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ELECTRICITY FOR EUROPE

Hydro in Europe: Powering Renewables

FULL REPORT

RESAP

This report is part of the EURELECTRIC Renewables Action Plan (RESAP).

The electricity industry is an important investor in renewable energy sources (RES) in Europe. For instance, it is responsible for 40% of all wind onshore investments. RES generation already represents a substantial share in the power mix and will continue to increase in the coming years.

EURELECTRIC's Renewables Action Plan (RESAP) was launched in spring 2010 to develop a comprehensive industry strategy on renewables development in Europe.

RESAP addresses the following key challenges in promoting RES generation:

- the need for a system approach to flexibility and back-up,
- the need for a market-driven approach,
- the need for a European approach to RES development.

RESAP consists of 13 task forces, including for example demand side management, market design, load and storage. The purpose of RESAP is to develop, through a series of reports and a final synopsis report, sound analysis with key recommendations for policymakers and industry experts.

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The **Union of the Electricity Industry–EURELECTRIC** is the sector association representing the common interests of the electricity industry at pan-European level, plus its affiliates and associates on several other continents.

In line with its mission, EURELECTRIC seeks to contribute to the competitiveness of the electricity industry, to provide effective representation for the industry in public affairs, and to promote the role of electricity both in the advancement of society and in helping provide solutions to the challenges of sustainable development.

EURELECTRIC's formal opinions, policy positions and reports are formulated in Working Groups, composed of experts from the electricity industry, supervised by five Committees. This "structure of expertise" ensures that EURELECTRIC's published documents are based on high-quality input with up-to-date information.

For further information on EURELECTRIC activities, visit our website, which provides general information on the association and on policy issues relevant to the electricity industry; latest news of our activities; EURELECTRIC positions and statements; a publications catalogue listing EURELECTRIC reports; and information on our events and conferences.

EURELECTRIC pursues in all its activities the application of the following sustainable development values:

Economic Development

- Growth, added-value, efficiency

Environmental Leadership

- Commitment, innovation, pro-activeness

Social Responsibility

- Transparency, ethics, accountability

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Hydro in Europe: Powering Renewables

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1. INTRODUCTION

Hydropower is a mature and cost-competitive renewable energy source. It plays a key role in today's electricity mix. As a multifunctional technology, it is indispensable to our electricity system, and will be even more important tomorrow.

Hydropower is situated at the crossroads of different policies, from water management to electricity generation or other environmental policies. Already today hydro power tries to balance these sometimes conflicting objectives.

The importance of a generation technology for the overall system depends mainly on its capability to stabilise fluctuations between demand and supply. Hydropower already contributes to balancing these differences – a function that will be even more valuable in the future.

Major changes ahead in the European electricity market

Europe's electricity landscape is undergoing profound changes, linked to the aim of a more renewable and low-carbon energy sector. The EU's integrated energy and climate change policy sets the ambitious target of producing 20% of its energy from renewable sources by 2020. Several countries have already put forth even more ambitious targets for the following decades. Many projections, and various commitments taken within the framework of the National Renewable Energy Action Plans (NREAPs), indicate that increasingly more variable renewables (v-RES) like wind and solar power will be introduced into the system. As a consequence, power systems will not only have to follow the varying electricity demand throughout the day, but also adjust to an increasingly variable power intake.

Ensuring system stability and a continuous flow of electricity by balancing fluctuations in frequency and voltage will be *the* challenge of the future. Although details of the exact future electricity mix are unknown, the increasing share of wind and sun is already a certainty. According to EU member states' NREAPs the share of those v-RES will have tripled by 2020.[1] As a consequence, the electricity system will face ever more generation-driven fluctuations. These fluctuations will have to be dealt with through back-up power and flexible generation.

This is where hydropower comes in.

Hydropower – the backbone of a reliable renewable electricity system

By providing the necessary flexibility and storage capacity to ensure the stability of the electric grid, hydropower already supports the integration of increasing amounts of wind and solar.

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[1] *EEA Report on NREAPs, 2011. http://www.ecn.nl/docs/library/report/2010/e10069.pdf*

With the scene set for an increasing share of v-RES, storage facilities will become more important. Storage can bridge the gap between demand and supply and support the integration of v-RES into the electricity system. Hydropower storage plants are the only large-scale storage technology available today. They are also the most efficient and economical way to store potential electricity. While pumped storage hydropower has a short to medium-term storage capacity depending on the size of its reservoirs, conventional storage hydro can offer significant long-term storage capacity. Although pumped storage is a net electricity consumer, it provides valuable regulation services to stabilise the electric system. Moreover, it can be used to store excess production of v-RES. Compared to all other storage technologies, pumped storage represents the most cost efficient option.

Keeping an electric transmission network in balance requires permanent monitoring and controlling. The key parameters for this task are frequency and voltage control as well as the provision of spinning reserve. These are the major driving forces providing the right balance between variable sources of electricity on the one hand and sources of electricity that can be dispatched at the request of power grid operators on the other. Dispatchable generation can be turned on or off upon demand, either to stabilise variations on the supply side, or to follow fluctuations on the demand side.

Storage hydro is able to deliver the entire range of system services.

The regional dimension is of prime importance, since demand is often spatially removed from supply. Power lines as well as transparent cross-border conditions are therefore key. Moving towards regional interaction and transparency also promotes a European electricity market, with regional integration acting as a first step towards European energy market integration. Promising developments are already underway, notably upcoming price convergence and an increase in traded electricity volumes.

Multipurpose hydropower projects also provide services beyond the electricity sector. They contribute to improved water management, such as flood and drought control, which could prove especially valuable in the context of climate change adaptation.

As for the decarbonisation agenda, hydropower has been identified as highly valuable for climate change mitigation, due to its low carbon footprint and high generation efficiency. This makes hydropower the most competitive and reliable renewable energy source.

About this report

This report provides facts and figures on hydropower in Europe.

Since the electricity market is not limited to the political boundaries of the European Union, statistics have been gathered from neighbouring European countries beyond the EU-27 area. More details on the underlying methodology can be found in Annex 1.

Chapter 2 documents the current role of hydropower in the European electricity sector and its remaining potential, with special attention paid to pumped storage facilities.

Chapter 3 outlines the basic characteristics of the electricity system, the different types of hydropower projects, and the different types of services they can provide. Case studies from various European regions demonstrate the value of hydropower in matching demand and supply, and in easing the introduction of v-RES.

Chapter 4 outlines policy challenges for hydropower.

Chapter 5 reflects on the strategic role of hydropower in Europe’s future electricity system.

The report concludes with a list of recommendations for policymakers in Chapter 6.

2. THE EUROPEAN HYDROPOWER LANDSCAPE: FACTS AND FIGURES

2.1. Hydropower's current role in the European electricity sector

Hydropower is the major renewable generation technology in Europe today. It delivers storage capacity and stabilising services for the power system which are crucial for a high security of supply of electricity. The following chapter provides an overview on data, which are missing today on a European scale. The enquiry taken out by EURELECTRIC has to be considered as a somewhat pioneer work, and at once as work in progress. [2]

Hydropower accounts for 16% in the overall electricity generation portfolio in EURELECTRIC Europe (Fig. 1).

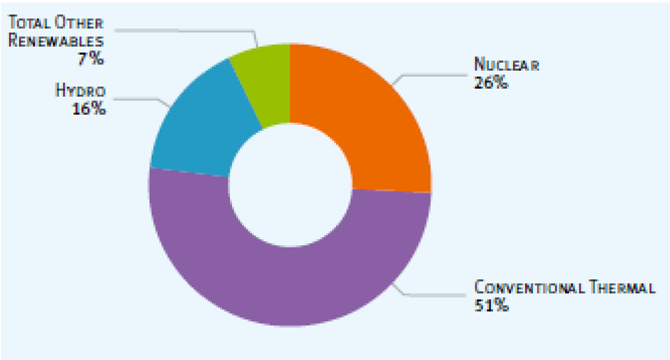

Fig. 1
Structure of electricity generation in EURELECTRIC Europe, 2009

Source:
EURELECTRIC 2010

In Europe, hydropower is the main renewable electricity generation source (69%), followed by wind (15%), primary solid biomass (7%), municipal waste (4%), biogas (3%), solar (1%) and geothermal (1%) power generation.[3]

The role of hydropower within the different national electricity generation portfolios varies greatly according to geographic conditions, climate, precipitation patterns, the availability of affordable energy supply alternatives, as well as institutional capacities and technical competences. Some countries have abundant water resources which they use almost exclusively for their domestic electricity generation (e.g. Norway, Albania). Other countries do not have the required natural conditions and thus have very little or practically no hydropower production or potential (e.g. Denmark, Belgium, The Netherlands).

In 2009 hydropower generation accounted for 338 TWh in the EU-27 and 553 TWh in EURELECTRIC Europe[4]. Hydropower generation by country is shown in Figure 2.

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[2] *EURELECTRIC is glad for comments which will be checked and taken into account if justified for updates*

[3] *International Energy Agency, 2008a*

[4] *EURELECTRIC Europe refers to EURELECTRIC's European members: EU member states Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, the Netherlands, the UK, plus Croatia, Iceland, Norway, Switzerland and Turkey.*

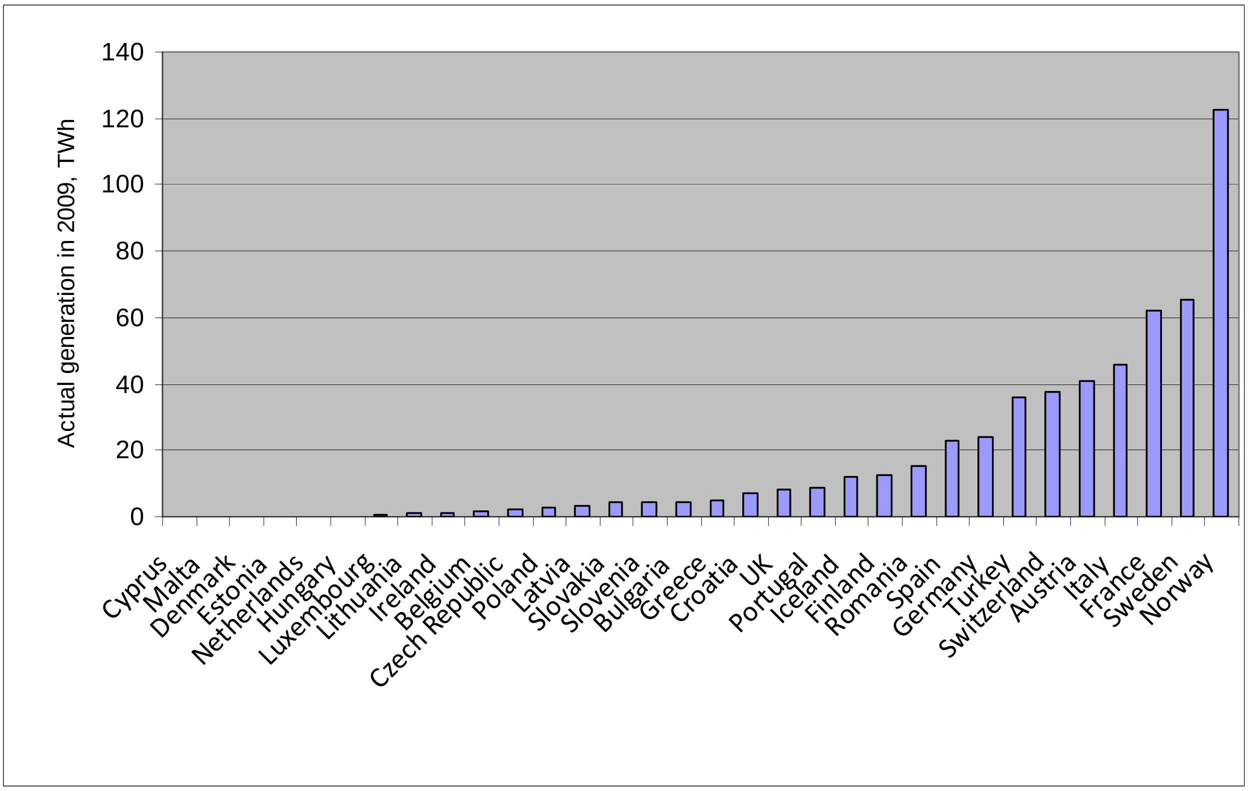

Fig. 2 Electricity generated by hydropower in EURELECTRIC Europe, TWh, 2009
Source: Own calculations, based on 2010 World Atlas & Industry Guide.[5]

Non-EU members Albania, Bosnia-Herzegovina, Former Yugoslav Republic of Macedonia, Moldova, Montenegro, Serbia and Ukraine also have hydropower industry and thus bring an additional 37 TWh of hydropower generation into the picture.[6]

According to the various national hydropower inventories[7], total installed hydropower capacity is 136 GW in the EU-27, with an additional 62 GW in Norway, Switzerland, Turkey, Croatia and Iceland combined. Thus, hydropower represents around 17% of the total installed capacity in the EU-27 and 20% in EURELECTRIC Europe (Fig. 3).

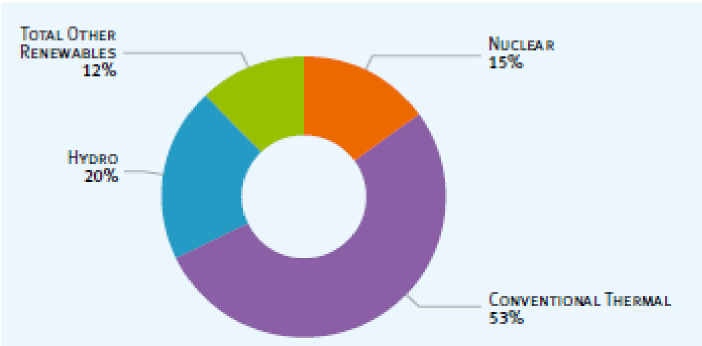

Fig. 3
Structure of installed electricity generation capacity in EURELECTRIC Europe, 2009

Source
EURELECTRIC 2010

[5] *World Atlas & Industry Guide 2010*

[6] *ibid. pp. 16 - 17*

[7] *ibid. pp. 16 - 17*

Figure 4 shows installed hydropower capacity per country. Several countries such as Cyprus, Malta, Estonia, Denmark, the Netherlands and Hungary do not have significant hydropower capacities installed and together provide merely 108 MW – these capacities therefore do not appear in Figure 4.

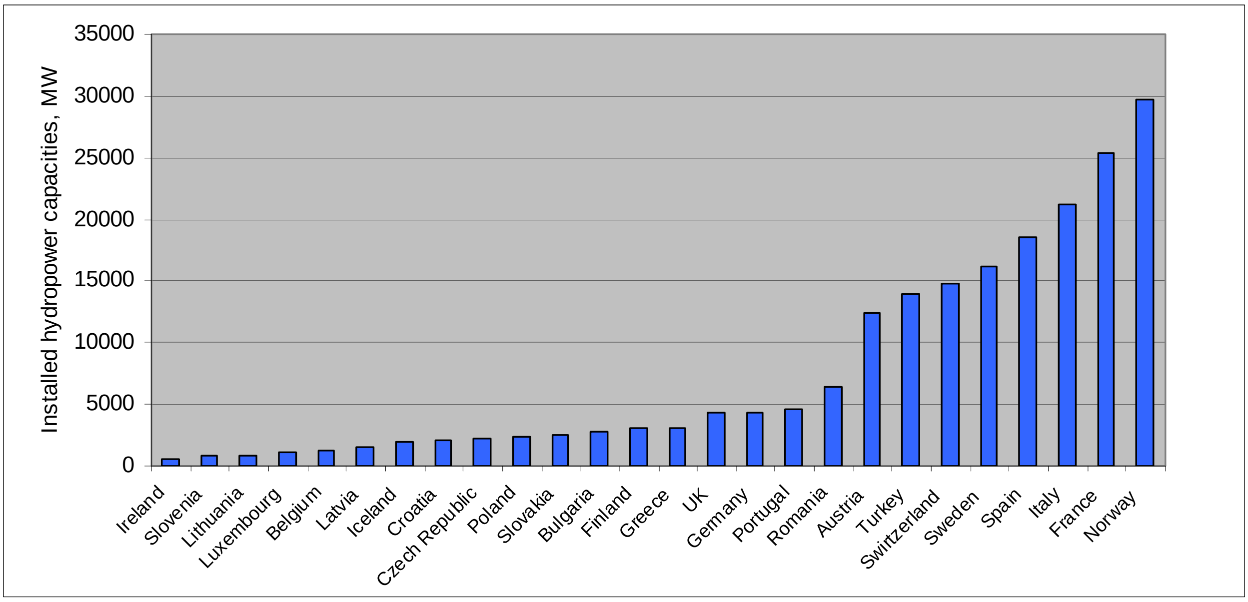

Fig.4 Installed hydropower capacities in MW in EURELECTRIC Europe, 2009
Source: Own calculations, based on 2010 World Atlas & Industry Guide.[8]

The total installed hydropower capacity in non-EU member states Albania, Bosnia-Herzegovina, Former Yugoslav Republic of Macedonia, Moldova, Montenegro, Serbia and Ukraine amounts to 12.5 GW.[9] Thus, looking at Europe from a larger geographical perspective, the total installed capacity is about 210 GW.

The total installed pumped storage capacity in turbine and pumping modes in EURELECTRIC Europe are around 35 and 30 GW, respectively[10]. Figure 5 shows the existing pumped storage capacity (turbine and pumping modes) per country. Data is missing for Italy, Romania and Sweden. In Cyprus, Denmark, Estonia, Hungary, Latvia, Malta, Slovenia and Turkey there are no pumped storage power plants in operation.

[8] *World Atlas & Industry Guide 2010*

[9] *ibid.*

[10] *Not including Italy and Romania since data for these countries are missing*

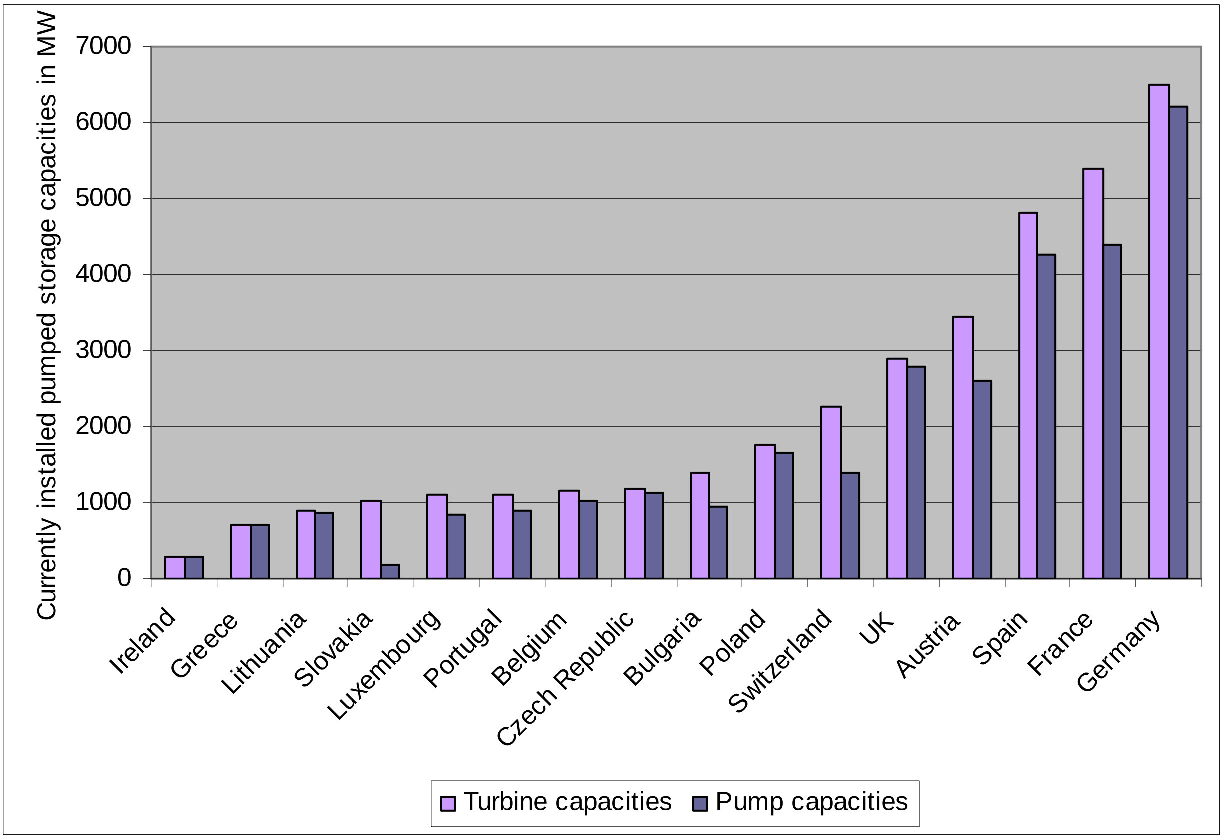

Fig. 5 Installed pumped storage capacities in MW in turbine and pumping modes
Source: EURELECTRIC[11]

In Norway and Sweden the building of pumped storage power plants has so far not been economically profitable, since these countries have many conventional storage hydropower plants, which effectively take care of all power system service needs. While pumped storage power plant in the traditional sense does not exist, a few Norwegian hydropower plants are used once a year during the wet season to pump excess water into higher located reservoirs. This maximises the long-term storage capacity and increases flexible power generation.

2.2. Remaining hydropower potential in Europe over 650 TWh a year

Although most of the best sites for hydropower plants have already been developed in Europe, **at present only about half of its technically feasible potential[12] has been developed for EURELECTRIC Europe and only about one third in the non-EU member states.[13]** There is thus additional potential of 600 TWh a year in EURELECTRIC Europe

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[11] *EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe*

[12] *The technically feasible hydropower potential per year is defined as the total hydropower generation potential of all sites that could be developed within the limits of the current technology regardless of economic or other considerations such as regulatory constraints or environmental preferences. For this report, the technical potential is used as a reference, as the economic potential fluctuates according to oil and gas prices and special incentives.*

[13] *Albania, Bosnia-Herzegovina, Moldova, Former Yugoslav Republic of Macedonia, Montenegro, Serbia, and Ukraine*

(of which 276 TWh a year in the EU-27), and of about 60 additional TWh a year in the non-EU member states – more than 650 TWh a year in total.[14]

Figure 6 shows developed and still available technically feasible hydropower potential per country in TWh. Denmark, Estonia and the Netherlands have very small hydropower generation today and with comparatively little development potential. Malta has neither hydropower generation, nor any potential. In total, the four countries make up only 0.178 TWh of hydropower generation a year and represent 0.6 TWh of hydropower potential that could still be developed. They are therefore not included in Figure 6.

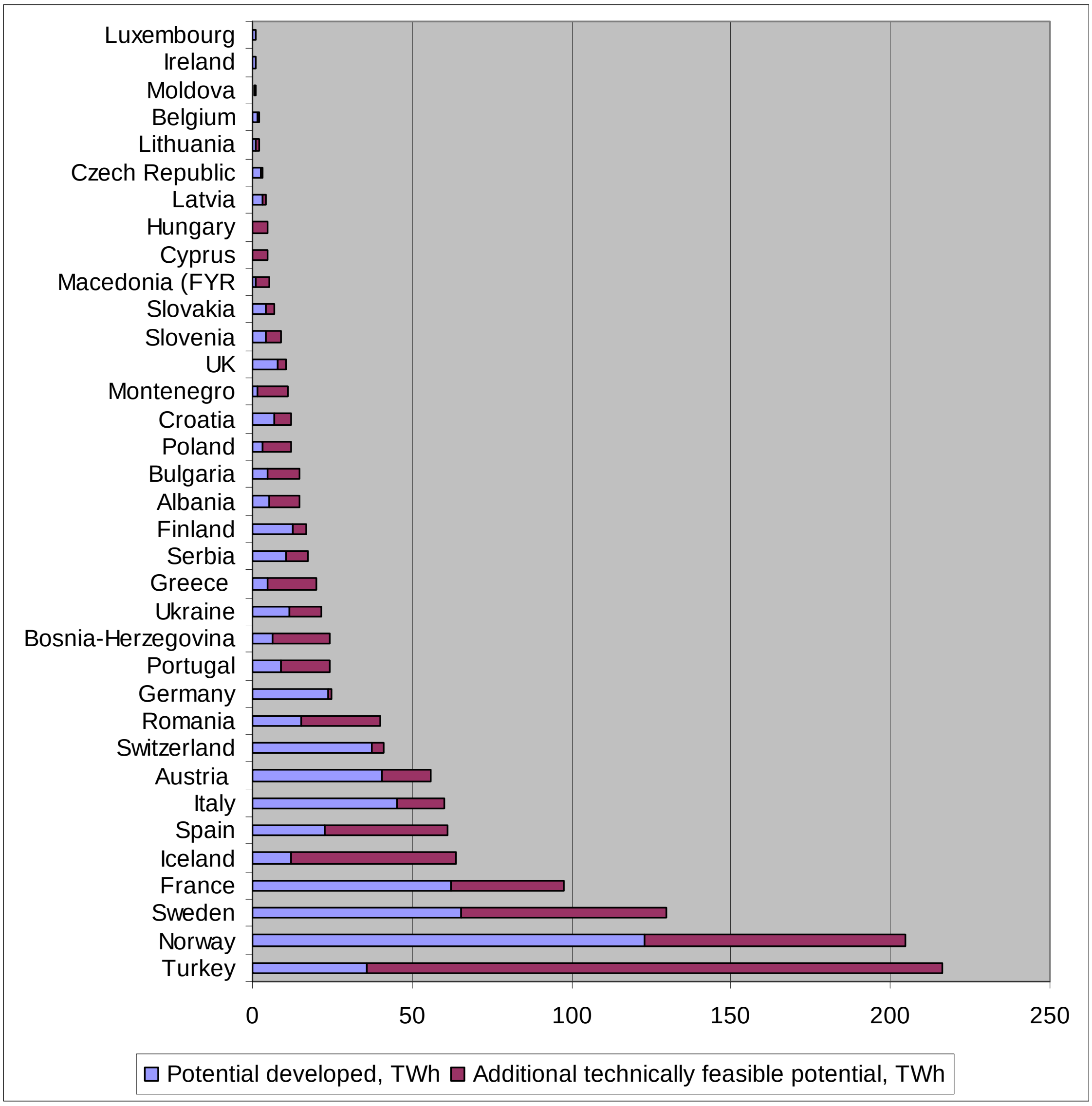

Fig. 6 Developed and remaining technically feasible hydropower potential in Europe per country in TWh

Source: Own calculations based on World Atlas & Industry Guide.[15]

[14] *World Atlas & Industry Guide 2010*

[15] *World Atlas & Industry Guide 2010; Electricity Authority of Cyprus for the data on remaining potential in Cyprus*

2.3. Pumped storage as the battery for v-RES

Pumped storage power plants provide important balancing and ancillary services, facilitating the integration of v-RES. According to the results of the EURELECTRIC questionnaire on pumped storage hydropower plants in Europe (see Annex 1), if all plants with obtained construction licence and all projects at an early planning stage were realised, the total installed pumped storage capacity in EURELECTRIC Europe would rise to over 30 GW.[16] Russia has an additional 7 GW of pumped storage capacity potential (both licensed projects and those in early planning).

Although large pumped storage capacities have already been installed, significant pumped storage potential in Europe remains. Figure 7 gives an overview of existing pumped storage capacities, licensed projects and projects at an early planning stage. Not only are countries with experience in pumped storage technologies planning to build new plants, but so are countries such as Cyprus, Estonia or Hungary that have no pumped storage plant in operation today and no or relatively small hydropower generation. For France, the data delivered in the French NREAP[17] have been used. Data for Romania, Italy and Sweden are missing. For Norway, only one project that is in early planning stage is shown, although preliminary technical feasibility studies on pumped storage potential in Norway indicate that additional pumped storage capacity of up to 20 GW could be installed by using existing reservoirs.

The following sections describe the contribution of existing, licensed and planned pumped storage power plants to the storage of excess electricity. Licensed pump-storage means here in advanced planning stage, eventually commissioned or under construction, whereas planned means 'in an early planning stage. Without this battery function, electricity exceeding instantaneous demand could not be fed into the system and generation would be lost.

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16 *Pumped storage potential in Norway has been preliminarily assessed at between 10-20 GW, which has not been taken into account in this figure.*

17 *République Française 2009, p. 98*

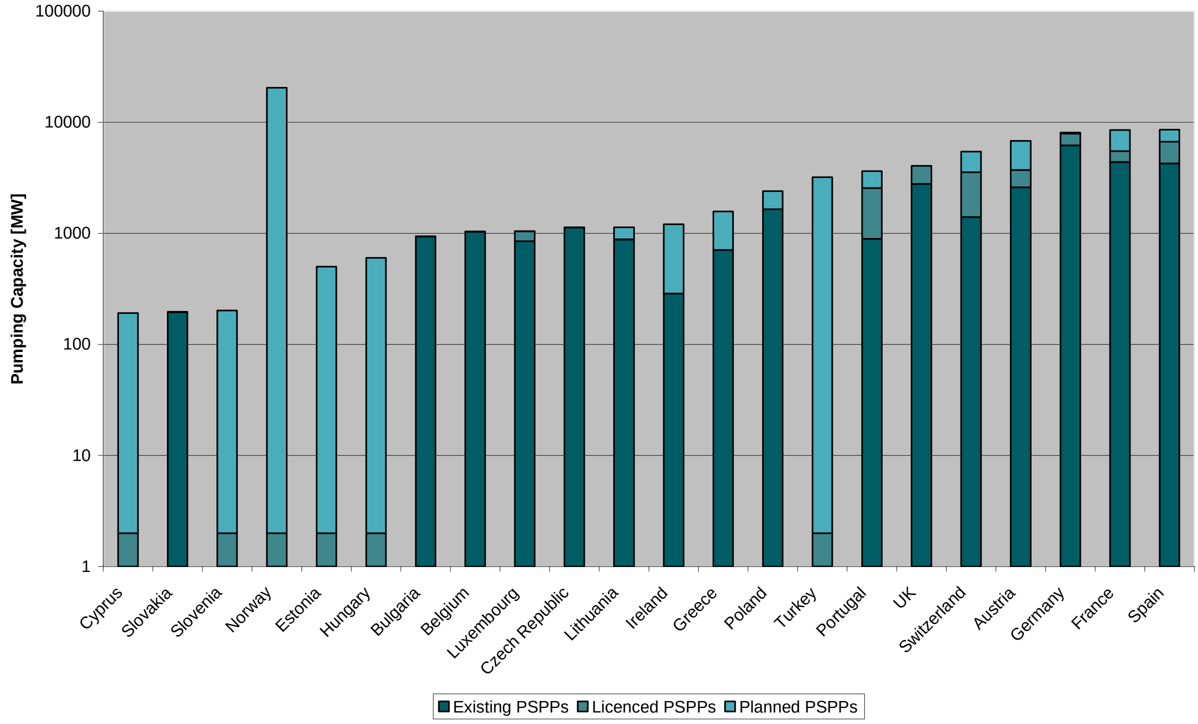

Fig. 7 Installed pumped storage capacities, licensed pumped storage capacities and capacities of pumped storage projects in early planning stage (LOGARITHMIC SCALE), MW

Source: EURELECTRIC[18]

The following analysis is based on the data received from the EURELECTRIC questionnaire[19], completed with additional information from the Internet, where data gaps could be filled[20]. The major obstacle in providing a truly European outlook lies in some countries not communicating their plant-specific data due to confidentiality concerns or difficulties in collecting and projecting the data. This is especially the case for data on pumped storage power plants in an early planning stage. No general assumptions can be made to fill in the missing data since pumped storage plants have very different, site-specific characteristics.

Contribution of existing pumped storage power plants

Information on available pumping capacity (as shown in Figure 7) is not sufficient to assess the battery function of countries or of individual pumped storage power plants. Capacity has to be related to energy. Figure 8 shows on a logarithmic scale for each country the total amount of energy that can currently be stored in one "ideal" pumping cycle[21]. Data is missing for Italy, Romania and Sweden. The figure on the top of each bar indicates this amount for each country.

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[18] *EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe*

[19] *ibid.*

[20] *Additional information was used to calculate the battery function of France, Switzerland and the UK.*

[21] *An ideal pumping cycle is defined as follows: all the upper reservoirs are empty, the lower reservoirs are full and water is pumped up with maximum capacity until either the upper reservoir is full (no more reception capacity) or the lower reservoir is empty (no more ejection capacity).*

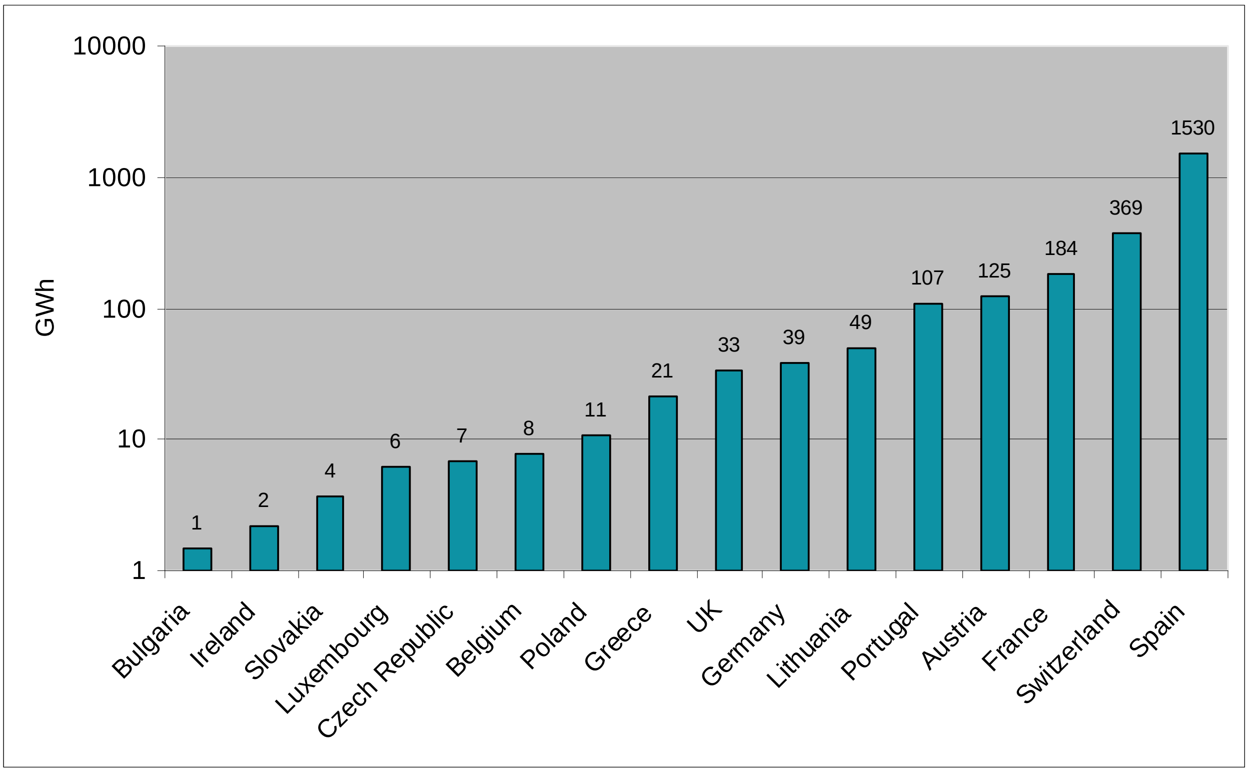

Fig. 8 Total amount of electricity (logarithmic scale) that can currently be stored in one ideal pumping cycle.
Source: EURELECTRIC[22]

Spain can currently store by far the highest amount of excess electricity (1,530 GWh in 17 pumped storage power plants), followed by the alpine countries Switzerland (369 GWh in 16 pumped storage power plants), France (184 GWh in 9 pumped storage power plants) and Austria (125 GWh in 15 pumped storage power plants). The 16 countries for which data is available (see Figure 8) can together store a total of 2.5 TWh in one ideal pumping cycle.

Obviously, the duration of a cycle differs between power plants and this temporal dimension is another essential characteristic of the battery function of pumped storage power plants. However, it cannot be realistically expressed in and compared with a single parameter (the amount of energy uptake is always dependent on time). Since plant-specific information is not available for most EURELECTRIC countries, the temporal availability of the European-wide storage function cannot be unequivocally reported here.

Plant-specific data is available for Austria, France, the United Kingdom, Spain and Switzerland and the pumped storage functions of these countries is represented in Figure 9. The surfaces below the graphs represent the total amount of electricity (MWh) that can be stored.

[22] *EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe*

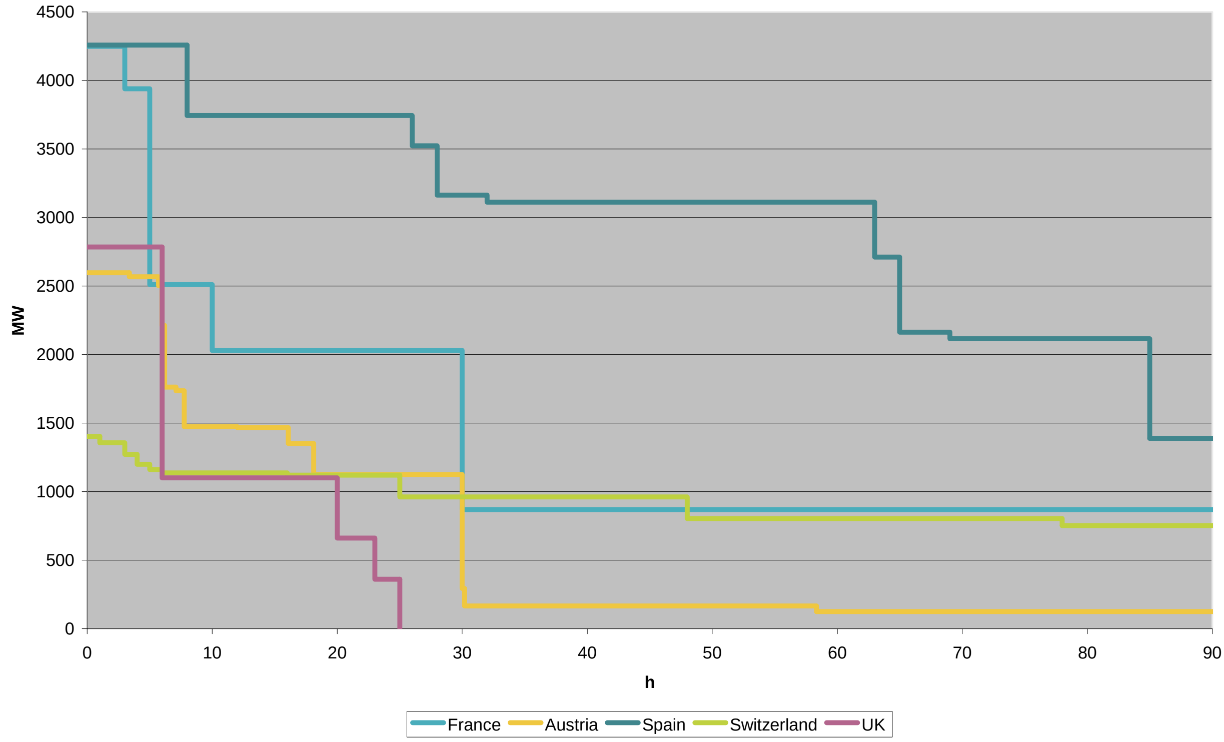

Fig. 9 The pumped storage functions of Austria, France, the United Kingdom, Spain and Switzerland in the first 90 hours of an ideal pumping cycle.

Source: EURELECTRIC[23]

Figure 9 shows the contribution of different "types" of pumped storage power plants to the energy storage function of individual countries. While during the first hours of an ideal cycle the full capacity is available, pumped storage power plants with limited reservoir capacities are the first to stop operating. The contribution of this "daily storage" is, due to number and often quite high pumping capacities, significant but only available for a very limited amount of time. The services that are delivered during these first hours are, however, critical for the security of supply of the national and European electricity systems.

Differences in daily storage between the above countries are obvious. While after one day the UK's entire pumping capacity is exhausted, the capacity of Spain still amounts to 3,744 MW (88% of the initial, maximum capacity). Pumping capacities of Austria, France and Switzerland drop to 43%, 48% and 80% respectively.

"Weekly storage" in turn manages to maintain the pumping capacity at a lower level for several days and weeks. After one week, pumping capacity in France is exhausted and the capacities of Austria, Spain and Switzerland drop to 5%, 24% and 54% respectively.

"Yearly storage", finally, is capable of pumping water for a long period of time. The ideal pumping cycle ends in Austria, Spain and Switzerland after 28, 232 and 106 days respectively. However, these "last" pumped storage power plants have only very

[23] *ibid.*

limited capacities and are often dispatched differently from the “powerful” pumped storage power plants, with the goal of transferring water (e.g. for irrigation or transfer purposes), not primarily for storing excess electricity.

Anticipated contribution of licensed pumped storage power plants

Eight countries in EURELECTRIC Europe have obtained licences to build new pumped storage power plants with a total installed pumping capacity of 11.6 GW (see Figure 7).[24] Licensed pumping mode capacity and the maximum full-load operation hours of the new pumped storage power plants in these countries are shown in Table 1. Blank cells indicate missing data.

Country	Licensed pumping capacity	Maximum time of full load operation
Luxembourg	194 MW	6 hours
France	1,100 MW	
Austria	1,115 MW	127 hours
UK	1,260 MW	
Portugal	1,660 MW	38 hours
Germany	1,700 MW	13 hours
Switzerland	2,140 MW	61 hours
Spain	2,424 MW	52 hours
Total	**11,593 MW**	

Table 1 Total pump capacity and maximum time of full-load operation of licensed pumped storage power plants
Source: EURELECTRIC[25]

Anticipated contribution of pumped storage power plants in early planning stage

Eighteen countries in EURELECTRIC Europe have new pumped storage facilities in an early planning stage (no licence yet). The total installed pump capacity of these plants is over 19 GW.[26] The total installed pump capacities for pumped storage power plants at an early planning stage are shown per country in Table 2. Blank cells indicate missing data.

[24] *EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe; no data received from Italy*

[25] *ibid. and own research.*

[26] *EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe; no data received from Italy*

Country	Pumping Capacity	Maximum time of full load operation
Germany	195 MW	9 hours
Slovenia	200 MW	4 hours
Cyprus	190 MW	11 hours
Lithuania	250 MW	51 hours
Sweden	250 MW	
Norway	445 MW	
Estonia	500 MW	15 hours
Hungary	600 MW	
Poland	750 MW	6 hours
Greece	864 MW	
Ireland	920 MW	10 hours
Portugal	1,080 MW	38 hours
Slovakia	1,700 MW	
Spain	1,885 MW	22 hours
Switzerland	1,900 MW	
Austria	3,075 MW	47 hours
France	3,000 MW	
Turkey	3,200 MW	7 hours
Total	**19,304 MW**	

Table 2 Total pump capacity and maximum time of full-load operation of the pumped storage power plants in early planning stage
Source: EURELECTRIC[27]; NREAP for France

These numbers show that technical feasibility is definitely not limiting the development of more flexible generation capacity from hydropower. Chapter 4 will highlight some of the major policy challenges which stand in the way of fully developing the storage capacities required by the integration of more v-RES in the European system.

This chapter has clearly highlighted the difficulties of assessing the storage functions of individual power plants and entire countries. Battery functions cannot be expressed and compared with a single number since capacity must be seen in relation with time (i.e. the actual availability of the maximum capacity). Moreover, many pumped storage power plants in mountainous regions are integrated into complex, pre-existing hydro storage systems with natural inflows. Data on such systems is not always reported in a consistent way. We also insist on the point that capacity can be increased manifold, beyond new projects, in upgrading existing plants.

Overall, current data collection procedures – and therefore also currently available data – do not sufficiently account for these complexities. Thus there is clearly a need to improve and harmonise hydropower data collection on an European level (see also policy recommendations in Chapter 6). There is no data available on hydrostorage with no pump storage. Insufficient data on hydro, as was outlined already in the beginning

[27] *EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe*

of this chapter, make this work work in progress, and we welcome all comments and contributions to this first data gathering.

3. CHARACTERISTICS OF HYDROPOWER

3.1 Key features of the electricity system

The electricity system can only function properly if electricity generation (supply) matches electricity demand (consumption). Planning generation according to the forecasted demand is therefore essential.[28] These plans, however, are not always met. Therefore any change in electricity demand or generation needs to be met by an equivalent adjustment either on the supply or the demand side. In other words, there is a need for balancing the plans. This is done through market actions or in some cases via TSOs.

Real-time demand and supply vary constantly. In a short timescale an unbalanced situation in the electricity system will cause frequency to deviate from normal ranges, i.e. to rise if generation is too high or to decrease in case generation is too little. Frequency deviations may cause stress on electric devices and jeopardise the stability of the whole electricity system, potentially causing blackouts. Therefore automatic frequency control, or primary control, is introduced to make generation units act on frequency deviations and change their generation within a few seconds. Secondary control, which is not automatic, is introduced when the generators used for primary control are reset to their original load and other generators change their generation plan instead. Both primary and secondary control are handled by TSOs through contracting generation plants and pumped storage hydropower plants.[29]

Thus, the TSOs together with electric power utilities have to ensure continuous and stable power supply at the lowest possible cost by coping with a wide range of electricity demand fluctuations.

In addition to these well-known variations in demand patterns, an increasing amount of v-RES contributes significantly to the challenge of keeping the electricity system in constant balance.

In a purely conventional power plant portfolio the load or the required/delivered amount of electric power falls into three categories: base load, intermediate load and peak load.

Base load refers to a relatively constant output of power plants over a period. It is typically delivered by power plants that are designed to generate electricity at a constant rate of output. In contrast, peak load refers to surges in electricity demand that occur at specific, usually predictable periods (i.e. evening peak load, when consumers simultaneously switch on lighting and other electric appliances). Due to their greater responsiveness, peaking power plants are able to provide electricity when demand is at a high. Finally, intermediate load refers to a situation where power

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[28] *Electricity demand is variable throughout the year. More electricity is consumed in winter than in summer. However, daily electricity demand always follows a similar pattern.*

[29] *The Nordic countries are an exception. They represent an example of a fully developed marketplace for balancing.*

output increases every morning and throughout the day and decreases in the evening. Intermediate load power plants run considerably more hours than peaking units, but fewer hours than base-load power plants.

Different types of electricity-generating plants are differently suited to operation as base-load plants or peaking units. Figure 10 shows the typical generation mix of a hydro-dominated system without nuclear power. In general, nuclear run-off-river and conventional thermal power plants are covering the base load demand. Utilities like gas-fired power plants and hydro storage power plants cover the peak load demand. Pump storage facilities are the only renewable energy source which can support the system by highly flexible power generation ancillary services (Tab. 3) and peak load generation. As shown in Fig. 10 pump storage power facilities are enabled to replace renewable or thermal power plants from base load to peak load generation.

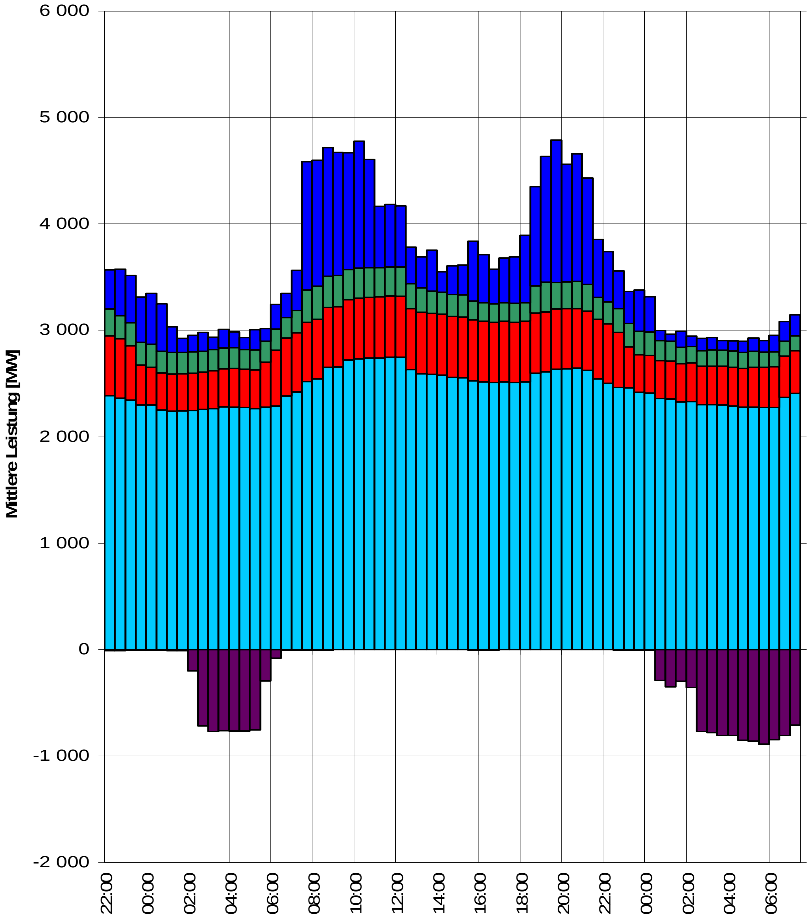

Fig. 10 Hydro power provides needed flexibility
Source: Verbund Hydro Power AG

Pumped storage Run-off- river Conventional thermal power plant

Short term hydro storage power plant (daily reservoir)

Long term hydro storage power plant (annual reservoir)

The capacity of the transmission lines also plays an important role in balancing the network. There is a need for transmission lines with sufficient capacity to connect generation and demand hubs. Improving cross-border conditions is an issue that needs to be addressed.

3.2. The different types of hydropower

Hydropower is a site-specific technology which is tailored to the features of a specific context (to suit particular energy and water management needs); therefore different types of hydropower plants exist. The design of a hydropower plant significantly depends on the local topography and geomorphology.

Hydropower is based on a simple concept: taking advantage of the gravitational energy that is set free by falling water. In all hydropower plants water flows through turbines which convert the water's energy (potential and/or kinetic) first into mechanical and then into electrical energy. Figure 11 illustrates this concept.

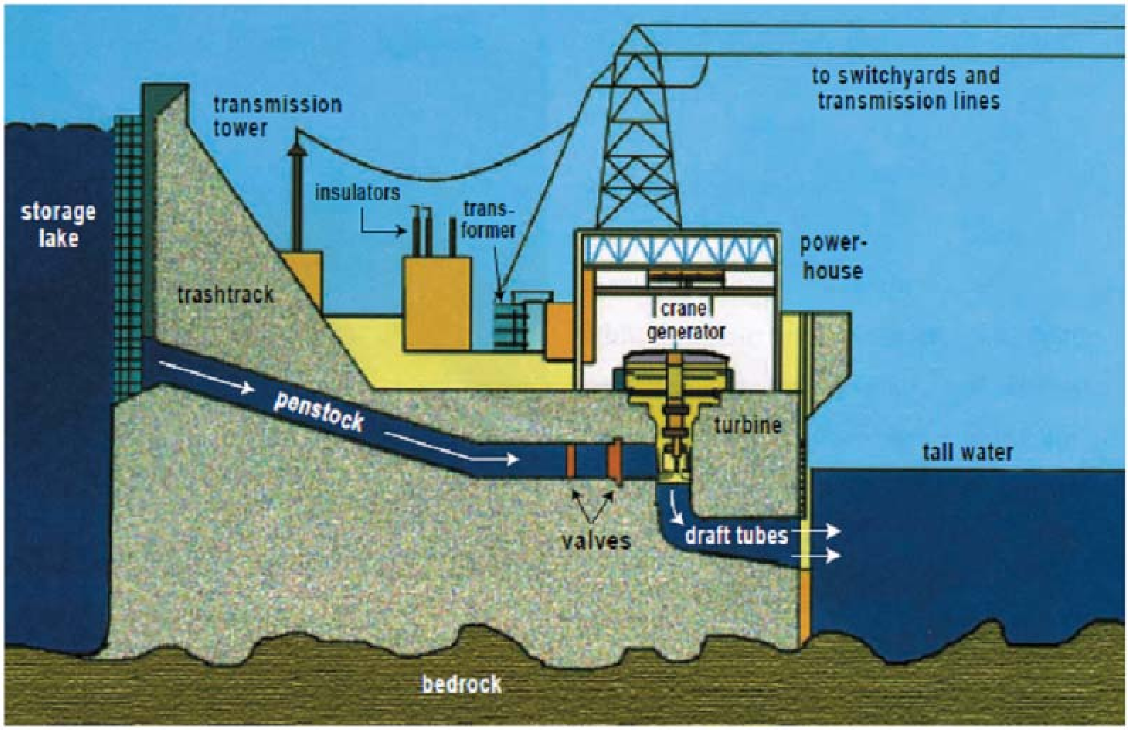

Fig. 11 Principle of a Hydropower Plant.

Source: IEA[30]

Although hydropower plants are designed on an individual basis, a broad distinction can be made between run-of-river plants and reservoir- or storage-type projects (conventional storage and pumped storage hydropower plants).

Run-of-river hydropower plants – base-load plants

Description

Run-of-river power plants use the flow of water from upstream without any substantial storage. This may be a natural flow or flow determined by other water use upstream. Run-of-river power plants use the flow of water within a river's natural range. These

[30] *IEA 2000, p.11*

plants are designed to use either a large flow rate with small head on large rivers with gentle gradient, or a small flow rate with high head in mountain areas. Pictures 1 and 2 show a low head run-of-river power plant and a high head run-of-river power plant in northern Norway, respectively.

Picture 1 Freudenau run-of-river power plant in Austria (a low head run-of-river power plant)
Source: Verbund

Picture 2 Nore power station – a high head run-of-river plant in Norway
Source: IEA

Electricity output of run-of-river power plants depends on the availability of water in the river and varies considerably throughout the year. Seasons, rainfall or snowmelt all influence the amount of water available for electricity generation. Because they lack storage, run-of-river power plants operate under the constraint of precisely controlling the water level at the intake in accordance with incoming river flow. Run-of-river hydropower plants without connection to upstream storage typically operate as base-load power plants since the hydrological forecast is sufficiently good for the timescales required in the electricity market.

Services

Run-of-river hydro plants have little or no storage capacity. Therefore they offer only very short-term storage possibilities (few minutes dynamic cycle), thus allowing for some adaptation to demand, especially for ancillary services such as frequency and voltage control.

Cascading hydropower schemes – a well orchestrated system

Other, upstream hydropower plants or reservoirs have to be taken into consideration when looking at the energy output of a run-of-river plant. A constant output from a run-of-river hydropower plant is possible if the river is already regulated further upstream by a hydropower plant with storage capacity (thanks to the reservoir). A commonly used strategy to optimise the energy output of hydropower plants on a river is to build a large storage reservoir in the upper catchment which will even out flows for several run-of-river or smaller reservoir plants downstream, as illustrated in Figure 12. Figures under each plant indicate how high from the sea level they are located.

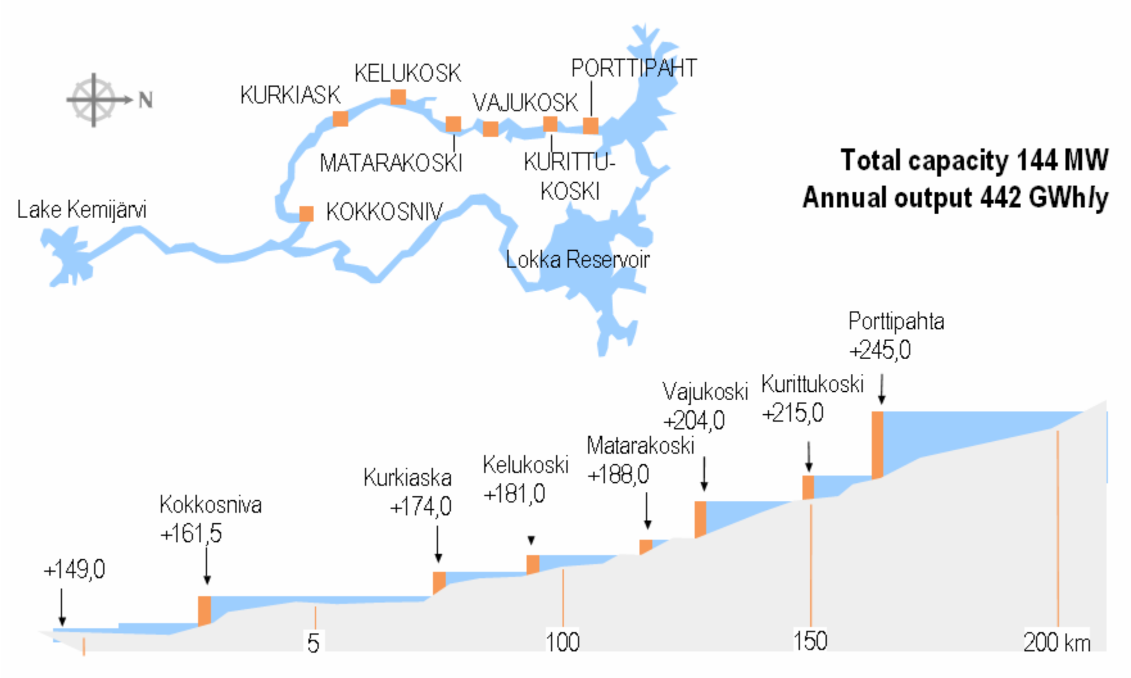

Fig. 12 Illustration of hydro chain concept on the Kitinen river in northern Finland
Source: Kemijoki OY

Beyond the energy storage function of reservoir plants, regulating a river in the upper area of a river basin with a reservoir will increase the energy potential of sites downstream, as the regulated river will typically flow more evenly throughout the year. As demonstrated by the example in Figure 12, multiple run-of-river power plants can be developed downstream of a reservoir type hydropower plant. That way, water is “re-used” to produce additional electricity as it flows down the same river. The combined cascade of dams and reservoirs allows an optimised electricity generation and may also be used to absorb excess energy when reducing river flow, thereby strongly enhancing the storage function from the upper reservoir.

<u>Reservoir-type hydropower plants – our flexibility tools</u>

Description

Reservoirs reduce the dependence on the variability of the natural inflow and enable adjustments of power generation to the variability in demand. These plants are operated on a scheduled basis in accordance with data regarding water flow forecast, market price and consumption. These plants are commonly used for intense load following and to meet peak demand. Generation of peak-load energy from reservoir-type hydropower plants allows the optimisation of base-load power generation from other less flexible electricity sources such as nuclear and thermal power plants. Generally, hydropower plants with reservoirs (also called storage-type power plants) introduce unique benefits to electricity system (described in more detail below in the subsection on services).

There are two types of storage hydropower plants:

a) hydropower plants with a storage reservoir; and
b) pumped storage hydropower plants.

The larger the reservoir of a hydropower plant, the more storage it can provide. Conventional reservoir-type hydropower plants generally have a more significant storage capacity in terms of volume than pumped storage plants. Pumped storage plants are used for short-term activities (within a day or week) and can adapt to electricity system needs very quickly. Larger conventional reservoirs are used for long-term storage but have in most cases also capacity to participate in short-term activities.

a) hydropower plants with a storage reservoir

Reservoir-type hydropower plants involve impounding water behind a dam. This enables flow regulation throughout a season or the year. Hydropower plants with large reservoirs can provide flow regulation even on a multi-annual basis. Large reservoirs not only provide an energy reserve to satisfy electricity demand during dry seasons and/or periods of peak demand, but they also allow the retaining of more water.

Reservoir-type hydropower plants are typically used for highly variable flows in the middle reaches of a river, or as energy storage in the upper reaches of a river. Reservoir-type hydropower plants on gorge or canyon systems also deliver high capacity.

Pictures 3 and 4 show examples of reservoir-type hydropower plants.

Picture 3 Orellana – a reservoir plant in Spain

Source:

Picture 4 Blåsjø reservoir of the Ulla-Førre hydropower scheme in Western Norway

Source: Statkraft 2011

The generating stations of reservoir-type hydropower plants are usually located at the dam toe, although they can sometimes be found further downstream. In the latter case the power plant is often connected to the reservoir by tunnels or penstocks (gates for water).

In areas with mountain plateaus and high-altitude lakes, these natural water bodies can be used as reservoirs which often preserve the characteristics of the original lakes. In these kinds of settings the power plant is often linked to the lake, serving as a reservoir via tunnels which are built like a drain under the bottom of the lake. This practice is also called lake tapping. For example, in Scandinavia natural high-altitude lakes often form the basis for high-pressure systems where the differences in height between the reservoir and the turbines may reach over one thousand metres. In other areas, it is common to create artificial lakes by inundating river valleys. A power plant can have tunnels connected to several reservoirs and can also be linked to neighbouring river basins via such an underground tunnel system.

Hydropower plants with a small reservoir are sometimes also called pondage plants. They are designed to modulate generation on a daily or maximum weekly basis. Pondage plants can provide flexibility services mainly through balancing power. They also provide frequency and voltage control as ancillary services.

Services
Hydropower plants with large reservoirs, compared to pure run-of-river or pondage hydropower plants, offer a very high level of services. First, and as a most fundamental asset, they provide long-term, large-scale energy storage during periods of low demand and can make this energy immediately available when the demand rises, for example during peak consumption periods. Second, their fast response time of less than 5 minutes enables them to instantaneously meet sudden fluctuations in demand. No other electricity production system can offer a comparable level of services.

These plants also provide the full range of ancillary services, including frequency and voltage control and black start capability. Black start capability refers to the situation where a prepared plan for starting up can be put into practice in case a total breakdown of electricity supply occurs. A group of hydropower plants is prepared for the task to excite a major transmission line and be able to start to take up load from different areas.

b) Pumped storage hydropower plants

Description
Pumped storage hydropower plants operate with two reservoirs: a lower and an upper one. A river, a lake or an existing reservoir can serve as either reservoir. In other cases a new reservoir must be created, the characteristics (i.e. size) of which depend on the site’s topographic and hydrological conditions. Figure 13 illustrates the concept of a pumped storage power plant.

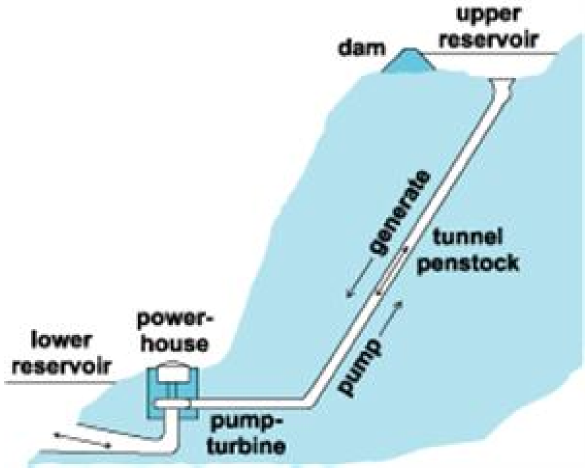

Fig. 13 Illustration of the operating principle of a pumped storage hydropower plant.
Source: Mechanical Writings [31]

Pumped storage power plants are characterised by:

- Installed capacity in pumping mode and in turbining mode (from several MW to more than 1,000 MW); and
- Storage capacity of two reservoirs determining the duration time for operation at full capacity.

Depending on whether either of the reservoirs is part of the natural river system, or whether both reservoirs are human-made storage basins, pumped storage hydropower plants can fall into one of two categories:

i) mixed pumped storage hydropower plants; and
ii) pure pumped storage hydropower plants.

Mixed pumped storage hydropower plants have natural inflow; pure pumped storage hydropower plants have none.

Picture 5 shows an example of a pure pumped storage hydropower plant with artificial reservoirs (upper and lower) outside the Leine river system (central Germany), while Picture 6 illustrates the concept of a mixed pumped storage hydropower plant using two natural lakes as lower and upper reservoir in southern Germany.

[31] *http://www.mechanical-writings.com/pumped-storage-power-plant/#entrymore*

Picture 5 Erzhausen – pumped storage hydropower plant with artificial reservoirs in Middle Germany

Source: Statkraft

Picture 6 Hydropower System Glockner Kaprun – a mixed pumped storage hydropower plant in Austria

Source: Verbund

Pumped storage power plants are operated on daily and weekly cycles and are designed to provide peak electricity during periods of high electricity demand. This can be done in a very short time, i.e. within minutes. The water is released from the upper reservoir through the turbines to generate electricity. However, the duration of electricity supply from pumped storage hydropower plants is limited. The upper reservoir normally contains a certain amount of water that can provide full operation during several hours.

Water is typically pumped up from the lower to the higher-level reservoirs during off-peak periods (i.e. during the night) using surplus electricity generated by conventional base-load power plants. The market electricity price also has an impact on when the water is pumped up: usually this happens when the electricity price is lowest.

In the EU electricity generation from pumped storage hydropower plants is not considered as renewable, since pumping the water up consumes electricity produced by other power plants in the grid and pumped storage power plants thus become net energy consumers. In fact, more electricity is needed to pump water from the lower to the upper reservoir than is generated when water is released from the upper reservoir into the lower one (overall efficiencies are in the range of 70-75%). However, this drawback is compensated for by the flexibility these plants can provide.

Pumped storage power plants are important to optimize the operation of the conventional thermal generation fleet. As pumped storage power plants cover peak-demand situations while consuming electricity in periods of lower demand, they allow thermal power plants to stay connected and generate electricity even when demand is low. Through this optimisation effect, pumped storage power plants also contribute to reducing greenhouse gas (GHG) emissions from thermal power plants, as they need not deviate from the most efficient load.

Pumped storage facilities work as a huge electricity storage resource by charging or discharging power according to the system's demand. Compared to conventional reservoir-type hydropower plants, pumped storage power plants use the water stored in the reservoirs repeatedly and do not need natural inflow into the reservoirs.
The role of pumped storage hydropower plants is twofold: balancing the grid for demand-driven fluctuations, and balancing generation-driven fluctuations – a new and increasingly important role due to the increase of v-RES in the electricity system[32].

Services
Like conventional reservoir-type hydropower plants, pumped storage power plants can provide the full range of grid-stabilising services, thanks to their ability to follow demand or generation fluctuations within only a few minutes.

Therefore storage hydropower is a key tool for TSOs to maintain a stable and balanced grid. Table 3 below summarises these grid-stabilising services, which are also called ancillary services.

Back-up and reserve	**Hydropower plants** have the ability to enter load into an electrical system from a source that is not on-line. **Hydropower** can provide this service while not consuming additional fuel, thereby ensuring minimal emissions.
Quick start capability	**Hydropower's** quick-start capability is unparalleled, taking just a few minutes – compared to 30 minutes for other turbines and hours for steam generation. This entails savings in start-up and shut-down costs of thermal plant and allows for a steadier operation, saving fuel and extending plant life.
Black start capability	**Hydropower plants** have the capability to run at a zero load. When loads increase, additional power can be loaded rapidly into the system to meet demand.
	Systems with available **hydroelectric** generation are able to restore service more rapidly than those solely dependent on thermal generation.
Regulation and frequency response	**Hydropower** contributes to maintaining the frequency within the given margins by continuous modulation of active power and to meet moment-to-moment fluctuations in system power requirements.

[32] *Generally, the predictability of v-RES is limited, even with highly sophisticated meteorological models.*

	Hydropower's fast response ability makes it especially valuable in covering steep load gradients (ramp rates) through its fast load-following.
Voltage support	**Hydropower plants** have the ability to control reactive power, thereby ensuring that power will flow from generation to load. They also contribute to maintaining voltage through injecting or absorbing reactive power by means of synchronous or static compensation.
Spinning reserve	**Hydropower** supports the dynamic behaviour of the grid operation. **Hydropower plants** can provide spinning reserve – additional power supply that can be made available to the transmission system within a few seconds in case of unexpected load changes in the grid. **Hydropower** units have a broad band of operations and normally operate at 60-80% of maximum power. This results in spinning reserve of up to 100%.

Table 3 Ancillary services that storage hydropower plants can provide.
Source: EURELECTRIC 2011

3.3 Hydropower as the flexibility tool

Not all electricity generating technologies have the same technical flexibility when it comes to balancing demand fluctuations or providing back-up capacity for v-RES. Although all generation technologies participate in balancing, hydropower stands out with important benefits compared to other generation technologies.

Hydropower plants may, depending on their design, provide electricity for base load and/or peak load. They are particularly valuable for meeting peak demand situations, as they are more responsive than other generation sources and can be started or stopped within a very short time.

Hydropower units are also able to rapidly increase or decrease their output – at least 10 times faster than conventional power plants.

Table 4 highlights some advantages of pumped storage power plants.

	Nuclear Power Plants	**Hard coal fuelled power plants**	**Lignite fuelled power plants**	**Combined-cycle gas power plants**	**Pumped storage power plants**
Start-up time **cold**	~ 40 hours	~ 6 hours	~ 10 hours	< 2 hours	~ 0,1 hours
Start-up time **warm**	~ 40 hours	~ 3 hours	~ 6 hours	< 1,5 hours	~ 0,1 hours
Load gradient increase **nominal output**	~ 5% per minute	~ 2% per minute	~ 2% per minute	~ 4% per minute	> 40% per minute
Load gradient decrease **nominal output**	~ 5% per minute	~ 2% per minute	~ 2% per minute	~ 4% per minute	> 40% per minute

Table 4 Flexibility of different power generation technologies
Source: VGB/EURELECTRIC33

3.4 Case studies illustrating flexibility

This section illustrates the flexibility of hydropower with summaries of concrete case studies. The cases are discussed more extensively in the annexes.
The selected cases are:

1. Hydropower in the Nordic power system (Annex 1)
2. Offsetting the black-out of 4 November 2006: hydropower's contribution (Annex 2)
3. Pumped storage for integration of v-RES in Germany (Annex 3)
4. The Polish Zarnowiec hydropower plant's contribution to system stability (Annex 4)
5. Norway's important storage capacity and potential (Annex 5)
6. The operational evolution of pumped storage operation in Switzerland (Annex 6)
7. Hydropower in Austria: e=H_2O[34] (Annex 7)
8. Implementation of the EU WFD: challenges for hydropower in the Weser river basin in the Northern Germany (Annex 8)
9. Wind Power and Hydro Storage in Ireland (Annex 9)

[33] *VGB/EURELECTRIC study on technical flexibilities of power plants. Full analysis in the upcoming EURELECTRIC report on requirements for flexible and back-up capacities*

[34] *Energy is water*

CASE STUDY 1 - Hydropower in the Nordic power system

Hydropower represents 55% of the 370 TWh of annual average electricity generation in the Nordic Power System NORDEL, comprising Norway, Sweden, Finland and East Denmark.[35] Hydropower plays a particular role in this system.

First of all, hydropower plants provide flexible generation capable of responding to large load variations (day/night, low/high outside temperatures), since hydropower's storage capabilities in the NORDEL system are huge (120 TWh in a season). Thus, hydropower plants in the NORDEL system are used for handling peak load.

Secondly, hydropower units make the power system more robust as they are capable of handling sudden disturbances in transmission or large generation units. Hydropower units are used for reserve needs in the system and are contracted by the TSOs to provide reserve in case of disturbances such as extreme weather conditions, high load demand, sudden loss of generation in a major nuclear plant, or technical faults in the transmission system.

Several trends observed today will change the future demand of system services provided by hydropower plants in the NORDEL system:

1. A large share of geographically distributed v-RES (here: large-scale wind) will create a significant number of new and different load situations in the grid. These totally new situations may trigger faults not discovered earlier or create a major disturbance in the grid. This may cause an extra need of actions in the power system and/or system services.
2. A fast growing share of v-RES in the system will increase the need to handle power ramps, balancing services and capacity planning. The Swedish TSO estimates that adding 4 GW of wind will require an additional 600 MW of intraday balancing reserve and 900 MW capacity reserve to handle a no-wind situation.
3. A growing intermittency in consumption patterns may add to the intermittency from RES sources, especially for balancing intraday needs.
4. Climate change may increase the frequency of extreme weather situations such as extreme temperatures, heavy storms or snow blizzards, which is why more investments in the power system and prepared services for robustness will be needed.

The hydropower plants in the NORDEL system still have a large remaining potential of regulating capabilities of different kinds. First estimates indicate that this potential in existing plants is double the capabilities present today. However, some of the potential may be restricted due to transmission system bottlenecks. This may apply both within

[35] *Nuclear and fossil energy sources represent 20% and 15%, respectively. 10% of electricity is generated from renewable energy sources other than hydro.*

the NORDEL system and to connections to other parts of Europe. The potential may also be limited by river regulation restrictions.

CASE STUDY 2 - Offsetting the black-out of 4 November 2006: hydropower's contribution

The incident of 4 November 2006 caused electricity supply disruptions to more than 15 million households. The immediate action taken by all TSOs according to the UCTE[36] security standards prevented this disturbance from turning into a Europe-wide blackout.

The chain of events led to occurrence of this disturbance resulting in Europe being split into three areas – Western Europe (Area 1), North-Eastern Europe (Area 2) and South-Eastern Europe (Area 3). The break-up into three systems led to strong disequilibrium between those areas. Because of the large frequency excursions/fluctuations, a significant number of generation units (more than 10,000 MW in the Western area) connected to distribution networks were disconnected from the network due to their protection systems. The investigations identified that non-fulfilment of the N-1 criterion and insufficient inter-TSO coordination were the two main reasons for this disturbance.

In order to quickly restore balance between electricity generation and consumption, several steps were initiated, with hydropower (run-of river, hydro with reservoirs and pumped storage power plants) playing a major role as summarised in Figure 14.

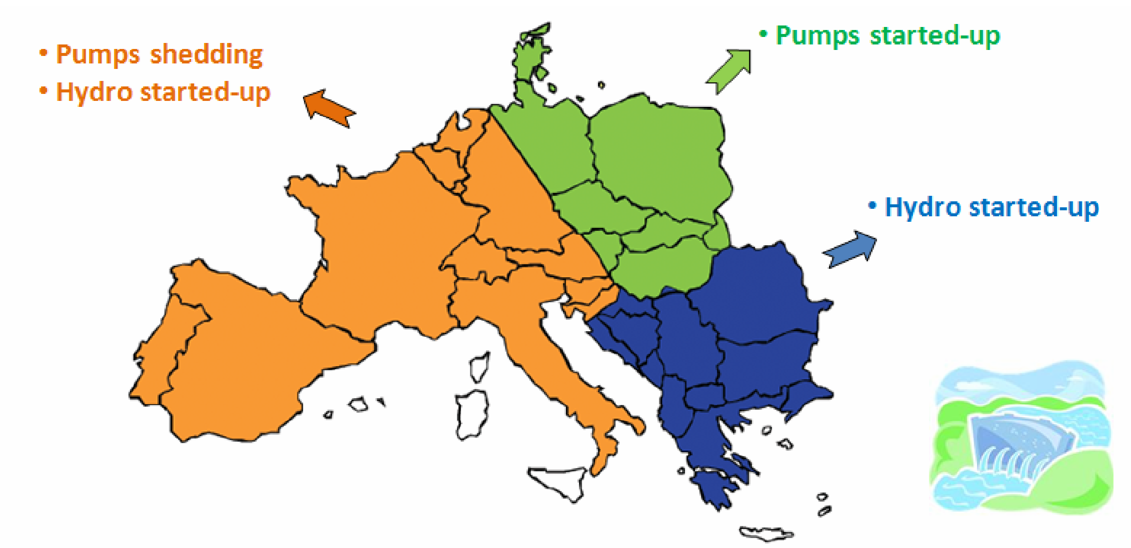

Fig. 14 Hydropower's role during the incident
Source: UCTE, 2007

Zoom on France and the restart of the system by French EDF hydropower plants

[36] *From 1 July 2009 onwards ENTSO-E, the European Network of Transmission System Operators for Electricity, took over all operational tasks of the 6 existing TSO associations in Europe, including UCTE, the Union for the Coordination of Transmission of Electricity.*

In France only run-of river and some storage hydropower plants (in total about 1 GW of capacity) were generating electricity when the incident occurred, at 22:10pm. The hydropower reserves were fortunately very large and could generate more than 5,000 MW within 40 minutes.

CASE STUDY 3 - Hydropower in Austria: e=H_2O

The use of hydropower has a long tradition in Austria and today accounts for over 60% of the total national electricity generation – one of the highest shares in Europe. Austria's electricity system is thus highly dominated by hydropower, with run-of-river hydropower plants providing for the base-load, storage hydropower plants covering the peak loads and pumped storage power plants storing excess electricity in times of low demand, mainly at night and over the weekends.

But this simplified operation pattern is about to change. With its favourable topography, high water availability and central location in the European electricity system, Austria will play an important role as a "green battery", storing excess electricity generated by the intermittent solar and PV plants in southern Europe and wind farms further north.

Annex 7 describes this new role and reflects upon the importance of Austria's hydropower capacity in the future of Europe's electricity supply.

CASE STUDY 4 - The Polish Zarnowiec hydropower plant's contribution to system stability

The flexible units of Zarnowiec, Poland's largest hydropower plant with 716 MW, play an important role in ensuring stability in the national electricity system where coal-fired thermal power plants dominate electricity generation.

The plant is located in a very sensitive area, with huge amounts of wind energy coming from Germany, but also soon from Polish sites, and the consequent need for balancing.

The Zarnowiec pumped storage power plant plays a regulatory function in case of abrupt changes in generation or demand. It also plays an important control and intervention role in the electricity system. In addition, it allows thermal power plants to limit their number of shut-downs and start-ups, lowers power change rates and improves their efficiency.

The Zarnowiec hydropower plant fulfills several essential functions for the Polish national electricity system:

- smoothening of the curve of daily system load;
- intervention operation through fast activation and disconnection units, covering sudden power drops or increases in the system;
- optimisation of the national electricity system by quick and constant regulation;

- controlling reactive power motion in the system (voltage regulation and reactive power control);
- establishment of the rotating reserve by means of second power controlling (primary control) and minute power controlling (secondary control);
- role in rebuilding the national electric power system in case of a system failure.

Zarnowiec was therefore an important part in managing the European blackout of 4 November 2006. Activating pumps helped to stabilize frequency and voltage and to reestablish the system after power failure.

The role of Zarnowiec in voltage control will fundamentally increase in the very near future, as several wind farms are to be built in the area.

CASE STUDY 5 - Norway`s important storage capacity and potential

Europe has three major renewables batteries: Norway and the Scandinavian region, the alpine region, and, to a lesser extent, the Pyrenees. Norway has a 96% share of hydropower generation in its electricity generation portfolio, producing on average 123 TWh of electricity a year. 60-70% of the annual hydropower generation is produced from conventional storage hydropower plants.

Norway has almost half of Europe’s reservoir (storage) capacity. Already today, the generation flexibility of Norway’s storage hydropower enables the integration of a high level of v-RES (>20%) within the Nordic market, mainly from wind in the electricity system of Denmark.

Norway could provide a significant back-up to the continental European electricity system. Preliminary studies on possibilities to expand Norway’s pumped storage capacities demonstrate that there is potential of 10- 20 GW for pumped storage capacities if the existing reservoirs were used in a different manner. However, the following challenges need to be met in order to enable the country to play this role:
- increased transmission capacity between Norway and the European continent;
- increased social acceptance for new transmission lines;
- incentivising business models for pumped storage power plants.

CASE STUDY 6 - The operational evolution of pumped storage operation in Switzerland

The existing park of fully flexible hydropower plants has been the reason why, despite good topographical and hydrological conditions, installed pumped storage capacity in Switzerland is relatively small. Grimsel 2, the biggest pure pumped storage power plant in Switzerland, has a total installed capacity of 350 MW.

Since its commissioning the operation mode of this plant has undergone some change. At the beginning the plant was exclusively used in the ‘classical sense’ to balance generation. From about 2000 onwards a shift in operation mode took place, after increased cross-border trade opened up new business opportunities. The plant enlarged their operational modes to market optimisation, while preserving their classical balancing role. Switzerland intends to set up new pumped storage plants in order to meet the increasing demand for sophisticated and large-scale services.

CASE STUDY 7 - Pumped storage for integration of v-RES in Germany

Electricity storage is no new topic in Germany: pumped storage power plants already exist and have been well-known for decades. Today, Germany has about 7,000 MW of installed pumped storage capacity. By 2020, new pumped storage hydropower plants with a capacity of about 2,500 MW will be added. For example, the project Atdorf in the southern part of the Black Forest is leading the current development of pumped storage schemes in Germany and Europe, in terms of overall electricity output, with an installed output of 1,400 MW, total capacity of 13 GWh and the ability to operate 9.5 hours at full capacity.

Picture 7 The Atdorf pumped storage power plant project in Germany.
Source: Schluchseewerk AG, 2011

The main features of Atdorf are upper and lower reservoirs with a storage volume of 9 million m^3 of water each, an underground powerhouse and six asynchronous pump turbines. Atdorf is envisaged to deliver storage and ancillary services by the year 2019.

The development of renewable energies and the changes resulting from this development require the energy industry to adjust generation and supply structures. Centralised, large-scale power generation technologies located close to consumption centres will be gradually replaced during the coming years by more volatile power generation technologies, which will be increasingly remote from consumption centres. Today, over 45,000 MW of PV and wind power are installed in Germany. In the National Renewable Energy Action Plan, the German government targeted an increase of this capacity to about 98,000 MW by 2020. Table 5 shows capacity projections for renewable energy sources in Germany.

Even though the permit process foresees public consultation, local communities and other stakeholders are often not fully satisfied with the participation opportunities offered by the formal planning process.

Existing communications outreach work have hence been intensified and took the form of a round table, which brings together all important stakeholders, including opponents to the project, to increase the transparency of the decision-making process. Reactions, especially on the political level have been very positive so far.

	2010	NREAP 2020
Wind-Onshore	27 GW	36 GW
Wind-Offshore	0.2 GW	10 GW
Photovoltaic	17 GW	52 GW
Biomass	6.3 GW	8.9 GW

Table 5 Existing and projected capacities for renewable energy sources in Germany.
Source: EURELECTRIC 2011, based on Power Statistics 2011; NREAPs; German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

The future integration of these variable power quantities requires a swift extension of national and European power storage capacities. The wind does not always blow and the sun does not always shine at the exact moment when consumers' power demands are high. Consequently, in order to make renewable energy available at times of peak demand, a large amount of storage capacity is required. Apart from the development of smart grids and the implementation of flexible generation plants, electricity storage facilities of any technology, such as pumped storage power plants, compressed-air reservoirs, accumulators, etc. will be of critical importance.

Pumped storage power plants alone cannot cover the necessary storage demand in the long term; research and investment into "new" storage technologies is necessary too. However, it will take years before these technologies are marketable and can make a similarly large contribution to system stability as pumped storage plants already do today.

To support the development of new storage technologies, all obstacles must be removed. Grid fees are one of these obstacles. Grid fees impede the construction of new power storage facilities, restrict the operation of existing facilities and increase the burden on power networks.

CASE STUDY 8 - Implementation of the EU WFD: challenges for hydropower in the Weser river basin in Northern Germany

Most run-of river hydropower plants located along the Weser River were originally built to generate the required electricity to operate the ship locks of the German Midland channel.

An official study from the Federal Institute of Hydrology[37] has concluded that on all federal navigable waterways, which are all defined as heavily modified water bodies (HMWB), a total of 260 water retention structures is an obstacle to ecological continuity. About half (160) of those water retention facilities are used for hydropower generation and fish passes have to be built or upgraded.

The German Federal Ministry of Transport assumes that the hydropower operators will contribute to the construction cost of 700 mn EUR[38]. These costs do not include the recurrent annual costs caused by increased maintenance expenses and production losses. In order to keep fish passes functional a certain amount of water is constantly required to flow through. This water is then no longer available for power generation, leading to reduced sales revenues as well as reduced production capacity for renewable electricity generation. Moreover, additional investments have to be made to ensure the ecological continuity on the weirs and barrages which are operated by the German federal states.

Implementation costs of the EU WFD

The EU Water Framework Directive aims at ensuring quality and sustainability of the use of the EU waters. It calls for increased ecological continuity in heavily modified water bodies.

In order to achieve ecological continuity, measures are expected to be taken in order to:

a) facilitate upstream migration,
b) facilitate downstream migration,
c) increase fish protection measures.

The example on the Weser river demonstrates how implementing measures to increase ecological continuity potentially results in significant investment cost and a loss of hydropower generation.

CASE STUDY 9 - Wind Power and Hydro Storage Initiative in Ireland

Ireland's west cost has some of the best sites in Europe for wind generation. It also contains numerous glacial valleys located close to the coast, which are perfectly suited for large scale, cost-effective, sea water pumped storage plants. The energy storage capacity of each valley ranges from 50 to 150 GWh within a compact area of only 3-5 km^2. This large storage capacity, used in conjunction with 1000 – 1500 MW pumped storage generation capacity, can overcome intermittency and smooth fluctuating output from 2000 to 3000 MW of wind turbines. The wind output powers pumping in the main power station to store seawater in a large hydro storage reservoir. There are

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[37] *Herstellung der Durchgängigkeit an Staustufen von Bundeswasserstrassen, Fischökologische Einstufung der Dringlichkeit von Maßnahmen für den Fischaufstieg. BfG Bericht 1697. www.bafg.de*

[38] *Frankfurter Allgemeine. 18. September 2010. 700 Millionen Euro für Fischtreppen by Henrike Rossbach at http://www.faz.net/s/Rub0E9EEF84AC1E4A389A8DC6C23161FE44/Doc~E11818A5C588C46A7990427F355B1FA1A~ATpl~Ecommon~Scontent.html*

over 50 valleys along the west coast of Ireland located 1-3 km inland from the Atlantic shore.

Natural Hydro Energy Ltd is currently raising capital for a massive hydro storage project formed from a rock fill dam across the mouth of one of these natural valleys. It is hoped this first and subsequent similar projects will make Ireland a significant player in European energy markets. The cost of the first 1,5GW station with networks to collect wind energy and transmit bulk hydro and combined wind power to the east coast for connection to the National Grid and interconnectors for export to the UK and Europe is some €2 Bn.

The plan envisages construction of large, industrial scale wind farms of around 100 MW, by independent operators. This size will ensure economy of scale. They will be connected to the Hydro Storage Reservoir by 220kV collection networks. Energy will be stored in the reservoir, primarily at night. The reservoir capacity of over 10 days full load generation will be released as hydro generation during the day and combined with incoming wind energy to eliminate fluctuations in wind output and provide a steady flow of controllable / dispatchable power. This will eliminate both wind intermittency and the need for curtailment.

3.5 Hydropower – highly efficient, affordable and climate friendly

Optimizing the use of available resources is certainly one way that leads to a more sustainable future. Therefore, it is also important to take energy efficiency considerations into account in the energy supply domain, where efficiency is essentially based on two factors:

- energy conversion rate, and
- energy payback ratio.

Energy conversion rate refers to the number of manipulations required until a primary natural resource, such as coal, is transformed into electricity. For example, hydropower and wind power convert natural flows of energy in the form of wind or water into the useful form of electricity. Both have very short and efficient energy chains, compared to fossil fuels, which require multiple processing steps.

Hydropower plants provide the most efficient energy conversion process. Modern plants can convert more than 95% of moving water's energy into electricity, while even the best fossil fuel plants are only about 60% efficient.

3.5.1 Hydropower is the most efficient of all renewable energy sources

Typically, hydropower efficiency rates are ranging between 85% to 95%, what is significantly higher when compared to about 55% for combined-cycle gas turbines, 30 % to 40% for coal or oil fired plants, 30% for wind power and 7% to 17% for solar photovoltaic panels (IEA. 2000. p.11). Achieving high efficiencies is possible thanks to the simplicity of the electricity generation process in a hydropower plant: there is no combustion involved; only direct conversion of mechanical energy into electricity.

In countries where renewable energy sources to not represent the majority of the national electricity supply portfolio, pumped storage hydropower is not considered as renewable, since it is a net energy consumer due to its pumping functions. Also its efficiency rate is slightly lower (usually about 70%-75%). Yet, believing that pumped-storage power plants might increase GHG emissions is wrong. Without pumped storage in the system, many thermal power plants operate at their partial load as reserve generators in order to cope with unexpected increases in power demand or sudden loss of generating power caused by system failures. Such reserve operation compels thermal power plants to operate at a suboptimal level which results in lower efficiency and an increase of both fuel consumption and GHG emissions.

If pumped storage is added to the electricity system, reserve operation of thermal power plants is no longer necessary. Thus, pumped storage contributes to reducing GHG emissions from the system. A study by Dr. F. C. Aris demonstrated that in the United Kingdom operation of the Dinorwig Pumped Storage Power Station (330 MW x 6 units) contributed to annual savings of SO_2 emissions of between 7,136 to 16,177 tons (0.45 to 1 percent of all UK power station production) and allows a reduction in NO_X emissions between 123 and 1,264 tons.

3.5.2 Hydropower provides the most reliable services while showing the highest energy payback ratio

Energy payback ratio refers to a ratio of energy produced during the normal life span of a power plant divided by the energy required to build, maintain and fuel the generating equipment. The larger the value is, the better the energy system is. Hydropower has the best performance with respect to the energy payback ratio. During its lifetime a hydropower plant produces more than 200 times the energy needed to build, maintain and operate it. It is illustrated by figure 15.

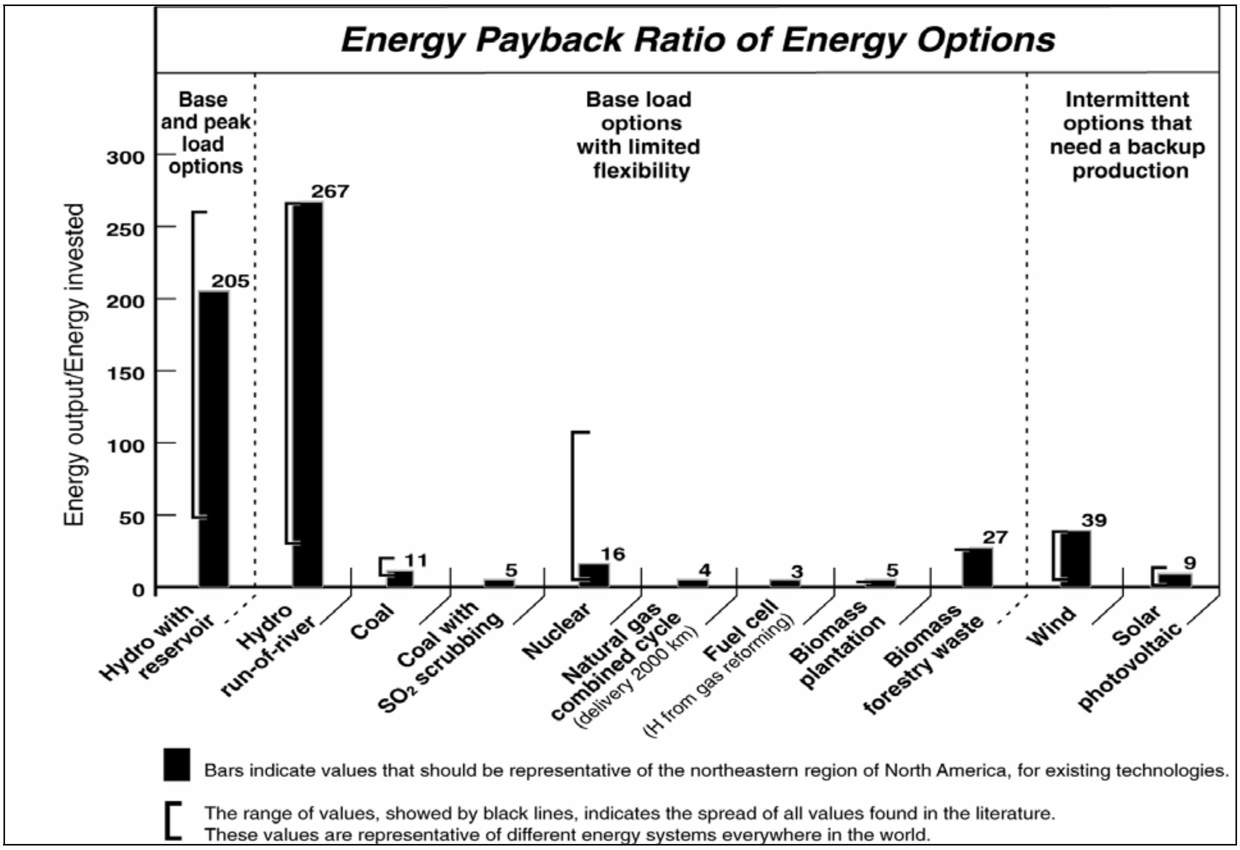


Fig. 15: Hydropower in the power generation options and respective energy payback ratios
Source: *Energy Policy*, 2002. p. 1276

3.5.3 Hydropower is the most affordable renewable energy source

Besides showing the highest energy efficiency rate and the best GHG performance, hydropower also is the most affordable renewable energy options as illustrated by the following figure 16 which presents the levelized costs of energy for selected commercially availabe renewable energy technologies

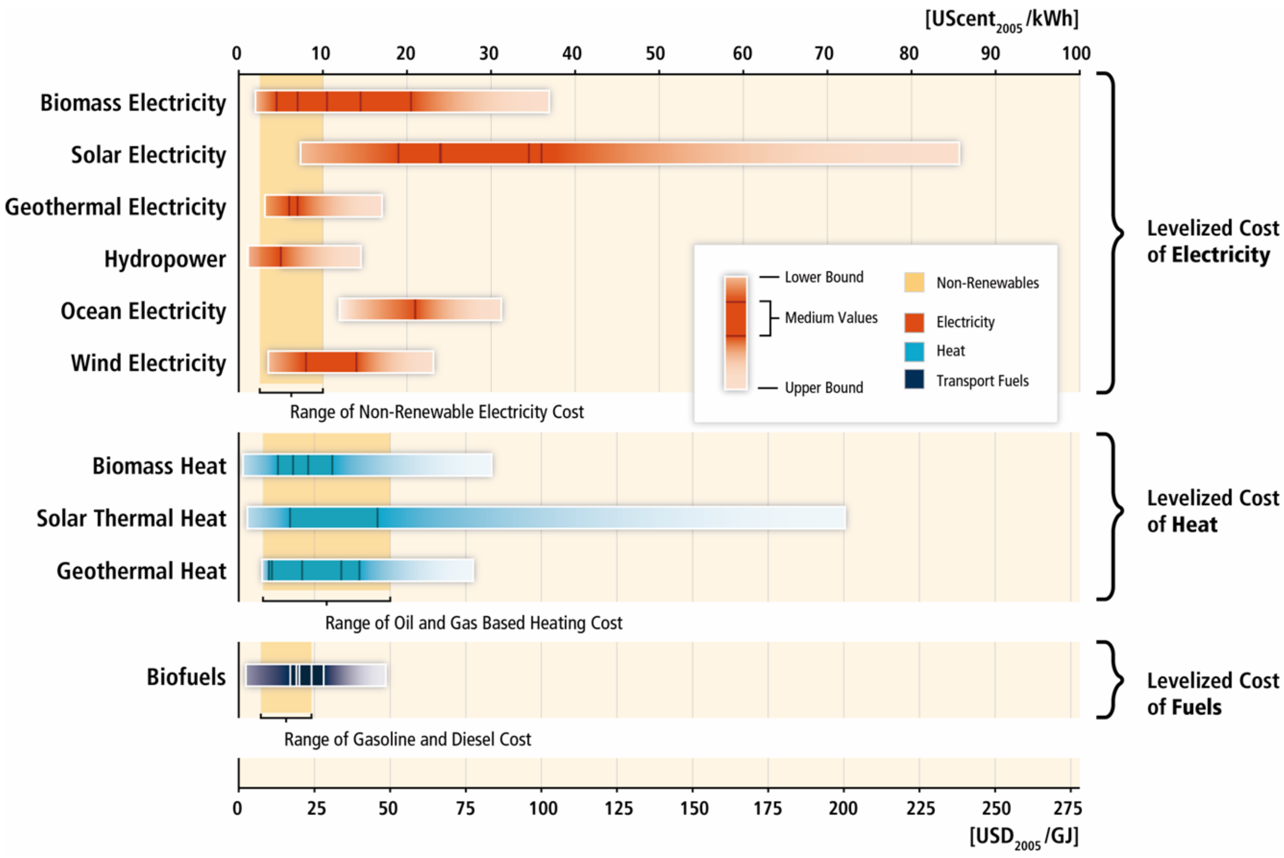


Fig. 16 Range in recent levelised cost of energy for selected commercially available RES technologies in comparison to recent non-renewable energy costs

Source: International Panel on Climate Change[39], 2011. Summary for Policymakers, p. 10.

3.5.4 Hydropower has the lowest carbon footprint and is the most climate friendly electricity generating technology.

As illustrated in the recently published Special Report on Renewable Energy Sources by the Intergovernmental Panel on Climate Change, hydropower also demonstrates the best performances when it comes to GHG emissions measured on a life-cycle basis. Figure 17 shows CO^2 emission for a broad category of generating technologies**.**

[39] *Special Report Renewable Energy Sources; Summary for Policymakers; http://srren.ipcc-wg3.de/report/IPCC_SRREN_SPM; p.10*

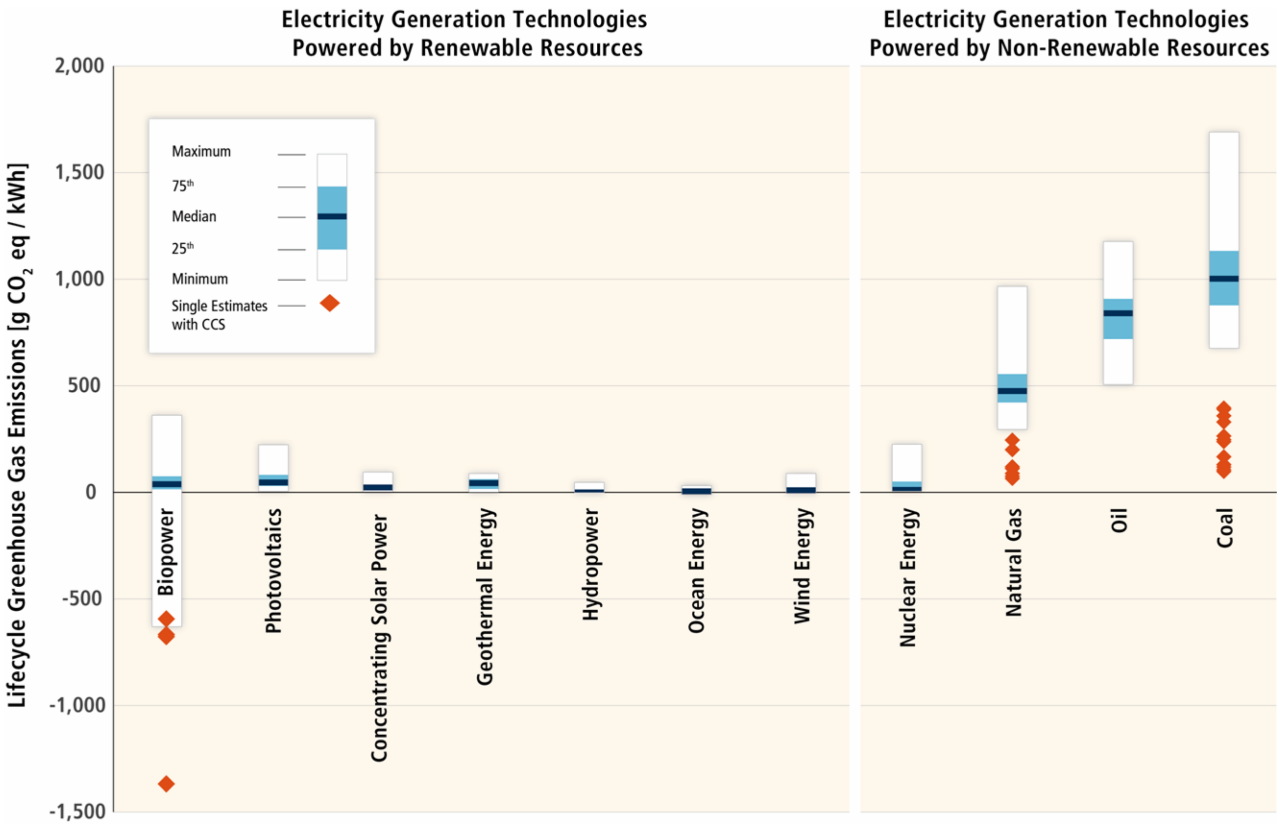


Fig. 17 Greenhouse Gas Emissions per Electricity Generation Technology (Life-Cycle Analysis)
Source: IPCC. 2011. Summary for Policymakers, p. 17

These results indicate that hydropower can make a significant contribution in addressing one of our centuries most important environmental changes: mitigating climate change thanks to its low GHG emissions profile.

4. POLICY CHALLENGES TO HYDROPOWER DEVELOPMENT

This chapter sets out how several ways in which the regulatory landscape influences the role of hydropower in contributing to Europe's energy and water security in the context of climate change.

Hydropower operators have an extensive experience in the management of water as a resource used for various society 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.

To name only a few examples: the multipurpose use of dams is common as dams may be built as freshwater reservoirs where electricity is generated when water is released. Dams may also create favourable situation for recreational areas or boat traffic with controlled situation of water levels and flow velocities as well as good locations for building locks. In many places the operative management of river "equipment" is all handled by the same company that operates hydropower plants.

Most governments are administrating hydropower projects and the related public water resource management through a public licensing processes at the project development phase and through concessions which comprise legally binding performance targets for the plant operator in the operating phase. The licensing process is usually the moment in a hydropower project's life span where all water, land use and infrastructure needs are assessed at a regional level. In the end it is the government who will arbitrate among conflicting needs and establishes for a limited time period the conditions under which a given hydropower plant has to be operated including other water uses to facilitate (such as navigation, irrigation, flood/drought control, water supply, aquaculture, etc). The outcome may be a water management. The operational responsibility usually belongs to the hydro plant owner.

The boxes shown on the following pages illustrate various multipurpose functions assumed by hydropower projects throughout Europe.

BOX 1 – FRANCE - A HYDROPOWER PROJECT SUSTAINING IRRIGATION, NAVIGATION, WATER SUPPLY, RECREATION, RENEWABLE ENERGY GENERATION AND FLOOD/DROUGHT CONTROL THANKS TO SERRE-PONÇON RESERVOIR ON THE DURANCE RIVER

The Durance, an unpredictable and uncontrollable river, has always been characterised by devastating floods and periods of drastic drought. From the twelfth century, the people of Provence have sought to find solutions. In 1955, it was decided to launch a project comprising three missions: the production of electricity, irrigation and supply of water to the population as well as the regulation of the watercourse. Taking into account its many goals, the Ministry of Agriculture funded 12.3% of the project, in exchange of water stocks covering 200 million m^3 for exclusive farming use contributing to the irrigation of more than 150,000 hectares. The Serre-Ponçon reservoir with a storage capacity of 1.2 billion m^3 as well as the 250 km long canal along the Durance, were completed in the 1970s by the development of the Verdon river with the Sainte-Croix, Quinson and Gréoux dams.

Today, the water taken from the Durance and Verdon river systems is used for agricultural purposes, drinking water and industrial water supply. The quantity of freshwater managed through this hydropower complex amounts to around 2 billion m^3 per year in average. The development of the Durance was followed up by a chain of 15 hydroelectric power stations. This represents average production of 7 TWh per year, the equivalent of 25% of the annual consumption of the regions Provence, Alpes and Côte d'Azur. This hydropower complex allows having 2000 MW production capacity available in 10 minutes and also plays a major role in providing drinking water to the region's towns. Marseille receives its water from the EDF canal, via the canal belonging to the Société des Eaux de Marseille. Société du Canal de Provence takes water from the Castillon and Gréoux dams for towns in Bouches du Rhône, Var and Vaucluse.

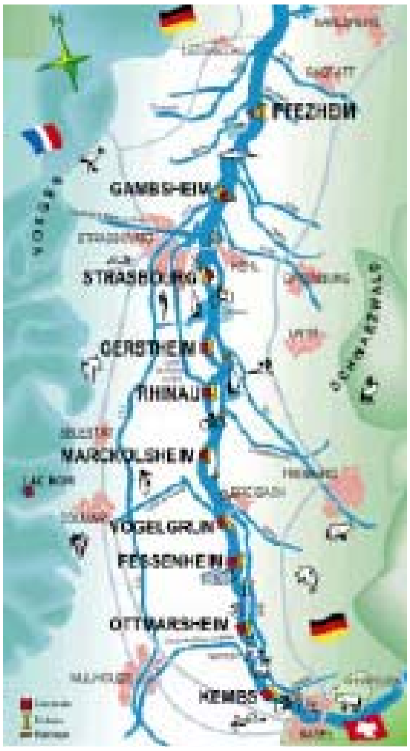
In addition, the Serre-Ponçon basin now represents around 40% of summer tourists in the Hautes Alpes enjoying sailing, water sports and industrial tourism. The presence of hydroelectric power stations also favours the practice of canoeing allowing the scheduling of water releases for sports competitions such s white water courses

Water supply point in Provence

Source: Eurelectric. 2005. Hydropower the renewable and sustainable energy

Box 2 THE EXAMPLE OF THE RHINE RIVER (**SWITZERLAND, FRANCE, GERMANY, HOLLAND) where hydropower projects are** facilitating environment-friendly and cost-effective river transport

Trade on the Rhine, established since Roman times, has accompanied the economic development of its neighbouring regions. The States have recognised its importance through strategic treaties such as, in 1868, the treaty “removing tolls and fees payable for navigation on the Rhine”. These agreements grant the operation of the 8 falls between Kembs and Strasbourg. Therefore, each hydroelectric dam was required to include a lock to ensure permanent and free navigation with guarantees vertical clearance of about 10 m. Thus were born, as of 1928, the great double locks of the Rhine (185×23 m; 185×12 m), which enable the great Rhenish barges and convoys to pass with 8,800 tonnes. Beyond Strasbourg, it is no longer EDF that manages the locks associated with the last two falls but government authorities. These last two structures (270 m long) can transit convoys of around 16,000 tonnes. Nowadays, river-based transportation offers several advantages in comparison with other transport modes: competitive prices per tonne/km transported, good adaptation to the transport of heavy goods and dangerous substances (chemical products, combustibles, etc.), high capacity reserves, low fuel consumption, low risk of accident, good integration into the landscape, etc. All these aspects show that river transport is particularly economic, safe and environment-friendly compared to road transport.



At Lauterbourg, 35 million tonnes/year cross the border. Switzerland transports 15% of its foreign trade via the Rhine, including 40% of its combustibles, thanks to the ports of Basel.

Source: Eurelectric. 2005. Hydropower, the renewable and sustainable energy

The long life span of a hydro plant creates occasions where the balancing discussion between different needs has to be updated due to new general policies from society or change in local situations. For these reasons in most countries concessions are time bound in proportion to the amount of capital investment or the terms and conditions of the concessions can be revisited upon demand of the government.

The evolving policy framework can create challenges as well as new opportunities for hydropower to contribute to a more sustainable development of Europe.

In the following chapter are discussed challenges related to EU policies such as the Directive (2009/28/EC) on the promotion of the use of energy from renewable sources (RES), the Water Framework Directive (WFD) and the security of water and energy supply.

Other EU policy areas which are critical for the hydropower sector are:

a) Flood risk assessment and management directive (2007/60/EC)
b) White paper on water scarcity and droughts
c) White Paper on climate change adaptation

For the time being the above-mentioned three EU policy documents have largely ignored the role which hydropower reservoirs can play in flood/drought management and hence in adaptation to climate change. The learning process from a past, where these policies where much more conflicting, has to be acknowledged.

4.1 Hydropower fosters the achievement of Europe's 2020 renewable energy targets

This chapter presents the role of hydropower in the EU-27 towards achieving a 20% share of RES[40] in 2020. It first highlights the main RES objectives, and then focuses on RES electricity41 in order to present the role of hydropower in the future European electricity mix.

Renewable energy 2020 targets in EU-27

The EU's renewable energy policy is largely defined by its Renewable Energy Roadmap together with the Renewables Directive[42] (see Figure 18).

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40 *Renewable energy sources in this directive include 3 sectors: (i) electricity (RE-electricity), (ii) heating & cooling (RE-H&C), and (iii) transport (RE-transport)*

41 *RE-electricity: hydropower ; geothermal ; solar PV, concentrated solar power ; tidal, wave and ocean energy ; on-shore wind, off-shore wind ; solid biomass, biogas, bioliquids.*

42 *Directive 2009/28/EC "on the promotion of the use of energy from renewable sources and amending, and subsequently repealing Directives 2001/77/EC and 2003/30/EC*

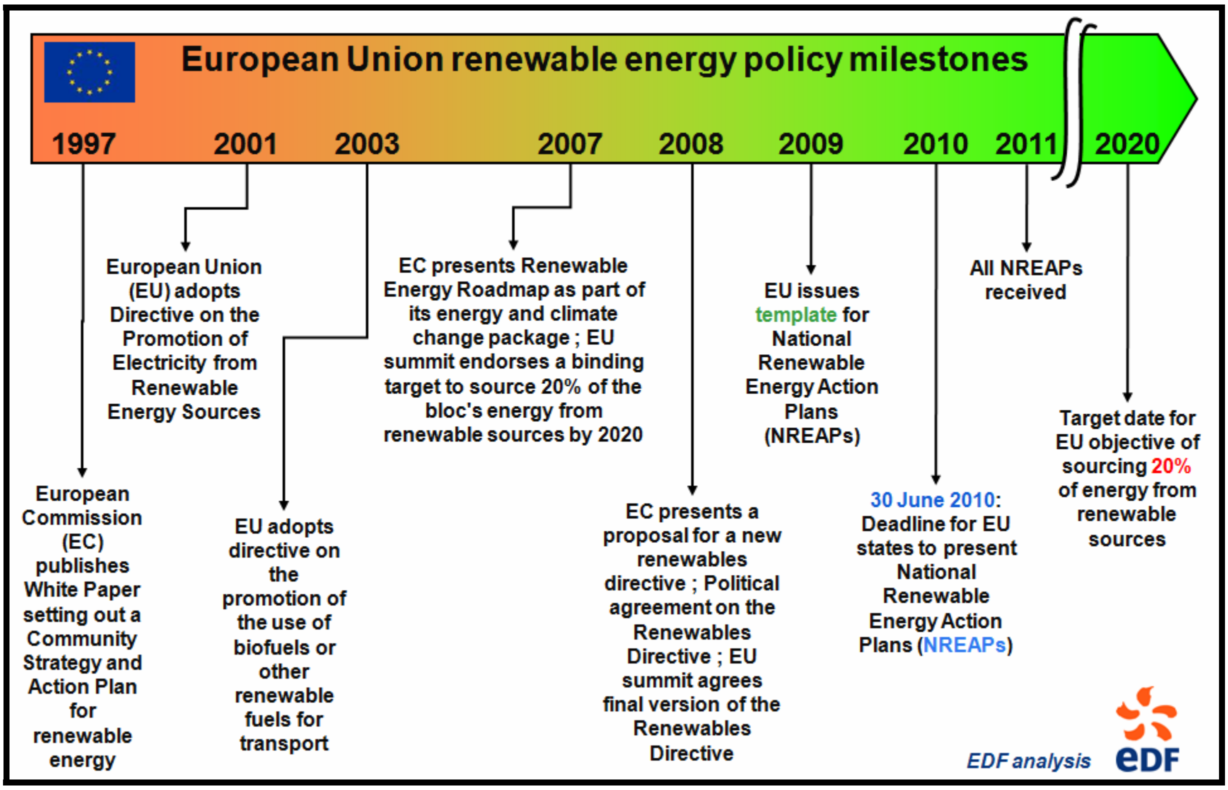

Fig. 18 EU Renewable energy policy milestones
Source: EDF

The Renewables Directive sets individual targets for each member state, as depicted in Figure 19.

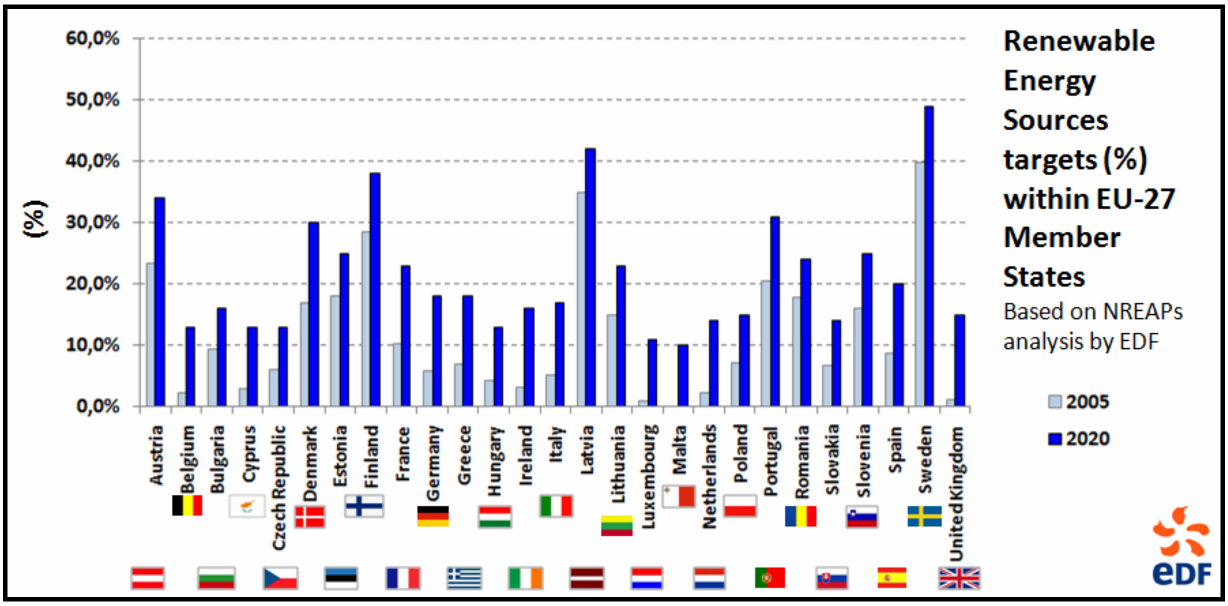

Fig. 19 National renewable energy targets within the Directive 2009/28/EC
Source: EDF

To ensure that those goals are reached, the directive set “indicative trajectories” – intermediate targets – for each member state. The National Renewable Energy Action

Plans (NREAPs), drawn by the member states, set out measures on how to keep up with the national trajectories.

The role of hydropower in achieving the 2020 RES targets

Figure 20 presents the "reference situation" in 2005 and the EU-27 member state projections in 2020 according to their NREAPS. In 2005 with an annual generation of 346.8 TWh, hydropower[43] is the largest renewable source in the electricity sector, representing 71% of all RES electricity. According to projections, in 2020 hydropower will be the second largest renewable energy source in the electricity sector with 370.3 TWh, and will account for 30% of all RES electricity. Absolute hydropower generation will therefore increase, although its share will decrease. It should be noted that RES electricity will represent 42.6% of all RES sectors in 2020 (after RES in heating and cooling with 45.4%, with the rest for RES in transport).

According to the NREAPs installed hydropower capacity will increase from 115 GW to 135 GW between 2005 and 2020, e.g. an additional 20.5 GW with an associated additional generation per annum of only 23.5 TWh (i.e. an equivalent load factor of 13%[44] for that extra generation!).

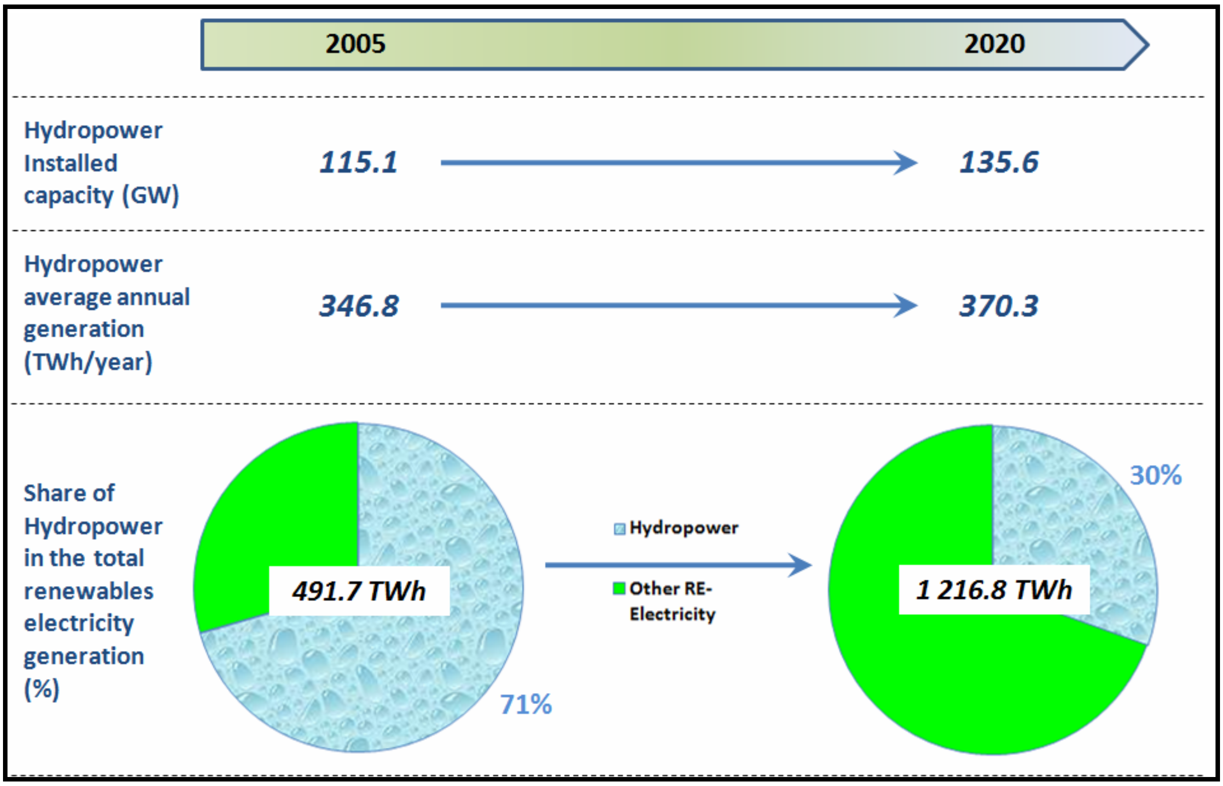

Fig. 20 Projected development of hydropower capacity according to the NREAPs
Source: EDF

[43] *Values presented exclude generation from pumped storage hydro.*

[44] *This figure highlights that existing hydropower facilities across Europe will have to decrease their generation output in order to be consistent with other EU Directives (EU WFD for instance).*

Pumped storage hydropower plants are not considered as a RES within the Renewable Energy Directive. However the technology helps to reduce the challenges of integrating v-RES into the European interconnected electricity transmission system. Therefore member states have included this technology in their NREAPs.

According to the NREAPs, the installed capacity of pumped storage hydro will increase by 16.1 GW from 18.7 GW in 2005 to 34.8 GW, led by new plants in Germany, Portugal, Spain, France and Italy (see Figure 21).

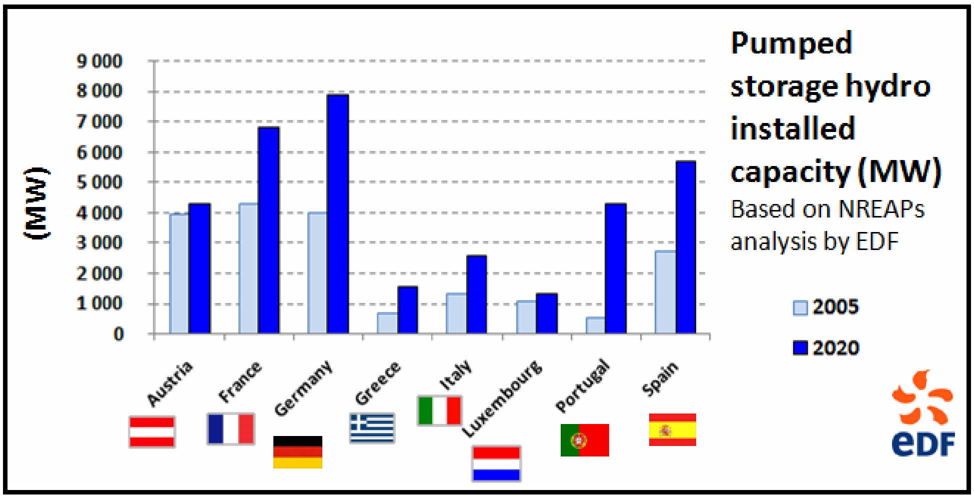

Fig. 21 Projected pumped storage capacity and the leading countries
Source: EDF

Pumped storage hydro is an area of significant growth for the hydropower sector in Europe, especially in the central and peninsular regions of the continent.

4.2 Hydropower in Europe´s water policy framework

The Water Framework Directive (WFD) is Europe centre piece when it comes to water management legislation. At once, water management is an inherent part of the hydropower business, and an important learning since decades has to be acknowledged here, with the rise of ecological concern. Make environmental legislation and hydropower development match should be the common objective both of the industry, and policy makers. EURELECTRIC deplores some mismatches, which are highlighted in the following chapter.

4.2.1 Challenges for hydropower related to the implementation of the EU WFD

Water policies have to be considered in the broader environmental- and climate context

The WFD has to be considered and implemented as a part of the overall environmental and climate legislation. Water protection can not be isolated from the entire setting, as is stated in the WFD itself:

"Further integration of protection and sustainable management of water into other Community policy areas such as energy, transport, agriculture, fisheries, regional policy and tourism is necessary. This Directive should provide a basis for a continued dialogue

and for the development of strategies towards a further integration of policy areas. " (Preamble 16 of EU ZFD)

In order to get here from promise to practice it is important to focus in the next WFD implementation phase on more:

- harmonized approaches between various EU legislations related to water, energy and climate change
- comprehensive considerations of water uses and services
- balanced impact assessments
    - not only the negative impacts on river ecology, but also
    - the positive impacts on the global environment and the benefits for society and the economy
- pragmatic solutions based on
    - scientific field studies
    - sound cost/benefit analysis
    - proven effectiveness beforehand
- economic incentives for environmental enhancement measures
- critical ecological elements to begin (ecosystem bottlenecks)
- water uses which are causing most deterioration
- collaboration between regulators and the hydropower sector

The implementation of the WFD shall not lead to distortion of the competition.
Measures have to be cost-efficient and Cost-Benefit Analysis have to be taken out. There are some spectacular examples, like the required environmental enhancement measures to reach good ecological potential: a satisfying level of ecological continuity for fish migration in Heavily Modified Water Bodies (HMWB) can vary from a 1,5 km fishpass costing 20 M Euro designed for fish species which even do not live in this river (Germany), to the possibility of using ship locks to facilitate fish migration (France) or to use fish stocking (Finland). Furthermore, ecological continuity can only be achieved, if all river obstructions can be overcome. According to a recent CIS study45 only about 3 to 20 % of Europe's river obstructions are caused by hydropower. One must thus see all the factors together, and avoid to single out hydropower.

4.2.2. How to avoid policy conflicts between the EU WFD, RES and climate change adaptation initiatives

The following measures could assist in achieving a more harmonised approach in common efforts for further integration:

- set up joint DG Energy – Environment working group responsible to harmonise implementation of WFD and RES
- create in DG Energy and DG Climate Action a position which is responsible and knowledgeable about hydropower
- provide guidance on which role reservoirs should play in the management of water scarcity, droughts and floods in climate change adaptation
- provide guidance on harmonised implementation of WFD and Floods directive

[45] *Water management, Water Framework Directive & Hydropower. Common Implementation Strategy Workshop, Issue Paper. 2011*

- provide guidance on socio-economic assessment of water uses beyond drinking water and waste water treatment
- provide guidance on assessment of water uses and water services aiming at clarifying both terminologies to avoid further ambiguous interpretations
- improve socio-economic cost/benefit assessments
- use existing effective legal frameworks to:
    - perform a more comprehensive assessment of water uses/services
    - arbitrate conflicting water use interests
    - Support case-by-case evaluation
- Assess the effectiveness of commended measures beforehand
- Give priority to measures which are not reducing existing hydropower generation or remaining potential, since the flexibility of hydropower is needed for a more renewable energy future un Europe.
- economic incentive programs to make the implementation of environmental enhancement measures economically feasible (e.g. favourable feed-in tariffs for environment-friendly hydropower plants regardless their size)

4.2.3 Opportunities for further collaboration between regulators and the hydropower sector

There are manifold opportunities for further collaboration in joint efforts to :

- ensure comprehensive cost/benefit assessments including all water services and water uses for a WFD implementation which takes into account sustainable water use management not only resource protection
- make existing guidance documents less dogmatic and more pragmatic to assist proper case-by case assessment of each hydropower plant (examine the relevance of the Hydropower Sustainability Assessment Protocol for this purpose which is currently under test in the EU program Hydro4Life)
- identify priority areas for environmental enhancement for each specific RB (ecosystem) what are the ecological critical elements (bottlenecks) to focus on
- determine the role of hydropower in climate change (increased need for flexibility in the power system)
- collect good and reliable data to support adequately the decision-making process
- develop an effective eco-systemic approach (for example for fish management) which is :
    - holistic (for example not only including the river basin but also the fjords/estuaries)
    - and river specific
- clarify remaining areas of uncertainty regarding effectiveness of :
    - upstream and especially downstream migration of fish
    - various fish ladders/by pass systems
    - protective measures for fish (reduced bar distance for grids)
- take into due consideration ecosystem services of regulated water bodies such as the stabilisation of adjacent ground water levels or water quantity management
- develop a compendium on good practice highlighting win-win examples

- share existing communication material on EU WFD to facilitate meaningful engagement of stakeholders which are not experts but on the local decision-making level

5. THE STRATEGIC ROLE OF HYDROPOWER IN THE CHANGING ELECTRICITY LANDSCAPE

Future generation portfolio

The future electricity generation portfolio is uncertain. It will be determined by technological development, learning curves of technologies, public acceptance, and the capability of the financial market to provide the necessary financial resources for the projects. It is clear that RES-based distributed generation will account for a significant share of this portfolio.

The future electricity supply system will consist of reinforced and upgraded transmission and distribution grids, which will incrementally evolve towards a smarter network.

The management of future network system

The management of the future transmission and distribution network is a challenge in terms of the required algorithms to control the grid, the necessary technical installations with the appropriate features and – crucially – the regulatory framework. This framework has to ensure transparency of any activity of the market participants and fair burden-sharing regarding the duties and rights or benefits. This is important in order to achieve an efficient and competitive supply chain.

The role of hydropower storage

Hydropower will link requirements of the demand side and the possibilities and limitations of the transmission or distribution side (i.e. unpredictability of the RES-based generation, need for back-up power). Pumped storage and hydro storage power plants will have a decisive role thanks to the benefits of this technology.

Technical role of storage in general - technical maturity

Storage facilities can decouple supply and demand either in a short or long term.
One can differentiate three types of storage technologies:

- Mass storage;
- Local spread storage; and
- Indirect storage.

Reservoir-type or pumped storage hydropower plants belong to the first group. Compressed air energy storage and thermal electric storage devices can also be placed in this category. Local spread storage technologies include batteries and fly-wheel energy storage devices. Finally, indirect storage technologies are those producing hydrogen and/or methane. These devices require additional generation facilities to burn hydrogen or methane and have a low efficiency balance. Nevertheless, this technology could enable storage when the wind is blowing or the sun is shining and act as a buffer system.

As a mature technology, pumped storage hydropower plants are the only option available today to provide competitive large-scale storage. Other existing storage technologies are all limited in their operation and still require significant R&D.

Optimisation

Europe's current energy landscape is characterised by a predominance of fossil and nuclear generation, while the efforts to increase the share of renewable energy are driven by unilateral, national or local development strategies. The consequence is a fragmented, disconnected and sometimes even distorted European energy market.
In order to optimise the use of all energy sources and to foster further deployment of renewables, much more integrated, large-scale pan-European resource planning and management will be necessary which takes into account synergies between technologies. A further goal will be to enhance the efficiency in coordination and the use of electricity generation, storage and consumption across key sectors such as the power sector, the transport sector and the heating sector.

Since the various renewable resources are located in different regions of Europe, an optimised resource use will require the establishment of enhanced interconnections. While generation from wind is expected to grow especially around the North Sea, significant growth in solar energy is likely to happen especially in the southern parts of Europe. To support the important growth rate of these two variable renewable sources and ensure energy security, storage hydropower will have an important function in securing grid stabilisation. Yet, these resources can also only be developed in specific European regions such as the Alps or Scandinavia. The concept for a sustainable power supply infrastructure to Europe, the Middle East and North Africa (EU-MENA) in form of a supra-regional super grid based on high-voltage DC power transmission as "Electricity Highways" was proposed by the Trans-Mediterranean Renewable Energy Cooperation (TREC) in 2003 and illustrates the idea of an optimised pan-European resource management.

Timing

In the transition to the new electricity generation and transport landscape, time-related aspects also deserve due consideration. The process from planning a new storage hydropower plant to its commissioning and full operation can take about 10 years. Building a new transmission or distribution line also takes at least 10 years. Without increasing efforts to erect new storage facilities and new transmission and distribution lines the whole process of transition could easily be compromised.

As outlined above, hydropower is already essential for the stable supply of electricity to consumers. This role will become more relevant for the future as fulfilment of the EU RES and climate targets for 2020 will require enhanced efforts to deliver the requested services at affordable prices.

6. Key Messages and Recommendations for Policymakers

1. **Hydropower is a major renewable generation technology in Europe's electricity mix: it is competitive, efficient, climate-friendly, and contributes to system stability. Its interaction with other RES will make the ambitious EU RES agenda a success.**
   Representing about 190 GW of installed capacity in EURELECTRIC Europe, hydropower represents around 70% of the total renewable electricity generation today.

   Hydropower has multiple advantages: it is competitive, it contributes to security of supply, it is highly efficient, it has a very low carbon footprint, and it is flexible.

   In it's interaction with other more variable RES hydropower will make the new RES system a success.

2. **Europe's hydropower potential has not yet been fully reaped. Hydro can and should be further developed in Europe.**
   The European hydropower potential has not yet been fully or nearly fully exploited.

   There is still significant hydropower potential to be optimized and developed in Europe. Only about half of its technically feasible potential has been developed for EURELECTRIC Europe and only about one third in the non-EU member states.

   In order to benefit from Europe's remaining hydropower potential, existing plants will have to be optimized and new ones will have to be built. The EU-27 should also support their European neighborhood in developing and optimizing their hydropower resources, improving efficiency of existing plants, promoting common sustainability and safety standards, and making best common use of the potential.

3. **Hydropower provides flexibility to the electricity system**
   Hydropower allows energy storage, which can increase system reliability and balance the intermittency of electricity produced by other renewable sources that are variable (such as wind or solar). Its quick response capabilities help provide the peak generation which is crucial for balancing the grid. Further development of hydropower will play a major role to secure system stability in the future.

4. **Hydropower helps to mitigate climate change.**
   Hydropower is a renewable generating technology with a very low carbon footprint and enables further deployment of v-RES. 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.

5. **Hydropower is the only large-scale and cost-efficient storage technology available today**
   Despite promising developments in energy storage technologies, hydropower with reservoirs is still the only technology offering economically viable large-scale storage. It is also a very efficient and competitive energy storage option. Pumped storage power plants are five times less expensive than batteries and four times less costly than compressed air energy storage technologies. Conventional storage hydro projects are even less expensive than pumped storage plants.

6. **Hydropower reduces Europe's import dependency**
   Europe is highly dependent on fossil fuel imports. Hydropower is part of Europe's domestic resources and should be fully developed in order to diversify the electricity mix and enhance security of supply.

7. **Hydropower is the most efficient power generation technology**
   Hydropower has both a high energy payback ratio and a high conversion efficiency, making it very resource-effective. It has the highest efficiency rate among all electricity generating technologies, and offers the highest levels of services. Operation efficiency rates for conventional hydropower plants range from 85-95% (70-75% for pumped storage power plants). This is significantly higher than the 55% for combined-cycle gas turbines, the 30-40% for coal or oil fired plants, the 30% for wind power and the 7-17% for solar photovoltaic panels.

8. **The potential of hydropower's technologies should benefit to the European system as a whole**
   Hydropower storage technologies are currently designed for a national or regional scale, with limited consideration for a European system. Since hydropower and pumped storage are scarce and highly valuable resources, their potential has to be used to its optimum on a European or even pan-European scale. Improved grids and interconnections are of prime importance to tap into this significant unused potential of renewable energy generation.

9. **Hydropower plays an important role in water management**
   Hydropower has a long history in acting in water management to plan energy generation but also in cooperation with other needs such as freshwater handling, boat traffic and flood control.

   EURELECTRIC acknowledges the important achievements of environmental legislation, from Natura 2000 to the WFD. To nevertheless ensure a sustainable perspective on water use management, the WFD should be applied based on a thorough socio-economic cost-benefit analysis that covers the full range of water services provided by hydropower. Since hydropower is a site-specific technology, arbitration should take place on a case-by-case basis.

10. **As electricity generation assets, hydropower plants should operate in a competitive and unbundled market environment. Pumped storage ownership claims by TSOs are truly unjustified and go against the provisions of existing Directives**[46]
EURELECTRIC strongly rejects the attempt by some European transmission system operators (TSOs) to claim property of pumped storage plants by referring to their role as service providers, as has for instance been the case in Spain or Italy. Any rebundling attempt should be rejected; there is no legal ground or justification for any such request. In addition, pumped storage hydropower plants are integrated into conventional storage hydropower systems and only generation companies have the necessary knowledge and capacities to operate such systems.

11. **Pumped storage shall not be treated as consumption in setting grid fees**
Pumped storage's main purpose is to stabilize the power system both in very short term timescale with in minutes (ancillary services) and in a little longer time scale (several hours) to balancing varying generation or load. Hydropower contributes to the stability of the system and should hence not been seen as a consumer.

[46] *See Directive 2009/72/EC*

More must be done NOW to fully exploit Europe's hydropower potential.
EURELECTRIC therefore urges policymakers on a European and national level to:

- Promote awareness among policymakers and the wider public of hydropower's key role and its unique multiple assets for the electricity system.
- Promote with all possible means the sustainable development of remaining hydro resources.
- Address on a case-by-case basis the trade-offs between implementing existing legislation and further developing hydropower and pumped storage.
- Develop efficient interconnections and grids to ensure large-scale system benefits from pumped storage for the entire European electricity system.
- Harmonise grid fees for pumped storage power plants on a European level.
- Reject all attempts by TSOs to claim property of pumped storage plants.
- Ease permitting procedures.
- Ensure that the European Commission's DG Energy, DG Climate and DG Environment each have a specific contact for hydro who is aware of the specificities of this technology, and promotes it in the European interest.
- Harmonize the implementation of water and energy related EU policy instruments
- Formalize cross-sector collaboration between DG Energy, DG Environment and DG Climate on hydropower, a technology involved in generation of renewable energy, energy storage, system security, water storage, quantity and quality management, climate change adaptation and climate change mitigation.

ANNEX

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17. Directive 2007/60/EC on assessment and management of flood risks
18. Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending, and subsequently repealing Directives 2001/77/EC and 2003/30/EC
19. Working Document on Natura 2000.

Glossary

Ancillary services	Services required by the transmission or distribution system operator to enable them to maintain the integrity and stability of the transmission or distribution system as well as the power quality
Base Load	In a demand sense, the amount of power that varies only slightly over a time period. In a supply sense, a plant that operates at a constant level of generation
Black start capability	The capability of a generating unit to start up without an external power supply, called on as a means of restoring supplies following a major failure on all or part of the network. This service allows system operators to provide auxiliary power to more complex generation sources that could take hours or even days to restart.
Black-out	A short or long-term loss of electric power to an area
Capacity factor	Measure of productivity, the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full capacity the entire time
CCGT	Combined cycle gas turbine
CO_2	Carbon dioxide, greenhouse gas, product of fossil fuel combustion
Energy conversion rate	Refers to the number of manipulations required until a primary natural resource, such as coal, is transformed into electricity
Energy payback ratio	The energy produced during the normal life span of a power plant divided by the energy required to build, maintain and fuel the generating equipment
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
Frequency	One of the key parameters for control of an electric transmission network; characterized by the balance between electricity generation and demand, on one hand, and by the control of the electricity network by appropriate technologies such as pumped storage hydropower plants, on the other
FRMP	Flood Risk Management Plan
GHG	Greenhouse gas
Grid	Network of transmission and distribution lines carrying electricity from sources of generation to consumers
GW (gigawatt)	Unit of power equal to one billion of watts
GWh (gigawatt hour)	Unit of energy equal to the use of one billion watts for one hour
Head	In a run-of-river hydropower plant the vertical height of water reservoir located above the turbine
HPP	Hydropower plant
HVDC	high voltage direct current

Hz (hertz)	Unit of frequency in cycles per second
kW (kilowatt)	Unit of power equal to 1,000 watts
kWh (kilowatt hour)	Unit of energy equal to the use of 1,000 watts for one hour
Load	The amount of electric power delivered or required at any specific point or points in the electricity system
Load factor	Measure of output of a power plant compared to the maximum output it could produce
Load levelling	A method for reducing the large fluctuations that occur in electricity demand, for example by storing excess electricity during periods of low demand for use during periods of high demand
MW (megawatt)	Unit of power equal to one million of watts
MWh (megawatt hour)	Unit of energy equal to the use of one million watts for one hour
N1 criterion	A rule applied to evaluate security of energy supply. It requires that in case of tripping of a generation unit, a transmission line or a transformer, the security of energy supply should not be jeopardised
NORDEL	The Nordic Power System among Norway, Sweden, Finland and Denmark
NREAP	National Renewable Energy Action Plan
Peak load	The maximum electrical demand in a stated period of time.
Primary control	Automatically activated function of the turbine governor to adjust the generator output of a unit as a consequence of a frequency deviation
PSPP	Pumped Storage Power Plant
RBMP	River Basin Management Plan
RES	Renewable Energy Sources
Secondary control	The second frequency control level after primary control. Automatic, with purpose to restore frequency
Spinning reserves	The plant capacity, in excess of actual load, which can be called on to produce electricity at very short notice
TSO	Transmission System Operators
TW (terawatt)	Unit of power equal to one trillion watts
TWh (terawatt hour)	Unit of energy equal to the use of one trillion watts for one hour
UCTE	Union for the Coordination of the Transmission of Electricity
v RES	Variable renewable energy sources (wind and solar)
w (watt)	Unit of power
WFD	Water Framework Directive
WWF	World Wildlife Fund

Annex 1
Methodological considerations and EURELECTRIC questionnaire for the assessment of the potential of pumped storage power stations in Europe

Annex 2
Hydropower in the Nordic Power system

Annex 3
Offsetting the black-out of 4 November 2006: Hydropower's contribution

Annex 4
The Polish Zarnowiec Hydropower Plant's contribution to system stability

Annex 5
Norway's storage potential

Annex 6
The operational evolution of pumped storage operation in Switzerland

Annex 7
Hydropower in Austria: e= H_2O

Annex 8
Wind Power and Hydro Storage in Ireland

Annex 9
Implementation of the EU WFD: challenges for hydropower in the Weser river basin in the Northern Germany

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