The hydropower sector's contribution to a sustainable and prosperous Europe

Policy Report

On behalf of: A group of European hydropower companies and organisations/associations

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EXECUTIVE SUMMARY

The climate and energy policy of the European Union (EU-28) and many European countries, including Norway and Switzerland, is based on three over-arching objectives, i.e. to build an affordable, secure and sustainable energy system. In order to achieve these ambitious goals, a particularly high share of decarbonisation will have to be delivered by the power sector.

European hydropower delivers an important contribution to achieving these targets in a changing European energy system. At present, hydropower accounts for roughly 13% and 18% of total electricity generation in the EU-28 and Europe[1], respectively. Moreover, European hydropower is by far the largest source of renewable energy sources (RES) in the power sector today and represents roughly 50% of total electricity generation from RES in the EU-28 alone. It thus helps to avoid between EUR 15bn and 24bn of fossil fuel consumption and up to 350 Mt in CO_2 emissions in the EU-28, which is equivalent to 32% of total CO_2 emissions in the EU-28 power sector.

The hydropower sector directly and indirectly contributes to the European economy. The sector ensures more than 100,000 qualified jobs in Europe, and the average contribution to European GDP of each employee is eight times higher than the industry average in the European manufacturing sector. Overall, European hydropower contributes approx. EUR 25bn and EUR 38bn to GDP in the EU-28 and Europe, respectively. In addition, the European hydropower sector delivers about EUR 15bn in tax revenues to governmental budgets at a national, regional and local level.

Despite more than a century of development, there still is scope for expanding generation from hydropower. Given a positive economic and regulatory framework European hydropower companies may invest more than EUR 180bn over the next 15 years and increase electricity generation by 20%. Total electricity generation from hydropower in Europe may grow to some 700 TWh by 2030, whilst annual value creation may grow to some EUR 75bn to 90bn by 2030.

In line with the increasing share of electricity generation from variable RES, the role of European hydropower will furthermore evolve from providing clean electricity at competitive rates to taking a central role for enabling the transition to a future power system based on a mix of low-carbon technologies. Indeed, European hydropower already provides more than 150 GW of flexible and reliable capacity as well as 220 TWh of electricity storage to the European power system today. This makes hydropower a perfect instrument for dealing with the challenges of integrating growing volumes of variable RES into the European power system.

Overall, the findings of this study clearly illustrate that hydropower delivers a major contribution to reaching Europe's climate and energy goals. In addition to the supply of clean electricity, hydropower provides a wide range of economic and other benefits to the European economy and society today. Moreover, European hydropower will increasingly take a central role for enabling the transition to a future mix of low-carbon technologies that is able to ensure an affordable, secure and sustainable supply of electricity to European consumers.

[1] Unless stated otherwise, the term „Europe' refers to the 28 Member States of the European Union (excluding Malta and Cyprus) plus Norway, Switzerland and Turkey.

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1 INTRODUCTION

The climate and energy policy of the European Union (EU-28) and many European countries, including Norway and Switzerland, is based on three over-arching objectives, i.e. to build an affordable, secure and sustainable energy system. Many European countries, including the EU-28, have committed themselves to substantially reducing greenhouse gas emissions progressively. In order to achieve these ambitious goals, a particularly high share of decarbonisation will have to be delivered by the power sector. Renewable energy sources (RES) will have to play a central role for providing an affordable, secure and sustainable supply of electricity in the future.

With more than 600 TWh of electricity generated in 2013, hydropower represents the single largest source of electricity from renewable energy in Europe. Cumulatively, it supplies almost 18% of total electricity consumption in the EU-28, Norway, Switzerland and Turkey, and there still is further potential to explore in Europe. This is a significant contribution to providing clean electricity at competitive costs. In addition, hydropower provides a range of other benefits to the European economy and facilitates the integration of other renewable energy sources into the power system.

These facts illustrate that hydropower already delivers an important contribution to achieving Europe's targets in a changing European energy system. Moreover, as the share of variable RES in the power sector grows, European hydropower will increasingly take a central role for enabling the transition to a future power system based on a mix of low-carbon technologies.

It is against this background that a group of European hydropower companies and equipment manufacturers has commissioned this study. The overall objectives of this study are to analyse and highlight the economic and social value, which hydropower brings to the European society.

This study takes a comprehensive look at the benefits of hydropower. Apart from the cost-efficient supply of clean electricity, it also addresses a range of other benefits, which hydropower delivers to the European power system and the wider European economy (see Figure 1-1). In particular, this study specifically deals with so-called multipurpose benefits since many hydropower installations serve multiple functions and provide direct or indirect macroeconomic effects beyond pure electricity generation. Finally, this report also aims at highlighting the role of continuous innovation and development, which have allowed the European hydropower industry to achieve global technology leadership.

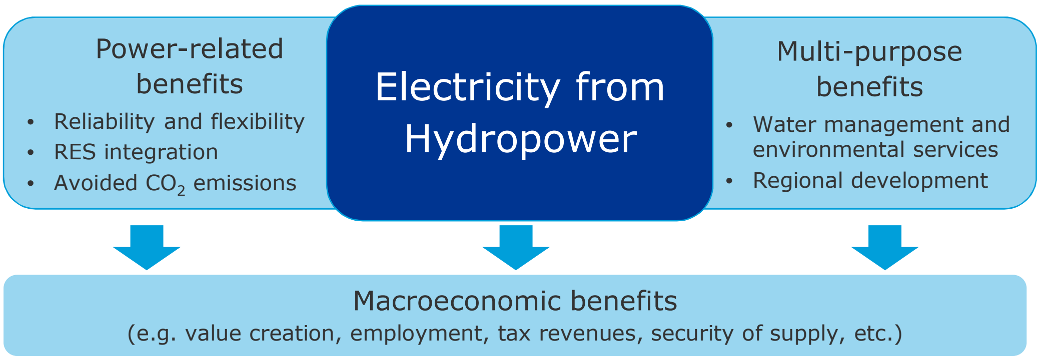


Figure 1-1: Benefits provided by hydropower
Source: DNV GL

Notes to the Reader

Unless stated otherwise, all values and results presented in this report refer to the 28 Member States of the European Union (excluding Malta and Cyprus) plus Norway, Switzerland and Turkey (compare Figure 1-2), which are cumulatively referred to as '***Europe***'. In addition, we also provide separate information for the European Union, which is referred to as '***EU-28***'.

The primary business of the hydropower sector is the generation of electricity, i.e. by run of river, storage and pump storage plants. Throughout this report, the term '***hydropower generation companies***' is used to refer to this part of the European hydropower industry. In addition, this report specifically addresses the sector of '***hydropower equipment manufacturers***'. These companies deliver electro-mechanical devices and other types of equipment that are specifically designed and manufactured for the construction and operation of hydropower plants. Please note that this definition does not cover civil works or other types of generic products and services, which the European hydropower sector purchases from other segments of the industry.

Figure 1-2: Geographical scope of 'Europe' as used in this study
Source: DNV GL

2 THE ROLE OF EUROPEAN HYDROPOWER TODAY AND IN THE FUTURE

Present and Future Electricity Generation from Hydropower

Electricity generation from hydropower has a long tradition in Europe. Starting with the construction of the first hydropower plants more than a century ago, hydropower has always played an important role for the supply of clean energy to European consumers at competitive rates. With a generation of approx. 600 TWh in Europe and 380 TWh in the EU-28 in the year 2013, hydropower represents one of the major sources of electricity and accounts for 18% and 13% of total electricity generation in Europe and the EU-28, respectively (see Figure 2-1). Hydropower generation is not evenly distributed across Europe. Due to geographic and climatic conditions, hydropower sources are concentrated in several distinct regions, including the Nordic countries, the Alps, the Iberian Peninsula as well as Turkey.

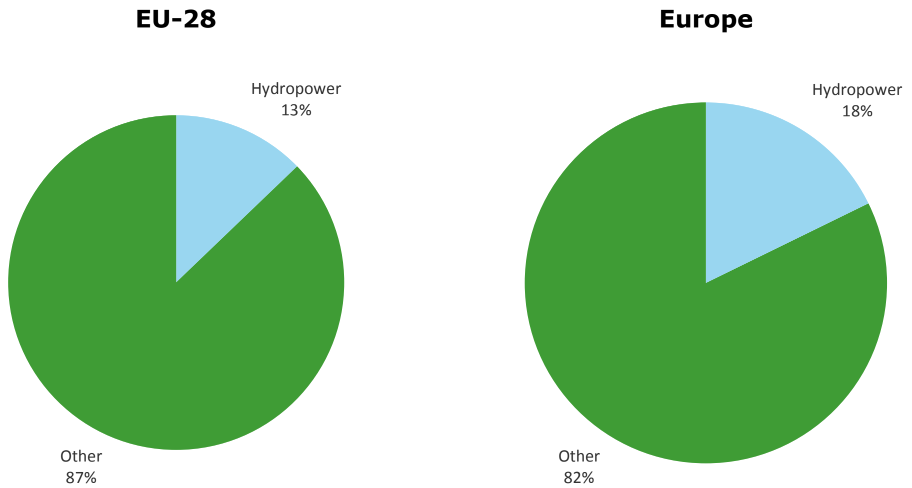


Figure 2-1: Share of hydropower in total electricity generation (2013)
Source: DNV GL analysis

Looking forward, there still is substantial scope for further expanding the use of hydropower in the future. Based on current predictions, electricity generation from hydropower in Europe may grow to some 700 TWh by 2030, and 750 TWh in 2050. Given a positive economic and regulatory framework, there even is the potential for generating up to almost 800 TWh in Europe by 2050 as illustrated in Figure 2-2. Compared to today, this would represent an increase of about 31%, or 200 TWh, which is more than the current electricity demand of countries like Poland, Sweden or the Netherlands.

Conversely, Figure 2-2 also indicates that deteriorating framework conditions may result in a significantly lower contribution of hydropower to the supply of low-carbon energy in the future. Apart from possible changes in economic conditions or an insufficient reward of flexibility in the future power markets, there is a risk that the construction of new and utilisation of existing hydropower plants may be inhibited by a range of other issues, such as difficult authorisation procedures, lack of public acceptance or increasingly strict environmental constraints, for instance related to implementation of the Water Framework Directive (WFD).

Hydropower supplies a significant share of Europe's electricity needs today, and there is potential for further increasing electricity generation from hydropower by up to 31% by 2050

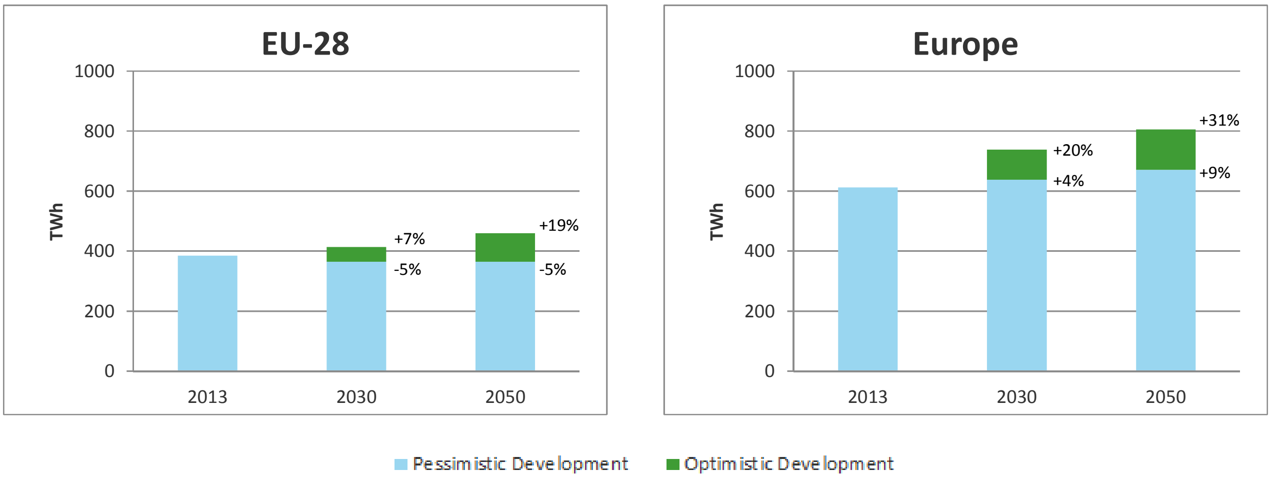


Figure 2-2: Possible evolution of electricity generation from hydropower until the year 2050
Source: DNV GL analysis

Hydropower as Major Source of Capacity and Electric Storage

At present, European hydropower plants have an installed capacity of more than 200 GW. This is equivalent to about 30% of the non-coincident peak load[2], which has been observed in Europe in the past. About three quarters of this capacity, or more than 150 GW, are provided by storage and pump storage plants, representing a major source of flexible and reliable capacity for the safe operation of the European power systems.

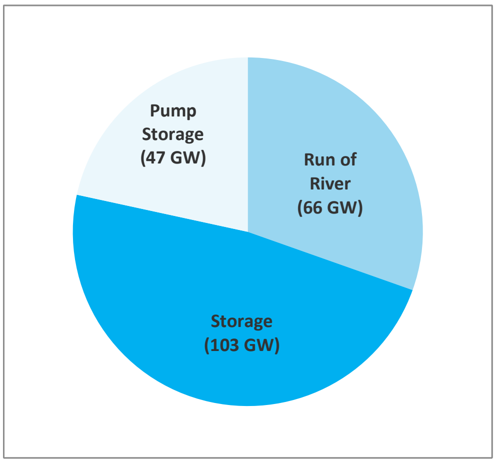
With an increasing penetration of variable RES, future power systems will increasingly benefit from, or even depend on, electricity storage. It is therefore worth noting that hydropower effectively represents the only large-scale storage technology available today. At present, European hydropower plants provide a combined storage capacity of more than 220 TWh, which is equivalent to nearly 25 days of average electricity consumption in Europe. The largest share of total storage capacity is located in the Nordic countries and Turkey, whilst the remainder is distributed across different parts of Europe (Figure 2-3) such that many countries and regions benefit from the associated flexibility.

Pump storage plants account for more than 20% of total installed capacity of European hydropower plants. These plants are perfectly suited for providing flexibility during daily operations and make it possible to temporarily store (excess) electricity and use it when it provides the largest value to the system. Based on actual generation and market prices, one can estimate that European pump storage plants were able to save up to an estimated EUR 1bn in fuel costs in the year 2013.

2 Calculated as the sum of instantaneous peak load of individual European countries, based on information published by ENTSO-E.

Hydropower provides more than 200 GW of reliable generation capacity and more than 220 TWh of electric storage capacity across different parts of Europe.

Installed capacity



Storage capacity

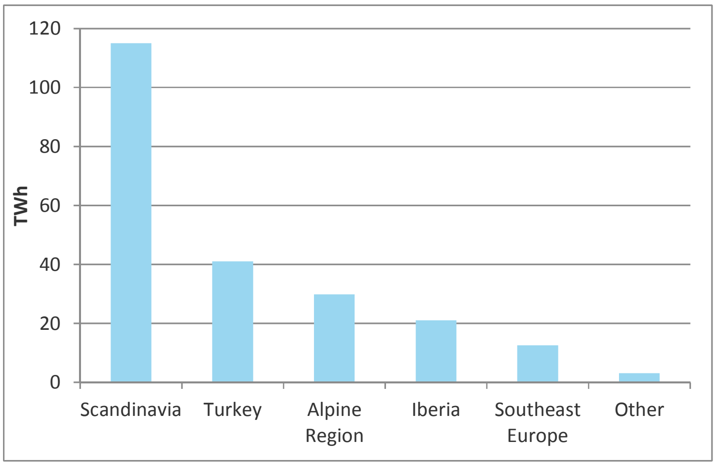


Figure 2-3: Generation and storage capacity of European hydropower
Note: Alpine region consists of Austria, France, Italy and Switzerland
Source: DNV GL analysis

3 THE CONTRIBUTION OF HYDROPOWER TO EUROPE'S ECONOMY

The hydropower sector directly and indirectly contributes to the European economy in several ways. Hydropower generation companies and equipment manufacturers generate substantial contributions to gross domestic product (GDP) at a national and European level, and provide high-value employment for tens of thousands of European citizens. In addition, hydropower stands out among renewable energies as it generates major revenues for public budgets at national, regional and local levels, which by far exceed the limited amount of subsidies which small hydropower receives. Besides these direct benefits, the hydropower sector creates additional value and employment in other sectors as well, for instance through the procurement of external services and extensive investments (compare Figure 3-1).

Hydropower is not only a cost-efficient source of electricity but also helps to reduce electricity prices. This effect induces further benefits to other sectors and contributes to the competitiveness of the European economy (see p. 0 for further details). Moreover, many hydropower reservoirs also serve other functions rather than just electricity generation. As further explained below (see p. 8), these so-called 'multipurpose benefits' may create substantial additional benefits at a local or national level, or even for multiple countries.

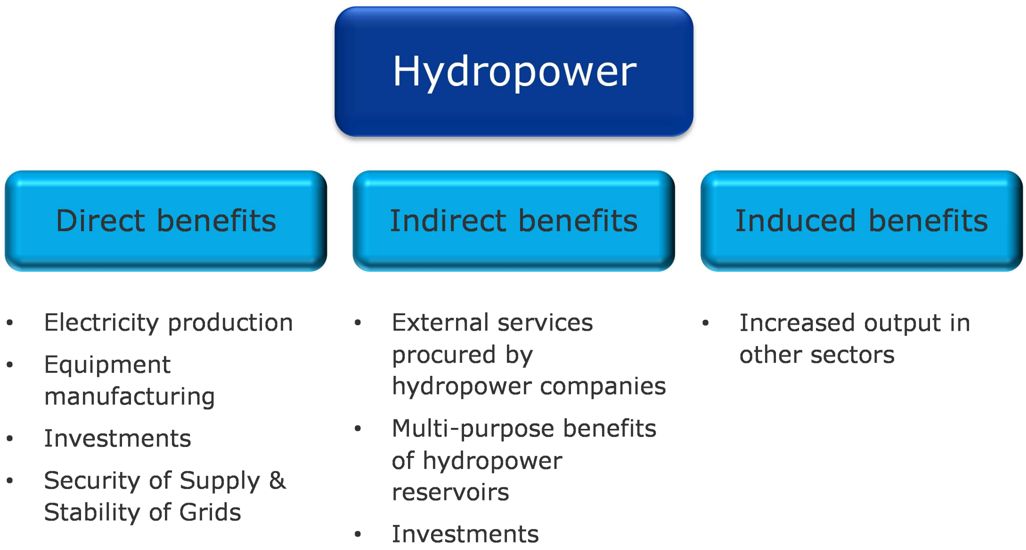


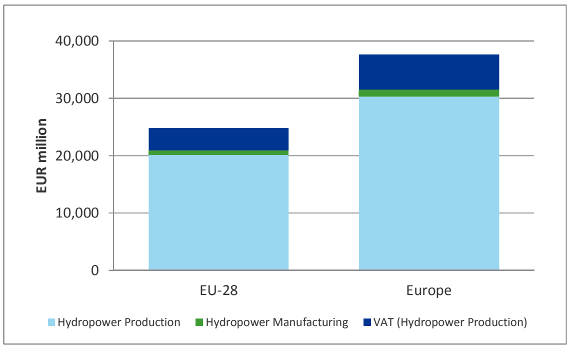
Figure 3-1: Overview over direct, indirect and induced benefits of hydropower
Source: DNV GL

Value Creation and Investments

The hydropower sector delivers an important contribution to the European economy, as reflected by its input to European GDP. At present, gross value creation by European hydropower generation companies and equipment manufacturers amounts to some EUR 38bn (see Figure 3-2). This value is comparable to the GDP of Slovenia, and is expected to further grow in the future. Besides the potential for additional hydropower generation (see p. 3), it is worth noting that the present value is heavily influenced by the relatively low price levels, which are observed in many European wholesale electricity markets today. The analysis in this report shows that, by 2030, the hydropower sector's contribution to European GDP may thus grow to a range of EUR 75bn to 90bn[3].

The contribution of the hydropower sector to European GDP is comparable to the national economy of Slovenia.

Gross value creation (2013)



Cumulative investments

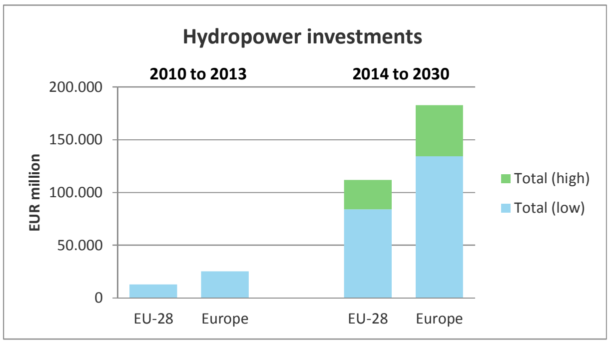


Figure 3-2: Value creation and investments in the European hydropower sector
Source: DNV GL analysis

The hydropower sector is a highly capital-intensive industry, which requires major investments into the construction of new plants as well as for the maintenance and refurbishment of existing ones. Between 2010 and 2013, European hydropower generation and manufacturing companies cumulatively invested an estimated EUR 25bn to 36bn[4], or between EUR 8bn and 12bn annually. This is eight times as much as the European pulp and paper industry invested in a similar 3-year period (2009 to 2012). Under favourable legal and regulatory conditions, which avoid any undue constraints for new and existing hydropower plants, cumulative investments in the European hydropower sector may amount reach more than EUR 180bn by the year 2030. Due to the longevity of hydropower plants (up to a hundred years or longer), which by far exceeds those of any other generation technology in the electricity sector, several generations of European citizens will benefit from these investments in the future[5].

Employment and Generation of Tax Revenues

As illustrated by Figure 3-3, European hydropower directly and indirectly ensures more than 100,000 jobs (FTE[6]). In the EU-28 alone, direct and indirect employment amounts to some 90,000 FTE – direct employment is comparable to the European agro-chemical industry. Based on the analysis carried out in this study, and considering two official scenarios published by the European Commission[7], total employment may grow to nearly 150,000 FTE by 2030.

3 Based on the 'Reference Scenario 2013' from the Commission's 'Trends to 2050' study ([17]), and the 'Diversified Supply Technologies' scenario from the European Commission's 'Energy Roadmap 2050' ([15]).

4 Due to the lack of exact numbers, these values have been estimated based on the capacity of new plants and an estimated range of specific investments costs for new hydropower plants of 1,500 to 2,500 EUR/kW.

5 Please that these investments will not be evenly distributed across Europe.

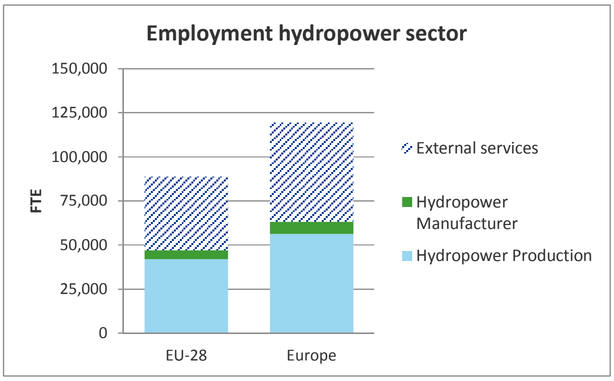
6 FTE = Full-time equivalent

7 See footnote 3

The average value produced by each FTE in the hydropower sector is considerably higher than in many other parts of the European economy. On average, each employee in the European hydropower generation sector creates an annual value of EUR 650,000, which is eight times higher than the average in the European manufacturing sector.

The European hydropower sector ensures high-value employment for more than 100,000 FTEs and generates an estimated EUR 15bn in tax revenues annually.

Direct and indirect employment



Annual tax revenues

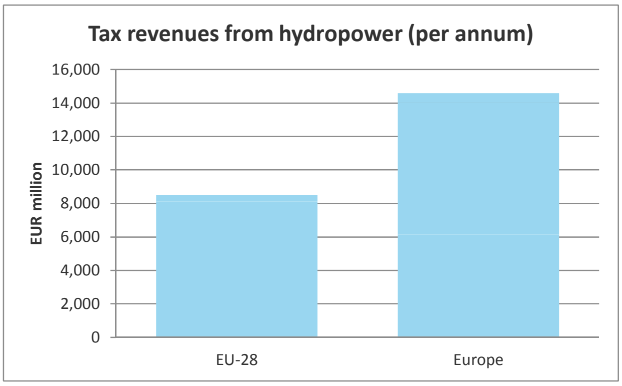


Figure 3-3: Employment and generation of tax revenues[8] in the hydropower sector (2013)
Note: Tax revenues include VAT
Source: DNV GL analysis

Apart from its considerable benefits to the European economy, the hydropower sector generates major revenues for governmental budgets at national, regional and local levels. Even when excluding profit taxes, direct tax contributions are estimated at almost EUR 15bn annually[9] (EU-28: EUR 8bn); see Figure 3-3. This corresponds to more than one third of total value creation and highlights that a substantial share of the total economic value of European hydropower is directly redistributed to the European society. Moreover, a significant share of these tax revenues goes directly to local and regional budgets and thereby helps to foster regional development.

Multipurpose Benefits

Electricity generation is the primary objective of most hydropower plants. But in many cases, dams and reservoirs also serve other purposes, or were originally built for purposes other than power generation. In addition to electricity production, many hydropower plants thus provide one or more so-called 'multipurpose benefits', which represent a particular feature of hydro dams and reservoirs. As indicated by Figure 3-4, some of the most important multipurpose benefits include flood control, supply of drinking water as well as water for irrigation and industrial needs, or the promotion of tourism and navigation:

- Especially in Southern European countries, water supply from reservoirs may deliver major economic benefits, in particular for irrigation. A review of other studies indicates that the overall value to the European economy may exceed EUR 10bn annually.

8 Tax revenues include hydro specific taxes, tax on personal income (i.e. wages) and VAT. Corporate taxes are excluded.

9 Payments under subsidised prices to small hydropower are limited to an estimated EUR 2.6bn per annum. The figure shows the net contribution of hydropower generation to public budgets.

- Flood control may render major economic benefits, i.e. in the form of avoided damages, which may otherwise be in the range of multiple billion Euros for individual events. Flood control is particularly valuable in more densely populated areas in Central Europe but is equally relevant in other parts of Europe.
- Various hydropower plants facilitate inland navigation. The associated benefits are estimated to be in a range of several hundred million to more than two billion Euros annually.
- The analysis carried out in this study shows that hydropower can also create substantial benefits for local tourism and may exceed EUR 200m per annum in individual regions.
- Finally, many dams or reservoirs also deliver a range of other benefits. These include such diverse aspects such as collecting and removing floating refuse, facilitating firefighting in arid regions, or water management and environmental services[10]. These benefits are important at specific locations only and may vary considerably by location.

Overall, the analysis carried out in this study suggests that multipurpose benefits of European hydropower plants may deliver an economic value of EUR 10 to 20bn annually. This value is in addition to the direct and indirect benefits identified above and does not include the value of flood control, which may help to avoid major damages to life and property.

10 For instance by helping to stabilise groundwater levels or support oxygenation, cleansing of water or sediment and habitat management

In addition to the generation of clean electricity,
many hydropower dams and reservoirs also provide one or more multipurpose benefits.

Water supply

- *Different purposes and water uses, incl. irrigation and agriculture, drinking water, industrial processes, cooling water*

Flood mitigation

- *Using storage capacity and dikes*
- *Avoiding or reducing damages from flood events*

Navigation

- *Transportation of goods using vessels*
- *Alternative to other modes of transportation*

Tourism

- *Facilitating water sports and other tourist activities at and around a hydro power plant's water reservoir*

Other

- *Various other functions, depending on the local needs and regulations*
- *E.g. garbage collection, assisting fire fighting through water provision, hosting fishing and aquaculture business*

Figure 3-4: Multipurpose benefits of hydropower reservoirs
Source: DNV GL; Edersee Touristik GmbH, M. Latzel; 'Bewertung von Einflüssen tschechischer und Thüringer Talsperren auf Hochwasser an Moldau und Elbe in Tschechien und Deutschland mittels Einsatz mathematischer Abflussmodelle', Busch et al., 2012

4 SUPPORTING EUROPEAN ENERGY AND CLIMATE POLICY

The climate and energy policy of the EU-28 and many European countries, including Norway and Switzerland, is based on three over-arching objectives, i.e. to build an affordable, secure and sustainable energy system (see Figure 4-1). The EU-28 has committed itself to reducing greenhouse gas emissions (GHG) to 40% below 1990 levels by 2030[11], and it is widely expected that a particularly high share of decarbonisation will have to be delivered by the power sector. But high unemployment and the continued lack of economic growth in many European countries since the financial crisis in the years 2008/2009 have illustrated that it is equally important to ensure the competitiveness of the European economy. Finally, recent events like the Ukraine crisis have highlighted that it is also essential to ensure security of supply.

Hydropower delivers on all three key objectives for the European power system. It is thus perfectly suited for reaching Europe's energy and climate goals.

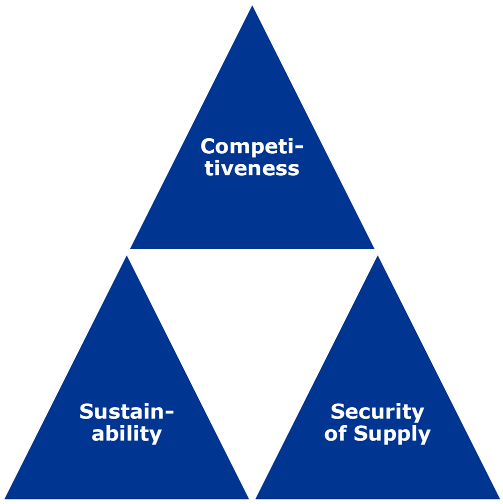


Figure 4-1: Key Pillars of European Energy and Climate Policy
Source: DNV GL

Promoting the Sustainable Supply of Electricity

Hydropower represents a cornerstone for a sustainable power sector. According to IPCC, it is one of a few technologies that have very low lifecycle GHG emissions and are available at a commercial scale at competitive costs today[12]. With an annual generation of some 600 TWh, European hydropower accounts for about one third of total electricity generation from low-carbon technologies in Europe and is by far the single largest source of electricity generation from renewable energy sources in Europe at present.

11 European Council (23 and 24 October 2014). Conclusions on 2030 Climate and Energy Policy Framework. SN 79/14. Brussels, 23 October 2014

12 According to IPCC (2014), p. 540, only wind, solar, nuclear, and hydropower '*can provide electricity with less than 5 % of the lifecycle GHG emissions of coal power*'. In addition, hydropower, onshore wind and nuclear are the only technologies that are assumed to be competitive with coal and gas fired plants in terms of levelised costs of electricity; see IPCC (2014), figure 7.7 on p. 541.

As illustrated by Figure 4-2, hydropower alone supplied nearly 50% of all electricity from renewable energies in the EU-28 in 2013, and almost 60% in Europe. Despite the anticipated growth of other types of RES in the future, it is estimated that hydropower will represent about one third of total generation by RES by 2030 in Europe.

European hydropower accounts for nearly 50% of total electricity generation from renewable energies in the EU-28, and almost 60% in Europe.

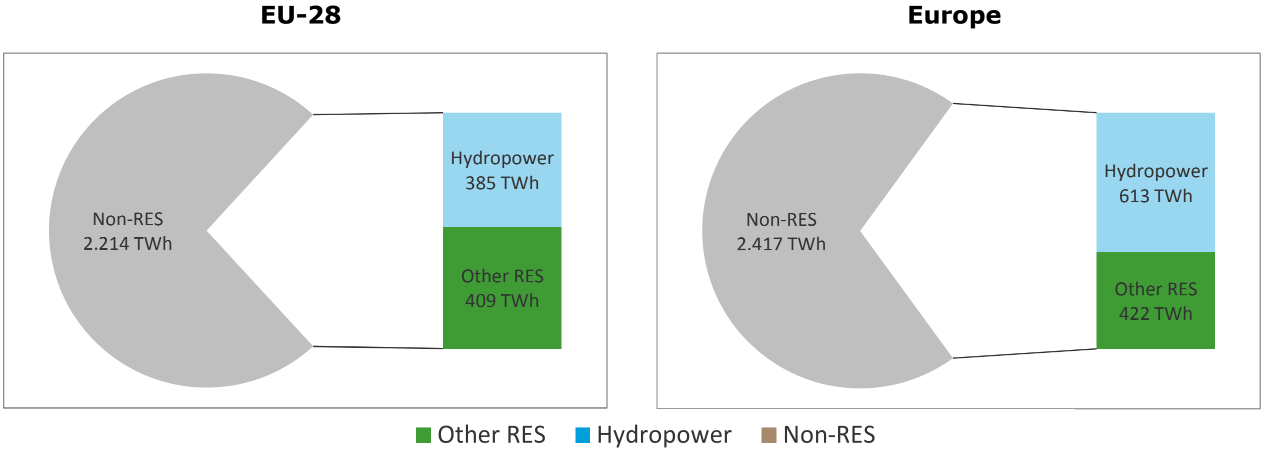


Figure 4-2: Contribution of hydropower to electricity generation (2013)
Source: DNV GL analysis

Due to its considerable share in electricity generation, hydropower significantly contributes towards the reduction of CO_2 emissions in the power sector. At present, hydropower helps to avoid between 180 and 350 Mt of CO_2 in the EU-28 (see Figure 4-3), which is equivalent to about 15% to 32% of total CO_2 emissions in the EU-28 power sector in the year 2010. For Europe, savings are even bigger with 280 to 530 Mt of CO_2, or 21% to 40% of European power sector emissions. Due to the increasing share of renewables, overall power sector emissions are expected to decrease in the future. Still, the analysis carried out in this study shows that hydropower will help to save about 50 to 130 Mt of CO_2 in the EU-28 in 2030, and 100 to 220 Mt in Europe. In relative terms, avoided emissions remain at comparable levels, with savings of 12% to 24% in the EU-28, and 24% to 43% in Europe.

European hydropower helps to avoid between 180 and 530 Mt of CO_2 emissions at present, which is equivalent to 15% to 40% of total power sector emissions.

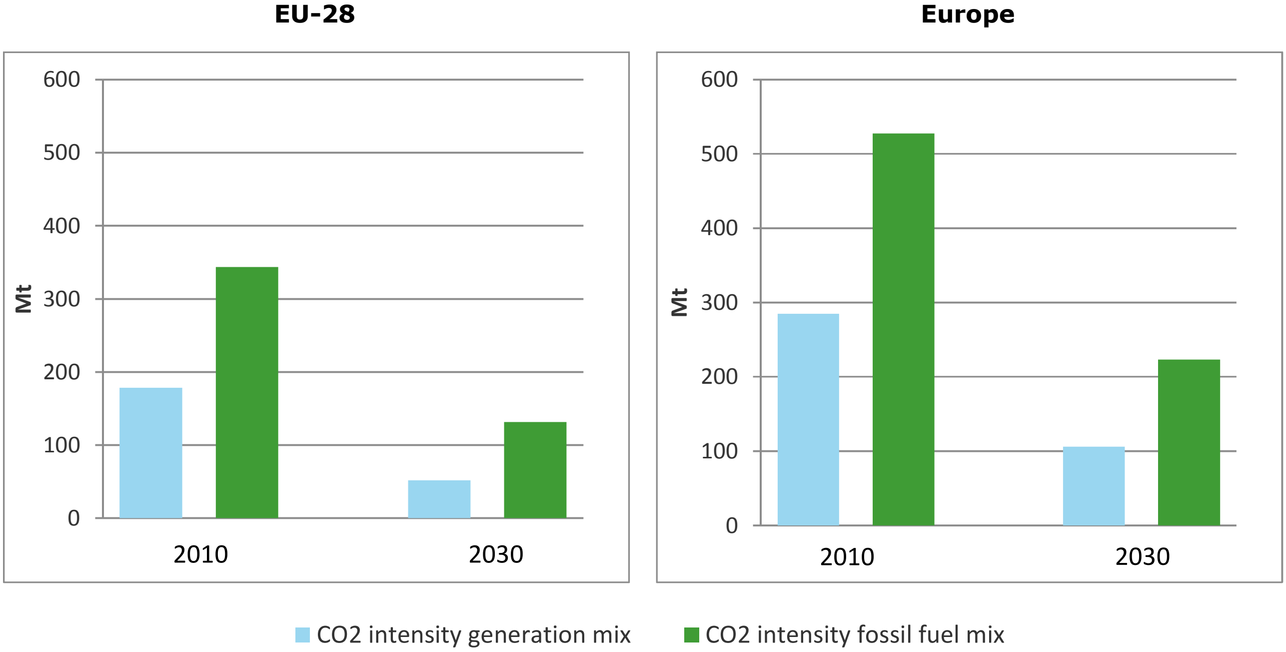


Figure 4-3: Avoided CO_2 emissions by hydropower
Note: Based on average CO_2 intensity of total generation mix (excl. RES) and electricity generation from fuels
Source: DNV GL analysis

Supplying Affordable Electricity and Supporting the Competitiveness of the European Economy

Hydropower is a mature and competitive technology, which benefits from more than a century of continued development and technical improvements. In many European countries, hydropower plants have successfully operated in the electricity market and helped to reduce electricity costs for European consumers for decades. Apart from the cost-efficient supply of electricity itself, the flexibility of hydropower plants helps to avoid price spikes in volatile energy markets, thereby reducing average costs to final consumers.

These benefits have become of increasing importance in recent years, which have been characterised by increasing electricity prices for many European consumers and growing concerns on energy poverty. Against this background, electricity generation from hydropower represents an important instrument for supplying **affordable electricity** to European consumers. For example, the analysis in this study indicates that a 10% increase of hydropower generation may deliver annual savings of between EUR 5bn and 10bn to final consumers in 2030.

In addition to direct benefits for final consumers, these price effects may trigger additional long-term benefits and contribute to the **competitiveness** of the European economy. Based on the simulation of selected development scenarios and a macroeconomic input-output analysis, the analysis carried out in this study shows that hydropower has substantial positive effects on value creation and employment, both in the hydropower sector itself as well as in other sectors.

For instance for the year 2030, a 10% increase of hydropower generation increases Europe's GDP by between EUR 9bn and 11bn and creates between 27,000 and 36,000 new jobs. As Figure 4-4 shows, most of the additional employment is observed outside the hydropower sector. Indeed, each additional job in the hydropower industry creates between two and seven additional jobs in the overall economy. These benefits are permanent and not related to temporary gains during the construction of new assets.

Input-output analysis for 2030 indicates that each additional job in the hydropower industry creates between two and seven additional jobs in the overall economy.

Figure 4-4: Estimated effects of additional hydropower on employment (2030)
Source: DNV GL

Contributing to security of supply

European storage and pump storage plants are a major source of flexibility for power system operations. With more than 150 GW of installed capacity, their capacity is sufficient to cover some 25% of European peak load. Hydropower plants thus contribute to generation adequacy as they can deliver electric power when needed. The availability of firm capacity has always been important for the reliability of the power system, and will be even more important as the penetration of variable RES grows.

Due to their flexibility, hydropower plants are perfectly suited to providing a wide range of ancillary services, which are essential for operating the power system in a safe and reliable manner. Such ancillary services include reserves and frequency control that help to balance the system in real time, but also other services, like voltage / reactive power control, or black start services for system restoration after a partial or full blackout. These services are important today and will become even more important in future power system with an increasing share of variable renewables.

Electricity generation from hydropower also helps reducing imports of fossil fuels. For instance in the EU-28, fossil fuel imports would have increased by an estimated 2,700 to 4,300 PJ without hydropower in 2010, which is equivalent to 7% to 11%[13] of total imports of fossil fuels in that year. Based on the range of average coal and gas prices in the years 2010 to 2013, this translates to savings of between EUR 12bn and 24bn for the EU-28 alone. When considering the entire European power system, avoided import volumes are even higher with 4,200 to 6,500 PJ, or EUR 18bn to 37 bn.

13 Based on the carbon intensity of fossil fuels and nuclear (lower bound) and fossil fuels (upper bound), respectively.

Similar effects can be observed for the year 2030, despite the assumption of continued decarbonisation of European power supply. Whilst the volume of avoided imports decreases in real terms, the analysis carried out in this study indicates that their value may even increase in monetary terms. These numbers clearly show that hydropower delivers an important contribution to the security of Europe's fuel supply and Europe's fuel bill.

Hydropower does not only contribute to security of supply by avoiding additional primary fuel imports, but also helps the EU-28 to limit its fuel bill.

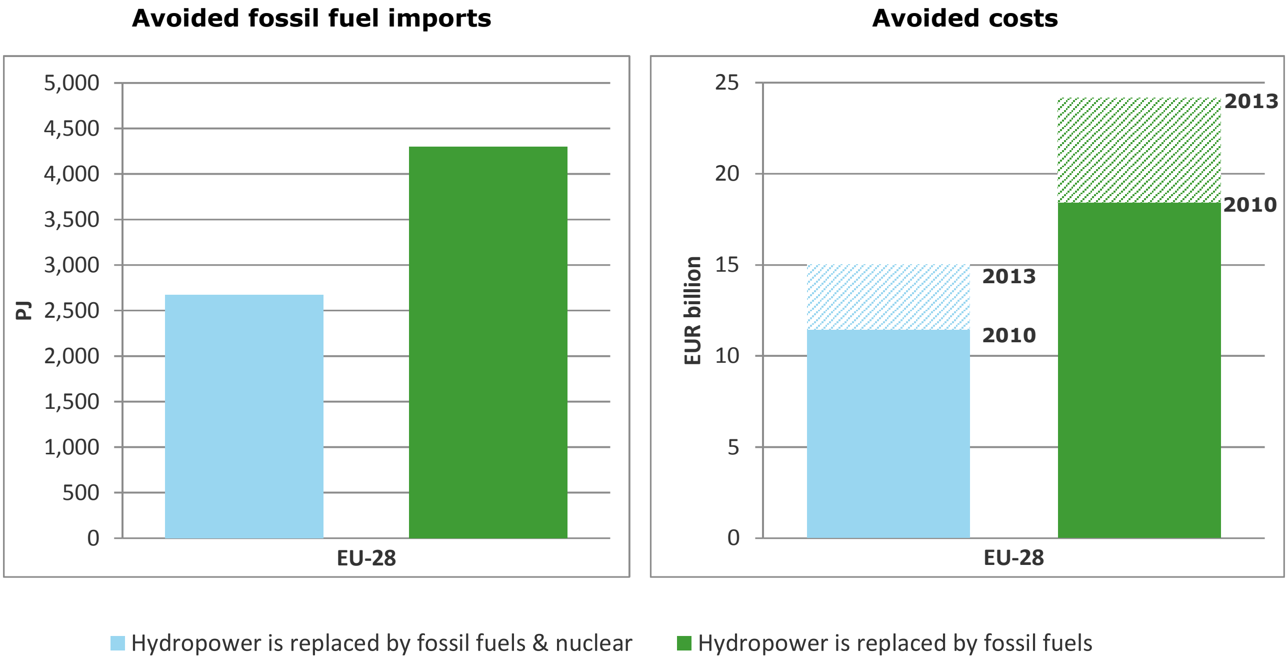


Figure 4-5: Avoided imports of fossil fuels in the EU-28 (2010)
Source: DNV GL analysis

5 HYDROPOWER AS ENABLER OF RENEWABLES INTEGRATION

In their decision on the 2030 climate and energy policy framework[14], EU policy makers confirmed a binding target of at least 27% for the share of renewable energy consumed in the EU in 2030. Achieving this ambitious target will require an ever higher share of renewable energies in the European power sector. Although the exact figures remain uncertain (compare Figure 5-1), it is generally expected that most of the additional capacity will come from variable sources like wind and solar power.

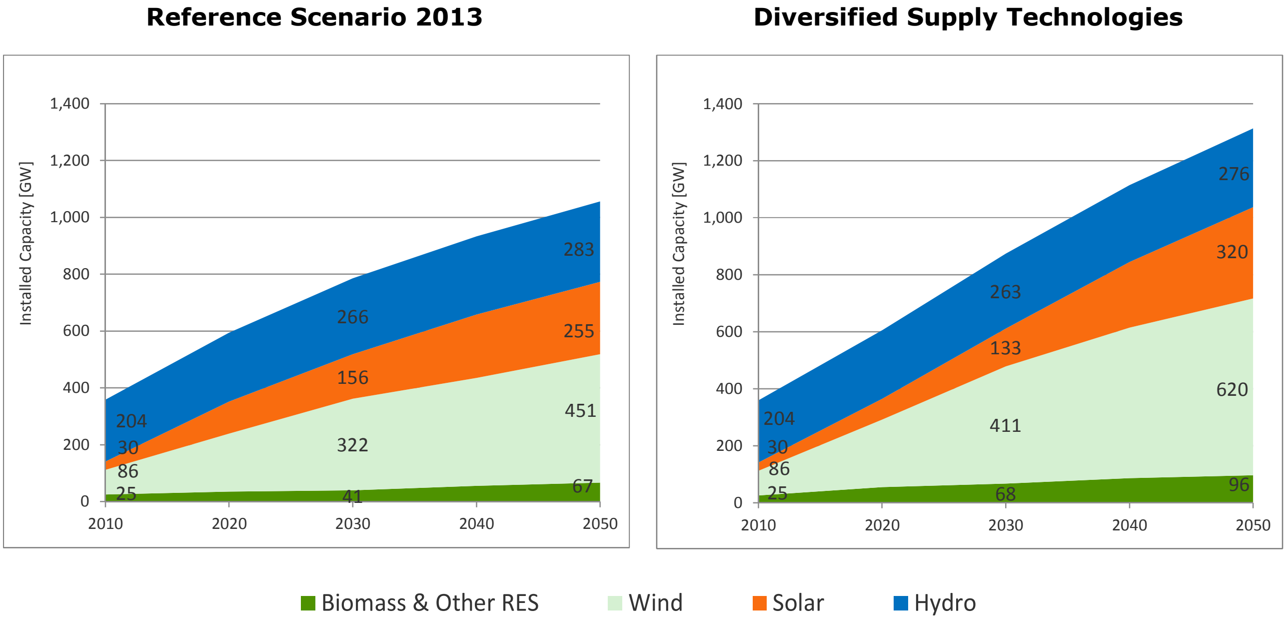


Figure 5-1: Expected growth of generation from renewable energies in Europe until 2030
Note: ‘Other RES’ include geothermal, wave, tidal generation technologies
Source: DNV GL analysis, based on DG ENER, ENTSO-E

Integrating these additional volumes of generation from variable RES will create serious challenges for the European power systems. In order to successfully deal with the variable nature of wind and solar power in particular, the future power system will need to be able to provide sufficient flexibility, firm capacity and the ability to balance volatile generation over a timeframe of several weeks or even months (see Figure 5-2). These developments will greatly increase the value of hydropower as it provides an ideal solution for these challenges. Apart from its flexibility, hydropower is the only form of electricity storage that is available on a large scale and across different time scales at competitive costs today. Moreover, their storage potential and flexibility enable hydropower plants to contribute to reliability by making power available when so required.

14 European Council. European Council (23 and 24 October 2014), Conclusions on 2030 Climate and Energy Policy Framework. SN 79/14. Brussels, 23 October 2014

The flexibility and storage capabilities of hydropower make it perfectly suited for facilitating the integration of variable RES into the European power system

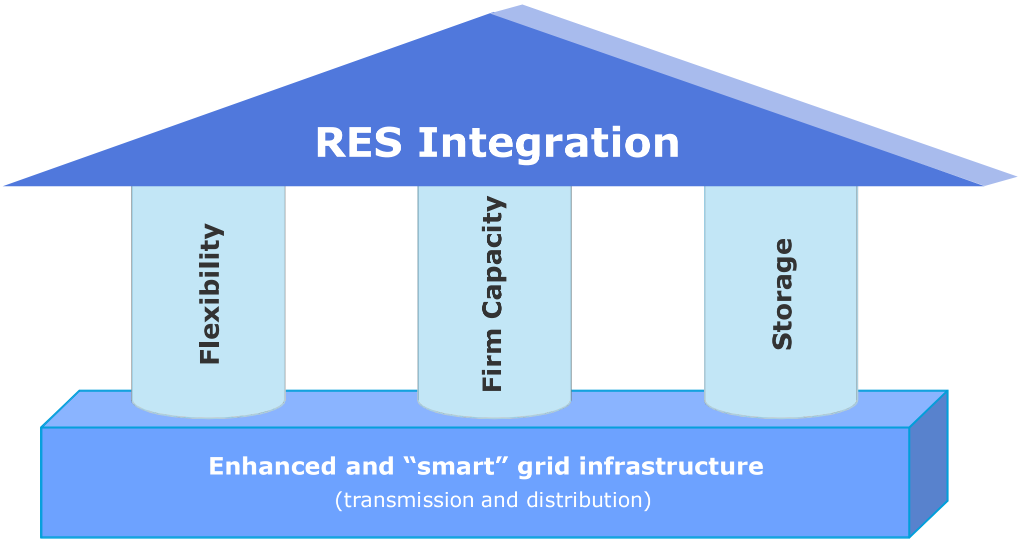


Figure 5-2: Essential pillars of RES integration
Source: DNV GL

Flexibility

Wind and solar power are characterised by considerable volatility across different scales, and their output cannot be predicted with certainty. In order to deal with the resulting variations and forecast errors, system operators as well as electricity markets will need to have access to increasing volumes of flexibility as the penetration of wind and solar power grows. Among others, this includes the ability to:

- Accommodate large variations in residual demand as the generation of wind and solar plants does not always coincide with load, which may lead to insufficient or excess supply during periods of peak and trough load, respectively,
- Offset unexpected variations in generation due to forecast errors in the intra-day markets or in the form of balancing power and ancillary services,
- Provide increasing ramp rates in real time, caused by sudden changes of generation by wind and solar power.

Due to their flexibility and size, hydropower plants are perfectly suited for supplying these capabilities to current and future electricity markets and power systems. Storage as well as pump storage plants can be quickly started and adjust their output within seconds. Consequently, hydropower plants are able to follow even major variations in real time.

For illustration, Figure 5-3 shows the ability of pump storage plants to mitigate the effect of a solar eclipse on a sunny day in Germany. Although the installed capacity of pump storage plants (6.5 GW) is less than 20% of that of solar power in Germany, they are able to effectively reduce the rate at which residual load changes. Indeed, the remaining variation is less than the typical ramp rate encountered in the early evening, such that it can be safely supplied by other types of generation, imports, exports and, where necessary, demand response. This example perfectly shows how even a limited volume of pump storage capacity makes it possible to effectively deal with even extreme events caused by variable RES.

Flexible use of pump storage plants can help to mitigate the impact of increasing volatility from variable RES even during extreme events

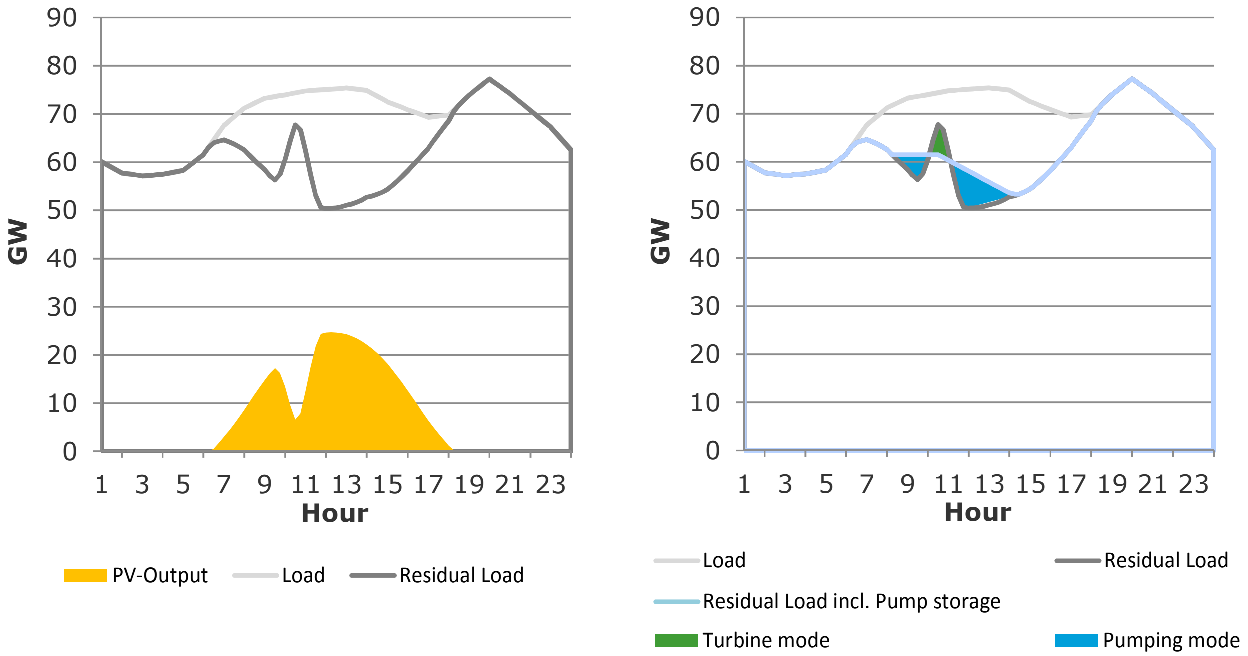


Figure 5-3: Compensation of PV ramp rates by pump storage plants during solar eclipse in Germany
Illustration based on: J. Weniger et al. Einfluss der Sonnenfinsternis im März 2015 auf die Solarstromerzeugung in Deutschland. Hochschule für Technik und Wirtschaft HTW Berlin. October 2014. p. 28

Similarly, hydropower plants support the compensation of variations in wind and solar generation over several hours or even days. This is illustrated by Figure 5-4, which shows the hourly pattern of load and generation on the Iberian Peninsula in a summer week in the year 2030. This figure clearly shows how the operation of hydropower, including generation as well as pump load, is optimised overall several days, in order to balance between days and hours with higher and lower generation from wind and solar plants. Moreover, one can again observe how hydropower helps 'flattening' the generation profile of other generation technologies, thereby helping to reduce thermal or mechanical stress and to improve the efficiency of operations of these plants.

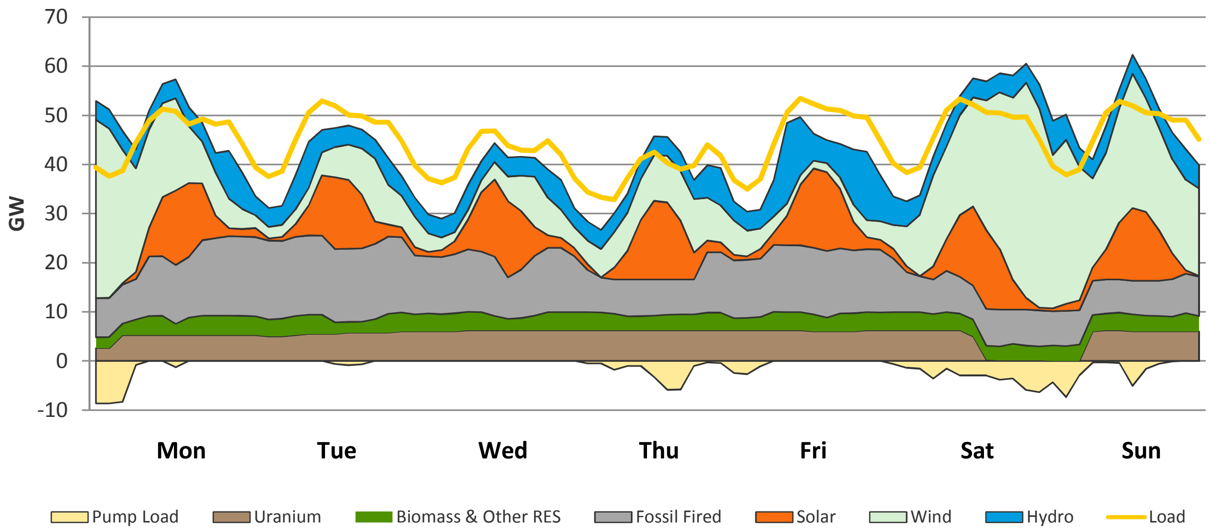


Figure 5-4: Hourly electricity generation in Iberia for a selected week June 2030, projection
Note: Net electricity exchanges are indicated as difference between electricity demand and generation
Source: DNV GL analysis

Firm Capacity

Whilst renewable energies are expected to supply an increasing share of electricity generation in the future, their contribution to generation adequacy will remain limited. Consequently, it will be necessary to 'back up' variable RES by other types of generation, which can produce electricity when needed. Indeed, practical experience and numerous studies show that there will remain periods when the aggregate generation by wind and solar power will be extremely limited, even when being considered across larger regions, or potentially all of Europe. For example, a recent study on behalf of the European Commission[15] found that the need for firm capacity in the year 2030 was largely independent of the penetration of wind and solar power, but rather dependent on the level of electricity demand.

Although hydropower plants are exposed to variable natural inflows, especially plants with reservoirs are able to provide firm capacity to the power system. Whilst the level of firm capacity may vary depending on hydrological conditions, reservoir size and the time horizon under consideration, hydropower plants with storage can provide significant benefits to the system.

As an example, Figure 5-5 shows the contribution of pump storage plants to generation adequacy in Southern Germany in the winter 2015/2016. The German TSOs are planning to procure 6,000 MW of 'Grid Reserves' for this period, in order to ensure generation adequacy in this region. In Figure 5-5, this requirement is compared to the level of 'firm' capacity[16] available from pump storage plants in Southern Germany and its neighbours to the South. As Figure 5-5 illustrates, pump storage plants in Southern Germany alone provide for almost 2,000 MW of firm capacity. Consequently, the need for grid reserves would increase by about one third if there were no pump storage plants in Southern Germany. Similarly, the aggregate level of firm capacity available from pump storage plants in Southern Germany, Austria

15 DNV GL, Imperial College and NERA. Integration of Renewable Energy in Europe. Final Report. Bonn. June 2014

16 In line with the current approach by the German TSOs, the 'firm' capacity of pump storage plants has been set to 80% of installed capacity.

and Switzerland is equivalent to the total need for grid reserves, i.e. even without considering the potential contribution by other storage plants with natural inflows.

Pump storage plants are able to substantially reduce the expected 6,000 MW deficit of generation adequacy in Southern Germany

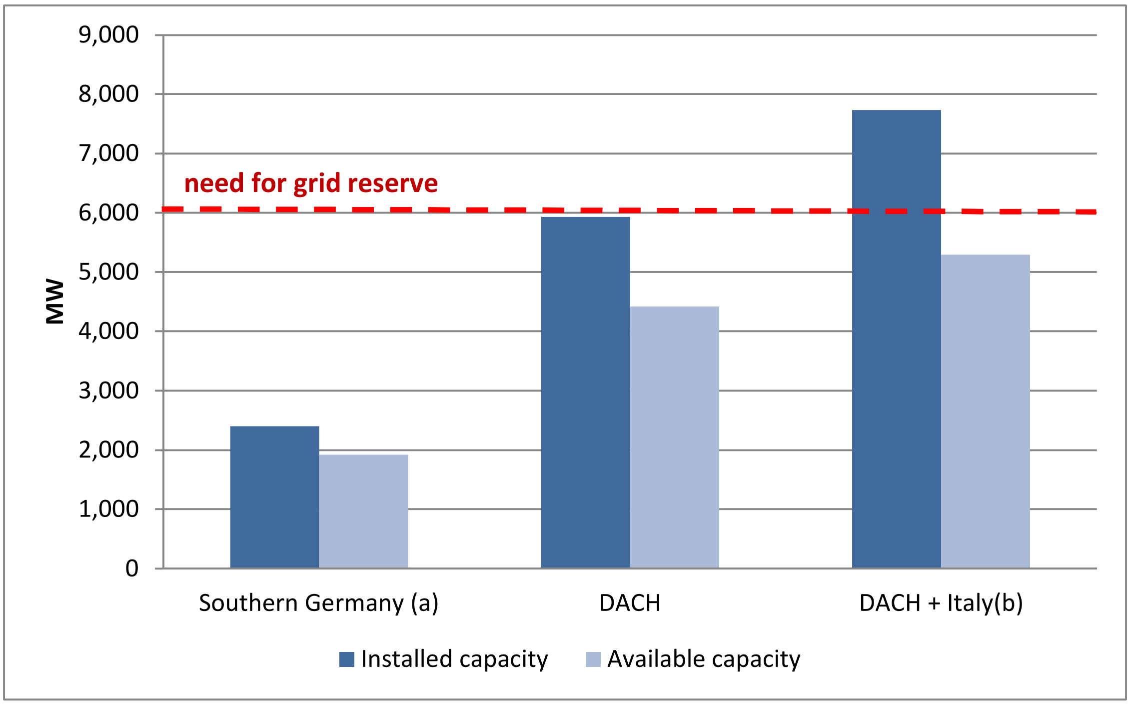


Figure 5-5: Contribution of Alpine pump storage plants to generation adequacy
Notes: Available capacity limited to 80% of installed capacity;
'DACH' = Germany, Austria and Switzerland
(a) – Analysis limited to pump storage plants located in Southern Germany
(b) – Contribution of Italian pump storage limited to maximum export capacity to Switzerland (1,800 MW)
Source: DNV GL analysis

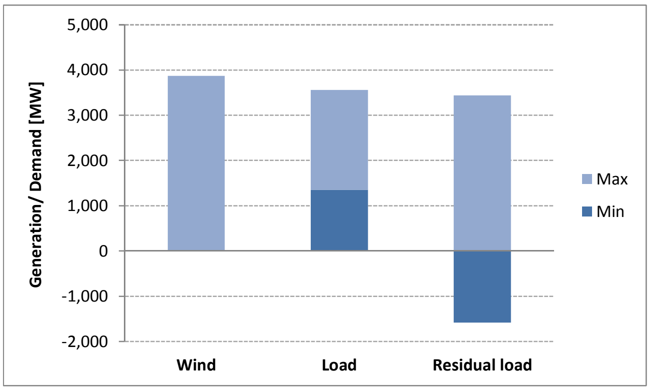
Electric Storage

Hydropower plants with significant storage capabilities are a perfect instrument for optimising the use of variable RES over longer periods, i.e. for weeks, months or even entire seasons. This makes it possible to utilise energy available when there is an excess of electricity by returning it to the system during periods when the supply of electricity from variable RES is limited.

With continuing development of renewables in Europe, the requirements for flexibility and storage are expected to significantly increase over the coming decades. A corresponding need for storage is often identified for future scenarios with a very high penetration of variable resources. However, hydropower already facilitates the integration of variable wind and solar power today, and has indeed done so for many years already. For illustration, Figure 5-6 shows the positive effects of Nordic hydropower on the use of wind power in Western Denmark. In the year 2013, the close coupling of Western Denmark with hydropower in Southern Norway made it possible to resolve most instances of negative residual load, i.e. when there was an excess of electricity in Western Denmark.

Access to Nordic hydropower avoids curtailment of wind power in Western Denmark by exporting excess electricity to Norway

Wind generation vs. demand (minimum and maximum values)



Distribution of negative residual load (excess electricity) with and without cross-border exchanges

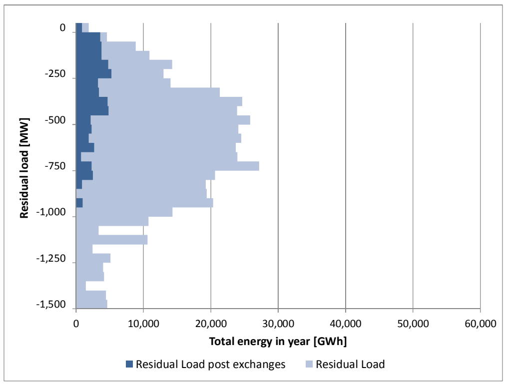


Figure 5-6: Reduction of negative residual load in Western Denmark by Nordic hydropower (2013)

Note: Right graph shows total energy available in hours with excess electricity (negative residual load) in the year 2013

Source: DNV GL analysis

6 TECHNOLOGY LEADERSHIP AND INNOVATION

The success of the European hydropower sector is based on its technology leadership and a high level of innovation. As a result, European hydropower equipment manufacturers enjoy a market share of 2/3 of the global market for hydro power equipment. This includes three global leaders, which account for more than 50% of the worldwide market, as well as a large number of small and medium-sized companies.

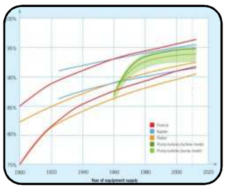
This success is built on close cooperation between generation companies, equipment manufacturers as well as academic and research institutions. Europe counts on a large number of leading research centres with a focus on hydraulic and electro-technical engineering as well as interdisciplinary issues. They trigger innovation, facilitate information exchange and contribute to technological progress.

Box 6-1: Technology leadership of European hydropower equipment manufacturers

- **3 global leaders, plus more than 50 small and medium-sized companies**
- **Global market share of two thirds of the world market**
- **Spending more than 5% of annual turnover on research and development (R&D) (more than twice the European average)**

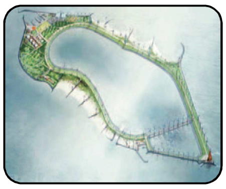
Source: DNV GL analysis

Hydropower is a proven and mature technology and the only large-scale energy storage technology available today. Nevertheless, equipment manufacturers and plant operators are constantly investing into different types of innovation. Today, innovation in the European hydropower sector focuses on five broader areas and challenges (see Figure 6-1), with the aim of preparing the European hydropower sector for the challenges of a future power system dominated by variable RES and maintaining global technology leadership. European manufacturers alone spend more than 5% of annual turnover on R&D, which is more than twice the European average.



Cost reduction and increased output

- Technological & process improvements
- Standardisation of equipment

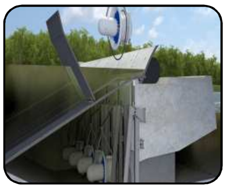


Flexibility for dealing with variable RES and a changing market environment

- Improved operational flexibility of hydropower plants
- Dispatchable power from small hydropower

Environmental-friendly development

- Mitigation of hydro- and thermo-peaking, landscape integration and river habitat friendly design
- New concepts for small hydropower plants



Complex site conditions

- Tailored design of low-head and kinetic flow turbines for specific applications (in canals, pipes, rivers)
- Dealing with more comlex site conditions and design constraints

Adaptation to climate change

- Analysing and predicting magnitude of changes
- Solutions for dam safety and safe operation of hydropower plants

Figure 6-1: Focus areas of innovation in the European hydropower sector
Source: DNV GL, HEA, EPFL

7 INCREASING ROLE OF HYDROPOWER ON THE ROAD TO A LOW-CARBON POWER SECTOR

Over decades, hydropower plants were mainly built and operated as a cost-efficient source of clean electricity. In addition, flexible hydropower has a long tradition of providing a range of ancillary services, which are essential for operating the power system in a safe and reliable manner. In combination, these specific features of hydropower have been the foundation for providing a range of technical and economic benefits to the electricity markets and the wider European economy and society. Apart from the direct and indirect benefits of the hydropower sector itself, many dams and reservoirs provide a range of so-called multipurpose benefits, for instance by promoting water supply, flood control, navigation or tourism. Similarly, the positive effects of hydropower on electricity prices contribute to affordable electricity supply for consumers and the competitiveness of the European industry.

Over the past 15 years, the role of hydropower has gradually evolved in line with the increasing penetration of wind and solar power. In this context, the flexibility and storage capabilities of hydropower plants have gained additional value as they represent an important instrument for dealing with the uncertain and variable generation of other types of renewable energies. To date, hydropower has already been instrumental for supporting the integration of variable renewables in countries like for instance Denmark, Germany or Spain.

In line with Europe's energy and climate goals, it is generally expected that the role of variable resources will continue to grow and that the future generation structure will increasingly be dominated by wind and solar power in particular. This implies that the challenges of RES integration will become ever more important in the future, which will make it necessary to rely on a range of different sources of flexibility, including more flexible generation, demand response or even new types of electricity storage. At the same time, this will further reinforce the value and importance of hydropower, which is perfectly suited to deal with these challenges, and which provides the necessary capabilities at a large scale at competitive costs.

On the road to 2050, the role of European hydropower will thus further evolve from providing clean electricity at competitive rates to taking a central role for enabling the transition to a future power system based on a mix of low-carbon technologies.

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