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Hydropower

Fact sheets

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In cooperation with

VGB POWERTECH

Hydropower plays a major role in meeting Europe's ambitious energy transition goals. In particular, it complements the increasing share of variable renewables in the European power system. Such a system, with large deployments of wind and solar, requires sufficient flexibility, firm capacity and the ability to balance variable generation. Hydropower has all these capabilities.

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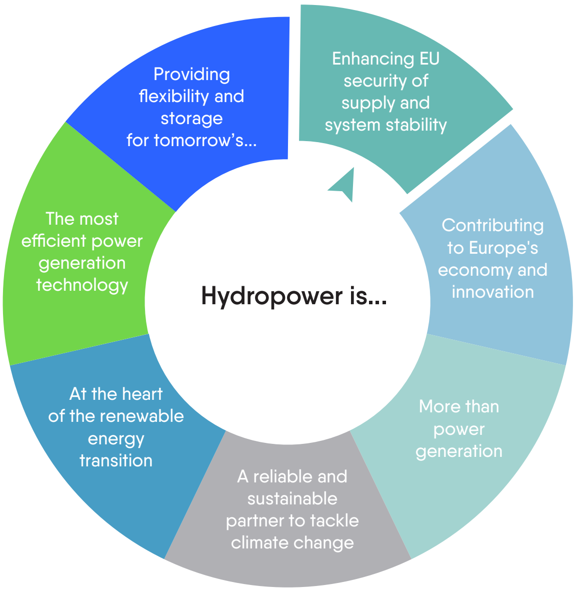
Hydropower

Enhancing EU security of supply and system stability



Hydropower fosters EU energy independency

For decades, energy demand and import dependency have steadily increased throughout Europe. In 2015[1], EU-28 gross energy consumption was about 1,626 Mtoe (i.e. 18,930 TWh). Energy demand has also grown worldwide, with an expected increase of 27% by 2030, leading to significant changes in energy supply and trade flows.[2]

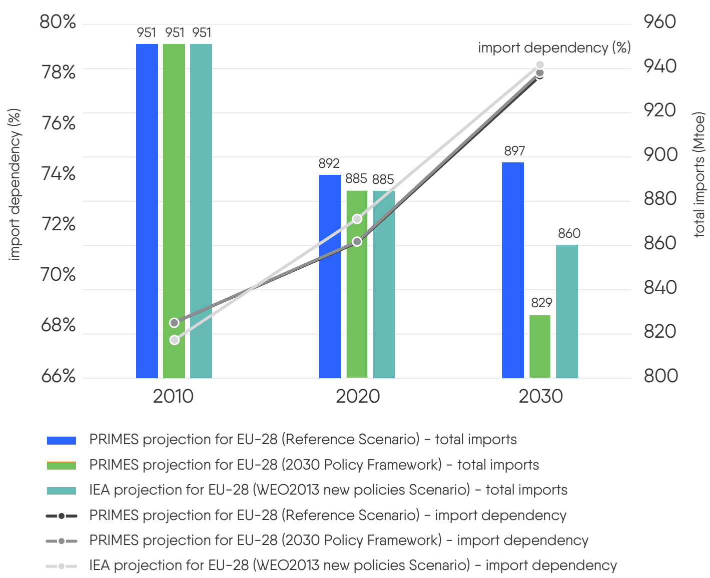
At a glance: Hydropower

- fosters EU energy independence.
- enables the integration of large volumes of variable renewable energy.
- has an exceptionally high level of guaranteed capacity.
- is crucial for system stability and security of supply.

So far, the EU-28 relies to a large extent on energy imports: Energy import dependency has increased from about 40% of gross energy consumption in 1990, up to 54% in 2015. Since 2004, EU-28 net imports of energy have even exceeded its own primary energy generation.

According to the EU Commission, import dependency will increase up to 70% and even more unless policy measures are taken. PRIMES and IEA World Energy Outlook deliver similar results (see figure 1) on this: import dependency will further increase till 2030, by 2020, total imports of all fossil fuels will decrease to 885 Mtoe, while for 2030, projections show a further decrease with EU importing some 830 to 860 Mtoe.[3] The European Energy Security Strategy[4] therefore explicitly aims at maximizing the use of Europe's indigenous energy sources, and in particular renewable energy sources.

Figure 1: Projected development of energy dependency and total imports in the EU-28[3]



Hydropower, as a renewable domestic resource, has contributed to increasing EU energy independency and security of supply. Optimising the output of existing hydropower plants as well as making use of the undeveloped European hydropower potential can help limiting the growing import dependency. Hydropower, being renewable and domestic, is the perfect enabler for the integration of more wind and solar generation due to its flexibility and storage capability.

[1] Eurostat, 2017; Statistical Pocketbook, 2017
[2] COM(2014)330 final
[3] IEA World Energy Outlook, PRIMES projection (Reference Scenario)

[4] SWD(2014)330 final/3

Snapshot – storage and pumped storage power plants

Storage hydropower takes advantage of existing large storage basins (reservoirs) with natural inflow of water. Technically, the water intake can be converted into electricity either by one single power plant or a cascade of hydropower plants downstream the reservoir. Typically, due to their size, they store energy for several days, months or even years. Up to a certain extent, storage hydropower plants can deliver flexibility, too. In periods of excess electricity generation from variable renewables, the flow of water from the reservoirs through the turbines can be stopped instantaneously and the water is kept as energy storage in the reservoirs.

Pumped storage power plants (PSPP) may either have natural inflow in the upper reservoir or not. In case of excess power supply, e.g. by strong wind and/or solar generation, they pump water to a storage basin, the upper reservoir. Systems services of PSPP are mainly used to balance the grid or generation-driven fluctuations in supply (peak, off-peak). Typically, PSPP store energy for several hours or days. They can be combined with natural storage but are increasingly installed where natural storage is not possible.

The very high guaranteed capacity of hydropower makes it a perfect partner for variable renewables such as wind and solar

- Electrical power output of wind turbines is determined by weather conditions typically correlated over several hundred kilometers. The output of solar systems also depends on environmental conditions such solar irradiance or ambient temperature.
- The total wind fleet output of 18 European countries extending over several thousand kilometers in north-south as well as east-west direction is highly volatile and exhibits a strong variable character.
- No significant smoothing can be determined, neither in a single country nor over Europe. Therefore, wind energy requires practically a 100% backup.
- Compared to wind or solar, hydropower requires practically no backup capacity.
- Depending on the regional location of the plants and due to different calculation methodologies, the guaranteed capacity defined as percentage of installed capacity ranges between 45 to 67% for run-of-river only.
- The guaranteed capacity of entire hydropower systems can increase up to 85%. This is due to the fact that hydropower plants often make use of the water forces in complex systems of several run-of-river power plants located in a cascade or combined with storage. In addition, hydropower has a naturally built-in storage: The soil retains part of the precipitation, which is released to the river in periods without rainfall.

Hydropower ensures system stability and security of supply

The performance of the power system depends on a stable frequency in the grid, which requires instantaneous supply adjustments to match variations in demand at any moment. Hydropower contributes to system stability and security of supply by delivering an entire range of system services:

Due to its high flexibility, hydropower contributes to the stabilisation of transmission voltages without increasing CO_2-emissions. In this way, hydropower helps managing voltage dropouts and reducing loop flows that may cause bottlenecks in the European power grids.

After a system collapse, grid operators need power plants with a so-called black start capability (a start-up without help from the grid) to restore grid operation. Hydropower plants constitute essential black-start sources. Especially, storage and pumped storage power plants strengthen the cross-border system stability and are required for grid reconstruction.

In addition, run-of-river hydropower plants offer another special feature: a very high level of guaranteed capacity.[5;6]

Outlook

Due to the projected increase of variable renewables, the importance of hydropower will rise in the future. A future power system with storage and flexibility services provided by hydropower will allow higher shares of wind and solar power without compromising the security of supply and stability of the system.

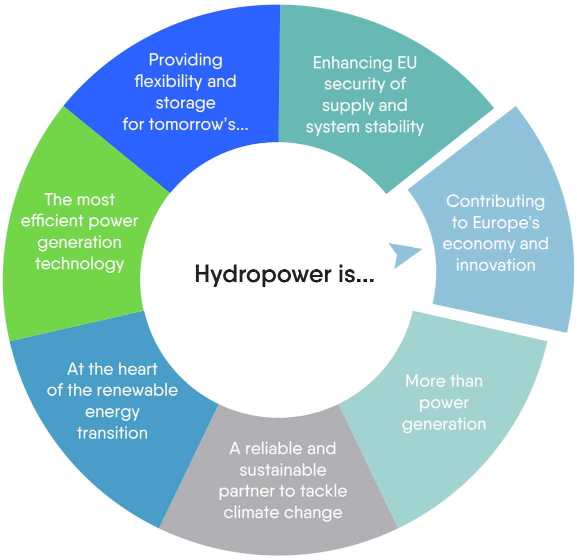
POLICY RECOMMENDATIONS

- Define system responsibilities for all actors in the competitive electricity market.
- Label ancillary and balancing services including all costs to support the establishment of a fair and transparent competitive market.
- Consider storage facilities as a part of the competitive market.
- Establish a level playing field for storage and pumped storage hydropower versus other storage technologies regarding support mechanisms (R&D, RES, CRM, etc.).
- Establish a level playing field on grid fees: no double grid fees for any storage technology.

[5] VGB Power Tech 6/2017 „Windenergie in Deutschland und Europa"
[6] VGB Power Tech 9/2015 „Gesicherte Leistung der Wasserkraft in Deutschland und Österreich"

Hydropower

Contributing to Europe's economy and innovation



Hydropower – a European core industry

Worldwide, the competence in hydropower equipment manufacturing is mainly based in Europe. It is estimated that the European hydro equipment industry accounts for more than two-thirds of the world market.[1]

Many leading universities and research centres specialised in hydropower are also located in Europe, thus ensuring that the competence remains very much alive. The equipment industry and hydropower operators invest in R&D, top-level education and training for their thousands of employees.

The EU-28 hydropower sector directly and indirectly provides more than 100,000 jobs (based on FTE = Full-time equivalents). Direct employment includes more than 50,000 FTE in generation and almost 7,000 FTE in equipment manufacturing.[1]

At a glance: Hydropower

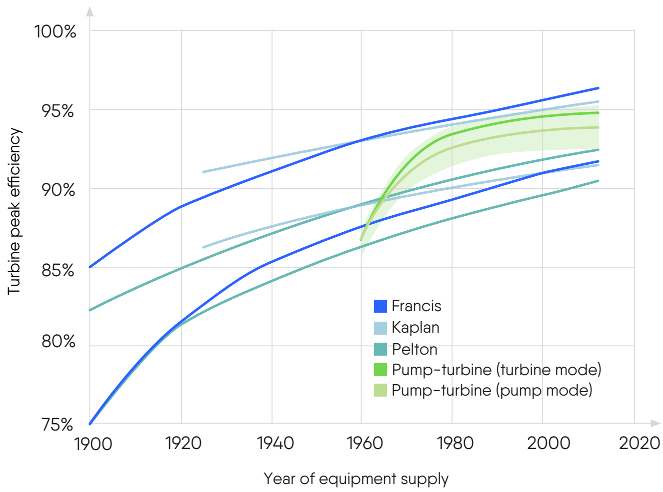
- is a European technology export business with more than 50% market penetration worldwide and securing thousands of jobs of highly skilled employees in Europe.
- delivers tailor-made and innovative systems solutions for hydropower plants of any size worldwide.
- creates significant investments and tax revenues for Europe.

Hydropower plants - reliable for centuries

The hydropower technology has a long history. The first hydropower plants date back to the 19th century. Since then, the technology has developed towards ever-larger power output, higher performances and efficiency. The lifetime of hydropower plants is by far the longest of all power generation technologies – on average 80 years and often longer.

Over the last decades, huge progress was made in turbine development. There has been a trend towards bigger turbine units and better turbine efficiencies or hydraulic performances (see figure 1). Today, the pumped storage technology can switch between the pumping and generating mode within 20 to 30 seconds. This can be realised thanks to fixed speed reversible units, variable speed pump turbines or ternary pump turbine units. It is the large-scale electricity storage technology with the shortest reaction time.

Figure 1: Efficiency development of turbines[2]



[1] DNV GL, The hydropower sector's contribution to a sustainable and prosperous Europe, 2015

[2] According to ANDRITZ HYDRO GmbH, 2018

Hydropower technologies: innovative and tailor-made system solutions

The hydropower sector has continuously been improving its technology. Tailor-made hydropower plants guarantee that sufficient non-variable renewable electricity generation is produced to meet the increasingly variable output of other renewable sources.

A new challenge for hydropower is to capture the energy potential of water flows and sites with a very low height difference between the upper and lower water level (head) e.g. at irrigation dams, low head weirs and ship locks. New technologies could be installed on existing structures, constituting a big potential for future renewable and distributed, clean power generation.

Hydropower means long-term investment

Today, new investments are required for the maintenance and refurbishment of existing plants and the construction of new ones. As hydropower plants have a longevity of up to 80 years and even longer, the benefit deriving from these investments will certainly last over generations.
The high upfront capital costs needed, combined with long construction and payback periods very often prevents the necessary investments from happening.

Although the costs for other renewables further decrease, hydropower remains ahead in terms of cost-competitiveness. Despite high initial investment costs, plants have a very long lifetime and their operation and maintenance costs are relatively low. Thus, hydropower has one of the lowest generating costs (Levelized Costs of Electricity, LCOE).[3;4]

Hydropower creates economic value

The hydropower market contributes positively to various economic sectors. At present, the gross value creation resulting from European hydropower generation companies and equipment manufacturers adds up to € 38bn. By 2030, the hydropower sector's contribution to the European gross domestic product (GDP) may grow to a range of € 75bn to 90bn.[5]

Hydropower stands out among renewable energies as it brings good revenues for public budgets at national, regional and local levels, i.e. in the form of taxes. The tax revenue from the European hydropower sector amounts to more than € 14bn in 2013, which means that more than 37% of the gross value created by hydropower in Europe is directly transferred to governmental budgets at local and regional levels helping to foster regional development.

Outlook

In terms of efficiency and flexibility, the outstanding performance of hydropower is expected to play a key role in achieving the EU renewable energy targets. Even more progress in the development of hydropower technologies is expected mainly regarding faster reaction times, broader operating ranges, improved materials and environmentally conscious design.[6]

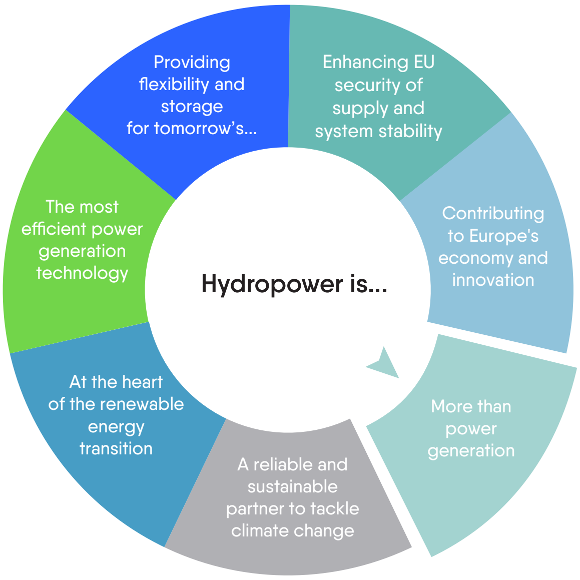
POLICY RECOMMENDATIONS

- **Incentivise investments into existing and new hydropower plants as they will last for generations.**
- **Consider lifetime and efficiency of storage and generation technologies within new energy policies.**
- **Offer EU R&D and technology programmes to support the hydropower industry and the outstanding universities to maintain Europe's technology leadership.**

[3] IRENA, Renewable Power Generation Costs in 2017, 2018
[4] VGB, Levelised Cost of Electricity, 2015
[5] DNV GL, The hydropower sector's contribution to a sustainable and prosperous Europe, 2015

[6] World Energy Council, Hydropower, 2016

Hydropower
More than power generation



Hydropower – at the crossroads

Hydropower represents a unique technology at the heart of the water-energy-nexus. It has to be observed and managed with special attention as hydropower can have both positive and negative effects on the environment.

Building and operating hydropower changes water levels and flows. This can impact land use and natural habitats. Water supply, waste water management, flood control and hydropower facilities have affected water courses for centuries. This has changed the original water courses to man-made nature. However, in order to prevent and mitigate adverse effects on the environment, multiple measures have been taken. So far, various specific environmental protection and nature conservation measures have been implemented, such as providing minimum residual flows, restoring river hydromorphology or the construction of fish passage facilities. In many cases, rich ecosystems have been created through careful local management around hydropower infrastructures – ecosystems often with protected biodiversity and/or designation as nature protection areas like Natura 2000.

Nevertheless, hydropower is confronted with various obstacles making it a renewable energy at the crossroads. This is the result of existing framework conditions including fragile economic models and regulations resulting from sometimes contradictory public policies and the low remuneration of services to the power system, to other sectors and to regions.

The distinct obstacles do not only lead to the deterioration of hydropower competitiveness but also make maintenance and modernisation of installed plants and the realisation of future projects more difficult.

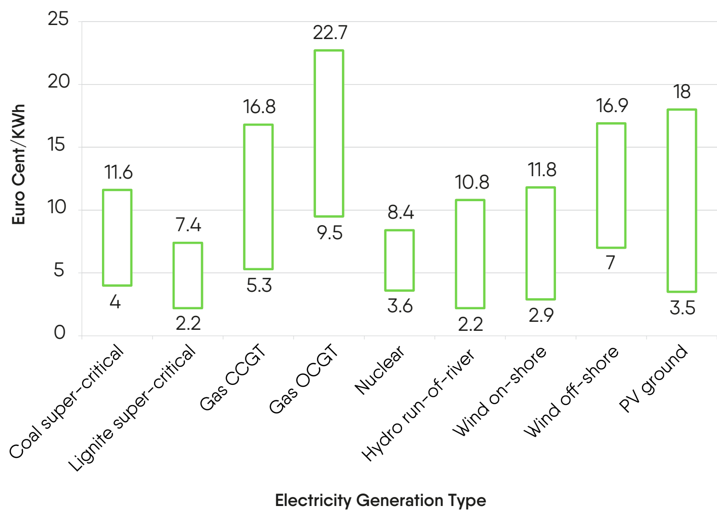
At a glance: Hydropower

- offers a multitude of ancillary services for balancing the grid.
- has important multipurpose benefits contributing to the development and sustainability of other economic sectors (e.g. culture and tourism, flood protection, irrigation, navigation, drinking water).
- contributes to the local economy of regions.
- is facing challenges concerning competitiveness while most services and benefits are not rewarded according to their real value.

Hydropower's disregarded additional benefits

Even though hydropower is ahead in cost-competitiveness (see figure 1), levelised cost studies still neglect most of the additional benefits and services provided by hydropower. The recent IRENA report[1] confirms that hydro has one of the lowest generating costs worldwide; even though, this report does not consider hydro services that are typically not remunerated. However, putting a value for all the benefits provided would be essential to face present competitiveness challenges.

Figure 1: Levelised cost of electricity (LCOE)[2]



[1] IRENA, Renewable Power Generation Costs in 2017, 2018

[2] VGB, Levelized cost of electricity, 2015 (real case)

Hydropower's multipurpose benefit

It is often overlooked that hydropower renders numerous additional services besides the generation of renewable electricity, such as:

Ecosystem services

- a low level of greenhouse gas emissions
- prevention of water pollution
- guaranteed downstream flows
- water quality management
- river continuity for fish and other creatures
- cleaning of rivers from litter
- river restoration
- creation of gravel banks
- mowing concepts for dams to secure biodiversity

Water quantity management

- flood prevention
- drought mitigation
- ground water stabilization
- water supply

Renewable energy source and other power services

- promotion of energy security
- provision of storage and flexibility
- hydro is predictable and controllable
- ancillary services (primary regulation, secondary regulation, fast reserve, etc.)
- electricity supply in remote areas

Local livelihoods

- infrastructure built and/or preserved
- flood and drought management
- supply of drinking water
- recreational activities
- barrier to saline water intrusion
- improved sanitation

Economic growth and regional development

- tourism
- regional development
- navigation
- aquaculture
- irrigation purposes
- domestic and industrial water
- improved infrastructure
- energy intensive industries

A harmonious and economically optimal operation of such multipurpose schemes may involve trade-offs between the various uses, including hydropower generation. This is why the recognition of all non-energy services is necessary as well as the inclusion of their real value within economic models. Analyses suggest that multipurpose benefits of European hydropower plants may deliver an additional economic value of € 10bn to 20bn annually.

Example: Contribution to the local economy

The operating group of the Durance and the Verdon valleys (France) generates between 30 to 50% of the total electricity consumption of the Provence-Alpes Côtes d'Azur (PACA) Region. Moreover, around 1,100 jobs (direct, indirect and induced) depend from the activity of the sector.

Outlook

It is feared that existing conditions with sometimes fragile economic models, regulations resulting from sometimes contradictory public policies and the low remuneration of services will further deteriorate the competitiveness of hydropower and make the maintenance and modernisation of installed plants but also the realisation of future projects more difficult.

POLICY RECOMMENDATIONS

- Acknowledge the contribution of hydropower for local water management and economy.
- Balance contradictory policy goals and recognise hydropower's multipurpose benefits to ensure the maintenance and modernisation of installed plants but also the realisation of future projects.
- Recognise the non-energy contributions of hydropower as well as the costs for operators, assess their value and integrate them into business models.

[3] EDF, Multipurpose Water Uses of Hydropower Reservoirs, 2015

Hydropower

A reliable and sustainable partner to tackle climate change

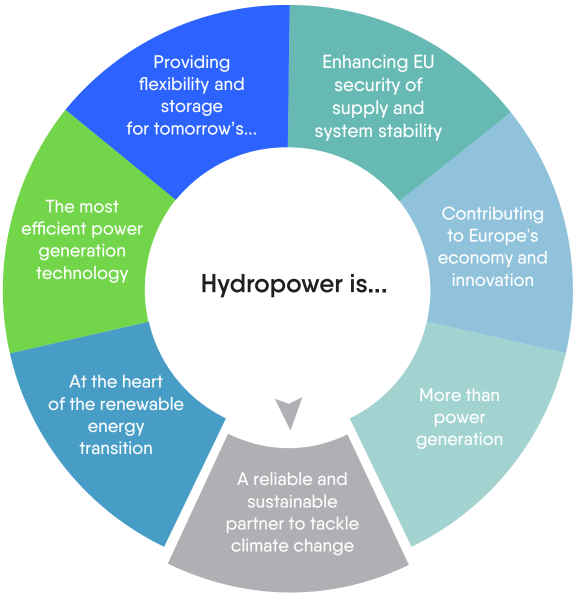
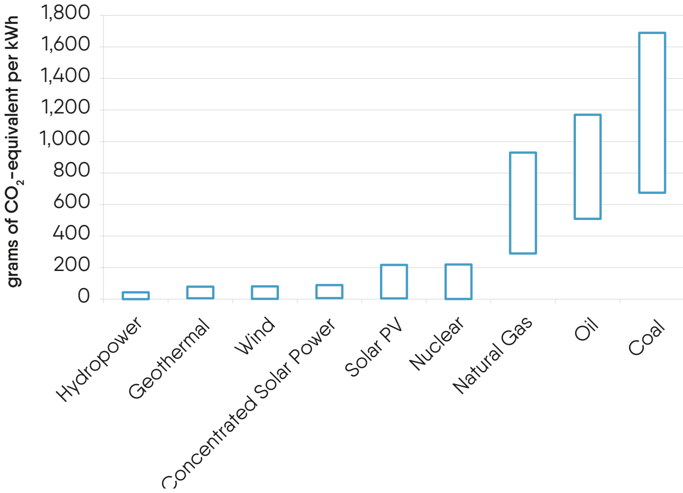


Figure 1: Life-cycle emission intensity of electricity generation by technology[3]



Hydropower has the lowest GHG emissions

According to the Intergovernmental Panel on Climate Change (IPCC), the main cause of ongoing climate change is the burning of fossil fuels, which produces greenhouse gases (GHG) such as CO_2. The world must cut GHG emissions in half before 2050 in order to prevent temperatures from rising up to more than two degrees. Since the energy sector is responsible for more than 50% of EU GHG emissions, replacing fossil fuel with renewable energy sources is crucial.

At a glance: Hydropower

- contributes to reach EU climate targets thanks to its very low carbon footprint.
- plays a unique role in mitigating and adapting to climate change.
- follows strict sustainability criteria.
- ensures coherence with the EU environmental legislation.
- offers water management opportunities.

Hydropower plants have the lowest carbon footprint of all generation technologies[1] (see figure 1). Emissions from hydropower only result from the construction of plants or can occur in some reservoirs[2].

Hydropower's unique role in mitigation and adaptation

With its low-carbon footprint, hydropower is crucial in mitigating climate change. It can provide significant volumes of renewable low-carbon electricity, both base and peak load. Hydropower provides quick and cost-efficient flexibility – necessary given the increasing shares of other variable renewable sources.

Hydropower generation contributes significantly to the efforts of reducing GHG emissions. Indeed, this technology avoids more than 180 Mio t of CO_2 emissions[3;4] per year equalling to 15% of the total CO_2 emissions in the EU power sector. Due to climate change, extreme weather conditions are more frequent. The ability to adapt to a changing climate largely depends on our reactions to lower the impact of extreme weather events. Hydropower plants with storage capacity help us to avoid flood disasters and provide water in dry seasons. Integrated water management will therefore become an important tool in adapting to climate change.

Hydropower follows strict sustainability criteria

Climate change is the biggest threat to our environment. The impacts are global, but the measures to decrease GHG emissions, such as the use of renewable energy sources, are local.

[1] The carbon footprint accounts for the total quantity of GHG emitted over the lifecycle of a product or a process.

[2] Note: Methane emissions from reservoirs have been registered. The discussion in this respect is an international one, but from minor relevance in the European context.

[3] IRENA 2011, based on IPCC.

[4] This estimate is based on the assumption that hydropower generation is replaced by the current generation mix.

Making use of the energy in water has a local impact on water systems. Modifying a water body will directly affect those who are near the influenced ecosystem. As for all construction projects, we are obliged to evaluate thoroughly, in cooperation with all stakeholders, the short and long-term costs and benefits for society, the environment and economy before construction work could start.

Europe's hydropower is a climate-friendly energy source providing sustainable electricity since all environmental, economic and social aspects are taken into account. This is ensured by obeying the respective legal frameworks (such as the Aarhus Convention, the Water Framework Directive, or the Birds and Habitats Directives) and applying voluntary criteria on sustainable development (like the Hydropower Sustainability Assessment Protocol) including social, environmental, technical and economic considerations.

Hydropower ensures coherence with the EU environmental legislation

All EU Member States have some relevant legislation for the permitting and supervising of hydropower projects and operations. These national and regional level policies shall also consider the European legislation for water environment, like the Water Framework Directive (WFD) and the network of Natura 2000 areas. The WFD enables Member States to take into account the important role of hydropower for society in mitigation of climate change and for security of the electricity system as well as the economic value of flexibility and generation. This can be done by setting different environmental targets to the so-called heavily modified waters in order to avoid significant harmful effects. The WFD also includes exemption criteria (art 4.7) to enable the permitting of new hydropower plants in the case of deterioration of a water body.

Hydropower's continuous mitigation efforts

Multiple measures to mitigate the environmental effects of hydropower plants have already been carried out due to obligations in the original permits. Frequently, these obligations include limits for water levels and discharges, and different kinds of measures to mitigate or compensate effects on land, roads, river beds and fishes.

Over the last decades, hydropower companies have pursued multi-fold research targets, concentrating on the improvement of the scientific basis for defining measures to implement the WFD as well as on topics with a different focus, such as storage, flexibility, markets, ancillary services and technical issues. For instance, the development of environmental measures of almost all relevant permits for the regulation of water bodies has been examined in Finland for 20-30 years.

However, when implementing the WFD, it is crucial that the measures that must be set in application of the WFD are based on proven scientific results and cost-benefit analyses. The first river basin management plans included numerous measures on rivers. For instance, the National Water Management Plan for Austria for the time period from 2009 to 2015 included 133 measures for the hydropower sector. The investment costs for these measures amount to € 190 million, of which approximately 20% were publically funded, as described in the following table.

Example: WFD measures based on the Austrian National Water Management Plan implemented from 2009 to 2015[5]

Numbers of mitigation measures	133
Ecological connectivity	68%
Morphology	19%
Residual water	13%
Total investments	189.5 Million €
Public funding	37.8 Million €
Total monitoring expenses	10.1 Million €
Yearly operating expenses	1.059 Million €/a
Yearly generation losses	160.2 GWh/a

In addition to the high financial outlay, the specific measures for fishes, those increasing the amounts of residual water and improving the ecological habitats, also caused a reduction of the national renewable electricity generation of about 160 GWh per year from 2009 to 2015 in Austria. This reduction corresponded to the average consumption of around 45,000 households.

Outlook

Hydropower's contribution to the challenge of climate change is key. 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 review further hydropower development potentials. 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 the WFD in order to avoid losses of flexibility and generation.

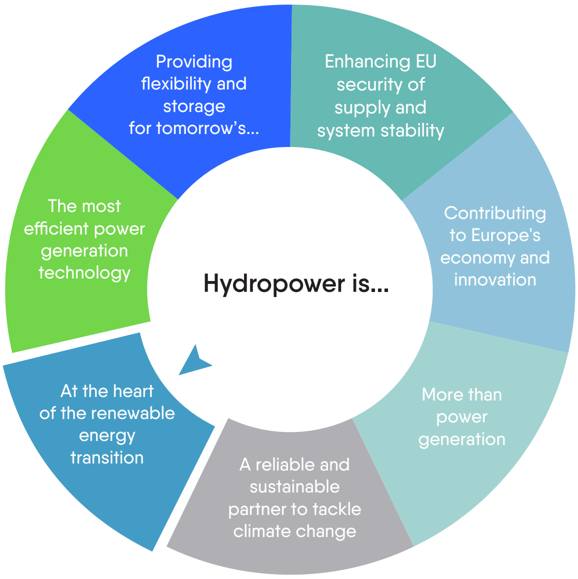
POLICY RECOMMENDATIONS

- Consider hydropower as a key technology for climate change mitigation and adaptation.
- Assess the impact of new regulations on energy transition and climate change adaptation.
- Adopt European policies in an integrated and transparent way to balance ecological, human and economic aspects.

[5] Oesterreichs Energie, The National Water Management Plan 2009 – Implemented Measures of Austrian Hydropower, 2016

Hydropower

At the heart of the renewable energy transition



According to the Intergovernmental Panel on Climate Change (IPCC), close to half of the solar radiation reaching the earth drives the hydrological cycle including evaporation, transpiration, condensation, precipitation, percolation and runoff (see figure 1). Hereby, nature itself secures the renewability of hydropower.

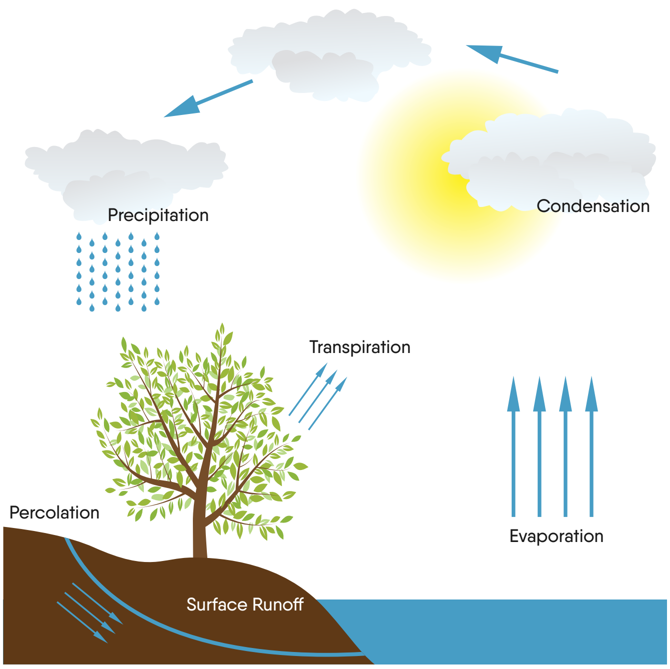
At a glance: Hydropower

- is crucial for the power system's stability and security of supply.
- provides vital storage and flexibility services.
- is the perfect enabler for the large scale integration of variable renewables.
- has a unique role in mitigation and adaptation to climate change.

Hydropower is renewable electricity

Mankind has benefited from using renewable energy sources long before the industrialisation and the large-scale exploitation of fossil fuels started. People have generated power from the energy of falling water for more than 100 years. Hydropower appears in different sizes, forms and ways of operation, making it very flexible and giving it the ability to regulate the energy system in a secure and stable way.

Figure 1: The hydrologic cycle

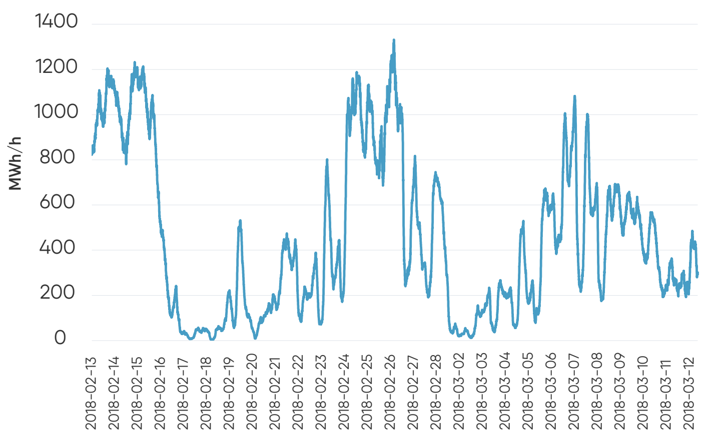


The family of renewable technologies

The renewable energy "family" consists of different energy sources – sun, wind, water or biomass – and technologies. Technologies that rely on the energy of water are hydropower, tidal power, wave power and osmotic power.

What the family members have in common is their renewability. However, wind, sun, waves and to some extent tides, are variable and often unpredictable (see figure 2 exemplifying the variability of wind power). Therefore, power generation from other sources is necessary if there is no wind or sun.

Figure 2: Example for the variability of wind power: wind power generation (MWh/h) in Finland between 13 February 2018 and 12 March 2018[1]



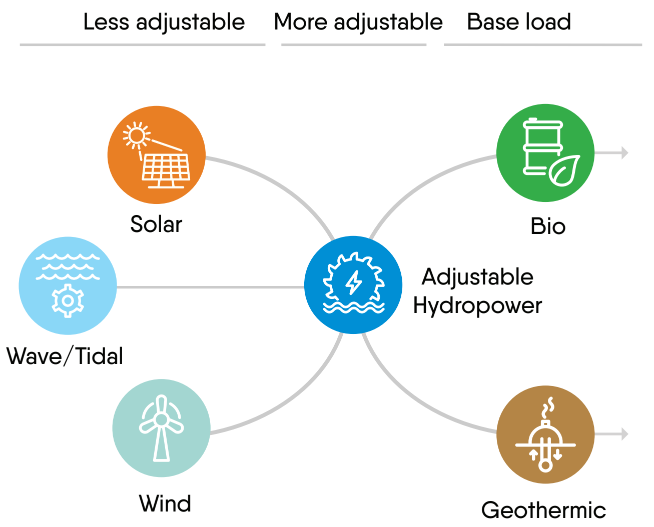
[1] Fingrid, 2018

Hydropower responds to variations in demand and variable generation by:

- Storage hydropower plants take advantage of large reservoirs with a natural inflow and with the possibility to manage (start or interrupt) the water outflow instantaneously.
- Pumped storage hydropower pumps water up to a reservoir with or without natural water inflow and turbine this water when needed.
- Run-of-river hydropower plants provide short-term flexibility.

Renewable energy technologies create synergies. As a consequence, their cooperation brings us faster to a future with more sustainable electricity. With its excellent flexibility and vast network of installations, hydropower is at the heart of this cooperation, among the renewable energy family members (see figure 3).

Figure 3: Hydropower at the heart of the renewable family



Hydropower differs from other renewable sources in its large capacity range (going from several kW to hundreds of MW), flexibility and storage capability when coupled with a reservoir. Hydropower has very high conversion efficiencies (about 85-95%) and low operational expenditures (OPEX).

Delivering the entire range of system services, hydropower has extremely short response times and the ability to black start (to start up without help from the grid). Altogether, this allows hydropower to complement the performance of other renewable technologies. This means that hydropower is able to optimise the total output from renewables and simultaneously to increase energy security.

As a consequence of economic growth and climate change, water availability and management has emerged as a political issue. Hydropower reservoirs can increase the residence time of freshwater and secure water availability for a multitude of purposes such as flood control, irrigation, water supply, recreation, and of course power generation.

Snapshot of hydropower

- With about 341 TWh of annual generation, hydropower is the most important renewable technology in the EU-28, equivalent to 36.4% of the renewable mix. In addition, pumped storage plants generate more 30 TWh electricity per year.
- Hydropower is crucial for the integration of variable renewables, providing flexibility by run-of-river, storage and pumped storage power plants.
- Hydropower secures water availability for several purposes beside power generation, such as flood control, ecological needs, irrigation, water supply or recreation.

Capacity and generation of hydropower in Europe[2]

Hydropower	EU-28	EU-28 + CH + NO + IS
Capacity of run-of-river and storage plants	105 GW	149 GW
Capacity of pumped storage plants	47 GW	51 GW
Generation of run-of-river and storage plants	341 TWh	529 TWh
Generation of pumped storage plants	30 TWh	33 TWh

Outlook

Given the ambitious European climate and energy policy targets, a massive shift from fossil to renewable sources is underway. Today, the share of wind and solar power is already significant. Furthermore, in its Clean Energy Package (2016) the European Commission proposed an EU target of 27% of renewable electricity for 2030. This target will mostly be achieved by feeding-in significant amounts of variable wind and solar power into the European power system. Hydropower will be able to complement these increasing shares of variable renewables with its flexibility, firm capacity and the ability to back up variable generation.

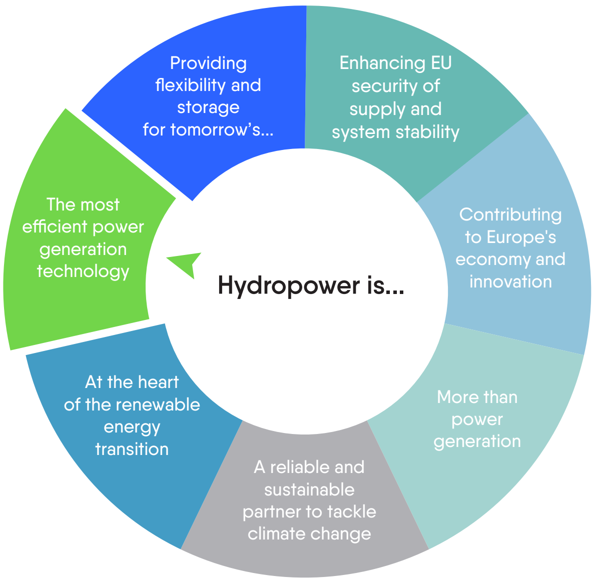
POLICY RECOMMENDATIONS

- **Regard hydropower as a renewable and sustainable resource being at the very heart of the renewable energy transition.**
- **Make use of synergies between renewable energy technologies and acknowledge hydropower's crucial role for the integration of variable renewables.**
- **Balance conflicting goals in the fields of water, energy, and climate policies.**

[2] Eurostat 2017; Bundesamt für Energie BFE, Stand der Wasserkraftnutzung in der Schweiz am 1. Januar 2015; ORKUSTOFNUN – Energy Statistics in Iceland 2015

Hydropower

The most efficient power generation technology

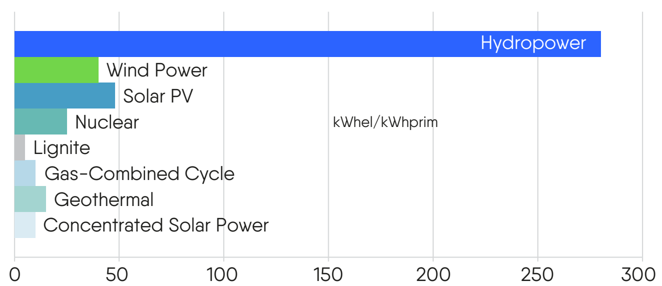


At a glance: Hydropower

- shows the highest energy payback ratio.
- is resource-efficient.
- has the highest electricity efficiency rate (85% to 95%).
- provides the most efficient storage technology.

Hydropower's top ranked environmental performance

Figure 1: Energy payback ratio of different technologies throughout their entire life cycle[1,2]



During its lifetime, a hydropower plant generates far more than 200 times the energy needed to build, maintain and operate it. This is the highest energy payback ratio[1] of all generation technologies – renewables, as well as conventional ones (see figure 1).

The reasons for the high-energy payback ratio relate to the very long lifetime of hydropower plants and the short/ efficient energy conversion process. Once built, hydropower plants can generate electricity for many decades (their lifetime reaches 80 years and even more). For this reason, life-cycle assessments for hydropower generally show a very good carbon footprint and energy efficiency profile.

Hydropower is highly resource efficient

Given its low carbon footprint and high energy efficiency profile, hydropower can help reducing pressure on natural resources. Hydropower does not contribute to water scarcity or water pollution as water is neither modified qualitatively nor quantitatively. Hydropower makes use of the waters' kinetic energy by running it through turbines and gives back the identical volume further down-stream. Hydropower can change landscapes and create opportunities for other users such as agriculture and tourism. The tailor-made adaptation of hydropower stations to local conditions enables an optimal utilisation of the resource and minimises any possible negative impacts on biological systems. Compared to other technologies, there is hardly any pollution (local, air) or waste production from hydropower generation.

Hydropower reservoirs create availability of water for multiple purposes and enhance the control of the resource. Instead of letting water flow unused from source to sea, it can be stored in reservoirs to make it available when needed.

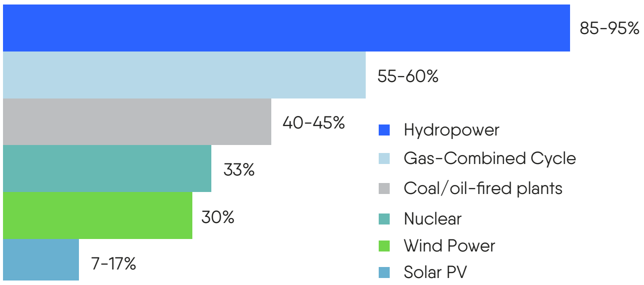
Hydropower has the highest electricity conversion efficiency

Hydropower's electricity conversion efficiency is by far the highest of all energy technologies, ranging from 85% to 95% (see figure 2). The electricity generation process is simple, since the water's energy is directly converted into mechanical energy and further into electricity. This minimises losses in the transformation process.

[1] The energy payback ratio puts in perspective the total amount of energy generated during a plant's lifetime with the energy needed to build, fuel, maintain and decommission the plant in question. It is a very important benchmark to measure the sustainability and efficiency of a power plant.

[2] Hydro-Québec Direction – Environnement, 2005

Figure 2: Electricity conversion efficiencies[3]



Hydropower is today's most efficient large-scale storage technology

Storage and flexibility facilities will become always more important as the share of variable renewable energy sources such as solar and wind will further grow. Storage facilities and flexible generation are necessary to bridge the gap between demand and supply, especially during periods with low wind speeds and no sunshine.

Thanks to its quick response capabilities, hydropower is able to follow changes in electricity demand and supply almost instantly. This is crucial to balance the grid and secure system stability.

The total installed storage and pumped storage capacity in Europe amounts to more than 150 GW[4], delivering short, medium and long-term storage capacity, depending on the size of its reservoirs.
Today, storage and pumped storage hydropower is the only mature large-scale storage technology. It can provide large volumes of electricity over long periods of time at very short notice and at competitive prices. This makes hydropower the most cost-effective storage option.

Despite the fact that the pumping activity consumes electricity, pumped storage power plants are still very cost-effective compared with other storage options.

Modern PSPP achieve a round-trip efficiency[5] of more than 80%, a very high value compared to other storage technologies. PSPP's high power and storage capacity underline its macro-economic importance and significant role for system stability.

Outlook

Hydropower, especially storage and pumped storage shall play a key role in achieving EU's renewable targets. Hydropower's excellent performance in terms of efficiency and flexibility providing all systems services will be needed for the security of supply in a more and more renewable power system.

The European hydropower sector pursues R&D efforts in order to be able to react to the steadily evolving challenges of the electricity market and societal expectations. The next developments will require significant steps forward in the following areas:

- highly dynamic operation of units delivering frequency control
- adaptation of existing hydropower technologies to meet the ever-changing requirements of the electricity grid
- management and upgrade of existing facilities
- new materials and coatings
- environmental benefits and cost reduction.

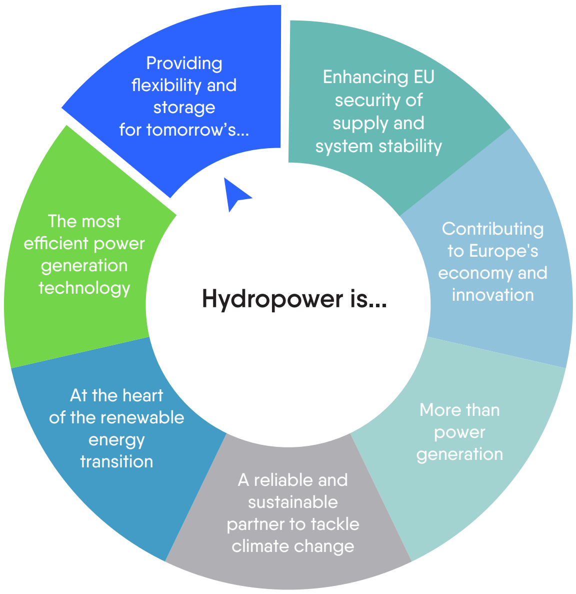
POLICY RECOMMENDATIONS

- **In view of the increasing importance of storage and flexibility services, create a level playing field for all technologies providing these services through clear and stable policies.**
- **Assess resource efficiency and results of life-cycle analyses when creating or modifying energy policies.**
- **Base new policies for storage and flexibility services on cost-effectiveness, efficiency and lifetime considerations.**

[3] Eurelectric, Hydro in Europe: Powering renewables, 2011
[4] IHA, Hydropower status report, 2016
[5] Round-trip efficiency is the ratio of energy put in, to energy retrieved from storage.

Hydropower

Providing flexibility and storage for tomorrow's renewable power system



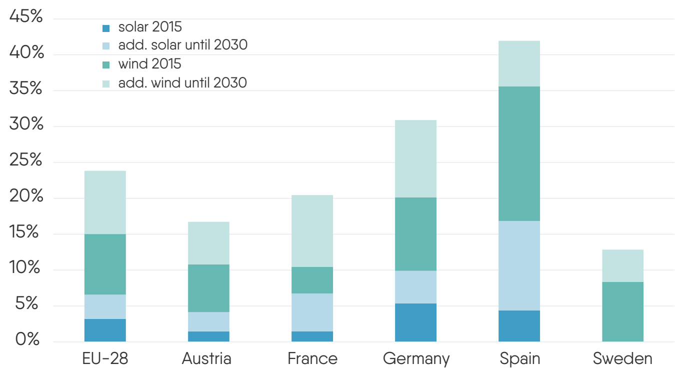
At a glance: Hydropower

- meets the crucial flexibility needs of the power system.
- provides electricity at times when generation from variable renewables is low.
- is able to store electricity when variable renewables generate more than what is needed for the load (pumped storage).
- is a cost-efficient and renewable source for highly flexible power storage.

The future power system has to integrate more variable renewables

The European targets for emission reductions will result in high shares of variable renewable electricity generation in the future European power system. A large share of generation will come from solar and wind power plants. A massive increase in variable renewables is expected in most European countries by 2030 (see figure 1).

Figure 1: Variable renewable shares of gross electricity generation in 2015 and expected additional shares until 2030[1]



Variable renewables increase the demand for flexibility

With rising variable shares of total electricity generation, the need for different types of flexibility in the power system increases. This is due to the mismatch between variable generation and consumption patterns, and to the fact that variable generation can ramp up and down quickly. Specifically, there can be both an excess and a shortage of generation from variable renewables (depending mainly on weather conditions). Flexibility needs include ensuring stability (very short term), power ramping within a few minutes, and energy provision over days or weeks. There is in particular a need to store surplus electricity and to address security of supply concerns at times of low generation from variable renewables. Different energy storage technologies can take different roles in the power system. Hydropower can meet flexibility needs at all timescales, being complemented by other storage technologies.

Hydropower meets flexibility needs

Hydropower includes pumped storage, storage (without pumping facilities) and run-of-river plants. Pumped storage is a form of electricity storage as electricity is used to pump water up into reservoirs (see fact box "Advantages of pumped storage"). Storage (without pumping) acts as an energy storage, mechanically storing energy in large reservoirs. Run-of-river plants can also act as energy storages by utilising the more short-term storage in dams and/or flowing water (see fact box "Flexibility of run-of-river plants").

[1] EU Reference Scenario 2016 based on PRIMES, GAINS

All types of hydropower plants can provide flexibility services to the system. In general, hydropower plants can ramp up and down quickly to respond to short-term system needs, and provide services for voltage and frequency stability. They can also serve longer-term flexibility needs based on their energy storage capacity. Hydropower can address congestions at both transmission and distribution level.

Fact box: Advantages of pumped storage

- Pumped storage is a mature and reliable large-scale technology with many decades of experience.
- It is highly efficient (modern PSPP achieve a round-trip efficiency of more than 80%).
- Pumped storage has low operating costs and relatively low capital costs per unit of generated electricity compared to all other storage technologies.
- Pumped storage stands out due to its very long lifetime.
- Pumped storage has a high-speed adjustment capability ensuring a stable supply of electricity.
- Pumped storage does not know a memory effect.
- Pumped storage does not consume valuable raw materials like rare earths and does not have disposal problems. Moreover, it can be combined with renewable electricity production (run-of-river-power stations; natural inflows into storage reservoirs).
- PSPP have a high importance not only regarding technical and storage issues but also for the stabilization of supply and electricity costs.

Fact box: Flexibility of run-of-river plants

Run-of-river plants are relevant sources of flexibility. It is often overlooked that the potential energy balancing capability of run-of-river systems (including pondage) is enormous. Run-of-river hydropower systems consist of two or more hydropower plants situated along the same river. Coordinated operations of these systems can mitigate unnecessary water spillage, stabilise reservoir elevations and flows, and maximise power generation. The (existing) run-of-river system in the EU-28 stands out with a power capacity of hundreds of MW and an energy capacity of dozens of GWh.

As the topics of storage and flexibility have been confused as well as electricity storage and energy storage definitions have been mixed up, it is necessary to provide exact definitions (see fact box “Storage and flexibility”). In this context, it has been overlooked that not only storage hydropower but also reservoirs of pumped storage power plants can have a natural inflow of water.

Fact box: Storage and flexibility

Energy storage means, in the electricity system, deferring the conversion of a renewable source of energy into electricity to when such electricity is needed **or** deferring the use of electricity to a later moment than when it was generated by converting the electrical energy into a form of energy which can be stored, the storing of that energy, and the subsequent conversion of that energy back into electricity or into another energy carrier.

Flexibility is the ability of the power system to deliver safe and secure access to electricity despite changes in the generation, consumption and availability of the grid. Flexibility can be provided by any storage infrastructure with an electricity output. The type of flexibility that can be delivered is governed by the storage's ramp rate, its energy and power capacity.

Outlook

Hydropower has been utilised as the main source of flexibility in many power systems for over a 100 years. Even though hydropower is a mature technology, current reports[2] even expect that the significance of pumped storage or reservoir hydropower will increase with the shift to a truly sustainable electricity sector as it is today the only technology offering economically viable large-scale storage. The flexibility of hydro power plants is a key asset making them fit for upcoming challenges.

POLICY RECOMMENDATIONS

- Ensure a level playing field for all technologies, as storage and flexibility facilities will become increasingly important.
- Provide clear and stable regulatory frameworks with exact definitions of electricity storage and energy storage.
- Eliminate policy barriers for the construction, renovation, upgrade and operation of hydropower plants as they constitute crucial sources of flexibility being relevant for the integration of variable renewables.

[2] IRENA, Renewable Power Generation Costs in 2017, 2018