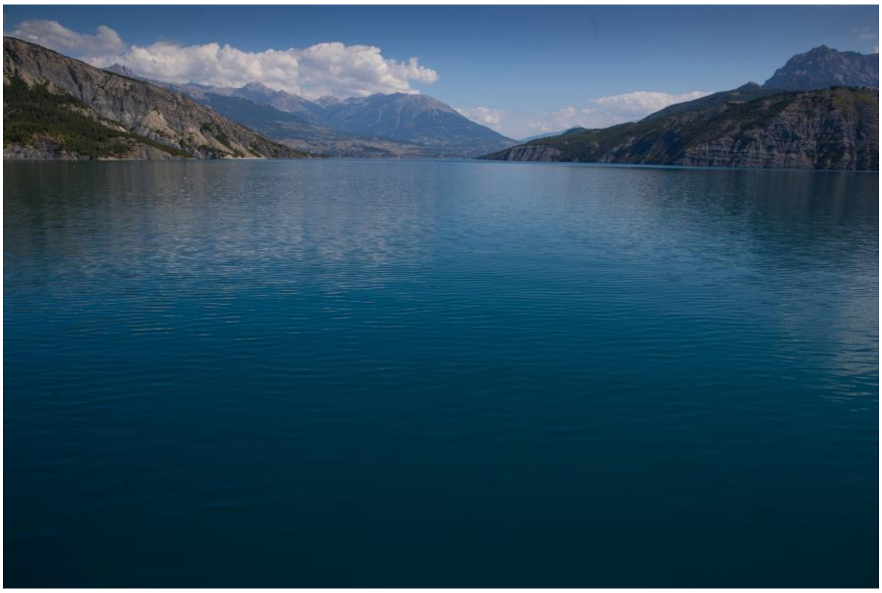
HYDROPOWER EUROPE

POWERING EUROPE IN A SUSTAINABLE WAY

Discussion Paper: Structure of the Strategic Industry Roadmap



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1 Introduction

The main ambition of the EU Energy Union Strategy, as well as the ongoing development of the EU long term strategy, is to achieve a low-carbon, climate-resilient energy system in a cost-effective way, while fostering growth and development. The main pillars of the future energy system in the EU are:

- Secure, resilient and reliable energy supply;
- Environmental protection;
- Affordable and market-based energy services.

The transition towards renewable energies is an essential part of this strategy. The increasing share of variable renewable energy sources, such as wind and solar energy, and the decreasing share of secured fossil-based generation pose significant challenges to the stability of the power grid. To build a secure and reliable power system with intermittent RES, increased power system flexibility will be essential. Flexibility in this context refers to "the extent to which generation or demand can be increased or reduced over a timescale ranging from a few minutes to several hours" (IEA, 2018).

There is a general consensus that hydropower is a key technology in the path towards a low-carbon and climate-resilient society. Hydropower is a mature technology, is a clean energy source, does not create waste or by products and offers the best energy conversion efficiency. Not only does it provide the highest degree of flexibility, but it also offers important balancing (through pumped storage) and power system ancillary services (through storage reservoirs), such as frequency control and primary to tertiary reserves.

Although Europe is the cradle of hydropower, investments for hydropower in Europe (EU28, Norway, Switzerland, Turkey) have decreased in recent years because:

- about 60% of the technically, economically and environmentally feasible potential for greenfield hydropower projects has already been exploited;
- high upfront investment costs of hydropower projects being confronted with distorted and low prices of the European electricity spot market as well as missing spreads lowered the expected return on investments of hydropower projects;
- long, legal proceedings; as well as
- public opposition.

Hydropower has to be observed and managed with special attention as hydropower can have both positive and negative effects on the environment. Hydropower operators spend significant resources to mitigate impacts on the river basins throughout Europe. Legislation and policies for environmental protection and sustainable water management have a significant influence on the current operations and future development of hydropower. As we face the severity of climate change consequences, it is important to weigh all environmental impacts (e.g. water, air, soil and climate) in an integrated manner and to review further hydropower development potential. Increasing variable electricity generation in Europe will require flexibility and storage capacities that can be provided by hydropower. It is important to take this fact into account when implementing environmental legislation in order to avoid losses of flexibility and generation which increases the risk of catastrophic blackouts.

As energy systems embark on their transition that aligns the European economy with ambitious climate and sustainability goals, a total transformation of the current energy system is underway. Hydropower, at the intersection between the energy and water systems, has the potential to play an important and vital role in ushering in this transformation. Despite the rapid rise of alternative renewable energies, especially wind and solar PV, hydropower remains amongst the largest provider of renewable energy within the EU28+ region. Where available, hydropower provides the bulk of power system flexibility, e.g., hydropower provides nearly 90 per cent of domestic power system flexibility services to the Finnish Grid (Fingrid, 2018).

Given the future requirements for additional system flexibility, it is imperative for European and national institutions to re-evaluate and re-consider the future role of hydropower in Europe. It is quite clear that the flexibility of hydropower can provide a contribution in the transition towards a renewable-based power system. It should be considered to what extent hydropower can be operated at such flexibility and what impacts changing operational regimes will have on the environment.

The main challenge is weighing economic development, climate goals, social inclusion, environmental and ecosystem health, and to find a balanced compromise between them all. Each policy decision will likely have negative and positive impacts and policy makers need to make these decisions under overwhelming compounded uncertainty.

The SIR looks to set a framework to balance the needs of all stakeholders in the European Union and to give direction to the institutions tasked with implementing the energy transition.

Hydropower-Europe forum

The EU-funded Hydropower-Europe project has the ambition to create a roadmap for hydropower development in Europe by collecting inputs and ideas from market operators, industry, research, academia, public bodies and environmental and non-governmental organizations. Through a series of on-line consultations, thematic workshops and expert reviews over a three-year period, the aim is to develop a broadly shared view of the role of hydropower in the future energy system and to identify, though a bottom-up approach, the steps to implement it. A balanced approach considering the broad range of market, technology, environmental and social issues is needed in order to reconcile divergent interests and ensuring synergies at the core of the water-energy nexus.

The pathway towards the Strategic Industry Roadmap

The main objective of Hydropower-Europe is to develop a broadly shared vision for sustainable hydropower development in Europe, in light of the challenges and opportunities posed by the transition to renewable energy, climate change, environmental protection and social inclusion. The project will deliver two strategic documents for the hydropower sector, namely:

- a **Research and Innovation Agenda (R&IA)**, which will outline the R&I priorities for hydropower to drive public funding and private investments;
- a **Strategic Industry Roadmap (SIR)**, which is intended to present best practice and provide recommendations on the future role of hydropower and its sustainable development.

This will be done through the broad involvement of stakeholders and civil society organizations and the organization of public consultations and regional workshop.

This **discussion paper**, as well as **the report on the state-of-the-art of hydropower technology**, are intended to set the basis for discussion, in view of the first round of stakeholders' consultation. Its goal is to provide food for thought and to guide the consultation process. Stakeholders are not expected to comment on the content of these documents, but rather to provide inputs, suggestions and recommendations to move further from the current situation and to value the hydropower contribution to the energy transition, while ensuring a high level of environmental protection, social inclusion and regulatory compliance.

2 Industry status and future perspectives

2.1 State of EU hydropower market

Hydropower has been playing a crucial role in supplying clean, renewable energy at competitive rates. The global installed hydropower capacity at the end of 2018 was 1289 GW (IHA, 2019), which generated an estimated 4150 TWh in 2018. In the same year, an estimated 145 GW greenfield hydropower projects were under construction and another 320 to 690 GW installed capacity is in the pipeline (Hydropower & Dams, 2018). Hydropower generation accounts for 15.8% of the global electricity generation (REN21, 2019).

With a total installed capacity of 251 GW and a total annual generation of 643 TWh in 2018 (IHA), of which almost 400 TWh is in the EU-28, hydropower is one of the main sources of renewable energy in Europe (EU-28 + Switzerland, Norway and Iceland). Hydropower provides about 11% of the total electricity generation in Europe, representing about 36% of the total renewable power generation.

Pumped-storage plants account for about 20% of the total installed hydro capacity. In 2018 pumped-storage plants in Europe had a generation capacity of about 53.9 GW and a pump capacity of about 49.8 GW (IHA, 2019).

However, hydropower generation is not evenly distributed across Europe. Due to topographic and climatic conditions, hydropower resources are concentrated in the transalpine range, the Carpathians and the Scandinavian countries (in Norway hydro generation represents 96% of total domestic power generation). Most of the unutilized hydropower potential is concentrated in Eastern Europe. Figure 2-1 shows the share electricity generated from hydropower in Europe in 2017.

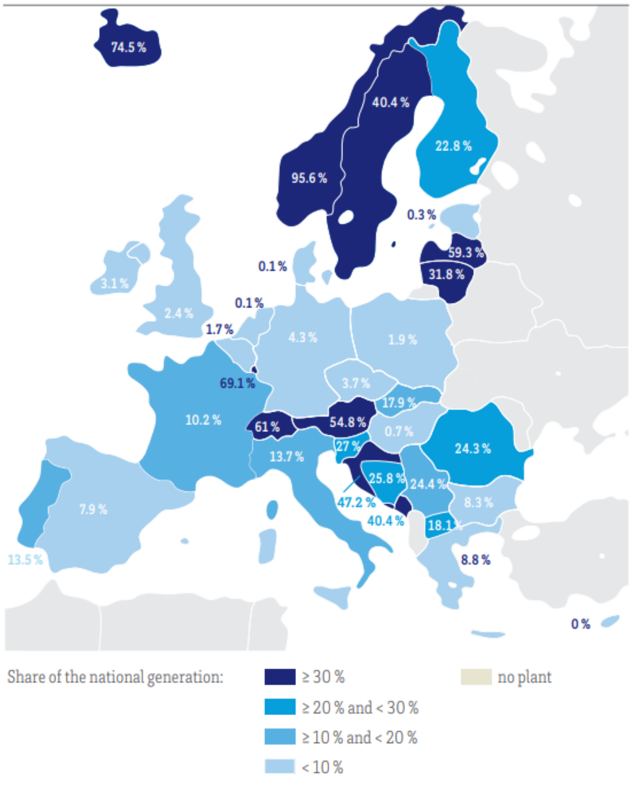

Figure 2-1 Share of hydropower generation in EU Member States in 2017 (source: Entso-E, 2017)

Hydropower potential is already relatively well exploited and expected future growth is rather limited. More than 60% of Europe's hydropower economic and environmental feasible potential has already been developed, but some potential is still to be found in specific countries.

As shown in Figure 2-2, Norway and Turkey have considerable unexploited potential (about 80 TWh each), whereas Sweden and France have unexploited potential of more than 20 TWh. Austria, Italy, Iceland have 10 to 20 TWh left, meanwhile countries like Belgium, Luxembourg or the Netherlands, due to morphological reasons, hold only a remaining potential of some hundreds of GWh.

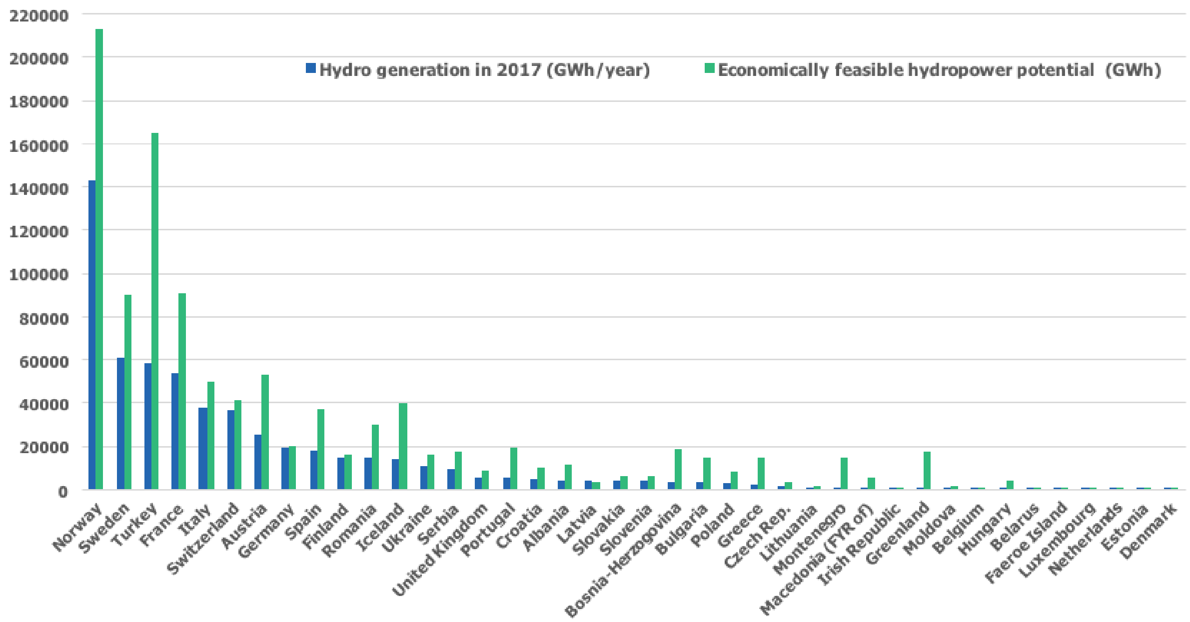

Figure 2-2 Unexploited versus developed hydropower potential in selected countries (according Hydropower & Dams World Atlas & Industry Guide, 2018)

The largest remaining potential in Europe lies with low-head (less than 40 meters) and medium-head (40 to 200 meters) plants, as well as in the refurbishment and extension of existing facilities. As for pumped hydropower storage (PHS), new projects are currently underway in several parts of Europe (especially in the Alps), including non-mountainous areas (PHS is less site dependent compared to other HP projects). In most cases, existing hydro facilities are extended or refurbished; in some other cases, projects are completely new. Alongside pumped-storage, conventional large hydro schemes are also being developed in certain selective, mainly non-EU European, areas.

A 2013 study by the European Joint Research Centre estimated the potential for pumped-storage capacity in Europe, while taking into consideration environmental constraints (Gimeno-Gutiérrez and Lacal-Arántegui, 2013). It concluded that the European theoretical potential is 54 TWh (11.4 TWh are in the EU-28), when a PHS can be built based on linking two existing reservoirs. When existing regulatory restrictions on the use of land are applied, the potential is reduced to a technical potential of 29 TWh in Europe, of which 4 TWh are in the EU-28. Including the possibility for PHS to be constructed by connecting one existing reservoir and a nearby, appropriately non-sloping site for a second existing reservoir (e.g. Frades 2), the theoretical potential reaches 123 TWh in Europe, of which 60 TWh is within the EU. The corresponding realizable potential is 80 TWh in Europe, of which 33 TWh are in the EU.

The vast majority of hydropower plants are of small size, as shown in Figure 2-3. In 15 countries, plants with less than 1 MW capacity make up more than 50% of the total plants. In some countries, these small plants even make up more than 90%. However, the big bulk of electricity generation comes from large plants, as shown in Figure 2-4. Hydropower plants with more than 10 MW capacity take up 60% to over 90% of the total installed capacity in most countries.

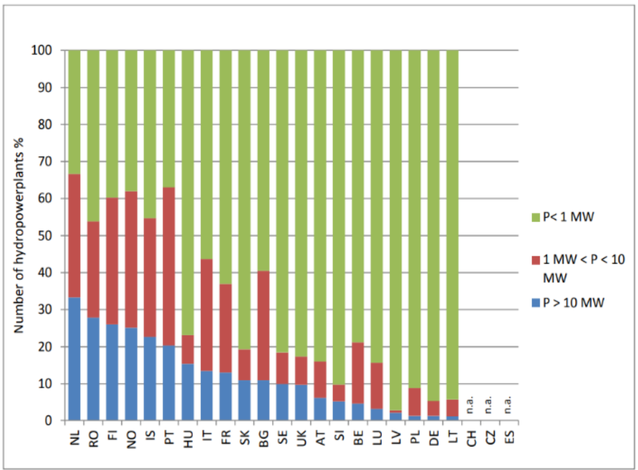

Figure 2-3 Percentage of number of existing hydropower plants for different plant sizes (source: EC, 2011)

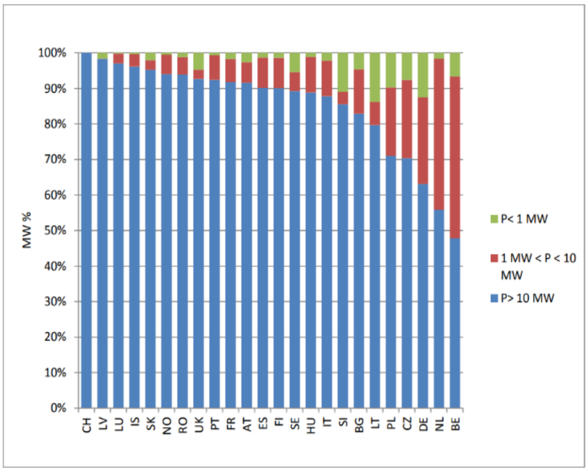

Figure 2-4 Percentage of total installed hydropower capacity for different HP plant sizes (source: EC, 2011)

The global number of large dams under construction worldwide remains almost constant, oscillating around 350 projects and showing that dams and reservoirs are vital water infrastructure to ensure energy, food and water, notwithstanding the economic crisis. Most of the existing or under construction dams are built for purposes other than power generation. However, since 2017, this number decreased below 300, mainly due to the difficult conditions within the Middle East. In Europe, without considering Turkey, the construction of large dams has decreased from around 35 before 2010 to 24 in 2018.

Small hydropower projects are also encountering difficulties due to the low prices of electricity, new regulatory requirements, the rapid expansion of other renewables and the lack, discontinuity and unpredictability of supporting schemes. However, small hydropower projects have been, and are being, realized in countries where beneficial incentives exist.

2.2 The industry status

Pioneering hydropower engineers and manufacturers largely originated from Central and Northern Europe and the technology soon spread globally. Europe has maintained a leading position in the field of hydropower design and manufacturing, as European hydropower equipment manufacturers command an estimated two thirds of the world market (DNV GL, 2015). By developing technology and production methods in a fast-growing domestic market, European manufacturers have maintained a leading manufacturing edge over other parts of the world. Very little non-indigenous equipment has been installed in European hydropower plants. At the same time, European engineering companies have been designing dams around the world thanks to their leading position.

Three large European companies lead the large to medium scale electromechanical equipment supply worldwide, namely Alstom Power Hydro (recently acquired by General Electrics), Andritz Hydro and Voith. Over 50 other European companies hold a recognized industrial position worldwide in the small turbine segment, which represents the bulk of the European market. These industries are mainly located in Italy, France, Germany, Austria and Sweden, but are also well represented in the Czech Republic, Poland and Slovenia. The activity of all these companies is largely geared towards export. Altogether these companies cover more than 50% of the world market (DNV GL, 2015).

Whilst investments in hydropower are stagnating in Europe, the large European operators invest heavily in and/or offer knowledge, expertise, or consulting to hydropower projects outside of Europe, where there is a considerable growth in projects. European companies have been essential components across the entire value chain of hydropower development.

2.3 Economic benefits of hydropower

As shown in Figure 2-5, the contribution of hydropower (including electricity generation, manufacturing and VAT revenues) to the European gross domestic product (GDP) is estimated to be about EUR 38 billion (EU-28, Norway, Switzerland, Turkey), of which EUR 25 billion is in the EU-28 (DNV GL, 2015). This corresponds indicatively to 0.27% of European GDP. Figure 2-5 shows the gross value creation from hydropower generation and

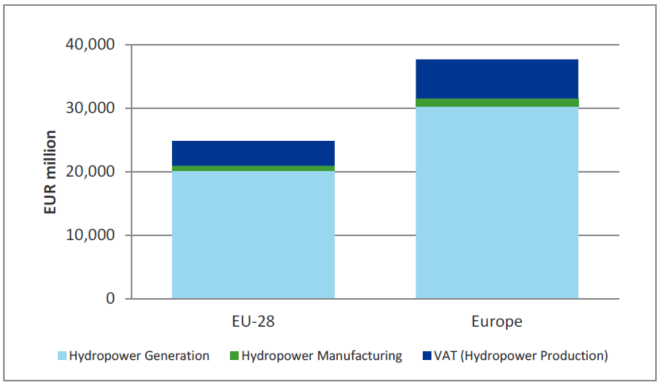

Figure 2-5 Gross value creation by hydropower generation and equipment manufacturing in 2013 (source: DNV GL, 2015)

hydropower manufacturing.

Hydropower contributes to employment in Europe with more than 100,000 full time equivalent jobs (DNV GL, 2015). Figure 2-6 shows how these jobs are distributed within the industry: about 42,000 are directly related to hydropower generation (42,000 in EU-28), 7,000 in manufacturing (5,000 in EU-28) and the remaining part in other sectors providing external services to the hydropower sector, including operations and maintenance, planning, engineering and consulting.

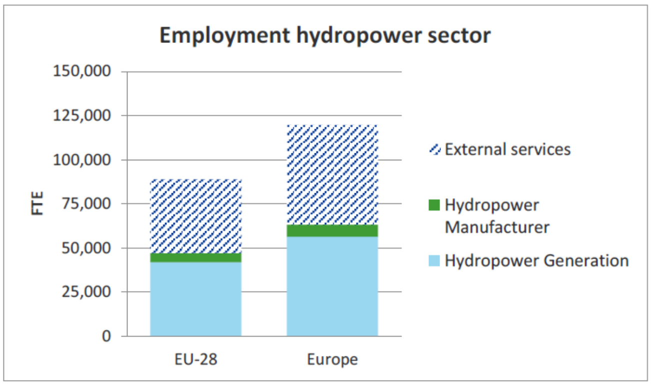

Figure 2-6 Employment in the European hydropower sector in 2013 (source: DNV GL, 2015)

Hydropower is also a considerable source of investments in the European economy. Hydropower is a capital-intensive generation technology and it requires considerable investments both for the construction of reservoir and hydropower plant and for maintenance and refurbishment. Investments in maintenance and refurbishment only, amounted to EUR 3.1-3.7 bn a year between 2010 and 2013, of which EUR 2.2-2.6 bn was in the EU-28 (DNV GL, 2015).

2.4 Hydropower and European Union policies

EU climate and energy policies have set ambitious targets for the development of renewable energy sources. The recast Renewable Energy Directive (RED II) has raised the overall EU target for Renewable Energy Sources consumption by 2030 to 32%. Hydropower can significantly contribute towards reaching this goal, as it currently is the most mature, widespread, efficient and cost-effective renewable energy resource over entire project life-times.

However, energy and environmental policies have traditionally been addressed separately, thus leading to regulatory divergence between the goals of renewable energy development, sustainable water management and ecosystem conservation. As hydropower is situated at the centre of the water and energy nexus, hydropower has contributed to the updated requirements of EU environmental law, which has been introduced to protect and restore Europe’s rivers and lakes. These legal requirements are laid down within the Water Framework Directive, the Floods Directive, the Birds and Habitats Directives, and the Environmental Assessments Directives (Environmental Impact Assessment - EIA and

Strategic Environmental Assessment - SEA Directives). The Water Framework Directive[1] (WFD) is the key element of EU water management legislation. The WFD takes a river-basin wide approach applicable to all ground and surface waters in the EU. The directive affirms the “no deterioration principle”, according to which greenfield or upgrading hydropower projects can only be allowed if there is no degradation of the existing situation. Good ecological status is defined in terms of the quality of the biosphere, as well as hydro-morphological, chemical and physio-chemical characteristics. Water quality is not an issue for hydropower, nevertheless the changes in flow impact the aquatic biotopes and innovation is needed to decrease these impacts.

In 2005, a risk assessment carried out for the WFD stated that hydro-morphological pressures and impacts were one of the most important risks that needed to be addressed in order to achieve WFD objectives. In the first implementation report of the WFD, hydropower has been identified as one of the main drivers to hydro-morphological alterations, loss of connectivity and to significant adverse effects on fish mortality. According to Article 4.7 of the Directive, an exception to these rules applies when:

- all practical mitigation measures are already taken;
- there are no significantly better environmental options;
- the benefits of the development outweigh the benefits of achieving the WFD objectives;
- the project and the reasons for it are reported in River Basin Management Plans.

The enforcement and implementation of the WFD has impacted, and will continue to impact, hydropower development. To meet both WFD and RED II requirements, win-win measures to improve the status of water bodies with acceptable loss of energy production would be eligible, as well as measures to increase hydropower generation without negative effects on water ecology, such as raising efficiency at existing sites and defining suitable sites for new hydropower plants by strategic planning tools and the application of Article 4.7 of the WFD.

In general, new hydropower schemes (greenfield developments) may be difficult to develop (except for multi-purpose schemes including wetland restoration, amongst other things), because of the resulting change of surface water bodies which does not comply with the provisions of the WFD (protection and enhancement of the status of aquatic ecosystems). However, development of new plants is possible at existing non-powered infrastructure. Repowering of existing stations, as well as modernization and upgrading (e.g. replacement

[1] To exercise the Union's competences, the EU institutions can adopt regulations, directives, decisions, recommendations and opinions. A regulation has a general application. It is binding in its entirety and directly applicable in all Member States. A directive is binding, as to the result to be achieved, upon each Member State to which it is addressed, but shall leave to the national authorities the choice of form and methods.

with more efficient components), generally results in less conflicts with the WFD and is commonly promoted among EU Member States.

2.5 Perspectives for hydropower development

One main barrier to the further development of hydropower in Europe is the lack of suitable sites, as the best of them have already been developed. Unpowered reservoirs exist which could be adapted for hydropower use, and Member States could make an inventory of these to gain a clearer picture of the available resources. The impact of large hydroelectric facilities on the environment is often perceived as significant and this makes it difficult to implement large projects. Smaller-scale installations, on the other hand, involve relatively less reservoir and civil construction works, so generally their environmental impact at a project level is lower as far as flow regime is not significantly altered (this is not true in the case of multiple small-scale hydropower projects, as current scientific research has shown its detrimental effects, especially when deployed without any integrated river basin planning). However, these observations cannot be generalized as the environmental impact is strictly related to site specific conditions; in other terms, the environmental impact of hydropower projects needs to be assessed case-by-case without prejudice, in order to avoid taking biased decisions. Moreover, institutional barriers still exist which hamper development, such as long lead times to obtain or renew concession rights, concessions locked to a holder that does not actually develop the scheme, and lack of grid connections. Furthermore, the design phase and administrative procedures for hydropower projects can take from some years to a few decades.

Pumped storage, together with passive energy storage, is the most important and economic solution for large-scale energy storage today. It is used to balance the variable output from wind and solar and therefore makes a significant contribution to future clean energy goals. However, even with pumped-storage, economic and political uncertainties can lead to some projects failing to progress.

All this considered, the majority of new projects in Europe involve pumped-storage hydro (8,600 MW planned or under construction) and small stations, with investments also going towards the refurbishment and modernization of existing facilities.

Refurbishment and upgrading of existing plants to improve efficiency, flexibility and system resilience and to minimize environmental impacts are the main hydropower activities in Europe today. This reflects conditions during the 1960s and 1970s, when the European economy showed impressive growth. Most countries invested in greenfield hydropower plants to meet rapidly increasing energy demand across both domestic and industrial sectors. As a consequence, almost 60% of Europe's total installed hydropower capacity is more than 40 years old and now needs to adapt to changing grid and environmental regulations, as well as to new operational requirements. Modernization, rehabilitation and uprating are essential for existing hydropower plants to increase their efficiency, flexibility and safety, prolong their lifetime and provide the required grid services.

Overall, perspectives for hydropower development in Europe mainly point in the direction of enhanced efficiency and increased flexibility, on one side, and sustainability, on the other side. However, at the moment, regulatory and market conditions do not foster developments in this direction. Proper regulatory and market frameworks are needed in order to provide the right incentives to hydropower operators. Investments to increase the flexibility of hydropower plants can become more attractive when mechanisms to reward flexible services are in place. Similar, multipurpose projects require the setting up of reward schemes for non-energy related services, in order to compensate hydropower operators for their generation losses.

2.6 Technology and innovation

Hydropower is a mature technology, but there is still room for improvement. Although breakthrough innovations in hydro equipment have not been registered in the past few decades, incremental innovation has led to significant increases in the overall peak efficiency of hydropower turbines, which today ranges between 90% and 96%, enhanced the flexibility of hydropower plant and reduced the environmental impact of hydropower generation (for more details, please see the technology state-of-the-art report published by Hydropower-Europe, Report Ref: WP4-DlRp-02).

In a preliminary survey among hydropower stakeholders, the Hydropower-Europe Consortium identified the following areas for technology improvement and innovation:

- **cost reduction, enhanced efficiency and increased outputs**: this includes enhancing the efficiency and the performance of hydropower equipment, upgrading existing plants, optimizing operations though digital solutions, developing new hydro schemes (such as hybrid power plants) and business models;
- **ageing and resilience of hydro equipment and infrastructures**: this includes developing more resilient solutions, mitigating the negative effects of ageing on existing infrastructures, enhancing safety and security;
- **new construction technologies** for efficient and safe underground excavations (tunnels, caverns) and dam construction, in order to reduce investment costs and minimize the environmental impacts**;**
- **flexibility**: further developing and supporting investments in storage and pumped-storage, increasing peak power, upgrading existing infrastructures;
- **enhancing the environmental and social value of hydropower**: this implies minimizing the environmental impact through environmentally-friendly solutions, mitigating hydro and thermo peaking (compensation basins, river morphology

restoration, fish refuges), enhancing the environmental services of hydropower (flood and drought mitigation, etc.);

- developing emerging **hydro-marine** solutions;
- **adaptation to climate change**: this implies better modelling and prediction of the magnitude of changes, availability of water resources and innovative methods for sediment management.

3 Opportunities and challenges for hydropower development

3.1 Advantages of hydropower

Hydropower has an excellent energy conversion rate (up to more than 95%) compared to fossil fuels and other renewable energy sources. Hydropower directly converts the natural flow of energy in the water into electricity and therefore has a very short and efficient energy chain.

Another advantage of hydropower is the very high energy payback ratio, which refers to the energy produced during the normal life span of a power plant divided by the energy required to build, maintain and run the generating equipment. Hydropower shows the best performance among all energy sources, as a hydropower plant typically produces more than 200 times the energy needed to build, maintain and operate it.

Hydropower also provide services that are essential for the security of supply and stable grid operation, such as back-up and reserve capacity, quick-start and black-start capabilities, reactive power and voltage control and frequency control.

Finally, hydropower is the most affordable renewable energy source, as it shows the lowest values of levelized cost of electricity (LCOE) - that is the average price that a generating asset must receive in a market in order to break even over its lifetime.

3.2 The strategic role of hydropower in the transition to renewables

The future portfolio of electricity generation is still uncertain, since it depends upon technological development, learning curves of technologies, public acceptance, and the capability of the financial market to provide the necessary financial resources for the projects. However, it is quite certain that variable renewable energy sources, in particular wind and solar energy, will account for a significant share of this portfolio. In this scenario hydropower still plays a strategic role for a series of reasons:

i. Hydropower helps to decarbonise the electricity system and to mitigate climate change

Hydropower is a mature and reliable renewable generating technology with a very low carbon footprint. Moreover, it is an extremely competitive energy source: it has the highest efficiency rate among all electricity generating technologies (85%-95% for hydropower, 70%-85% for pumped-storage hydropower), as well as a high energy payback ratio. Hydropower represents about 37% of the renewable electricity in Europe and about 11% of the total electricity generation. Considering that almost 60% of the hydropower technically feasible potential is still unexploited (Hydropower & Dams), it is very likely that hydropower will keep playing an important role in the energy mix. There is also significant potential to increase the supply safety in critical periods due to the enhancement of existing storage reservoirs. In addition, thanks to associated water management services like flood and drought control, hydropower can also play a key role in climate change adaptation efforts.

The role of hydropower in reducing GHG emission becomes even more evident with high levels of variable RES penetration. In this situation, pumped-storage hydropower allows the system to be balanced and hence to optimise electricity generation. Without storage and pumped-storage in the system, many thermal power plants would likely operate at their partial load, since reserve generators would be needed. This would lead thermal power plants to operate at a suboptimal level and result in overall lower efficiency and an increase of both fuel consumption and GHG emissions.

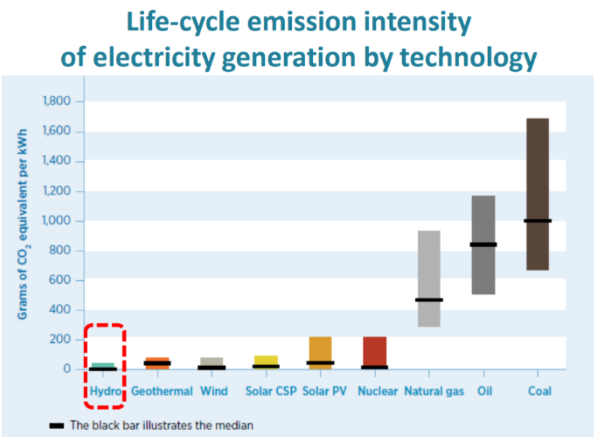

Figure 3-1 Life-cycle emission intensity of electricity generation by technology (Source: IRENA, 2014).

ii. Hydropower enables the integration of variable renewable energy sources

The high level of flexibility of hydropower, as well as its energy storage capability, allows balancing of variable and intermittent power generation. The quick response capabilities of hydropower help provide the peak generation, as well as inertia and frequency regulation, which are crucial for grid stability. With the phasing-out of fossil fuels and the increasing penetration of variable RES, flexibility in services will increase in importance. Whilst development of batteries and other storage technologies will become more significant in the future, hydropower remains the most mature and effective solution for bulk electricity storage. Further development of hydropower will play a major role in securing system stability in the future.

iii. Hydropower provides significant ancillary services to the grid

Besides the balancing services mentioned above, hydropower provides other important ancillary services, such as reactive power and black start capabilities that cannot be provided by other renewable energy technologies. Therefore, the importance of hydropower for grid stability will continue to grow with the phasing out of fossil fuels.

3.3 Key elements for hydropower development

The key elements to enhance the value and support the development of hydropower in Europe have been preliminarily defined as follows:

- **New technological solutions for achieving higher operation flexibility:** improved technological solutions are needed to increase hydropower efficiency and achieve higher levels of flexibility.
- **Expansion of storage and generation capacity:** the expansion of storage and generation capacity allows for more flexible operation to accommodate new and highly fluctuating demands. It requires compliance with environmental requirements and long negotiation for solving conflicts of interest. Expansion of storage and generation capacity can come both from upgrading and retrofitting of existing infrastructure and greenfield projects. However, considering that many HPP will need to go through major refurbishment anyway during the coming decades, upgrading and retrofitting seems more promising in the short and medium term.
- **New business models and market conditions:** new business models are needed to better value the role of hydropower both in energy generation and in water management. At the same time, suitable market conditions need to be put in place (e.g. avoiding double taxation for pumped-storage electricity generation) in order to facilitate investment projects.
- **Mitigating the impact of ageing and improving power plant and dam safety:** The average age of several thousand hydropower plants is about 60 years. Ageing can lead to fatigue of equipment and infrastructure. New materials and new rehabilitation techniques can maintain plant efficiency and reduce the risk of operational failure. New technologies for assessing and/or monitoring the state of hydropower infrastructure, and for improving public safety in a significant way, can improve social acceptance and civil society confidence in hydropower. Intelligent monitoring and diagnosis of the generation equipment will enhance its reliability and availability and increase the efficiency of operation and maintenance of hydropower.
- **Innovative environmental strategies for harsher operation regimes:** the effects of HPPs new and harsher operation regimes on operation safety and on aquatic ecosystems have to be assessed, and strategies to reduce these impacts need to be developed (e.g. innovative strategies of environmental flow releases and hydro and thermo peaking mitigation measures).
- **Climate resilience and mitigation of the impact of global warming:** in the future, changes in potential for generation are expected due to the effects of global warming, which are likely to impact water availability. These effects, as well as the risk of new natural hazards, need to be carefully analyzed and mitigation measures need to be adopted.

3.4 Environmental impact

The major impacts of hydropower stations on river basins include the barrier function, damage and mortality of fish species, modified flow regimes and habitat conditions, changes in nutrient and physio conditions and changed sediment transport dynamics. However, the degree of actual impact of a specific hydropower plant is determined by the sensitivity of the river basin, which mainly depends upon its natural characteristics and the range and magnitude of existing pressures. A number of mitigation measures are available, including but not limited to: the installation of fish passes, the setting of natural flow variations, the application of a minimum flow, the attenuation of hydro and thermo peaking by mitigation measures and restoration of river morphology. Enhanced tools, based on recent advances in hydropower sustainability and negotiations with NGOs, can ensure better outcomes for hydropower development. For instance “Hydropower by Design” is an effective framework developed by the Nature Conservancy.

The main areas to further improve the environmental sustainability of hydropower include:

- **Protection of biodiversity**: innovative solutions for upstream and downstream fish migration; improvement and common approach for the management of ecological flows according to water regimes and EU guidance document N°31; development of tools to set up appropriate mitigation measures on biodiversity under climate change;
- **Availability and quality of water**: solutions for hydro to maintain or improve water quality in rivers and reservoirs; increase of storage capacity to ensure future water availability;
- **Sediment management:** innovative efficient sediment evacuation systems (structural and operational); improved sediment management as part of dam safety and operation within Integrated River Basin Management policies, in order to increase the lifetime of the reservoir, the operability of the power plant and reduced impacts on biosystems. Replenishment of sediments downstream of dams in combination with the release of artificial floods and sediment flushing;
- **Decommissioning of existing hydropower infrastructure**: this should be the result of a basin-level analysis that addresses both the increase of hydropower efficiencies by refurbishment and equipment upgrading and should be aimed at eliminating barriers where electricity generation is marginal or not effective**.**

3.5 Social issues

When talking about the sustainable development of hydropower, the social aspects have often led to problems and therefore became subject to concerns regarding the development of new projects. Integration of stakeholders and the early involvement of potentially affected citizens and communities in projects a long time ahead of any works is key to project success. An integrated plan shall manage all of the following social aspects:

- **Affected people and vulnerable groups**: during the planning of hydropower projects it is important to identify who will benefit from the project and especially who will be exposed to negative impacts through a proper social impact study. Project affected people may be within the catchment, reservoir area, downstream, or in the periphery where project-associated activities may occur; in some cases it may also include those living outside of the project affected area. The influx of workers and creation of transportation corridors should also be properly controlled and managed. Particular attention needs to be paid to groups that might be considered vulnerable with respect to the degree to which they are marginalized or impoverished and their capacity and means to cope with change. Negative impacts can be minimized for such communities if they are involved in the development of a hydropower project, rather than perceiving it as a development imposed upon them. Appropriate time and resources should be dedicated to think through project consequences and to define, on a consensual basis, the conditions in which they would be prepared to proceed with the proposed development.
- **Cultural heritage**: exceptional natural landscapes or physical features of the environment are an important part of human heritage. The creation of a reservoir might lead to the disappearance of exceptionally valued landscapes such as spectacular waterfalls and canyons. Long-term landscape modifications can also occur through soil erosion, sedimentation and low water levels in reservoirs, as well as through associated infrastructure impacts (e.g. new roads, transmission lines). It is therefore important that appropriate measures are taken to preserve natural beauty in the project area and to protect cultural properties with high historic value. Possible measures to minimize negative impacts include: a) conserving, restoring or relocating important physical and cultural resources; b) creating a museum in partnership with local communities to make archaeological findings, documentation and record keeping accessible; c) including landscape architecture capabilities within the project design to optimize harmonious integration of the infrastructure into the landscape; d) re-vegetating dumping sites for soil and excavation material with indigenous species; e) putting transmission lines and power stations underground in areas of exceptional natural beauty.
- **Involuntary population displacement**: although not all hydropower projects require resettlement, involuntary displacement is one of the most sensitive socio-economic issues surrounding hydropower development. It consists of two distinct processes: displacing and resettling people on the one side and restoring their livelihoods through the rebuilding of their communities on the other side. When involuntary displacement cannot be avoided, a number of measures can contribute to mitigate the impact on communities involved: a) involving affected people in defining resettlement objectives and reestablishment solutions; b) rebuilding communities and moving people in groups; c) publicizing and disseminating project objectives and related information through community outreach programs; d) providing necessary

income restoration and compensation programs; e) implementation of long-term integrated community development programs.

- **Sharing development benefits**: in many cases, hydropower projects have resulted both in beneficiaries and disadvantaged: affected local communities have often borne the brunt of project related economic and social losses, whilst people outside of the project area have benefited from better access to affordable power and improved flood/drought protection. Special attention has to be paid to those local and regional communities that have to cope with the negative impacts of hydropower projects, in order to ensure that they get a fair share of benefits from the project as compensation. This may take many forms including business partnerships, royalties, development funds, equity sharing, job creation and training, jointly managed environmental mitigation and enhancement funds, improvements of roads and other infrastructure, recreational and commercial facilities (e.g. tourism, fisheries), sharing of revenues, payment of local taxes, granting preferential electricity rates and fees for other water-related services to local companies and project-affected populations.

4 Roadmap to implementation

4.1 Barriers to large scale deployment of all sizes of hydropower

The goal for the current consultation process is to gather and analyse stakeholder inputs to define a Strategic Industry Roadmap (SIR), in order to foster the sustainable development of hydropower in Europe. The SIR will focus on three major non-technical barriers for hydropower development, namely:

- Understanding why communities reject new hydropower schemes and bridging the gap between the parties;
- Managing environmental and social issues related to hydropower plant construction and operation;
- Proposing new financial schemes and business models for hydropower development to overcome investor concerns and ensuring financial streams for hydropower development.

4.2 Hydropower for a better society

4.2.1 Assessment of community reluctance to develop new hydro sites

Within the Hydropower-Europe forum, stakeholders (including enterprises, academia, national administrations and civil society organizations) are invited to provide feedback, to better understand how hydropower projects are perceived and how different interests and perspectives can be reconciled. Regional working groups will address specific macroregional issues. The negative and positive externalities of hydro generation will be acknowledged.

4.2.2 Best practice in bridging the gaps between conflicting interests

The scope of consultation is also to gather and analyse details of best practice dealing with environmental and social issues and to provide recommendations on how to best reconcile them. The result of this analysis will be included in the Strategic Industry Roadmap.

4.3 Hydropower and the protection of environment

Hydropower operators have extensive experience in the management of water as a resource used for various societal needs, which includes electricity production. This means that there is often a strong interaction between water and energy, one being needed for the use of the other.

Climate change will place increasing pressure on water resources, thus leading to a real need for new reservoirs. This is an opportunity for hydropower to be creative in developing better engineering of the ecological features of the reservoirs to ensure environmental sustainability.

Hydropower-Europe intends to gather best practice to help minimise the environmental impact of hydropower and provide recommendations to decision makers and the hydropower community. It will also provide recommendations to the EU in view of the upcoming evaluation of the Water Framework Directive (WFD).

4.4 Funding hydropower research and deployment

4.4.1 Enhancing finance for hydropower investors

Hydropower-Europe will assess the main barriers for funding hydro projects and will propose solutions (e.g. new business models, financial schemes and regulations) to ensure sustainable sources of funds and suitable market conditions for hydropower development. Examples of possible solutions include:

- the general system of public incentives, not only for hydro but generally for renewables and even others (e.g. coal, nuclear);
- private-public investment with low discount coefficients;
- developing new hydro and PSP investment through suitable PPA models;
- developing shared methods to assess total costs including externalities, in order to value non-market costs and services;
- new methods to evaluate properly the total market value of hydro generation including ID and balancing market, to optimize the value from hydro;
- development of new market schemes for hydro within the framework of the European grid code, including a revision of network codes for energy storage;
- exemption from grid costs and avoidance of double taxation for pumped hydro power;
- simple procedures to carry out structural safety assessments to avoid unnecessary loss of generation;
- innovative design approaches for new multi-purpose hydropower schemes;
- system-scale planning approaches at the river-basin level to better assess siting and potential decommissioning of existing infrastructure.

4.4.2 Implementing the research and innovation agenda (R&IA)

Increased R&I efforts and strategic alignment of national and EU programs are necessary to realize all the potential embedded in technology innovation and hydropower generation. Hydropower-Europe will present recommendations to contribute shaping national and EU funding strategies. Proposals will be made to European States to ensure the flexibility and security of their electricity network while developing the multi-use of water and regional development using hydropower.

4.4.3 Review of outputs and relationship with EC

Hydropower-Europe is intended to form the basis for a permanent forum for the hydropower community in Europe. After the end of the project the option for stakeholder permanent cooperation, in the form of a European Technology and Innovation Platform or consultation forum, will be considered depending on stakeholder interest and participation.

5 References

Aggidis G., Avellan F., Deniz S., Lund U., Moro A., Muntean S., Novara D., Pérez-Díaz J-I, Quarantai E., Schild P., Theodossiou N., (2019). Analysis of emerging technologies in the hydropower sector. Renewable and Sustainable Energy Reviews, Volume 113, October 2019, 109257. https://doi.org/10.1016/j.rser.2019.109257.

DNV GL, (2015). *The hydropower sector contribution to a sustainable and prosperous Europe*.

ENTSO-E, European Network of Transmission System Operators for Electricity, (2017). Annual report. https://annualreport2017.entsoe.eu/wp-content/uploads/2018/06/ENTSO-E_Annual_Report_2017.pdf

ENTSO-E, European Network of Transmission System Operators for Electricity, (2017). *Electricity in Europe*.

European Commission, (2011). *Water management, Water Framework Directive & Hydropower*. Common Implementation Strategy Workshop. Brussels, 13-14 September 2011.

Fingrid, (2018). https://www.fingridlehti.fi/en/why-is-hydropower-a-good-reserve/

Gimeno-Gutiérrez, M., Lacal-Arántegui, R., (2013). *Assessment of the European potential for pumped hydropower energy storage*. JRC Report EUR 25940 EN. January 2013 DOI: 10.2790/87037

HP&D, Hydropower & Dams, (2018). 2018 *World Atlas & Industry Guide*, Aqua Media Int. Ltd.

IEA. International Energy Agency, (2018). *Status of Power System Transformation*.

https://webstore.iea.org/status-of-power-system-transformation-2018

IHA. International Hydropower Association (2019). *2019 IHA Hydropower Status Report*.

IRENA, International Renewable Energy Agency, (2014). *Rethinking energy*: *towards a new power system*.

Kumar, A., T. Schei, A. Ahenkorah, R. Caceres Rodriguez, J.-M. Devernay, M. Freitas, D. Hall, A. Killingtveit, Z. Liu, (2011). *Hydropower*. In IPCC Special Report on Renewable Energy Sources O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlomer, C. von Stechow (eds), (2011). *Climate Change Mitigation*. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

REN21, (2019). Renewable 2019 Global Status Report. https://www.ren21.net/gsr-2019/

WEC, World Energy Council, (2016). *World Energy Resources: Hydropower*.

https://www.nature.org/media/freshwater/power-of-rivers-report.pdf and (2) The Power of Rivers: A Business Case –

https://www.nature.org/content/dam/tnc/nature/en/documents/powerofriversreport_final3.pdf

https://www.consilium.europa.eu/en/press/press-releases/2019/06/25/council-outlines-principles-and-priorities-for-the-future-of-energy-systems-in-the-energy-union/