Macroule – Saint Renan (© Aurélien Audevard)

The Plobsheim basin offers a major ecological advantage for birds, as it is one of the most important sites in Alsace and the Grand Est region for birdlife, particularly water birds.

- **Wintering shelter**: Every winter, it hosts a large concentration of waterbirds (up to 15,000 individuals in some winters), including species that are rare locally and nationally. It is the leading site in Alsace for waterbirds to winter, providing shelter during the harsh season? And the second largest wintering site in France after the Camargue.

- **Nesting and reproduction:** Twenty species of waterbirds nest there regularly, such as the kingfisher (A. atthis), great crested grebes (P. cristatus), greylag geese (A. anser), etc., mainly in the southern part of the basin, which is wilder and more protected.
- **Migration**: The basin is an essential stopover during migration in spring and autumn for thousands of birds of more than 50 species, which benefit from a significant food source in the form of a substantial biomass of fish and insects.
- **Rarity and biodiversity**: 234 species of birds have been recorded on the site, including 99 nesting species and 33 listed on the regional red list. Some, such as the osprey, use the basin as their main feeding area.
- **Regulatory protection**: The site benefits from specific protections (Natura 2000, SPA, hunting reserve, biotope), which regulate human activities to limit disturbance and preserve the tranquillity necessary for these sensitive species.

In terms of flora, there are also protected species such as the marsh helleborine (E. palustris), the early purple orchid (D. incarnata) and the common adder's tongue (O. vulgatum). However, mowing operations cause changes in the macrophytic flora.

Recommendations

Environmental Considerations

the Plobsheim basin is a vital refuge for local and migratory birdlife, thanks to its calm waters, diverse habitats and the protective measures in place. To keep

Moreover, the vast majority of EDF Hydropower sites are located near or within a Natura 2000 area. Some reservoirs create remarkable habitats for water birds, as illustrated by the examples of Cadarache and Plobsheim, which have been protected by the Special Protection Areas (SPAs) regulation for birds.

7.11.5 References

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Fédération du Bas-Rhin pour la Pêche Et la Protection du Milieu Aquatique (2017). Résultats de la campagne 2017. Etude visant à déterminer les causes des mortalités piscicoles du plan d'eau de compensation de Plobsheim.

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7.12 2020 – Sabart Rehabilitation with Desman and Trout Protection

7.12.1 Project details

- Location: Sabart HPP, Vicdessos River, Ariège, France
- Project Type: Replacement of penstocks of the Hydroelectric Power Plant
- Project stage: Operation
- Installed capacity: 31,5 MW
- Assessment Year: 2020.
- Key Stakeholders:
  - Operator: EDF SA
  - State services
  - Environmental associations : ANA Conservatoire d'Espaces Naturels d'Ariège, Ariège Naturalists' Association, Nature Midi-Pyrénées and the Departmental Fishing Federation.

Figure 7.19 Renovation work on the Sabart HPP penstocks (© EDF)

7.12.2 Objectives

The renovation of the Sabart power plant equipment took three years from September 2018 to March 2020. Most of the work involved replacing two penstocks, each 320 m long, on a 73-degree slope. Other work included turbine maintenance to optimise the site's renewable electricity production, maintenance of the 15 km gallery and replacement of a flap gate upstream of the facility.

Environmental objectives

To minimise the impact of the work on wildlife and particularly on the rare and protected species (desmans, trout, Egyptian vultures, bearded vultures, bats, etc.) in the Vicdessos valley.

To improve the knowledge on the Pyrenean Desman and contribute to the EU LIFE Desman programme.

Social objectives

Set up the construction site in close collaboration with local stakeholders: municipalities, regional companies, environmental associations.

Economic objectives

Beneficial spin-offs for the local economy are generated by involving regional companies in the project work, particularly the construction and installation of the new penstocks.

7.12.3 Main types of best practice implemented

- Biodiversity Management
- Governance and Procurement
- Labour and Work Conditions
- Community impact and Infrastructure safety

7.12.4 Lessons learnt

Main Challenges

Technical challenge: replacement of penstocks involves working with large-diameter, high-pressure pipelines that are part of difficult-to-access mountain infrastructure restricting vehicle access, equipment delivery, and safe work conditions.

Environmental challenges: Protect the river ecology during the works with two focuses: the brown trout (Salmo trutta L.) and the Pyrenean desman.

Feedback on environmental management

In support of the regulatory procedure governing the work, the manager of the hydropower plant (EDF) wished to conduct a consultation and co-construction process with local stakeholders in the management of aquatic environments. In collaboration with the Ariège Naturalists' Association, Nature Midi-Pyrénées and the Departmental Fishing Federation, the State services, accompanied by a specialised environmental monitoring committee, EDF Hydro Aude-Ariège is committed to an ecological monitoring programme.

For example, a census of various sensitive species (Egyptian vulture, bearded vulture, desman, trout, bat) has made it possible to identify areas likely to be disturbed by the construction site.

EDF has therefore adapted flight plans to take into account the potential nesting areas of protected bird species and has implemented appropriate river flow management to preserve fish life in the Vicdessos.

An approach based on analyses of environmental sensitivity, ecomorphological risks and hydraulic studies enabled the implementation of measures to mitigate the impacts of the hydropeaking:

1) Inventory of sensitive species with local naturalist associations started in 2011 in order to define the environmental measures to be taken during works (Figure).

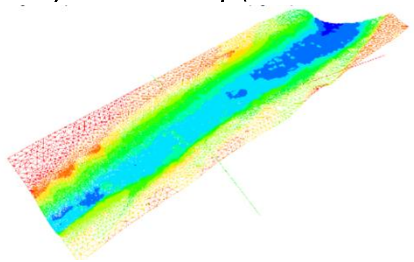
Figure 7.20 Inventory of sensitive species around the Sabart HPP

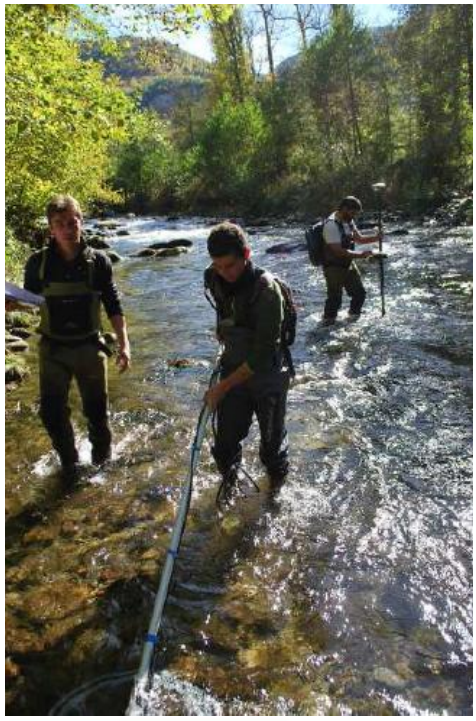
2) apply the Avoid-reduce-offset hierarchy principle (Table 4)

Site Camp	
Avoid	Lay a geotextile under material brought to define site tracks to help avoid the spread of invasive species
Avoid	Limit earthworks to build camp (polluted ground)
Reduce	Install a septic tank
Cable materials transport	
Reduce	Mark cables to avoid bird strikes
Reduce	Adapted schedule for foundations rock stripping & concreting works (rock avifauna)
Reduce	Specific management of excavated polluted soil
Penstocks replacement works	
Avoid	Adapted schedule for scaffold installation (rock avifauna)
Reduce	Choice of cable materials transport instead of helicopter
Reduce	Recovery of dismantled steel penstocks
Reduce	Invasive species management
Monitor	Rock avifauna & bats
Montréal intake works	
Reduce	Water quality measures during emptying & works within the river
Reduce	Fish rescue
Reduce	Installation of a floating dam to limit risks from accidental pollution
Reduce	Recovery & treatment of concrete sawing water

Table 4 Application of the avoid-reduce-offset hierarchy principle for the Sabart works (extract)

3) Implement mitigation measures: hydropeaking impacts on brown trout (Salmo trutta L.) life cycle within a 14 km reach of the Vicdessos river during works were assessed thanks to:
    - An environmental risk assessment (estimate of maximum possible flows in relation to the trout reproduction cycle).
    - An eco-geomorphological risk assessment (in situ test of gravel movement with pit tags).
    - An hydraulic study (numerical model).





In order to allow the conservation of the spawning activity and good hydraulic conditions during the emergence period.

Hydropeaking impacts were mitigated thanks to (Figure 7.22):

- Monitoring of spawning activity and thermal regime allowed the timing of mitigation measures to be determined.
- A targeted 3-week shutdown of upstream plants generation during the trout spawning period.
- A reduction of the number of hydropeaks during the emergence period.
- A stepwise flow increase.

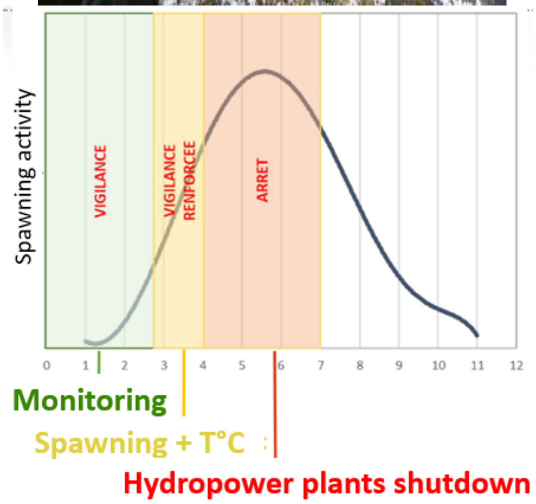


Figure 7.21 Mitigation of hydropeaking impacts on Trout cycle

The results of fish sampling carried out at two stations in the by-pass section before and during the works were related to the intensity of winter and spring high flow. The mitigation measures made it possible to maintain high trout spawning activity during the works (51 and 37.5 redds/100m respectively during and before the works) and 68% of the optimal level of fry densities.

The contribution to LIFE Desman Programme

The Vicdessos and its tributaries provide a favourable habitat for the Pyrenean desman.

Figure 7.22 Pyrenean desman spotted near an EDF water intake (© EDF François Sirvin)

The Pyrenean desman has been known locally since the inventories carried out by the ANA Conservatoire d'Espaces Naturels d'Ariège in the early 2000s. Although the abundance of the Pyrenean desman in the area is known, before the rehabilitation works it was impossible to quantify its population dynamics due to a lack of knowledge about the species and current means of investigation. The rehabilitation project provided an unique opportunity to remedy this lack of data.

Hydrological changes can pose temporary risks to this species. As part of the preparations for the renovation of a penstock, these risks were assessed jointly by EDF and ANA-CEN Ariège. The risk assessment of the hydrological changes led to the hypothesis that the Desman's habitats were established during annual low water periods and would be protected from the hydrological changes associated with the works. To support this hypothesis, follow-up studies were planned to document their effects on the local Desman population. This protocol was based on techniques involving the search for signs of presence (faeces) for genetic sequencing, following a protocol developed as part of the European LIFE-Desman programme.

Monitoring revealed the presence of faeces before and after the works. Although it is not possible to quantify precisely the effects on population dynamics, the number of faeces collected in 2020 is higher than before the works for a similar number of individual desmans. This suggests that the temporary impact of changes in water flow during the two years of work did not jeopardise the conservation status of this species in its core area, bypass section and tributaries.

Recommendations for environmental Considerations

Genetics-based protocols offer interesting prospects for desman studies: they are a non-invasive and reproducible method that provides information on population size and dynamics, individual movements and diet. This genetic monitoring of the desman showed that careful hydropeaking had not a significant impact on the species in the 14 km by-pass section studied.

The environmental success of trout protection is above all a collective success based on four pillars: (1) a dynamic of consultation, (2) the expertise of local stakeholders, (3) an analysis of environmental issues and risks, and (4) a biological monitoring. Finally, it is important to note that it was the shared governance process that enabled the management of hydropeaking to be adapted in real time to best suit the trout's biological cycle. The biological results reflect the commitment of all internal and external stakeholders.

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7.132021 - Swiss Round Table Hydropower

7.13.1 Project details

- Location: Switzerland
- Project type: power system expansion with 15 Hydropower schemes for winter generation
- Project phase: preparation
- Capacity: 2TWh would be added
- Key stakeholders:
    - Initiator: The Swiss Federal Council DETEC (until 12.2022) Fed. Dept. of Environment, Transport, Energy and Communications (Simonetta Sommaruga) invited 5 stakeholder Groups (3 experts per stakeholder group):
    - Environmental protection agencies (NGO)
    - Hydropower operators and industry associations
    - Cantonal authorities
    - Federal office of energy
    - Federal office for the Environment

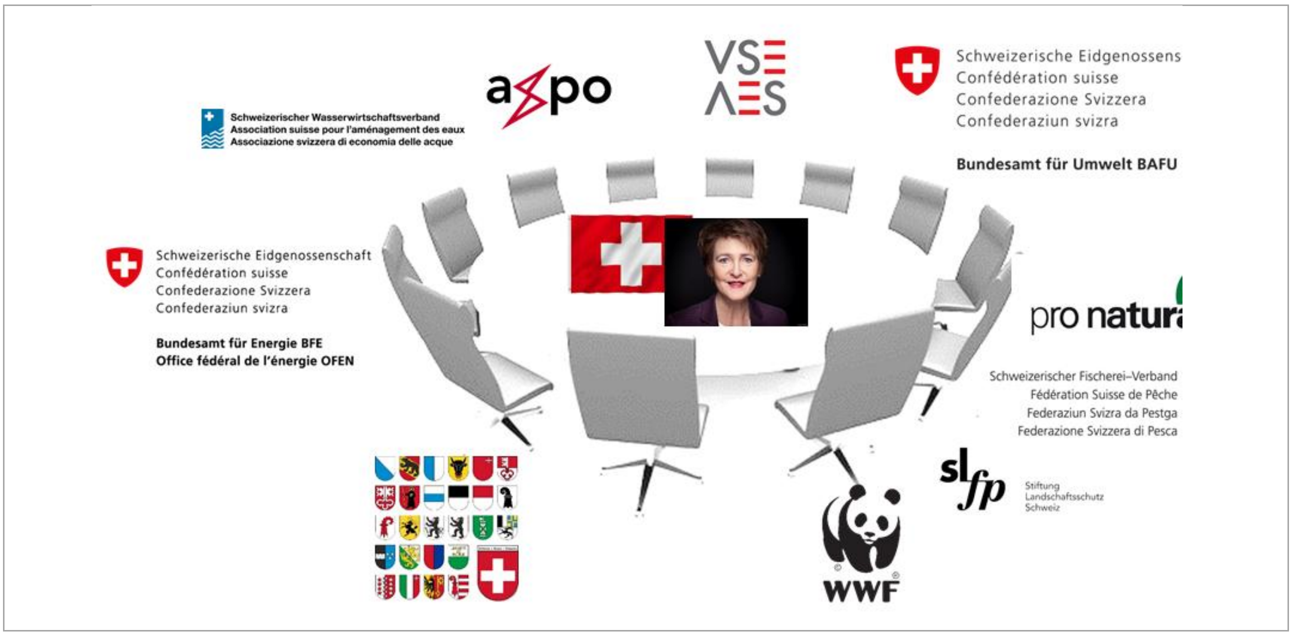

Figure 7.23 The five stakeholder groups

Recommended Storage projects	Photo of the valley
New reservoir **Gorner (GD)** Zermatt/VS +650 GWh/a winter +200 GWh/a year	

New Upper Stage **Trift (KWO)** Gadmen/BE +245 GWh/a winter +145 GWh/a year	
Heightening Earth dam **Mattmark (KWM)** Saas Almagell/VS +65 GWh/a winter +0 GWh/a year	
Heightening Concrete DAM **Sambuco (Ofima)** Fusio/VS +46 GWh/a winter +0 GWh/a year	

Figure 7.24 Four examples of Storage Projects Recommended for Development

By 2050, Switzerland will lack 12 TWh of winter power owing to increasing power consumption and the elimination of nuclear power. In total, Switzerland needs to expand renewable energies by about 50 TWh if it is to meet future annual demand. The Round Table was initiated in August 2020 to find solutions for the necessary expansion of hydropower to achieve a seasonal storage capacity amounting to 2 TWh by the year 2040, as an important component of the energy transition.

7.13.2 Objectives

The Round Table purpose was to generate a common understanding and draft a common recommendation for the challenges of:

- expanding hydropower to support the energy strategy 2050
- reaching zero emissions target
- ensuring security of energy supply
- preserving biodiversity.

Social objectives: The Round Table is a proactive initiative, bringing together the most important players in the sector. This is an important step, especially as discussions around the protection of the biodiversity versus the use of hydropower can often become quite intense. Bringing the proposed projects to the finish line, however, require a willingness to compromise on the part of all parties involved.

Environmental objectives: Identify and rate Impacts (impact on valuable habitats + impact on habitat function of water bodies + impact on priority species + impact on landscape) and identify ecological compensatory measures with project specific and general recommendations.

Economic objectives: Identify Hydropower projects with the energetically most promising potential for:

- additional winter generation in GWh/year
- with the least impact on biodiversity and landscape
- realizable until 2040.

7.13.3 Main types of best practice implemented

- Environmental and Social assessment
- Water quality and sediments
- Community Impact and infrastructure safety
- Biodiversity and invasive species
- Communication and consultation
- Hydrological resources
- Climate change mitigation and resilience

7.13.4 Lessons learnt

Challenges

After 1 year 4 workshops and 3 subgroup meeting stakeholders reaffirmed their concerns:

- NGO: loss of biodiversity (2 TWh target no priority)
- Cantonal Authorities: shift of power from local to national authorities
- Operators: missing the target
- 49 project proposals pre-assessed:
  - 17 with low conflict potential
  - 18 with higher conflict potential
  - 14 with very high conflict potential or big technical challenges
- No common agreement on ecological compensation measures

During the second year, to address the challenges explicit assignment was:

- Nominate a moderator with a strong background in negotiation and conflict management
- Confirm the assignment and commit to the target
- Agree on «Rules of the Game»:
  - Transparency,
  - Confidentiality,
  - Will for Consensus
  - Communication.

- Define and agree first on method to rate project proposals with two criteria:
    - Ecological impact: the weighted sum of scaling ()
    - Energetic potential: additional winter generation per year
- Rate and select of project only after agreement on method.

Feedback

<u>Results</u>

After rating and ranking 34 projects, a key statement was signed that included a list of 15 projects intended to reach the target of 2 TWh in winter production (Figure 7.26).

Nr.	Poject Name	Kt	Ecological Impact, weighted [1,5]	Additional Winterproduction (GWh/a)		Ecological Impact per GWh/a Winterprod.
1	Gorner	VS	3.4	650.0		5.2
2	Trift	BE	1.7	215.0		8.1
3	Chummensee	VS	1.3	165.0		8.1
4	Gougra	VS	1.1	120.0		9.1
5	Grimselsee	BE	2.4	240.0		10.0
6	Curnera Nalps	GR	1.1	99.0		10.8
12	Oberaletsch Speicher	VS	1.0	50.0		20.0
13	Lac des Toules	VS	1.1	53.0		20.1
14	Lago del Sambuco	TI	1.0	45.8		22.1
15	Griessee	VS	1.0	46.0		22.6
	Project 16		1.2	50.0		23.5
	Project 17		1.0	36.3		28.2
	Project 18		1.9	40.0		48.7
	Project 19		2.6	52.8		49.0
	Project 20		2.3	43.2		52.4
	Project 21		2.6	42.5		61.5

Figure 7.25 The ranking of the first recommended projects

It is important to note in Figure 7.26 that **the largest projects with the largest impact have the smallest unit ecological impact per GWh/y**.

The key success factors are:

- Top floor driven & lead and top floor participants of stakeholders at Round Table
    - Minister of energy herself led the round table
    - Top level of stakeholders at the Round Table: Empowered to Decide
    - Minister of Energy
    - CEO's of Companies
    - Presidents of Associations
    - Presidents of NGO's
- Unconditional commitment of the Round Table to goal
- Definition of clear and explicit targets by Round Table:
- Acceptance of these targets by all members of the Working Group
- Confidentiality to allow open exchange
- Tough independent moderator to drive process and keep the flock in line
- Sufficient time for discussion and negotiation

- Time pressure to generate results – WG meetings open-end
- Escalation path of non-resolvable differences

Recommendations

Round Table Recommends:

- to develop the 15 projects identified with priority
- to negotiate specific ecological compensation measures in early stage of development of every project
- next Steps
    - Government to establish positive boundary conditions (funding)
    - Project owners to develop projects (technical, ecological, legal)
    - Authorities to facilitate and support permitting process
    - NGO’s to participate in development early and support implementation

7.13.5 References

2023 Hydropower Day. Swiss round table hydropower. 15 new storage projects negotiated with civil society. Peter Lustenberger, Axpo Power, Switzerland

7.14 2021 – Hafslund Tolga Fish Pass

7.14.1 Project details

- Location: Tolga, Glomma River, Norway
- Project type: Establishment of safe fish migration routes for a new hydropower plant
- Project phase: implementation
- Capacity: 45 MW
- Owner: Akershus Energi; Hafslund Kraft AS

Figure 7.26 The Tolga hydropower plant, Hafslund (© Halfslund)

7.14.2 Objectives

Establishment of safe fish migration routes passing a new hydropower plant.

- Installed a slanted trash rack with a 15mm light opening to prevent fish swimming into the turbines.
- Installed two diverters with a total of 2m^3/s flow capacity at top of the trash rack to guide fish safely passing the intake to below the dam.
- Up and downstream migration was secured through two fish passages. The main passage is a vertical slot fish ladder with a 5m^3/s flow capacity, providing migration opportunities for all present fish species. Additionally, there is a more natural passage with a 3m^3/s flow capacity.
- At large water flows, migration is also possible over the entire length of the intake dam.
- Through minimum flow requirements (12 m^3/s in summer and 7 m^3/s in winter) water is secured in the fish passages all year round.

7.14.3 Main types of best practice implemented

- Environmental and Social assessment
- Biodiversity and invasive species

- Hydrological resources.

7.14.4 Lessons learnt

Challenges

- The licence application for the plant was met with notable opposition from fishing associations, local stakeholders, and environmental authorities. The objections were largely related to expected negative impacts on fish and fishing. In order to obtain a licence it was crucial to include solutions maintaining safe upstream and downstream fish migrations; and
- Exact monitoring of fish migration in the fish passages will require invasive methods limiting the migration.

Feedback

Results:

- Local stakeholders satisfied with the process and solutions.
- The effects of the measures are monitored through a survey programme.
- There has been no negative impact on fish populations indicated thus far.
- Positive fish trends indicated by increases sale of fishing licences.

Recommendations

Success factors are:

- Use of best available competence to develop best possible solutions;
- Implementing environmental solutions in the early project stages, ensuring thorough planning and beneficial technical solutions;
- No invasive fish counting implemented, but rather a programme monitoring fish populations and fishing activity in the influence area; and
- Obtaining public acceptance by implementing effective measures for fish migration.

7.14.5 References

2024 Power Plant 2.0. A guidebook to electrify in harmony with nature. Eurelectric.

https://www.hafslund.no/no/kraftverk/tolga

7.15 2020 – Fish Continuity at Hunderfossen HPP

7.15.1 Project details

- Location: Gudbrandsdalslågen River, basin in Trondelag,Norway
- Project type: Hafslund Hunderfossen hydropower plant - optimisation of minimum flow, gate manoeuvring and non-intrusive fish counting
- Project phase: Operation
- Capacity: 112 MW
- Owner: Hafslund Eco and Akershus Energi

Figure 7.27 The Hunderfossen hydropower plant, Hafslund (© Halfslund)

7.15.2 Objectives

Improve the migration of nationally valuable brown trout (Salmo trutta) passing the dam, as well as improving spawning and nursing conditions on the minimum water stretch downstream.

7.15.3 Main types of best practice implemented

- Environmental and Social assessment
- Biodiversity and invasive species
- Hydrological resources.

7.15.4 Lessons learnt

Challenges

- The hydropower plant was built in the 1960s and has had a significant, negative impact on the trout population, leading to public demand for the improvement of conditions for the trout.
- Between the 1960s and the 2000s, the five-year average rarely exceeded 250 trout per year. To compensate for reduced natural recruitment, the authorities imposed a requirement for 15,000 cultivated two-year-old trout to be released upstream of the dam annually.

- Retrofitting an old power plant reduces the number of available i.e. cost-effective solutions at hand.
- Energy production lost due to minimal flow.

Feedback

Measures undertaken:

- Implementing a voluntary new water manoeuvring regime with increased minimum water flows to improve spawning and growth conditions.
- Attraction floods to stimulate migration by mimicking naturally occurring patterns.
- Optimised gate manoeuvring for improved migration, with minimal loss of Energy generation.
- Replaced the fish ladder's manual trap and handling with an automatic fish counter, to improve data quality in a non-intrusive manner.

Results:

- A large increase in wild trout numbers passing the fish ladder. After implementing the measures, a new record for fish migration was set in 2023 with 1,561 trout passing the dam.
- Due to the success of the measures and increase in wild trout natural recruitment, the obligation to stock fish was removed in 2023.
- estimated cost based on energy production lost due to minimal flow is 70 000 EUR per annum.

Recommendations

Success factors are:

- Long-term monitoring data and extensive research as a basis for assessment and implementation of the measures.
- Having detailed historic scientific data, knowledge of long-term conditions, and detailed, specific local knowledge and expertise.
- Good post-measure monitoring to reveal the impacts.
- A holistic approach to habitat bottleneck by understanding the interconnectedness of the
- individual challenges hindering fish migration.

7.15.5 References

2024 Power Plant 2.0. A guidebook to electrify in harmony with nature. Eurelectric.

https://www.gem.wiki/Hunderfossen_hydroelectric_plant

7.16 2024 Romanche-Gavet Project Implementation Assessment

7.16.1 Project details

- Project name: Romanche-Gavet Hydroelectric Plant
- Project location: Romanche River, South-Eastern France
- Project type: Modernisation with replacement of 5 plants cascade by 1 new plant
- Project assessment stage: implementation in 2013
- Installed capacity: 94 MW
- Project owner: Électricité de France SA (EDF)
- Photo: Figure 7.29

Before renaturation works	After renaturation works
	
	
	

Figure 7.28 Decommissioning of 5 old hydropower plants and renaturation of their sites (©EDF)

7.16.2 Objectives

Six old hydropower plants and five dams are decommissioned and replaced by one dam, one 10 km long tunnel and one new hydropower plant (Figure 7.30).

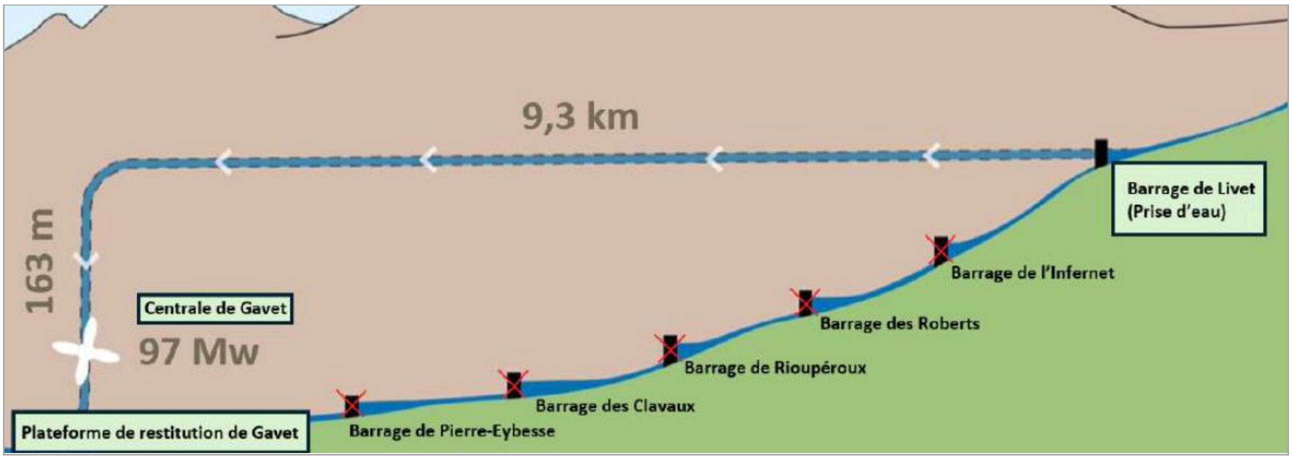

Figure 7.29 The Romanche Gavet HPP project with the 5 decommissionned dams on Romanche River (©ERN)

Environmental objectives

The project enables the restoration of ecological continuity and habitats along a 37 km stretch enabling Fario Trout to be free to move.

Landscaping & renaturation of 105 000 m^2 complies with the requirements of the 'Végétal local' label, which aims to reintroduce local species. EDF has partnered with the ONF, an expert in ecological engineering, to collect local seeds and plants (hazelnut trees, cherry trees, alder buckthorn, holly, elderberry, etc.) within a 25 km radius of the five former power plants in order to replant them on around ten hectares of land.

Offset area: 570 000 m^2 & 15 years of monitoring

Preservation of 1 weir to maintain the river bed stability and manage flood impacts and modification of this weir to insert 1 fish path.

Innovative system for energy dissipation to limit the impact of hydropeaking in the river.

Provisional reuse on site of 60 000 m^3 of demolished concrete and 70 000 m^3 of excavated materials and recovery of steel parts. Waste quarry materials and old sediments are embodied in backfill reshaping the landscape.

Social objectives

Several industrial wastelands have been dismantled to free up 8 hectares of space, improve the local environment and restore the valley's tourist appeal.
The call for tenders from companies in the region supports local employment and also promotes access to or return to employment, as EDF has included a social integration clause in its calls for tenders.
A safe cycle path was created along the Romanche River down to Grenoble.
Industrial heritage preservation with restoration of Les Vernes plan (Figure 7.31).

Figure 7.30 The restoration of Les Vernes hydro plant

Economic objectives

Increasing the capacity to 94 MW and the generation to 560 GWh/y (+40%).

7.16.3 Main types of best practice implemented

- Water quality and sediments management
- Biodiversity management
- Hydrological resources
- Downstream flow regimes
- Community impact and infrastructure safety
- Communication and consultation
- Governance and procurement
- Public health

7.16.4 Lessons learnt

Challenges

The cost and the duration of the project

Feedback

The discovery of asbestos veins during the excavation of the tunnel caused significant delays and additional costs.

Recommendations

This project shows that it is possible to both increase energy production and restore ecological continuity.

7.16.5 References

2013 Hydropower Sustainability Assessment Protocol (HSAP).

Étude de cas sur la Moyenne Romanche restauration écologique de la vallée. European Rivers Network France. Juin 2025.

How to avoid potential pollution sources and to mitigate environmental impacts by innovative measures and concepts. 8 June 2021.EU green Week 2021 Partner event.

7.17 2024 – Ripping to Enhance Fish Habitat in River Suldalslågen

7.17.1 Project details

- Location: Rogaland County, Norway
- Project type: Hafslund Hunderfossen hydropower plant - optimisation of minimum flow, gate manoeuvring and non-intrusive fish counting
- Project phase: Operation
- Capacity:
- Stakeholders:
  - Owner: Statkraft
  - Fishing community
  - Municipality
  - Landowners

Figure 7.31 River ripping (© Statkraft)

7.17.2 Objectives

Enhance the habitat conditions and improve the natural reproduction levels of Atlantic salmon (Salmo salar) in a river designated as nationally important for salmon.

One way to improve this is through ripping, which is a mechanical removal of fouling and sediments clogging the riverbed by excavators. By ripping and improving natural reproduction of salmon it is also a goal to phase out stockings and prevent possible epigenetic effects, while at the same time strengthening the salmon population.

7.17.3 Main types of best practice implemented

- Environmental and Social assessment
- Water quality and sediments
- Biodiversity and invasive species.

7.17.4 Lessons learnt

Challenges

- Two large hydropower production schemes upstream have led to reduced flow during summer and less peak floods, causing fouling of the riverbed, in particular affecting shelter and breeding areas for fry. Lack of such habitats is regarded the main bottleneck to the natural reproduction of salmon in the river.

Feedback

Measures undertaken:

- Conducting a pilot ripping project to garner knowledge and experience.
- Acquiring the necessary permits, regarding which period to execute the work, gaining permission to reduce water flow to operate the excavators safely, and accessing the suitable river areas.
- Mapping suitable areas and reaching agreements with landowners on where heavy machinery could access the river.
- Undertaking a large-scale ripping project along the entire river.

Results:

- Follow-up investigations of the pilot project in 2019 and ripping performed in 2021 have shown 2-3 times greater densities of fry in the ripped areas as compared to reference stations.
- No negative effects from the work were observed downstream.
- Given the general low nutrient content and low temperatures in the river, fouling processes are relatively slow and the positive effects of ripping are expected to last for many years before a need to repeat.
- Cost including machine operation, surveillance, administration, and monitoring was low-range.

Recommendations

Success factors are:

- Performing a pilot project and building upon research and design knowledge.
- Thorough mapping of suitable areas for ripping, avoiding areas with clay and silt which can cause harm downstream and pose security risks to operators, and paying particular attention to spawning areas, cultural heritage sites, and infrastructure.
- Dialogue with landowners, the fishing community, and the municipality.

- Seeking clarity from authorities regarding all necessary permits.
- Timing works to avoid crucial periods to biodiversity, to minimise conflict with stakeholders, and to adapt to variations in unregulated waterflow.
- Utilising local services providers.
- Long-term monitoring.

7.17.5 References

2024 Power Plant 2.0. A guidebook to electrify in harmony with nature. Eurelectric.

7.18 2029 - The Danube and Inn Rivers Improved Ecological Continuity

7.18.1 Project details

- Project name: Verbund life Projects
- Project location: River Danube and River Inn, Austria and Germany
- Project type: Improved ecological connectivity around existing hydropower plants
- Project stage: implementation up to 2029
- Installed capacity: 14 MW
- Project owner: Verbund (Austria)
- Projects LIFE:
    - Owner: Verbund
    - State services
    - Policymakers
    - NGO.

Figure 7.32 Renaturation of the Danube and Inn (© https://www.life-blue-belt-danube-inn.eu/en)

The LIFE Blue Belt Danube Inn project aims to preserve and improve endangered river fish on the Danube and Inn. The Jochenstein (Danube), Schärding-Neuhaus (Inn) and Passau-Ingling (Inn) power plants will be equipped with fish migration aids. The Austrian Danube power plants Aschach and Ybbs-Persenbeug will also become barrier-free. Ultimately, the Danube is to become fish passable by 2027. The riverbank structures on the Danube and Inn will create habitats and protected spawning zones for Danube fish.

7.18.2 Main types of best practice implemented

- Environmental and social impacts
- Community impact and infrastructure safety
- Governance and procurement
- Communication and consultation

- Hydrological resources
- Climate change mitigation and resilience

7.18.3 Objectives

Environmental objectives

Improve ecological connectivity around existing hydropower plants in the Danube and River Inn and link Natura 2000 areas. Improve habitat conditions and species conservation status for endangered fish, wetland fauna and flora, and breeding, resting, and wintering bird species.

7.18.4 Lessons learnt

Challenges

The cost and the duration of the project: with an investment totalling 60 million euros, comprehensive measures in the form of fish migration aids and bank restructuring are intended to bring about ecological improvements.

Feedback

Actions implemented

The project created a 10 km new river corridor at Traisen. Straightened sections of the river were broken up to create a larger natural river ecosystem connected to tributaries and floodplains typical of the Danube. The floodplain was lowered at 60 m, creating 60 ha of new floodplain. 30 ha of dry grassland was also created. It took 15 years in design, planning, financing, and obtaining authority permits since conceptualisation, whereas the measures have been under construction for 3 years. Restored river habitats and created bypass rivers at HPP Ottensheim-Wilhering, HPP Greifenstein, and HPP Abwinden-Asten. For example, a 14.2 km bypass river at Ottensheim was created in 2016 to enable fish migration and provide high-quality key habitats, which contributes to the Water Framework Directive and the Habitats Directive. The fishway was designed to integrate and restore natural water bodies, creating and improving habitat connectivity. Restored fish connectivity at Ering on the river Inn by creating a 2.6 km bypass fishway (slope max 4.7%, discharge 2-12 m^3/s) and creating spawning and nursery grounds, as well as the construction of an island tributary system with flat banks, oxbow lakes, and dismantling of the river with water stones and fortified shore. Created a 13 km bypass channel at Altenwörth with engineered log jams and sufficient flow to secure river dynamics. A wetland was also created, and four additional fishways reconnected fish from the river to floodplains.

Project results

LIFE+ Traisen witnessed the number of onsite bird species increase from 72 in 2009 to 111 in 2018, with common kingfisher (*Alcedo atthis*) breeding pairs increasing from 1 to 7, sand martin (*Riparia riparia*) colonising steep riverbanks, high dragonfly (*Anisoptera*) densities, and 60ha of softwood and willow (*Salix*) forest created. The general ecological status of fish increased from bad to good. The site at Altenworth saw sand martin breeding pairs in tubes increase from 63 in 2022 to 169 in 2023, with common kingfisher (*Alcedo atthis*) and little ringed plover (*Charadrius dubius*) territories establishing exclusively within the restored river sections. The fish biomass increased from < 50 kg to > 300 kg/h.

Recommendations

Key factors are:

- Stakeholder Consultation
- Scientific Justification
- Site specific solutions
- In-house technical expertise and thorough design
- Obtaining public acceptance
- Well established cooperation between developers and administrations
- Collecting and using high-quality data
- Knowledge sharing / lessons learned.

7.18.5 References

Eurelectric (2024). Power plant 2.0. A guidebook to electrify in harmony with nature. June 2024.

8 ACKNOWLEDGMENTS

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