DNV·GL

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

# Main Report

**On behalf of: A European Hydropower Initiative of Hydropower Companies and (supported by) Associations**

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# A. EXECUTIVE SUMMARY

This study has taken a comprehensive look at the significant benefits, which hydropower brings to the European society in terms of its contribution to economic and social welfare and for reaching Europe's energy and climate goals[1]. Indeed, hydropower is not only a cost-efficient source of low-carbon electricity but also delivers a range of other benefits to the European power system and the wider European economy. Among others, this study has analysed the direct and indirect macroeconomic effects of hydropower, at present as well as for two scenarios with different penetrations of variable renewables in the year 2030. In addition, this study has specifically addressed so-called multipurpose benefits since many hydropower installations serve multiple functions and provide direct or indirect macroeconomic effects beyond the generation of electricity.

Decarbonisation of the European power system will require an increasing penetration of variable renewables. Therefore, this report also illustrates how the flexibility and storage capabilities of hydropower plants greatly facilitate the integration of other, variable types of renewable energies, such as wind and solar power. Finally, chapter 5 highlights the role of constant innovation and development, which have allowed the European hydropower industry to achieve global technology leadership.

In the following, we briefly present the main findings of the analysis in this report.

## Contribution to Europe's Economy

The hydropower sector directly and indirectly contributes to the European economy in several ways:

- With an annual value creation of approx. EUR 38bn today, which may grow to some EUR 75bn to 90bn by 2030, the hydropower sector makes an important contribution to the European economy, which is similar to the gross domestic product (GDP) of Slovenia.
- At present, European hydropower generation and manufacturing companies invest an average of EUR 8bn to 12bn per annum. Projected investments in the European hydropower sector may reach up to EUR 180bn by 2030, but may be lower in the case of deteriorating framework conditions[2]. Due to the longevity of hydropower, which by far exceeds those of any other type of generation technology in the electricity sector, several generations of European citizens will benefit from these investments[3].
- Directly and indirectly, European hydropower ensures more than 100,000 jobs (FTE), which is comparable to employment in the European aluminium industry. In addition, each FTE in the hydropower generation sector produces an average annual value of approx. EUR 650,000, which is equivalent to eight times the average productivity in the European manufacturing sector.
- The European hydropower sector generates major revenues for governmental budgets at national, regional and local levels. Direct tax contributions are estimated at almost EUR 15bn annually, or more than one third of total value creation, which is several times more than the limited volume of

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1 Please note: 'EU-28' refers to the 28 Member States of the European Union (excluding Malta and Cyprus). 'Europe' refers to the EU-28 plus Norway, Switzerland and Turkey.

2 Apart from possible changes in economic conditions or an insufficient reward of flexibility in 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).

3 Please that these investments and benefits will not be evenly distributed across Europe.

subsidised payments to small hydropower[4]. A substantial share of this value goes directly to local and regional budgets and helps to foster regional development.

- In addition to these direct contributions, many hydropower plants deliver further benefits by serving several functions at the same time. Some of the most important multi-purpose benefits include flood mitigation, supplying drinking water as well as water for irrigation and industrial needs, or the promotion of tourism and navigation. Whilst it is difficult to estimate the associated benefits, the analysis carried out in this study indicates that the multipurpose functions of hydropower represent an additional annual economic value of EUR 10bn to 20bn, even when neglecting the potential value of avoided damages from flood events, which may be substantial. Due to climate change, these benefits can be expected to further increase in the future, for instance due to an increased need for water management and flood control.

## Support to the Key Pillars of EU Energy and Climate Policies

As already mentioned above, the 2030 climate and energy policy framework of the EU-28 includes binding targets for reducing greenhouse gas emissions by at least 40% compared to 1990 and increasing the share of renewable energy in the EU's total energy consumption to 27%. This decision is part of a wider policy framework for building an affordable, secure and sustainable energy system. Hydropower is perfectly suited to supporting these targets as it delivers on all three key objectives for the European power system.

### Sustainability

- Hydropower represents a cornerstone for a sustainable power sector. At present (2013), it supplies 13% and 18% of the total electricity generation in the EU-28 and Europe, respectively. Similarly, it accounted for 49% and 59% of electricity generation from RES in the EU-28 and Europe, respectively. Although the future growth of hydropower is expected to be substantially lower than that of other types of RES (e.g. wind and solar power), it is estimated that hydropower will represent about one third of total generation by RES by 2030.
- At present, hydropower helps to avoid approx. 180 Mt[5] of $CO_2$ emissions in the EU-28, which is equivalent to about 15% of total $CO_2$ emissions in the EU-28 power sector. For Europe, savings are even bigger with 280 of $CO_2$, or about 21% of total power sector emissions.

### Affordability & Competitiveness

- Hydropower helps to supply **affordable electricity** to European consumers. Besides the cost-efficient supply of electricity itself, the flexibility of hydropower plants helps to avoid price spikes in volatile wholesale electricity markets. Together, these effects help to mitigate the trend of increasing electricity prices, which final consumers have been faced with in many European countries in recent years. As wholesale electricity prices only represent one component of final consumer prices[6], the impact on final consumers may be more limited. Nevertheless, the analysis in this study shows that by 2030 a 10% increase of hydropower may deliver annual savings of EUR 5bn to 10bn to final consumers.

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4 Estimated at EUR 2.6bn p.a.

5 This estimate is based on the assumption that hydropower generation is replaced by the current generation mix. When alternatively assuming that the loss of production was replaced by electricity from fossil fuels only, avoided emissions would amount to about 350 Mt of $CO_2$, or 32% of total $CO_2$ emissions in the EU-28.

6 In addition, final consumer prices include network charges, taxes and potentially other levies and surcharges.

- The price effects may trigger additional long-term benefits and contribute to the **competitiveness** of the European economy. Our analysis shows that hydropower has a positive effect on value creation and employment in other sectors. For instance a 10% increase of hydropower in the year 2030 would create up to 27,000 jobs in the EU-28, or almost 35,000 in Europe, mainly outside the hydropower sector itself. Indeed, the analysis in this study shows that the effects of employment in other sectors are significantly greater than in the hydropower industry itself, i.e. each additional job in the hydropower industry creates up to seven additional jobs in the overall economy.

**Security of Supply**

- Hydropower directly contributes to the reliability of the European power system, by providing flexible and reliable capacity that can be safely called upon when needed. Both aspects will become increasingly important in the future as the penetration of variable resources grows.
- Electricity generation from hydropower helps to avoid the combustion of fossil fuels. In 2010, fossil fuel consumption in the EU-28 would have had to increase by an estimated 2,700 to 4,300 PJ[7] without hydropower, which is equivalent to approximately 7% to 11% of total imports of EU-28 fossil fuels imports in that year. Based on the range of coal and gas prices in the years 2010 to 2013, this corresponds to annual savings of between EUR 12bn to 24bn[8] for the EU-28.
- European hydropower plants provide a combined storage capacity of more than 220 TWh, which is equivalent to nearly 25 days of average European consumption.
- Pump Storage plants are perfectly suited for providing flexibility during daily operations and allow for the temporary storage (excess) of electricity and use it when it provides the largest value to the system. Based on actual generation and market prices in the year 2013, European pump storage plants were able to save up to an estimated EUR 1bn in fuel consumption.

## European Hydropower as the Enabler of RES Integration

In order to reach its ambitious decarbonisation goals, EU policy foresees that generation by other types of renewables energies will strongly increase by 2030. The variable nature of some of these resources will create major challenges for the future European power systems. In particular, volatile generation by wind and solar power will require increasing flexibility from other generation technologies, as well as the ability to sometimes efficiently deal with excess power supply and shortage situations at other times. Furthermore, the availability of variable RES cannot be guaranteed, such that they need to be backed up by other types of generation.

These developments will greatly increase the value of hydropower as it creates an ideal solution to cope with these challenges. Due to its flexibility, hydropower can efficiently contribute to the balancing of variable generation from wind and solar power across different timescales, and mitigate the impact of sudden changes in residual load, which has to be supplied by conventional plants. Moreover, pump storage plants are the only form of electricity storage that is available on a large scale and at competitive prices today. This makes it possible to efficiently store electric energy for varying periods of time, i.e. from several minutes or hours to weeks, months or even on a seasonal scale. Similarly, other types of hydropower power storage may adjust their output to the variable generation by RES. The

7 Based on the carbon intensity of the fossil fuel mix (upper bound) and the average mix of nuclear energy and fossil fuels (lower bound) in the year 2010.

8 Based on the range of avoided consumption of fossil fuels (see footnote 7) and the commodity prices in 2010 (lower bound) and 2013 (upper bound), respectively.

storage potential of hydropower plants thus increases reliability by providing power as required by the system.

Overall, the flexibility and storage capabilities of hydropower plants make them a perfect instrument for dealing with the challenges of integrating increasing volumes of variables RES into the European power system. Leading up 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.

## Technology Leadership and Innovation

The success of the European hydropower sector is based on its technology leadership, as reflected by the fact that European equipment manufacturers account for an estimated two thirds of the world market. This includes three current global leaders, which account for more than 50% of the worldwide market, plus a large number of small and medium-sized companies. In order to maintain its leading position and to be prepared for dealing with the challenges of the transition to future power systems dominated by variable RES, the European hydropower industry is continuously investing in research and development and innovative technologies. European manufacturers spend more than 5% of annual turnover on R&D, which is more than twice the European industry average.

## Increasing Role of Hydropower on the Road to a Low-Carbon Power Sector

Hydropower has been a cost-efficient source of clean electricity for more than a century. At present, it supplies about 380 TWh of electricity to the EU-28 and 600 TWh to Europe, which is equivalent to 13% and 18% of total electricity generation, respectively. Given a positive economic and regulatory framework, total electricity generation from hydropower in Europe may grow to some 700 TWh by 2030, and 750 to 800 TWh in 2050. Compared to today, this would represent an increase of approximately 31%, or 200 TWh, which represents an important contribution for the decarbonisation of the European power sector.

In addition to the supply of clean electricity, 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. As outlined above, 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. Indeed, the role of hydropower has gradually evolved in line with an increasing penetration of wind and solar power over the past fifteen years. To date, hydropower has already been instrumental for enabling the successful integration of variable renewables in countries such as Denmark, Germany or Spain, and in some cases based on the contribution of hydropower in neighbouring countries (e.g. Norway, Austria and Switzerland).

In line with Europe's energy and climate goals, it is generally expected that the share of variable resources will continue to grow and that the future generation structure will be dominated by wind and solar power in particular. This implies that the challenges of RES integration will become even more important in the future, especially as increasing substitution of fossil fuels by clean electricity may lead to additional electricity demand. In turn, this will require an even larger penetration of variable RES and further increase the future need for and value of flexibility. Some of the corresponding capabilities may be provided by more flexible generation, demand response or even new types of electricity storage. Nevertheless, this development will further reinforce the value and importance of hydropower, which is perfectly suited to deal with these challenges, and which provides the necessary capabilities on a large scale at competitive costs.

Leading up 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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# List of Acronyms and Abbreviations

| | |
|---|---|
| bn | Billion |
| DG ENER | Directorate General for Energy (of the European Commission) |
| ECF | European Climate Foundation |
| ENTSO-E | European Network of Transmission System Operators for Electricity |
| EU | European Union |
| FTE | Full time equivalent (employee) |
| GDP | Gross domestic product |
| GJ | Giga Joule |
| GWh | Gigawatt hour |
| ICOLD | International Commission on Large Dams |
| mn | million |
| MW | Megawatt |
| MWh | Megawatt hour |
| Mt | Megatonne (one million tons) |
| OECD | Organisation of Economic Cooperation and Development |
| PJ | Peta Joule |
| RES | Renewable energy sources |
| TEIAS | Türkiye Elektrik İletim A.Ş. |
| th | Thousand |
| tkm | Tonne-kilometer |
| TSO | Transmission system operator |
| TWh | Terrawatt hour |

# 1 INTRODUCTION

## Scope and Objectives

The climate and energy policy of the European Union (EU-28) and many European countries, including Norway and Switzerland, is based on three overarching 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.

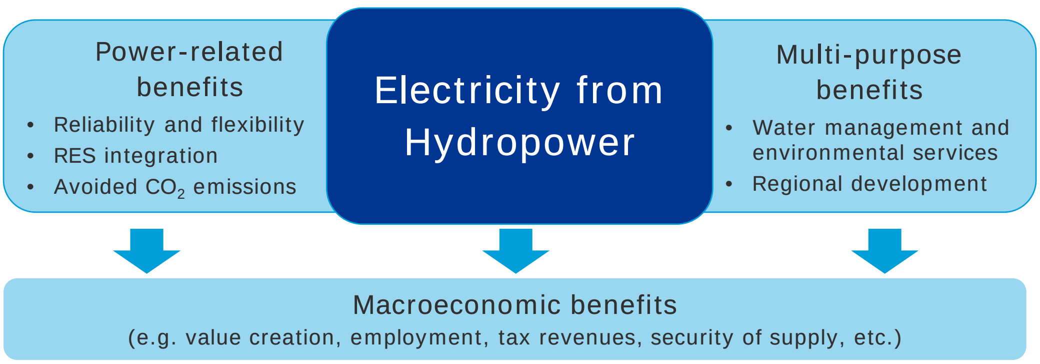


**Figure 1-1: Benefits provided by hydropower**
Source: DNV GL

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.

## Brief Methodological Outline

This study addresses a range of different topics and benefits in multiple areas. In order to ensure a consistent and comprehensive analysis, we have used a differentiated approach that uses multiple methods. Apart from detailed power market simulations at the European level, this includes economic data analysis, input-output analysis, the use of questionnaires and fact-based case studies. Moreover, significant efforts have been spent, in order to establish a comprehensive data set of European hydropower.

In the following, we briefly describe key components of our approach and the methodologies used. More details on the power market simulations and the input-output analysis can be found in the appendix in chapter 7.

### Comprehensive Data Set for European Hydropower

The analysis in this study required access to a wide range of different data. In preparation of our analysis, we have collected relevant information from a variety of different sources and established what we believe is the most comprehensive economic data set on the European hydropower sector available to date. This information is key for deriving meaningful insights into important economic features of the sector. In order to collect this information, we have used several different instruments as explained below.

Within the framework of this project, we conducted three surveys among hydropower producers and equipment manufacturers (see section 7.1 in the Appendix for more details). In addition to the companies that were directly involved in the project, these surveys also covered various other companies and organisations that are either members of the working group ‘Hydropower’ of Eurelectric or the Hydropower Equipment Association (HEA).

The use of these surveys was complemented by analysis of publicly available studies, reports and statistics, financial statements, and other relevant sources of information. To a larger part, we used publicly available data to derive general information that is readily available and can be used to ensure a consistent data basis. To a smaller part, such sources were used to cover areas where the surveys had not produced sufficient results, for instance in the case of employment and investments.

Where insufficient data was available, we completed our data set by extrapolation of existing data and expert estimates. For most of the target variables, we used installed capacity for linear extrapolation on a country-by-country basis, unless power produced or turnover where deemed more appropriate. Due to considerable diversity among different countries, the resulting values have not always been extrapolated to a European level where information was missing on individual countries.

Based on these different sources, the final data set represents more than 90% of installed generation capacity from hydropower in the relevant region (EU-28, Norway, Switzerland and Turkey), and more than 50% of the world market for hydropower equipment. For illustration, Figure 1-2 shows the regional coverage of key variables considered in the macroeconomic analysis and the type of method employed in deriving these values.

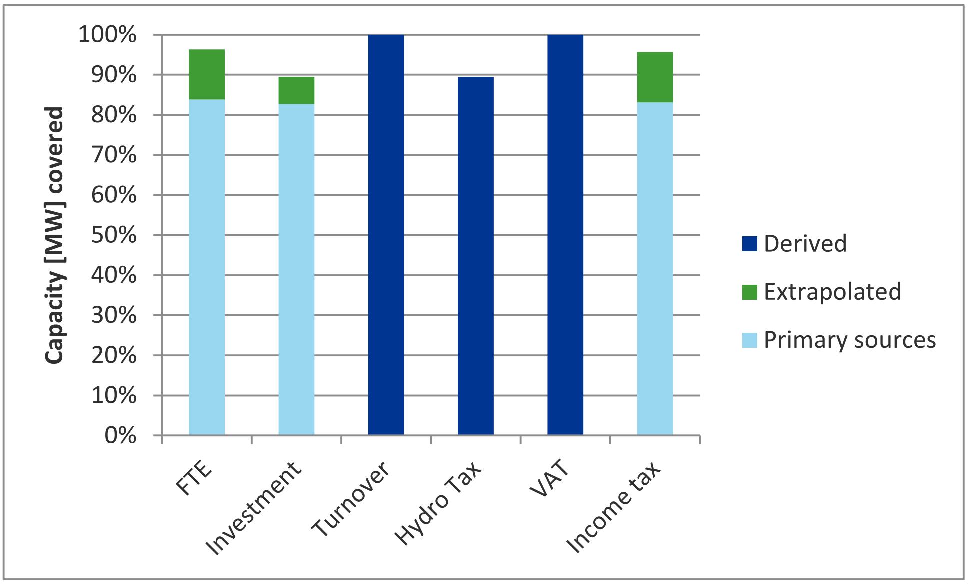


**Figure 1-2: Regional coverage of key parameters collected for the European hydropower generation sector by source**

Notes: 1. Primary sources encompass answers to the questionnaires, information from official statistics and company reports; 2. 'Extrapolated' refers to data extrapolation on country-by-country basis: 3. 'Derived' covers parameters that have been derived from other basic economic variables on the basis of official data

Source: DNV GL

## Power Market Simulations

To assess the contribution of hydropower towards achieving the EU climate and energy policy targets, DNV GL undertook scenario-based market modelling for two agreed scenarios. The power market simulations were conducted for two selected scenarios, which are based on the European Commission's 'Energy Roadmap 2050' (EU Commission 2011) and the recent 'Trends to 2050' study (EU Commission 2013). As far as possible, all information was directly taken from the underlying studies; otherwise, we have derived missing data and assumptions from other sources or our own estimates.

We used our European electricity market model to perform capacity expansion as well as electricity market simulations for the European and Turkish power systems. A detailed presentation of our European electricity market model is given in the Appendix 7.2. Although the analysis focused on the year 2030, we undertook capacity expansion modelling until 2050, in order to properly take into account the impact of long-term decarbonisation as well as RES targets on the development pathway of the power system.

The incremental benefits of hydropower were assessed by varying the share of hydropower in the market simulations. For this purpose, we created and simulated two additional hydropower sensitivities around the basic scenarios, in which the share of hydropower was varied compared to the basic scenarios (see section 7.2.2 in the Appendix).

## Macroeconomic Analysis

The macroeconomic analysis covers the contribution of hydropower plants as well as the manufacturing of hydropower equipment. As depicted by Figure 1-3 the analysis covers:

- Direct benefits of hydropower use: value creation and employment, tax revenues and investments in the hydropower sector;

- Indirect benefits of hydropower use: value creation, employment and investments created by the demand of the hydropower sector for external services such as engineering, planning and consulting; in addition, this category includes multipurpose benefits of hydropower, such as water supply, flood mitigation or navigation;
- Induced benefits on other parts of the economy: i.e. value creation and employment in the future economy, induced by electricity prices reductions that are engendered by an enhanced use of hydropower.

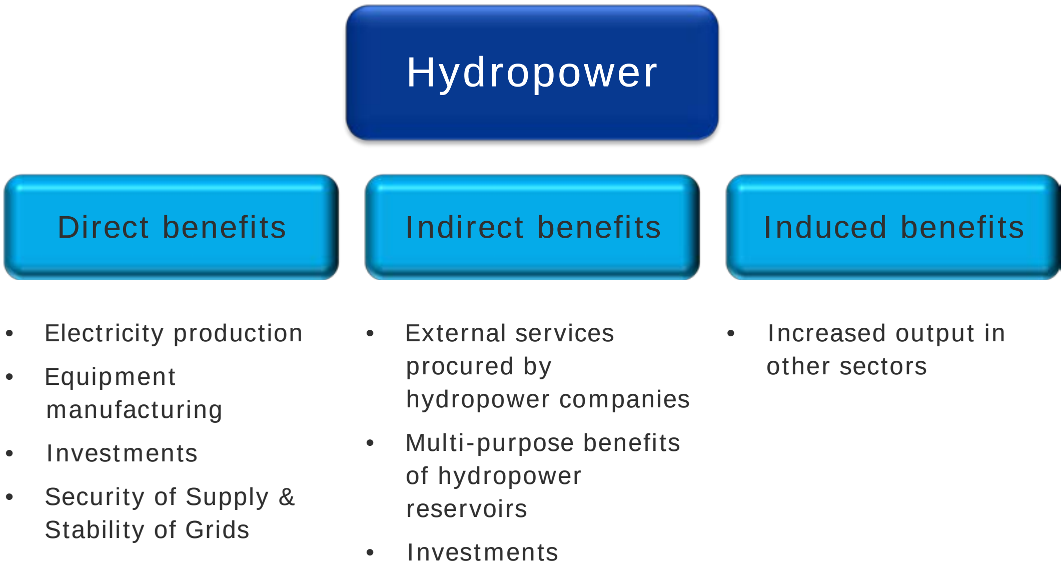


**Figure 1-3: Overview over direct, indirect and induced benefits of hydropower**
Source: DNV GL

The direct benefits presented in the study build mostly on the data set described above, encompassing data from our survey and from public sources. In case of some variables, such as value creation, we have derived the values from publicly available data and well known economic relationships. As for indirect benefits, we have estimated them on the basis of our survey and further data from official studies as described above.

To calculate induced economic benefits, we have used input-output analysis. This methodology allows for a quantitative impact assessment of the changes in one sector on all other sectors. In our analysis, we focus on the impact of electricity price reductions enabled by the use of hydropower generation on other sectors in the economy[9]. From the sectoral price effects, we derive corresponding output and employment effects. Details of the methodology can be found in section 7.3 in the appendix.

The approach used for the input-output analysis is principally valid for limited changes of the underlying variables (prices, volumes) only. We have, therefore, limited application of this method to the sensitivities of each of the two scenarios considered by the power market simulations as described above.

## 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

9 To determine the impact on prices in other sectors, we use a so called cost-push analysis, where the term ‘cost-push’ analysis reflects the fact that the methodology is typically used to calculate the impact of a sectoral price/cost increase.

Figure 1-4), 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 1-4: Geographical scope of 'Europe' as used in this study**
Source: DNV GL

# 2 THE ROLE OF HYDROPOWER IN EUROPE AT PRESENT

## 2.1 The Role of Hydropower in the European Power System at Present

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) [10].

However, 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. In the EU-28, actual hydropower generation amounted to some 385 TWh in 2013, while Switzerland, Norway and Turkey accounted for 228 TWh.

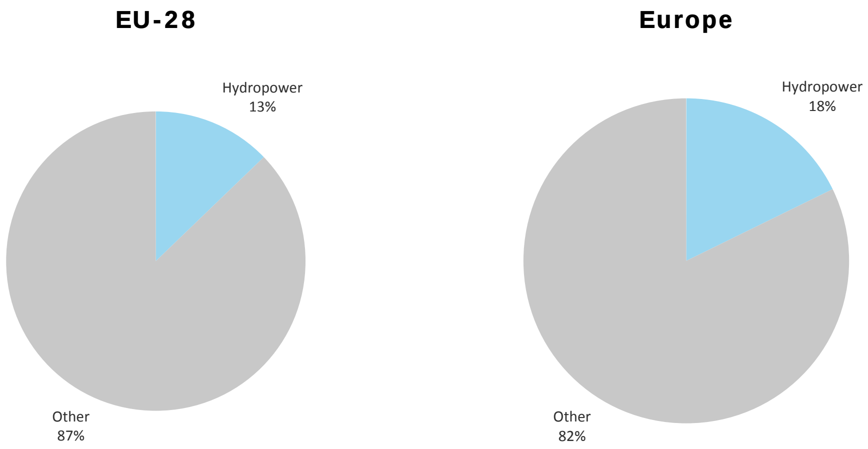


**Figure 2-1: Share of hydropower in total electricity generation (2013)**
Source: DNV GL analysis

With growing shares of generation from 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 technology available today that enables the efficient storage of electric energy at a large scale. These storage capabilities are provided by conventional hydropower plants with water reservoirs, including pump storage plants.

Today, Europe has an approximate reservoir capacity of about 220 TWh, which is equivalent to nearly 25 days of average electricity consumption in Europe. The largest share of this volume is located in the Nordic countries (approx. 115 TWh) and Turkey (approx. 41 TWh); see Figure 2-2. The remaining

10 Please note that these values may vary in individual years due to the variability of natural inflows.

volumes are distributed across different parts of Europe such that many countries and regions benefit from the associated flexibility.

In addition, European hydropower plants have an installed capacity of more than 200 GW. This is equivalent to about 30% of the non-coincident peak load[11], 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.

Pump storage plants account for more than 20% of total installed capacity, with a generation capacity of approx. 47 GW and a pump capacity of about 40 GW. Pump storage plants are perfectly suited for providing flexibility for daily operations and make it possible to temporarily store (excess) electricity and use it when it is needed. While some of these plants are designed for daily operation with reservoirs that allow generation of a few hours only, several pump storage plants in Alpine countries and Iberia are equipped with larger hydropower reservoirs. In 2013, pump storage plants delivered an estimated 35 TWh of electricity from pumping operations to the European power systems[12]. Based on recent market prices, we estimate that pump storage plants helped to between EUR 0.3bn and almost EUR 1bn in costs for European consumers in this year[13].

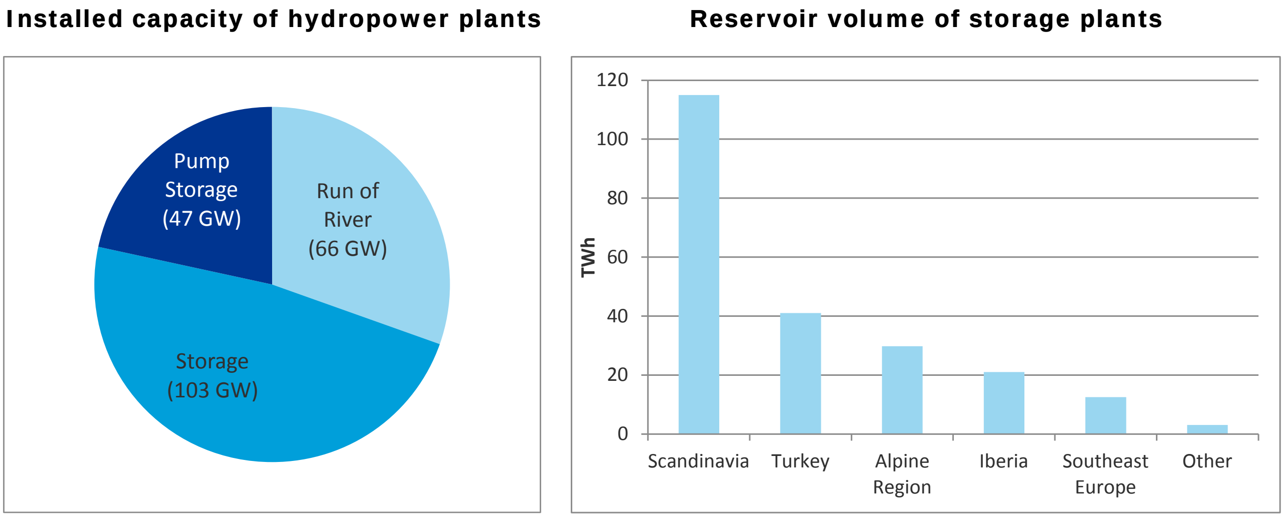


**Figure 2-2: Currently installed capacity and reservoir volumes of hydropower plants in Europe**
Note: 'Alpine' refers to Austria, France, Italy and Switzerland, whereas 'Southeast Europe' includes Croatia, Bosnia and Herzegovina, Bulgaria, Romania and Serbia
Source: DNV GL analysis

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

12 Based on a total pumping consumption of 45.7 TWh and an estimated round cycle efficiency of 78%.

13 Based on average wholesale prices (EEX) as reported by Bundesnetzagentur / Bundeskartellamt (2014); in addition to average peak and offpeak prices, we have also considered the upper and lower quartile of peak and offpeak prices. In addition, dena (2010) estimates that a new 1,400 MW pump storage plant in Germany might render savings of between EUR 11 and 21 million per annum. When extrapolatng this number to a european level, this corresponds to an estimate of EUR 0.3 to 0.7bn.

## 2.2 Contribution to Carbon Abatement and Security of Fuel Supplies

### Avoidance of $CO_2$ Emissions and Fuel Imports

Hydropower represents a cornerstone for a sustainable power sector. According to IPCC (see Figure 2-3), 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[14].

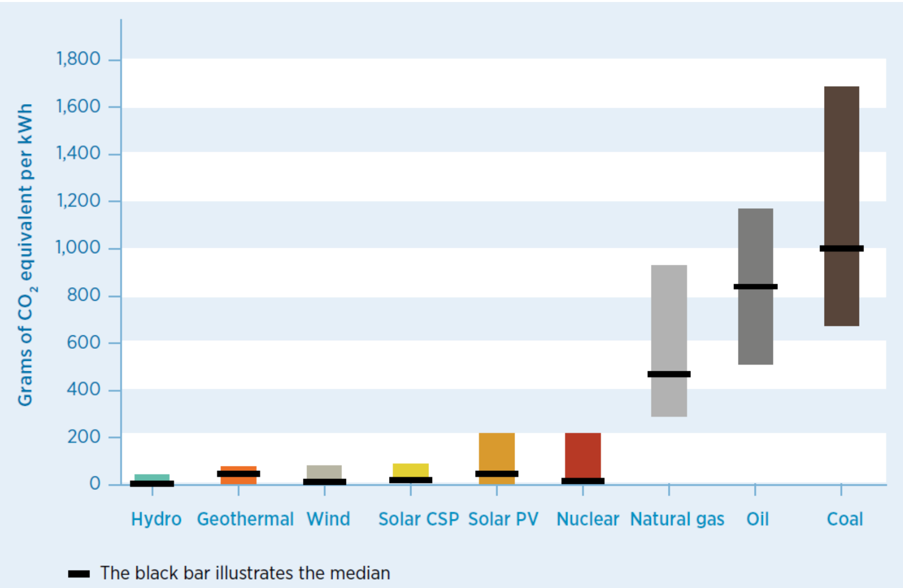


**Figure 2-3: Life-cycle emission intensity of electricity generation by technology**
Note: Methane emissions from some reservoirs have been registered. The discussion in this respect is an international one, but from minor relevance in the European context.
Source: IRENA (2011), based on IPCC

With an annual generation of some 600 TWh, hydropower accounts for about one third of total electricity generation from low-carbon technologies in Europe at present. Moreover, hydropower is by far the single largest source of electricity generation from renewable energy sources in Europe. As illustrated by Figure 2-4, hydropower alone supplied more than 60% and 50% of all electricity from renewable energies in Europe and the EU-28, respectively, in 2013.

14 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.

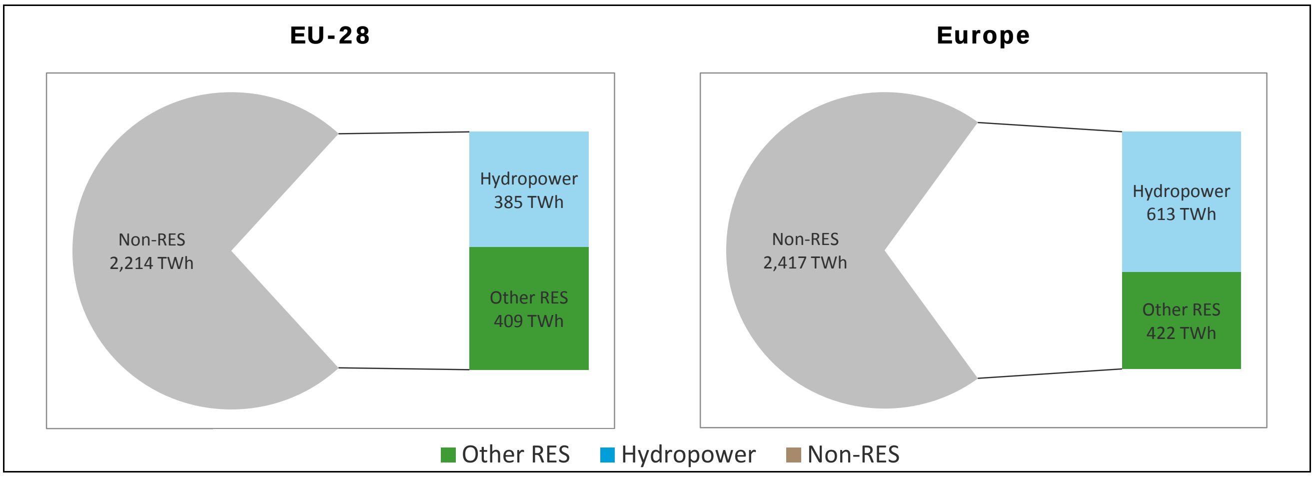


**Figure 2-4: Contribution of hydropower to electricity generation in 2013 [TWh]**
Source: DNV GL, based on ENTSO-E, TEİAŞ

Due to its considerable share in electricity generation, hydropower contributes significantly towards the reduction of $CO_2$ emissions in the current power system. Without hydropower generation, overall $CO_2$ emissions would likely increase as hydropower generation was replaced by other generation technologies, incl. those based on fossil fuels. For illustration, Figure 2-5 shows the (theoretical) impact on $CO_2$ emissions if hydropower was not available to the European power system in the year 2010. To capture some of the uncertainty around the technology mix that might compensate hydropower generation, we have analysed two scenarios in which we replace hydropower by electricity from other sources:

1. Based on the average carbon intensity of total electricity generation (excl. hydropower),
2. Based on the average carbon intensity of electricity generation from fossil fuels.

Based on our calculations, $CO_2$ emissions in the EU-28 would increase by 178 Mt or 15% in case hydropower was replaced by the current generation mix (see Figure 2-5). If hydropower was replaced by the current mix of fossil fuel technologies (including coal and gas), avoided $CO_2$ emissions would increase by approximately 344 Mt $CO_2$, or 28% of 2010 emissions (1226 Mt). For Europe, including countries with a high share of hydropower (e.g. Norway, Switzerland and Turkey), the corresponding numbers range between 285 and 527 Mt of $CO_2$.

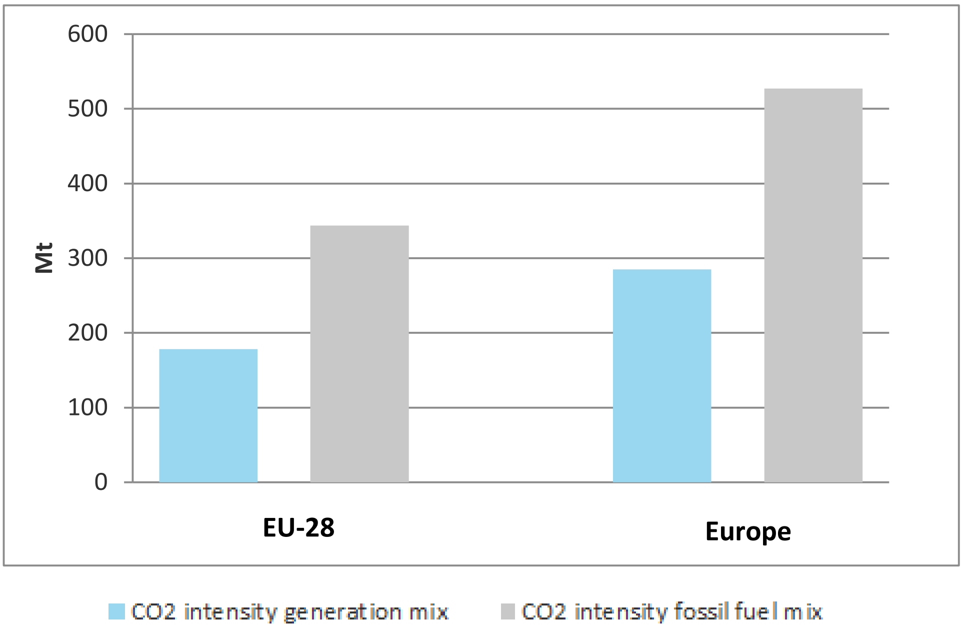


**Figure 2-5: Avoided $CO_2$-emissions by hydropower in EU-28 and Europe in 2010**
Source: DNV GL, based on DG ENER, ENTSO-E

Similarly, hydropower contributes significantly towards security of supply by reducing Europe's use of fossil fuels and therefore its dependency on fuel imports. Again for the EU-28 and Europe, we have calculated the savings in fossil fuel imports for two scenarios, in which hydropower generation is replaced by:

1. The average mix of fossil fuels and nuclear technologies (i.e. excl. RES),
2. The average mix of fossil fuels.

In both cases, our calculations are based on the assumption that additional demand for fossil fuels is satisfied by fuel imports only, i.e. we have not considered any contribution from increasing the use of renewable energies or indigenous sources of fossil fuels.

As presented in Figure 2-6, fossil fuel imports would have increased by an estimated 2,700 to 4,300 PJ without hydropower in 2010, which is equivalent to between 7% and 11% of total fossil fuel imports 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.

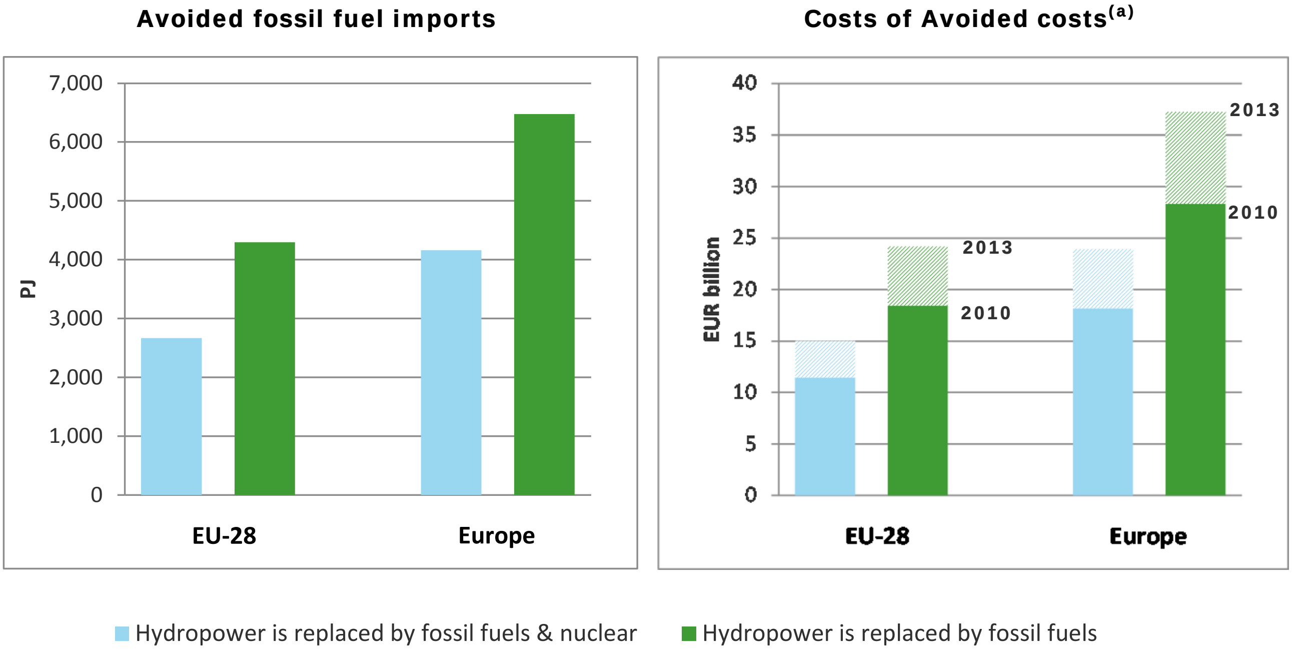


**Figure 2-6: Avoided imports of fossil fuels in 2010**
(a) – Based on average fuel prices in the years 2010 and 2013, respectively
Source: DNV GL analysis

## Case Study – Contribution of Alpine Pump Storage Plants to Generation Adequacy in Southern Germany

After the Fukushima accident in 2011, the German government decided to phase out nuclear power by 2022. This decision has direct consequences for generation adequacy in Southern Germany where several of the nuclear plants are located. Due to the limited capacity of alternative sources of generation, there is a risk that this region might face potential capacity deficits after the closure of the nuclear plants. In response to this situation, the Federal Grid Agency as responsible regulator is carefully assessing the situation on a regular basis. Based on its analysis, the regulator has barred several operators from decommissioning conventional plants in the region. In addition, it has entitled the German TSOs to contract for a special type of reserves ('Grid reserves'), in order to ensure that the Southern German power system can deal with peak load situations during the winter season.

For the winter 2015/2016, the regulator has recently set the necessary volume of 'Grid Reserves' to a level of 6,000 MW. When determining this value, the German TSOs also considered the contribution of pump storage plants to available capacity, using an average non-availability of 20%. Similarly, both German and foreign pump storage plants are principally entitled to provide 'Grid Reserves'.

Based on this information, we have used three different approaches for estimating the potential contribution of Alpine pump storage plants to generation adequacy in Southern Germany as follows:

1. Option 1:
   Based on installed capacity of pump storage plants, assuming an average availability of 80%,
2. Option 2:
   As for option 1, but additionally considering possible restrictions due to the limited storage capacity of relevant pump storage plants (assuming an average specific storage capacity of 8 h),

3. Option 3:
   Similar to option 2, but based on an average capacity availability of 95%.

Whilst option 1 considers available capacities only, options 2 and 3 also account for the limited storage capacity available from pump storage plants.

This approach is illustrated by Figure 2-7 which shows the relation between the desired reduction of peak demand and the required storage capacity. Pump storage plants located in Southern Germany, Austria and Switzerland have a combined installed capacity of approx. 5,900 MW. In addition, they can theoretically provide an additional 47.5 GWh of electricity during peak load hours, assuming that reservoirs were filled to their maximum before. When using this volume of energy to supply demand during peak hours, this allows reducing peak demand by 4,419 MW (see dark blue area in Figure 2-7). This value is equivalent to 75% of installed pump storage capacity in the region. This observation shows that the contribution of pump storage plants to generation adequacy is limited by storage capacity and not installed generation capacity in this particular example.

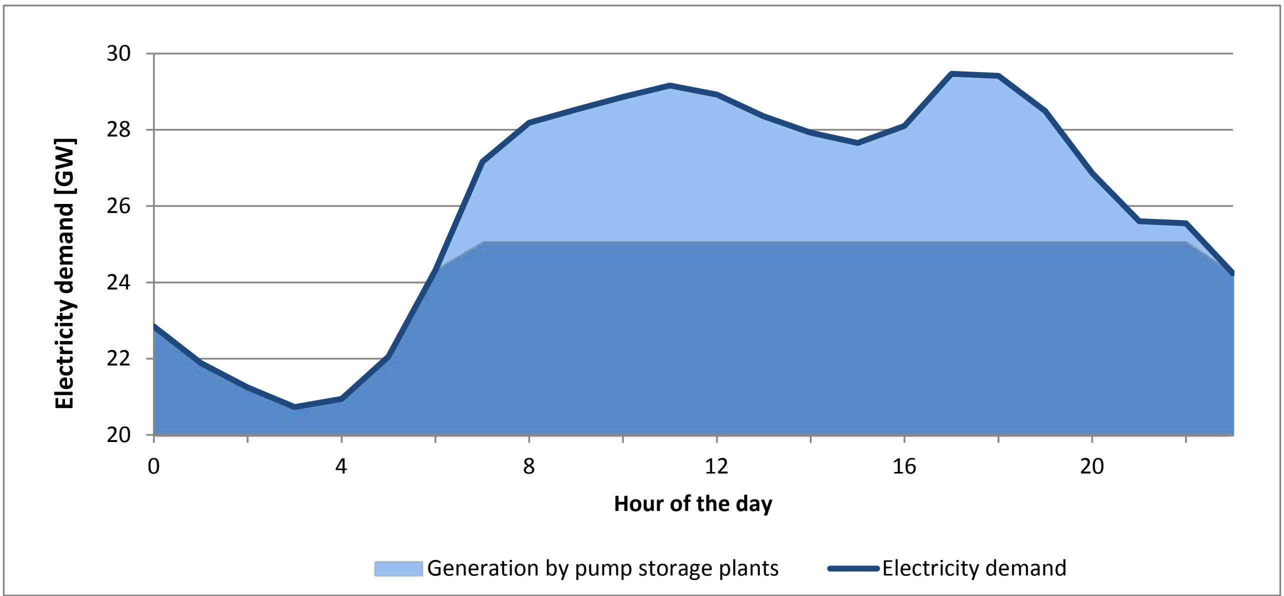


**Figure 2-7: Relation between reduction of peak demand and required storage volume**
Source: DNV GL analysis

Based on these assumptions, Figure 2-8 provides an overview of the volume of firm capacity, which can be provided by different sets of pump storage plants under the different options. The contribution of pump storage plants in Southern Germany, which can be assumed to be already considered by the analysis of the German TSOs mentioned above, amounts to a minimum of 1,920 MW. In other words, the total need for 'Grid Reserves' for the winter 2015/2016 would increase by about one third without any pump storage capacity in Southern Germany.

The other columns show how the possible contribution of pump storage plants increases when also considering plants located in Austria, Switzerland and Italy. In comparison with the first column, the contribution of pump storage plants to generation adequacy increases by between a little more than 2,000 MW and more than 4,000 MW. This difference indicates that foreign pump storage plants can provide substantial amounts of firm capacity to Southern Germany. Even when excluding plants located in Southern Germany, pump storage are able to supply more than 3,000 MW of capacity, which is more than 50% of the total volume of Grid Reserves required in the winter 2015/2016.

In summary, this simplified analysis indicates that pump storage plants can play an important role for ensuring security of supply in Southern Germany, both in terms of limiting the need for Grid Reserves and as a potential source of corresponding reserves. Indeed, the combined impact of pump storage plants from Southern Germany and its Southern neighbours (AT, CH, IT) is roughly comparable to the total need for Grid Reserves identified by the German TSOs for the winter 2015/2016.

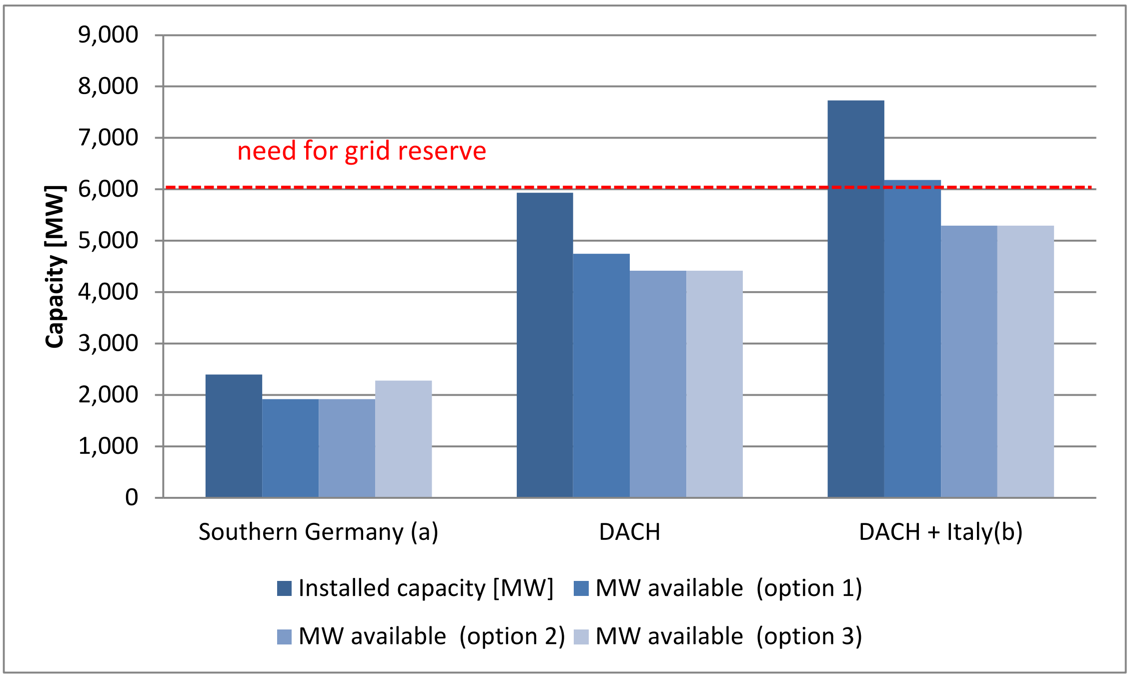


**Figure 2-8: Contribution of Alpine pump storage plants to generation capacity in Southern Germany**

Notes: [(a)] – Analysis limited to pump storage plants located in Southern Germany;
[(b)] – Contribution of Italian pump storage limited to maximum export capacity to Switzerland
DACH – Germany, Austria and Switzerland

Source: DNV GL analysis

This case shows how hydropower plants are able to provide firm capacity to the power system. Whilst the level of firm capacity may vary depending on hydrological conditions, the relative size of the reservoir and the time horizon under consideration, they can provide significant benefits to the system.

## 2.3 Economic Benefits of Hydropower

As outlined above, hydropower generation contributes to security of electricity supply and carbon abatement in Europe. In addition, its use also entails considerable economic benefits. In this section, we comment on the following areas:

- Hydropower creates significant value to the European economy,
- Hydropower provides high-value employment,
- Hydropower contributes a large share of its value creation to tax revenues,
- Hydropower companies invest into new capacity as well as maintenance and refurbishment

- Many hydropower installations also provide so-called multipurpose benefits to other sectors, for instance in the form of water supply, flood control or by facilitating navigation and tourism.

In the following, we briefly present a summary of the main facts and benefits in each of these areas.

## Value Creation

Value creation comprises of the contribution of different economic sectors to gross domestic product (GDP)[15]. The contribution of the hydropower sector to European GDP is depicted in Figure 2-9. For the country sample considered in this study, i.e. the EU-28, Norway, Switzerland and Turkey, value creation amounts to around EUR 38bn (EU-28: EUR 25bn). This number refers to gross value creation, encompassing value creation by electricity generation, exports of hydropower equipment and value added tax on the final output of the sector. Please note that these numbers to not include further value, for instance from multipurpose benefits as separately discussed below.

The overall value creation by hydropower generation and equipment manufacturing amounts to approx. 0.27% of European GDP, which is comparable to the GDP Slovenia. Moreover, the hydropower sector is a mature industry, and only a small share of value creation is due to capacity expansion. Consequently, value creation in the sector can be expected to remain stable in the future and is not artificially inflated by short-term effects.

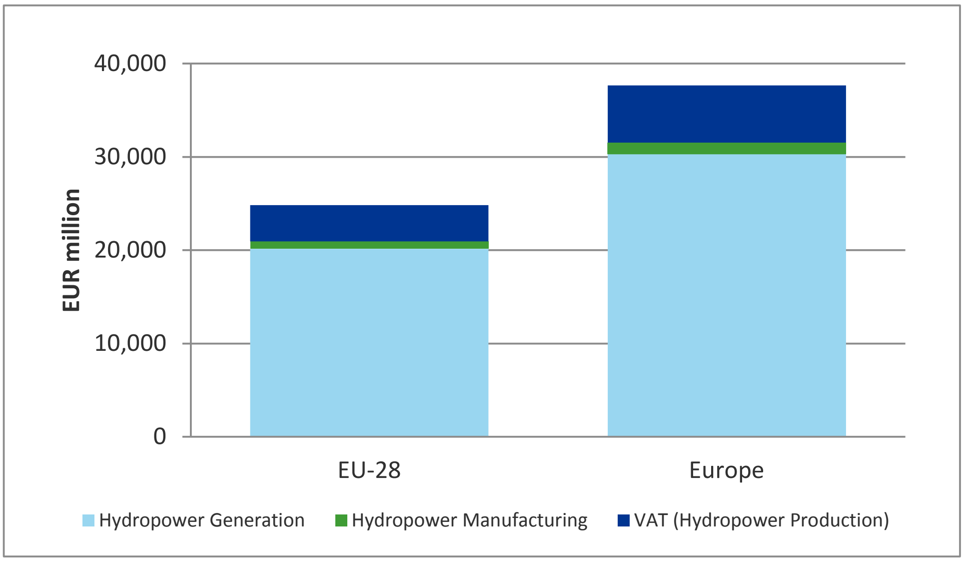


**Figure 2-9: Gross value creation by hydropower generation and equipment manufacturing (2013)**
Note: The value for equipment manufacturing in EU-28 is based on the estimated share, as we dispose of numbers for the total sample only.
Source: DNV GL analysis

15 Please note that all figures presented in this report refer to gross value creation, in the sense of national accounting.

## Employment

As shown by Figure 2-10, European hydropower directly and indirectly ensures more than 100,000 jobs (FTE[16]). Direct employment includes more than 50,000 FTEs in generation and almost 7,000 in equipment manufacturing (EU-28: 42,000 for power generation and 5,000 in manufacturing). Based on our survey, we estimate that a similar level of employment is ensured for professionals in other sectors who provide external services to the hydropower sector, including operations & maintenance, planning, engineering and consulting. Please note that these numbers do not include other types of indirect employment, which are induced by lower electricity prices (compare section 3.3).

In the EU-28 alone, direct employment is comparable to the European agro-chemical industry, whereas the sum of direct and indirect employment in the European hydropower sector is comparable to the European aluminium industry.[17]

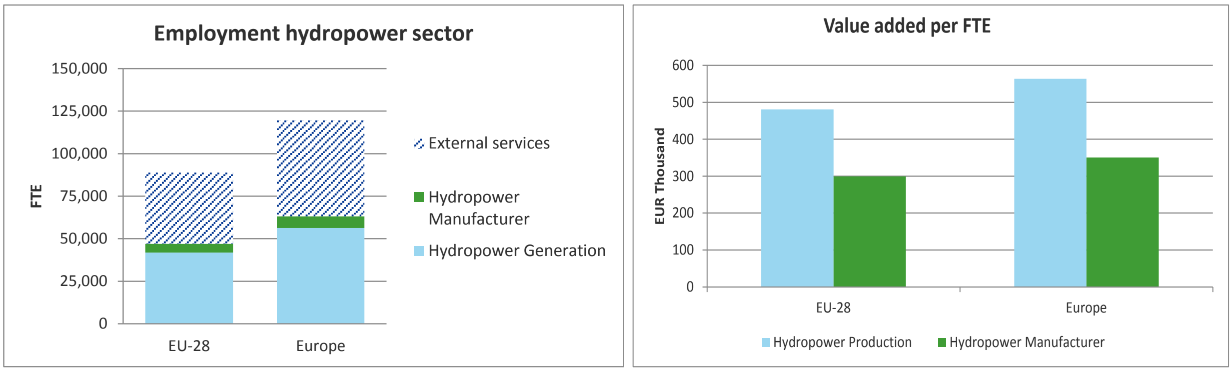


**Figure 2-10: Employment and value added per FTE in the European hydropower sector (2013)**
Note: 'HP' - Hydropower
Source: DNV GL analysis

In addition, Figure 2-10 also shows the average value added per FTE in the EU-28 and Europe, respectively. On average, each employee in the European hydropower generation sector creates an annual value of more than EUR 500,000, whereas the corresponding number is still above EUR 300,000 in the manufacturing sector. These values are considerably higher than in many other parts of the European economy. On average, each employee in the European hydropower generation sector creates more than eight times as much value as the average in the European manufacturing sector or ten times more than in the construction sector[18].

16 FTE = Full-time equivalent
17 Cf. EAA (2010)
18 Cf. Eurostat (2014)

## Tax Revenues

Above, we have considered the contribution of European hydropower to gross value creation. In addition, we have also analysed, which share of this value is transferred to governmental budgets, i.e. in the form of taxes or other sources of governmental income.

More specifically, we have considered[19]:

- Value added tax (VAT) on electricity produced from hydropower,
- Income taxes on salaries in the hydropower sector,
- Hydropower specific taxes and levies.

The first two components, i.e. VAT and income tax (in personal salaries), are commonly found throughout the economy. In contrast, this third group is specific to the hydropower industry. It encompassed a large variety of different taxes and levies that are used in different countries, including but not necessarily limited to taxes or levies on hydropower generation (e.g. in Scandinavia), installed capacity of hydropower plants (e.g. Italy, Switzerland), or water use (e.g. Germany, Eastern Europe).

Figure 2-11 shows the total tax collection from the hydropower sector in the year 2013. In total revenues for governmental budgets amount to more than EUR 8bn for the EU-28, or EUR 14bn when also including Norway, Switzerland and Turkey. In other words, more than 32% and 37% of the gross value created by hydropower in the EU-28 and Europe, respectively, are directly transferred to governmental budgets. Moreover, it is worth noting that these numbers are net of (limited) subsidies to small hydropower plants in EU Member States[20]. These numbers clearly illustrate that hydropower generates major revenues for governmental budgets at national, regional and local levels. At the same time, they highlight the unique feature of hydropower, which currently is the only renewable energy source that creates significant net income to public revenues.

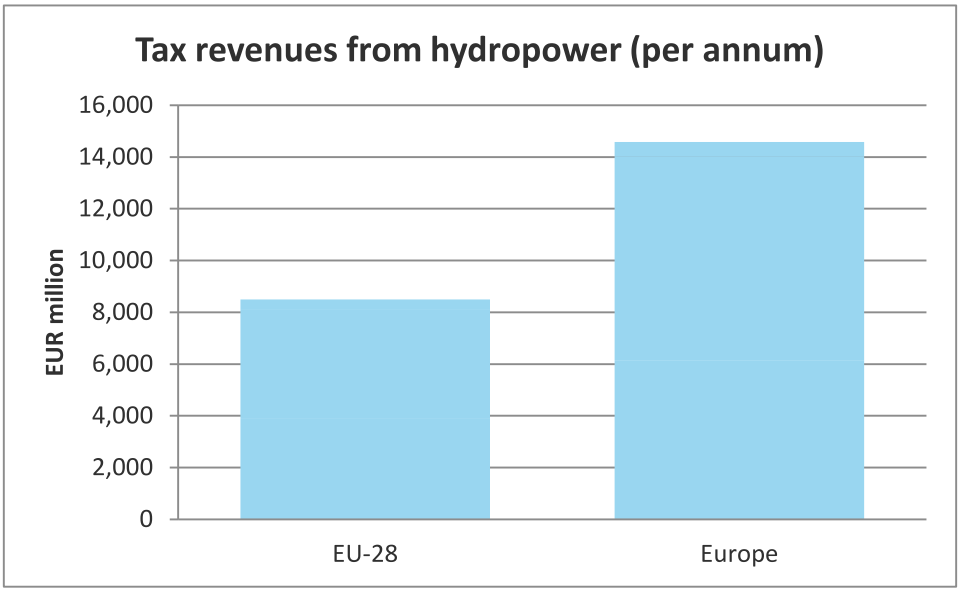


**Figure 2-11: Tax collection from hydropower (excl. corporate taxes, 2013)**
Source: DNV GL analysis

19 Please note that we have not considered corporate income tax, as we do not dispose of sufficient data on profits of hydropower companies.
20 Payments under subsidised prices to small hydropower are estimated at approx. EUR 2.6bn per annum.

## Investments

Hydropower is a capital-intensive generation technology. It requires considerable investments, both for the initial construction of hydropower plants and reservoirs, as well as for ongoing maintenance and refurbishment.

The survey carried out under this project shows that annual investments into maintenance and refurbishment of hydropower plants in the years 2010 to 2013 amounted to EUR 3.1bn to 3.7bn p.a. in Europe, EUR 2.2bn to 2.6bn in the EU-28. This is roughly as much as the European initiative for bio-based industries plans to invest over ten years.

In addition, the European hydropower industry is also investing into the construction of new plants. Between 2010 and 2013, annual investments into new hydropower capacity ranged between EUR 5.2bn and 8.7bn[21] for Europe, resulting in total annual investments into hydropower of between EUR 8.3bn and 12.4bn. For the period from 2010 to 2013, i.e. over a period of four years, this corresponds to cumulative investments of between EUR 25bn and 36bn. For the EU-28, annual investments in the same period were in a range of EUR 5.0bn to 6.3bn, or EUR 15bn and 19bn cumulatively.

Overall, investments by the European hydropower sector are roughly twice as high as in the EU pulp and paper industry[22], which delivers a similar contribution to European GDP contribution.

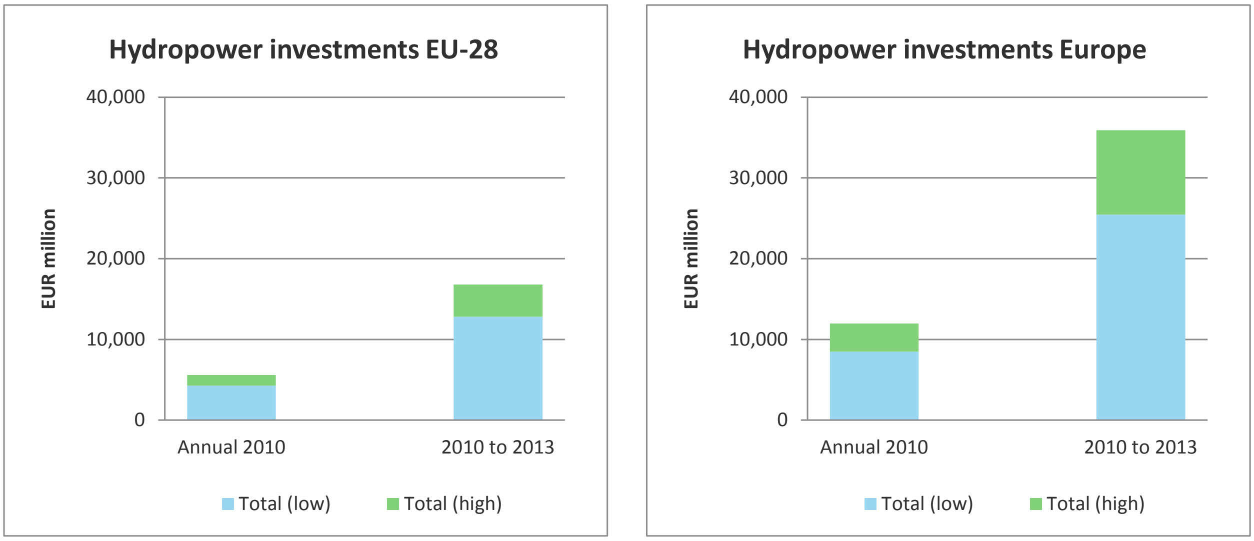


**Figure 2-12: Investments into hydropower capacity (2010 to 2013)**
Note: High and low estimates reflect range of assumptions on specific investment costs of new plants
Source: DNV GL

## Multipurpose Benefits

As discussed in the previous sections, electricity generation from hydropower represents the main economic benefit of hydropower. But in addition, many of the dams and reservoirs, which are necessary to generate electricity from hydropower, also serve for other purposes, or were indeed originally built for purposes other than hydropower. The concept of **multipurpose benefits**, therefore, represents a

21 As detailed figures for investment costs of individual plants are not readily available, we have used a range of typical assumptions for the specific investment costs of hydropower plants, which have been derived from available literature. Consequently, investments into new plants, as well as total investments are reported as a range.

22 Based on the period 2009 to 2012

particular feature of hydropower dams and reservoirs as they may serve multiple purposes, and hence create multiple benefits, at the same time.

The overview in Table 2-1 shows that one can identify a range of multipurpose benefits and that these can be grouped into two general categories:

- Water management and environmental services cover the use of dams for controlling the downstream flow of water, for instance as a measure for flood and/or drought control; in addition, dams may help to stabilise groundwater levels or support oxygenation, cleansing of water or sediment and habitat management;
- Promotion of regional development, for instance in the form of direct or indirect support of other economic activities, such as navigation, leisure and tourism, aquaculture or water supply for drinking water, irrigation or industrial purposes.

**Table 2-1: Overview of multipurpose benefits**

| Water management and environmental services | Regional development |
|---|---|
| • Drought control | • Navigation / transport |
| • Ground water stabilisation | • Water supply for other uses: |
| • Oxygenation and temperature dispersion | - Drinking water |
| • Cleansing of water | - Irrigation (agriculture) |
| • Sediment and habitat management | - Process water (industry) |
| | • Leisure and tourism |
| | • Aquaculture (fisheries and food) |

Source: DNV GL analysis

Based on a survey among European hydropower operators and associations and a supplementary analysis of a global database on large dams (ICOLD[23]), we identified a limited number of multipurpose benefits, which can be expected to, directly or indirectly, deliver relevant contributions to economic development, either at a national or local level.

As illustrated by Figure 2-13, this includes the following types of multipurpose benefits:

- **Water supply** for irrigation, as drinking water and for industrial purposes represents an important multipurpose benefit especially in Southern European countries (incl. Turkey). Water reservoirs allow for a more stable supply of water, making it possible to compensate the changing availability of water resources throughout the year. Moreover, they may help reducing differences between regions with different natural water resources, provided that water can be transported from a reservoir to other regions with scarce water resources. This function is by far the most common purpose of dams and reservoirs in some of these countries, i.e. hydropower often represents a 'by-product' rather than the primary purpose of dams in many cases. Often, water supply from reservoirs is considered as a key enabler of local economic growth, for instance where agriculture is a major source of economic wealth.
- **Flood control** is often considered as one of the most important multipurpose benefits. It covers the ability of dams and reservoirs to mitigate the impact of (major) floods by retaining water during critical situations, in order to reduce downstream water levels. In addition, this ability can be used to strategically release water in advance and store additional volumes during a flood event. This can help to avoid or at least mitigate a concurrence of peak water levels from upstream rivers at a certain point and reduce the impact for downstream areas.

23 The database of the International Commission on Large Dams (ICOLD) provides a basic overview on large dams and reservoirs all over the globe. It currently covers more than 6,000 large dams which are in operation and with a defined purpose (power generation, or any other).

- Various respondents across Europe consider the promotion of **tourism** as an important multipurpose benefit, even though it is generally considered as less important as the previous functions. Hydropower reservoirs may enlarge the spectrum of available tourist activities, or even provide the basis of it, for instance by enabling water sports.
- In certain regions, dams serve the dual purpose of hydropower and enabling or facilitating **inland navigation** on river system. Compared with other transport means, inland river navigation in particular helps to reduce the costs of transporting mass and heavy goods.
- In addition to these four major functions, respondents have also mentioned several other multipurpose benefits that are of particular importance in certain regions:
    - In some parts of Southern Europe, like Italy or Portugal, hydropower reservoirs facilitate **firefighting**, i.e. by providing (additional) places where firefighting planes can load water. Similar to flood control, the main value of this function relates to avoided damages.
    - Some operators also reported fishing in the proximity of hydropower plants as a potential multipurpose benefit. Still, publicly available data and statistics show a limited role of commercial fishery[24] and a limited link between hydropower and aquaculture[25].
- Operators of hydropower plants often are responsible for collecting and removing **floating refuse** from rivers and reservoirs. For instance in Germany, one operator reported the annual removal of approx. 15,000 t (90,000 m³) of waste annually; considerable numbers have been reported from Italy as well.

***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 hydropower 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 2-13: Selected multipurpose benefits of hydropower reservoirs**
Sources: 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

[24] Catch limited to EUR 10mn even in larger countries
[25] Mainly due to requirements on sewage water treatment

Our analysis indicates that multipurpose schemes may create substantial value at a local, national or European level. The additional value varies between different multipurpose benefits as well as for different parts of Europe. For illustration, Figure 2-14 provides an indicative comparison of the relative value of different multipurpose benefits, the geographical size of the areas affected and their relevance for different parts of Europe.

In summary, Figure 2-14 indicates the following:

- Water supply arguably delivers the largest economic value, which is estimated to be in excess of EUR 10bn annually. It is most relevant for countries in Southern Europe[26] and may affect local as well as larger areas.
- Flood mitigation by hydropower may also render major economic benefits. Although it is difficult to quantify its economic value, there is ample evidence showing that floods may cause major damage to life and property. Flood control is relevant across different parts of Europe, but its economic value is highest in more densely populated areas in Central Europe. The benefits of flood control may reach across larger regions or even multiple countries.
- The benefits of hydropower for inland navigation are concentrated to some major waterways in Central Europe. Compared to the previous two cases, the economic value of inland navigation remains limited.
- The analysis of selected examples shows that hydropower creates substantial benefits for local tourism in specific regions, which amount to similar levels as inland navigation.
- We have not assessed the value of other multipurpose schemes, like firefighting or garbage collection, in detail. They may be of considerable importance for specific regions or locations but are assumed to remain much smaller than the categories discussed before.

Overall, our analysis suggests that multipurpose benefits of European hydropower plants may deliver an additional economic value of EUR 10bn to 20bn annually[27,28]. This value is primarily made up of water supply for different purposes and the facilitation of tourism and navigation, whereas we have refrained from quantifying the economic value of flood mitigation. We emphasise that these values are in addition to the direct and indirect benefits as identified above.

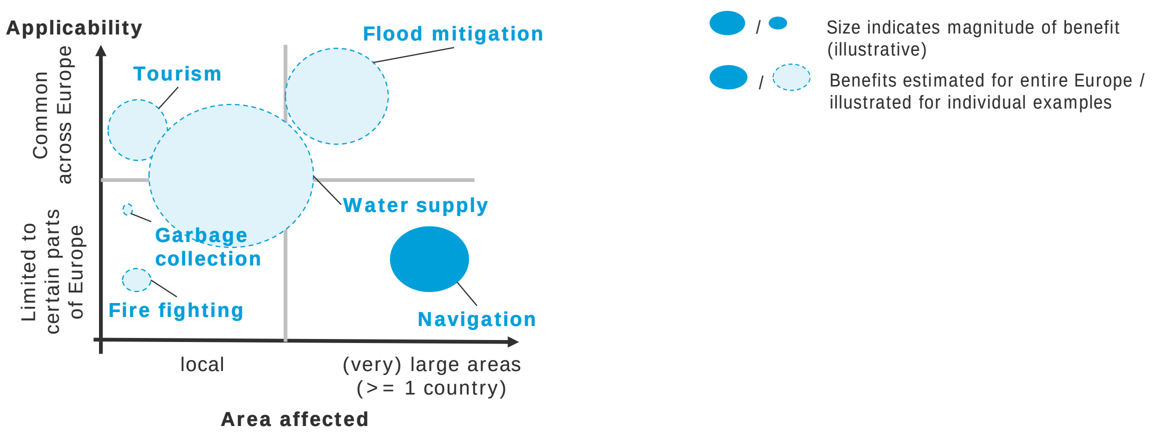


**Figure 2-14: Indicative comparison of multipurpose benefits**
Source: DNV GL

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26 However, exceptions do exist, for instance between Spain and Portugal.

27 This range reflects the uncertainty on some of the estimates, including in particular on the economic value of water supply (compare section 7.4 in the Appendix).

28 Please note that some of these benefits cannot be fully attributed to hydropower, especially in those cases where hydropower is a 'by-product' rather than the primary function of a dam or reservoir.

# 3 THE ROLE OF HYDROPOWER IN THE FUTURE

The previous chapter has presented and analysed the current role of hydropower in the European power system and its contribution to the European economy. This chapter continues this analysis to the future. Based on the example of the year 2030, we illustrate how hydropower can help to achieve the goals of European climate and energy policy. In addition, this chapters shows how the macroeconomic benefits of European hydropower will further grow in the future. The latter analysis furthermore expands the analysis beyond the hydropower sector itself and also assesses the additional benefits, which hydropower can induce to other parts of the European economy. More specifically, we show how reduction of wholesale electricity prices that are caused by increasing electricity generation from hydropower gives rise to additional economic value creation and employment in other sectors.

## 3.1 The Role of Hydropower in the Year 2030

The future role of hydropower will be strongly influenced by the overall development of the European power sector. In line with European climate and energy policy, the electricity sector is expected to undergo fundamental changes, with a need for strongly decreasing $CO_2$ emission and a rapidly increasing penetration of variable RES. However, the exact scope of these changes as well as the success in reaching the EU's policy goals remain subject to considerable uncertainty. For these reasons, the analysis in this study is based on two basic scenarios that take different assumptions on the success of the EU decarbonisation policy.

More specifically, we have considered the following two development scenarios[29]:

- '**'Reference' scenario**', i.e. the ''Reference' scenario 2013' from the Commission's 'Trends to 2050' study,
- '**Diversified Supply**', i.e. the 'Diversified Supply Technologies' scenario from the European Commission's 'Energy Roadmap 2050'.

The scenario 'Diversified Supply Technologies' follows the EU's long-term decarbonisation pathway and uses a mix of different technologies, including RES. It achieves a significant reduction of carbon emissions in the power sector (> 95% by 2050) and assumes a strong growth of RES, mainly wind power. In contrast, the ''Reference' scenario' reflects a more conservative development scenario that fails to meet the ambition carbon reduction targets by 2050.

Implicitly, this scenario framework also includes variations in terms of RES shares as the level of decarbonisation is a significant driver for the development of (variable) RES.

In our modelling, we have based the assumptions on the development of RES and nuclear power on the two EU scenarios. Figure 3-1 below compares the RES assumptions for the reference region (Europe) in both scenarios. The scenario 'Diversified Supply' has significantly higher installed RES capacities in the long-run, i.e. 1,300 GW compared with 1,050 GW in the 'Reference' scenario in 2050. However, in both scenarios, RES development is mainly driven by wind generation (both on- and offshore) with a limited contribution by solar PV.

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29 Please see section 7.2.2 in the Appendix for further details

The overall generation of hydropower (net of pump storage generation) is at comparable levels in both scenarios. While hydropower development in Europe sees only moderate growth, significant development is expected for Turkey, which is assumed to increase hydropower generation by a factor of approximately 2.7 between 2010 and 2050.

For further details on other assumptions, for instance with regards to fuel and $CO_2$ prices, please refer to section 7.2.2 in the appendix.

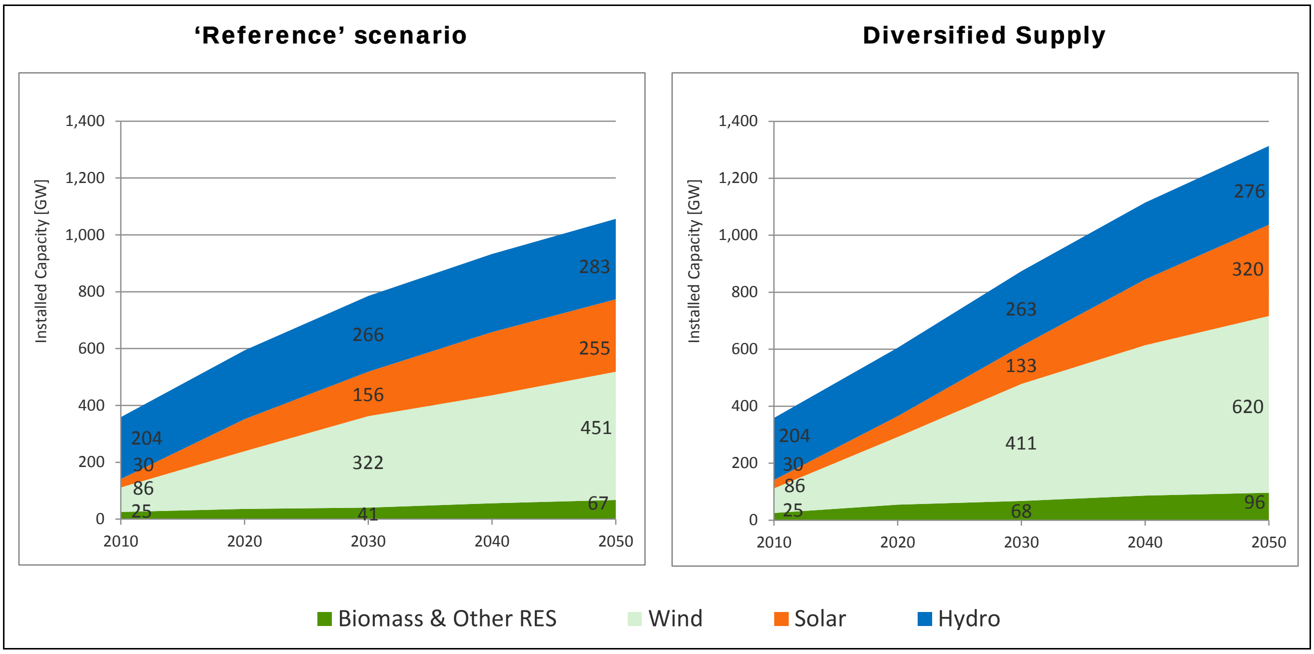



**Figure 3-1: Mix of RES capacities in the two basic scenarios (Europe)**
Note: Other RES include geothermal, wave and tidal generation
Source: DG ENER, DNV GL analysis

As mentioned above, the expected development of hydropower generation is roughly comparable in the two basic scenarios. In order to assess the incremental benefits of hydropower, we have additionally analysed two sensitivities for each basic scenario. These sensitivities principally assume the same level of capacity as in the basic scenarios but a variation of electricity generation from hydropower as follows:

- 'High' sensitivity, with increased hydropower generation (compared to the basic scenarios), assuming an improved environment for hydropower,
- 'Low' sensitivity, with decreased hydropower generation (compared to the basic scenario), assuming deteriorating framework conditions for hydropower.

The overall development of electricity generation for the two development scenarios and the respective High and Low sensitivities is presented in Figure 3-2. The development of hydropower in the sensitivities of the 'Reference' scenario is similar to the 'Diversified Supply' scenario, although at a slightly higher level. In 2030, the differences between the Low and High sensitivity are 91 and 85 TWh in the Reference and 'Diversified Supply' scenario, respectively.

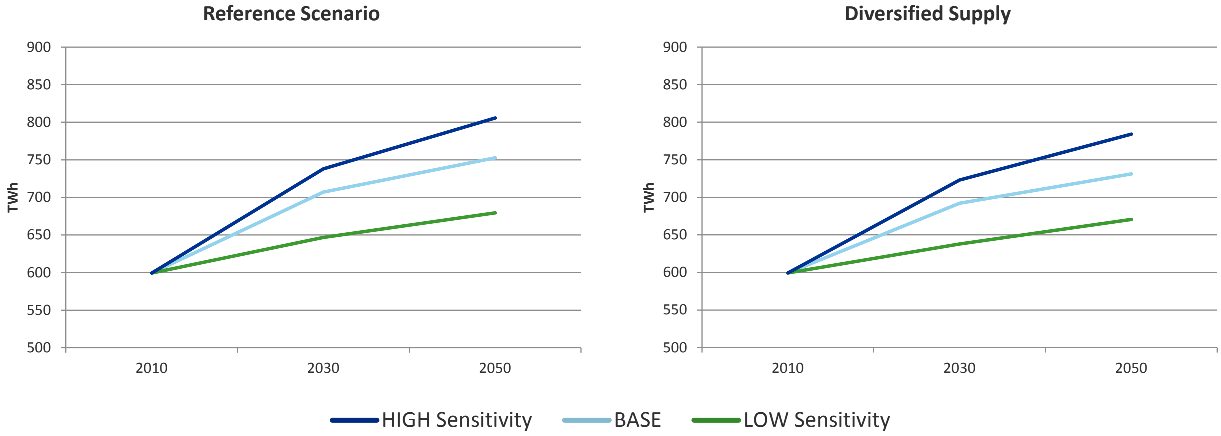



**Figure 3-2: Development of electricity generation in High and Low sensitivities of the two basic scenarios (Europe)**
Note: Generation figures exclude generation from pump storage
Source: DNV GL analysis, based on EU Commission (2011), and EU Commission (2013)

## 3.2 Contribution to Carbon Abatement and Security of Supply

### Carbon Abatement

Similar to the analysis of the present situation in section 2.2 above, we have analysed the volume of $CO_2$ emissions, which can (theoretically) be avoided by hydropower generation. While the analysis for 2010 was based on historic power system data, the analysis for the year 2030 is based on the results of our power market simulations. Based on the projected fuel consumption and $CO_2$ emissions in 2030, Figure 3-3 shows the contribution of hydropower to $CO_2$ abatement in the two basic scenarios.

Figure 3-3 shows that $CO_2$ emissions in the EU-28 would increase by some 52 to 70 Mt, or about 12 to 13%, if hydropower was replaced by the average future generation mix. Alternatively, when assuming that hydropower was replaced by fossil fuels only, additional $CO_2$ emissions would amount to some 101 to 132 Mt, or about 23 to 24% of total $CO_2$ emissions.

We note that absolute $CO_2$ savings are somewhat smaller than in 2010 (compare Figure 2-5 on p. 10). This is not surprising as overall carbon intensity is decreasing in both scenarios until 2030. Indeed, as the share of RES in overall electricity generation increases and underlying commodity prices cause a shift of electricity generation from coal to natural gas, overall $CO_2$ emissions as well as the consumption of fossil fuels decrease in both scenarios.

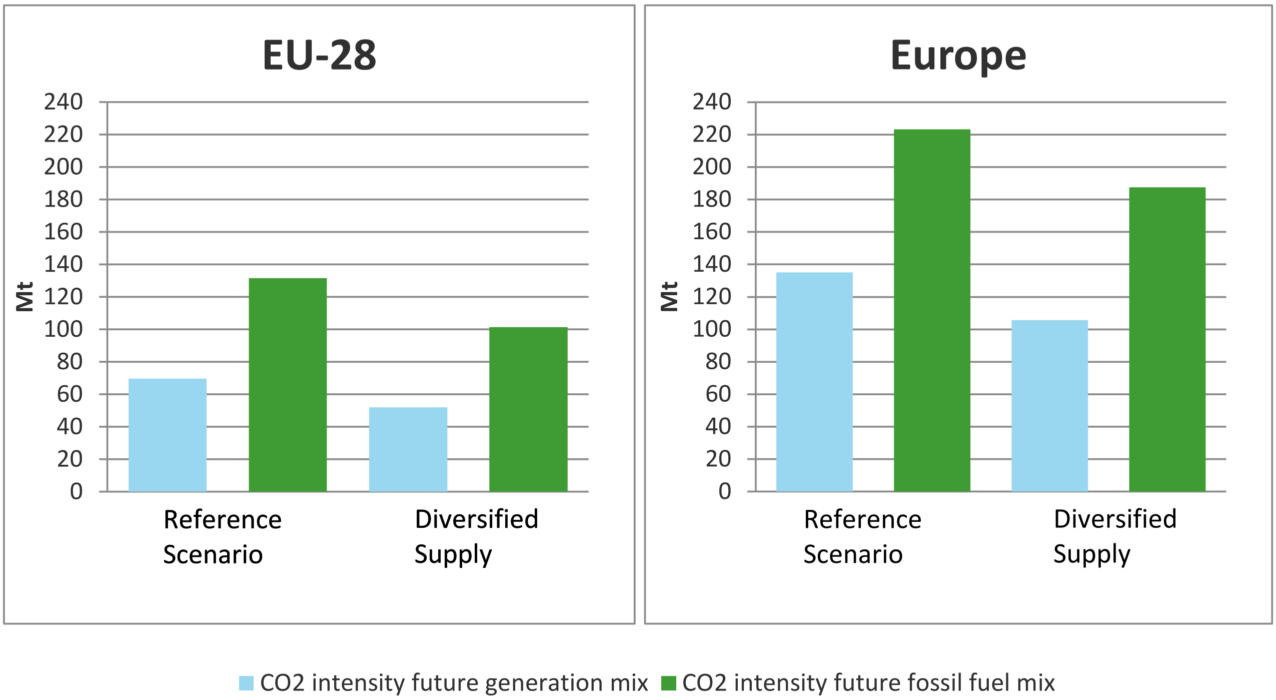



**Figure 3-3: Avoided $CO_2$-emissions by hydropower in EU-28 and Europe in 2030 (basic scenarios)**
Source: DNV GL analysis

## Security of Supply (Reduction of Fuel Imports)

Figure 3-4 shows the corresponding results with regards to the reduction of fuel imports in the year 2030. These numbers are based on the results of the power market simulations for 2030 and the same approach as applied in Section 2.2. For the EU-28, additional imports of fossil fuels in 2030 amount to some 1,250 to 1,450 PJ if hydropower was replaced by a mix of fossil fuels and nuclear technologies, or 2,100 to 2,500 PJ in case hydropower was exclusively replaced by fossil fuels. In relative terms, this corresponds to approx. 3% to 7% of total fossil fuel imports into the EU-28 in 2030 in the two scenarios[30].

Similarly, hydropower theoretically helps to avoid consumption of approx. 2,300 and 4,300 PJ of fossil fuels in Europe in the year 2030.

30 Based on the corresponding figures provided in EU Commission (2011) and EU Commission (2013)

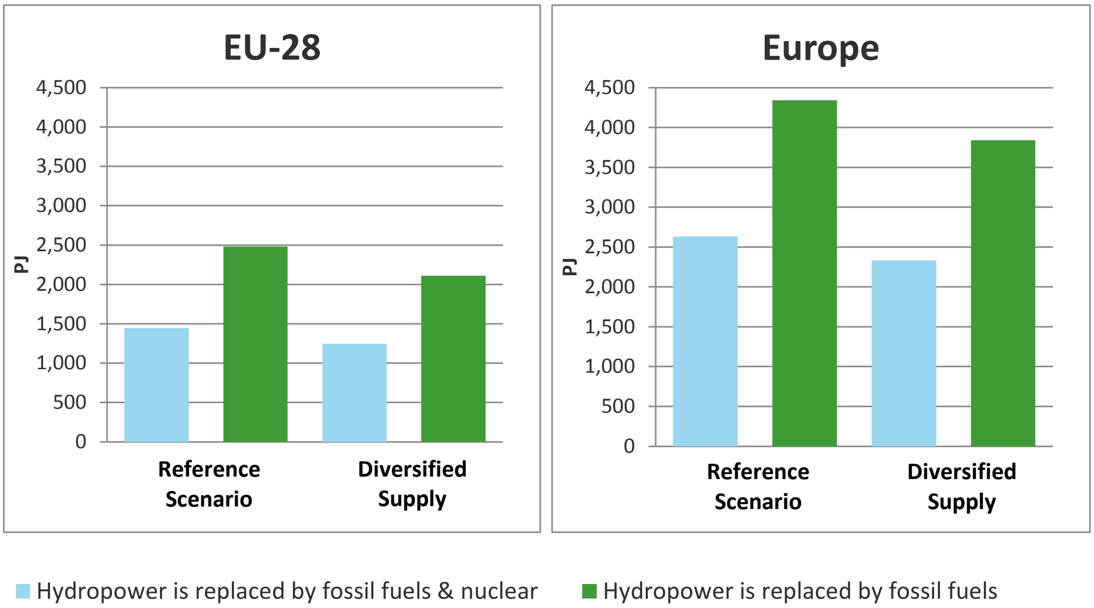



**Figure 3-4: Avoided fossil fuel imports by hydropower in the basic scenarios (2030)**
Source: DNV GL analysis

Applying the scenario specific commodity prices, we have calculated the resulting savings due to avoided consumption of fossil fuels. As presented in Figure 3-5, annual savings for the EU-28 range between EUR 10bn to 13bn and EUR 16bn to 22bn for the two scenarios, respectively. Again, we have based our calculations on the assumption that all additional demand for fossil fuels is satisfied by imports.

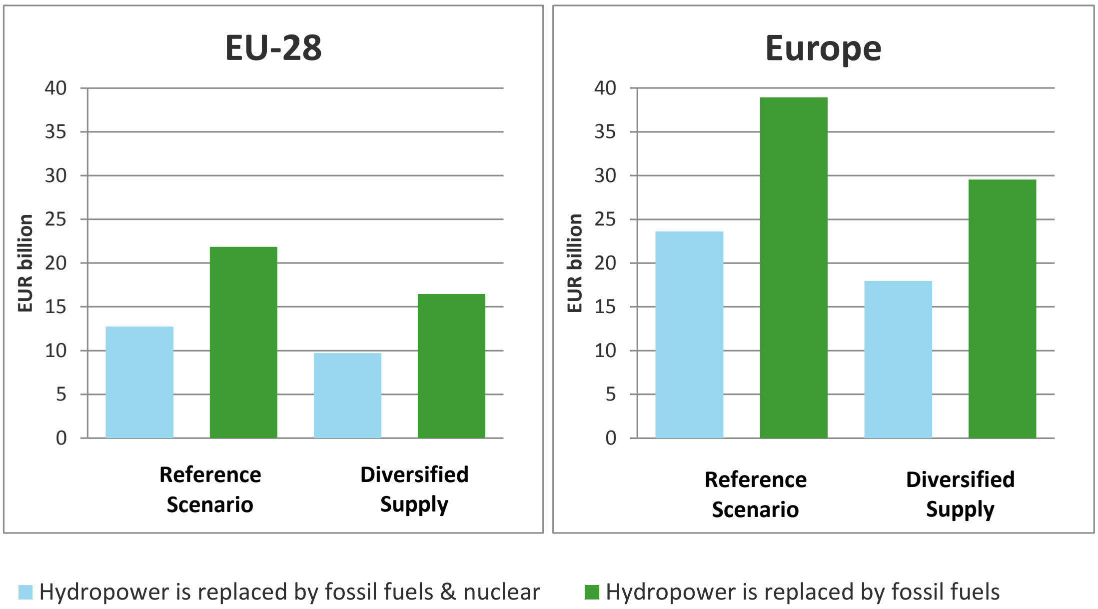



**Figure 3-5: Cost savings due to avoided consumption of fossil fuels in the two basic scenarios (2030 )**
Source: DNV GL analysis

## Incremental Savings in Fuel and $CO_2$ Costs

The results presented so far are based on the two basic scenarios. In addition, we have also analysed the impact of an incremental variation of hydropower on the total variable costs of power generation. For this analysis, we have used our electricity market model to quantify fuel and $CO_2$ savings in the two hydropower sensitivities presented in Section 3.1 and calculated the resulting cost savings.

As presented in Table 3-1, an increase of hydropower generation by about 10% in Europe reduces fossil fuel consumption by about 514 to 577 PJ (5% to 7%) in Europe, or 275 to 344 PJ (4 to 5%) in the EU-28. In addition, it also helps to reduce $CO_2$ emissions by 25 to 35 Mt (4 to 6%) in Europe and 12 to 22 Mt (4% to 5%) in the EU-28. Based on these results, the combined cost savings from reduced fossil fuel imports and $CO_2$ emissions can be calculated to approx. EUR 6.4bn to 7.4bn in Europe, or EUR 3.8bn to 4.2bn in the EU-28. In relation to the additional volumes of electricity generation from hydropower, this corresponds to specific savings of 75 to 80 EUR/$MWh_{hydro}$ for Europe and 107 to 114 EUR/$MWh_{hydro}$ for the EU-28. These numbers indicate that hydropower is a very efficient option for reducing fossil fuel consumption and $CO_2$ emissions.

**Table 3-1: Impact of an incremental increase of hydropower generation on fossil fuel consumption and $CO_2$ emissions in 2030**

| Scenario | Region | Additional energy from hydropower | Fossil Fuel Savings | | $CO_2$ Savings | | Combined Savings | |
|---|---|---|---|---|---|---|---|---|
| | | TWh | PJ | $MWh_{fuel}$ / $MWh_{hydro}$ | Mt | t / $MWh_{hydro}$ | EUR million | EUR / $MWh_{hydro}$ |
| Diversified Supply | Europe | 85 | 577 | 1.9 | 35 | 0.4 | 6426 | 75 |
| | EU-28 | 33 | 344 | 2.9 | 22 | 0.7 | 3774 | 114 |
| 'Reference' scenario | Europe | 91 | 514 | 1.6 | 25 | 0.3 | 7338 | 80 |
| | EU-28 | 39 | 275 | 1.9 | 12 | 0.3 | 4173 | 107 |

Incremental generation from hydropower corresponds to an increase by approx. 10%.
Source: DNV GL analysis

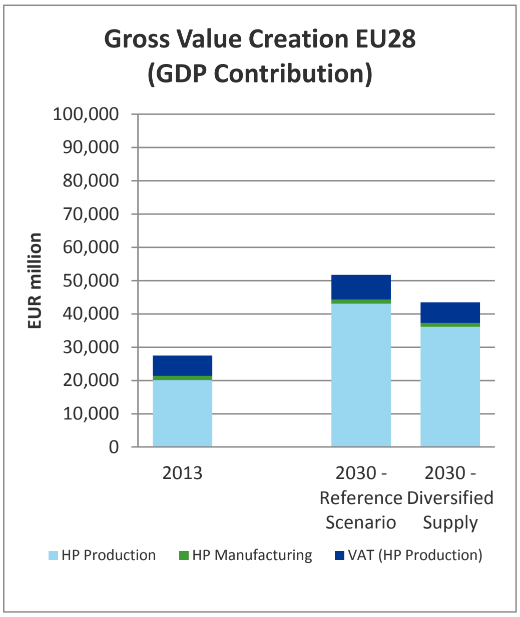
# 3.3 Economic Benefits of Hydropower

## Value Creation Employment and Investments[31]

The analysis in section 2.3 has assessed the direct and indirect economic benefits of hydropower at present. Figure 3-6 shows the corresponding results for the year 2030 for the two basic scenarios, which are based on the results of the power market simulations. For ease of comparison, the 2030 figures are separately shown for both scenarios as well as for the year 2013, both for Europe and for the EU-28.

31 Please note that this analysis does not cover future tax revenues since taxation is subject to regulatory changes and thus difficult to predict.

Figure 3-6 shows that the contribution of hydropower to European GDP increases considerably in both scenarios. In the EU-28 as well as Europe, value creation increases by more than 100% in the 'Reference' scenario and roughly 70% in the 'Diversified Supply' scenario. This increase is driven both by an expansion of hydropower generation and an increase in electricity prices (due to higher prices for fuel and $CO_2$ allowances).



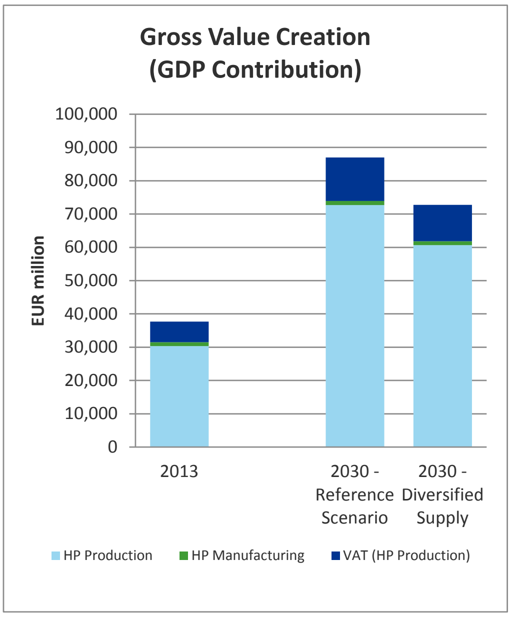




**Figure 3-6: Gross value creation by the hydropower sector in the two basic scenarios in 2030**
Source: DNV GL analysis

Figure 3-7 shows the development of employment in hydropower. Compared to value creation, the rise is less pronounced. More specifically, it is almost negligible for the EU-28 and limited to between 17% and 20% for Europe. This limited impact can be explained by the fact that the increase in value creation is only partially driven by additional capacity but also be increasing fuel and $CO_2$ prices. However, the latter do not have any impact on direct and indirect employment in the hydropower sector. In addition, most of the additional capacity is built outside the EU-28, which further reduces the estimated impact on employment in the EU-28 hydropower sector.

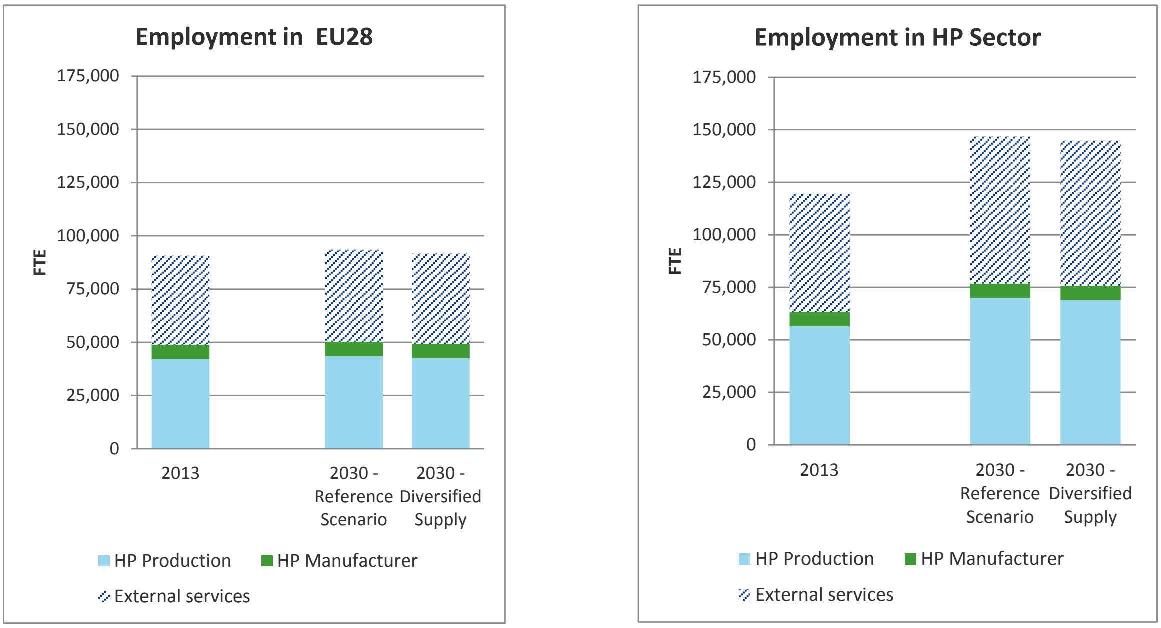



**Figure 3-7: Projection of direct and indirect employment in the hydropower sector in the two basic scenarios in 2030**
Source: DNV GL analysis

Finally, Figure 3-8 shows cumulative investments in the period until 2030[32]. It clearly shows that the possible expansion of European hydropower by 2030 will lead to considerable investment streams to the benefit of the European economy. Under favourable legal and regulatory conditions, cumulative investments in the hydropower sector until the year 2030 may amount to more than EUR 110bn in the EU-28, or more than EUR 180bn in Europe. 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[33].

32 Due to the small difference between the two basic scenarios in terms of installed hydropower capacity, Figure 3-8 shows a single value for both scenarios only.

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

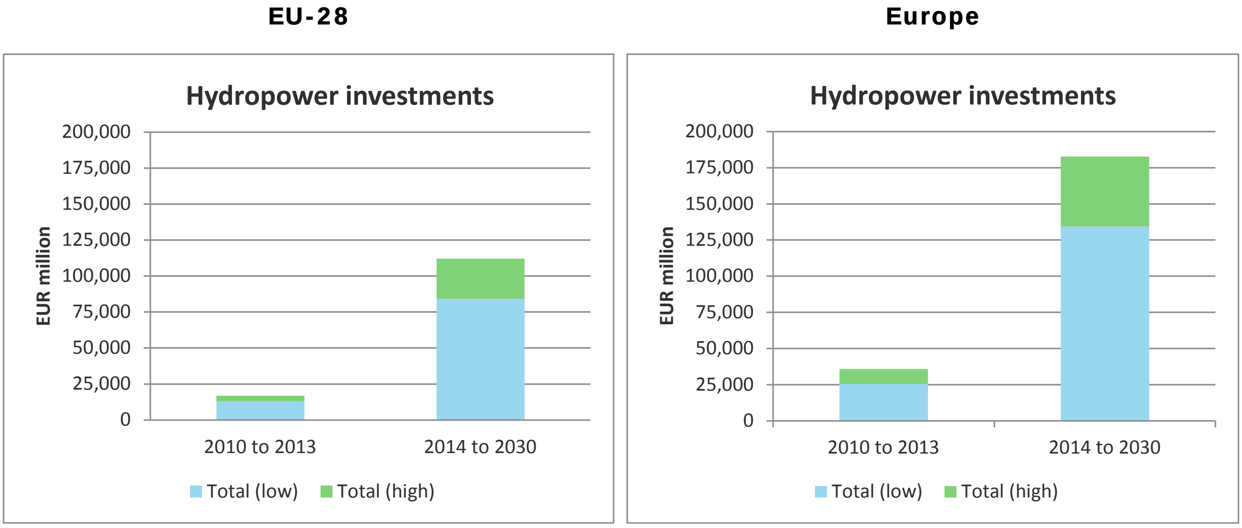



**Figure 3-8: Projection of total investment in the hydropower sector**
Note: High and low estimates reflect range of assumptions on specific investment costs of new plants
Source: DNV GL analysis

## Induced benefits of decreasing electricity prices for other sectors

Hydropower is not only a cost-efficient source of electricity but also helps to reduce electricity prices. This effect induces further benefits and contributing to the competitiveness of other economic sectors. In turn, this allows other sectors to increase their own output and hence also overall GDP as well as employment. As briefly outlined in section 1 and further explained in the Appendix (section 7.3), we have analysed the corresponding impacts by means of an input-output analysis for selected countries and industries[34].

The corresponding analysis has been based on the sensitivities of the two scenarios as introduced in section 3.1[35]. To put the subsequent analysis perspective, we recall the differences between the Low and High sensitivities (compare Figure 3-2 on p. 22 above):

- In the 'Reference' scenario, electricity generation from hydropower increases by 91 TWh in Europe, which corresponds to roughly 2% of total electricity generation.
- In the 'Diversified Supply' scenario, hydropower generation grows by 85 TWh, or 1.9% of total generation in Europe.

The differences between the High and Low sensitivities do not represent more than 2% change of additional generation. Nevertheless, Figure 3-9 shows that these changes already induce substantial changes. On average, the limited increase of hydropower generation reduces average wholesale electricity prices in the country sample by approx. 2.0% in the 'Reference' scenario, and 2.7% in the 'Diversified Supply' scenario. Variations at a national level are more significant. Here, price differences range between +2% and -9.4% in the 'Reference' scenario, and between +0.5% and -10.4% in the 'Diversified Supply' scenario.

34 As explained in the Appendix, in our numerical calculations we have limited ourselves to an input-output analysis of twelve countries with significant price changes.

35 Please note that the results presented below are based on a ceteris paribus analysis: only hydropower capacity and generation capacity are altered, whereas all other parameters, including demand, are kept constant.

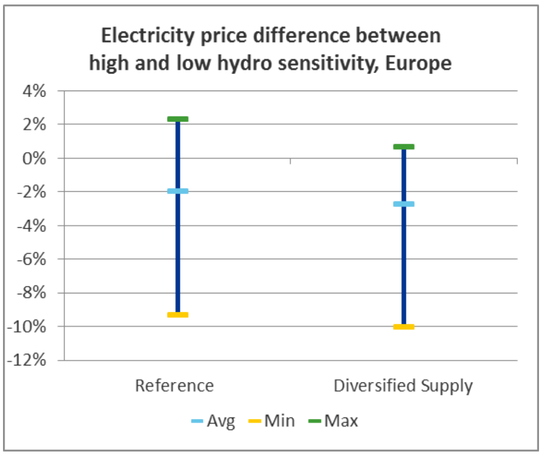



**Figure 3-9: Percentage change of electricity prices between high and low hydropower sensitivity**
Source: DNV GL analysis

Lower electricity prices reduce input cost for production in other sectors and may hence lead to lower prices of the corresponding goods and services. In turn, reduced prices for such goods or services spur demand and lead to an increase in output, the scope of which varies depending on the sectoral price responsiveness[36]. By means of the input-output analysis, it is possible to estimate the corresponding effects, both in terms of additional output (GDP) and additional employment associated with the output increase.

The results of this analysis are presented in Figure 3-10 and Figure 3-11. To facilitate interpretation, the induced change in output and employment is shown alongside the corresponding direct and indirect effects, which are caused by the underlying increase of electricity generation from hydropower. As discussed above, direct effects comprise of increased electricity sales as well as employment in the hydropower sector, whereas indirect effects cover an increase of GDP and employment in sectors that are serving the hydropower sector.

Figure 3-10 shows that induced value creation remains small compared to direct and indirect effects[37]. In both scenarios, induced output in other sectors is substantially smaller than the sum of direct and indirect effects in the hydropower sector itself. In other words, an increase of hydropower generation mainly creates additional GDP in the hydropower sector itself as well as in the sectors serving the hydropower industry. In contrast, the induced effects in other parts of the economy, caused by decreasing electricity prices, remain much more limited.

36 As it is standard in an Input-Output analysis, the changes represent *first round effects*, i.e. the underlying assumption for the changes is that the basic structure of the economy does not change. In technical terms, responsiveness of output to price changes are called sensitivities.

37 Please note that the variation reflects uncertainty on the price responsiveness of output and employment to changes of input factors (here: electricity prices).

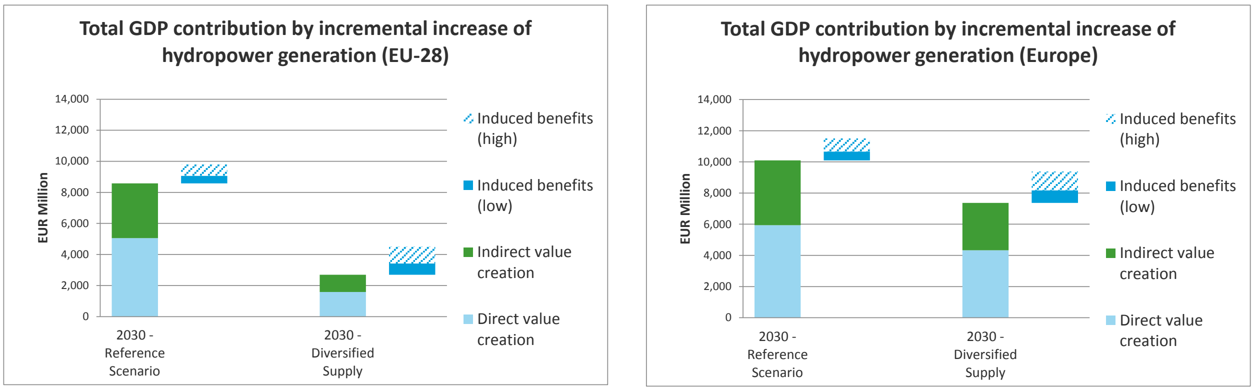



**Figure 3-10: Impact of an incremental increase of hydropower generation on GDP in the EU-28 and Europe (2030)**
Source: DNV GL analysis

In contrast, Figure 3-11 shows a different picture with regards to employment effects. In this case, the additional employment induced by reduced electricity prices in other sectors is considerably higher than the increase of direct and indirect employment in the hydropower sector itself. These numbers indicate that the employment effects of additional hydropower generation largely occur outside the hydropower sector itself. This remarkable difference between the results for value creation and employment reflects the high share of value creation per FTE and the very low labour intensity in the hydropower sector, which is much lower than in many other sectors outside the hydropower sector.

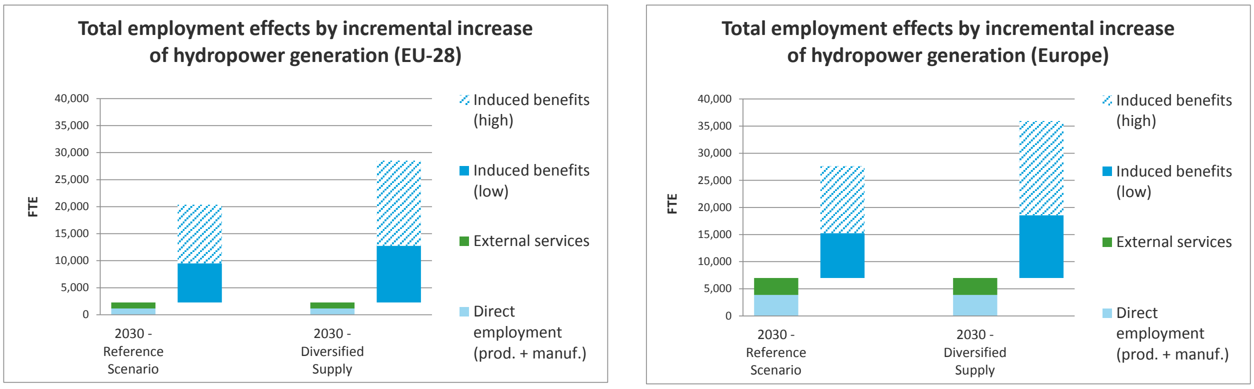



**Figure 3-11: Impact of an incremental increase of hydropower generation on employment in the EU-28 and Europe (2030)**
Source: DNV GL analysis

## 3.4 Benefits of an Incremental Increase of Hydropower Generation by 10% in 2030

Besides looking at the future role of hydropower in general, the previous sections have analysed the impact of a 10% increase of hydropower generation. Figure 3-11 presents a summary of the corresponding findings. This graph clearly shows that even this incremental increase delivers significant benefits to European society.

Both fossil fuel consumption and $CO_2$ emissions are reduced by more than 10% at the level of the EU-28 and Europe. In addition, this limited increase of hydropower generation delivers between EUR 3.8bn and

7.3bn to consumers in the EU-28 and Europe. These values are equivalent to specific savings of between 75 and 144 €/MWh of additional electricity generation from hydropower and highlight the large benefits which hydropower can bring to consumers. These savings correspond to an increase of value creation in the hydropower sector by between EUR 4bn and 11bn, including induced output in other parts of the economy. Finally, even this incremental increase of hydropower helps creating more than 25,000 new jobs in the EU-28, and more than 35,000 in Europe. As discussed above, most of these jobs are created outside the power sector, emphasising the overall net benefit of hydropower to the European economy.

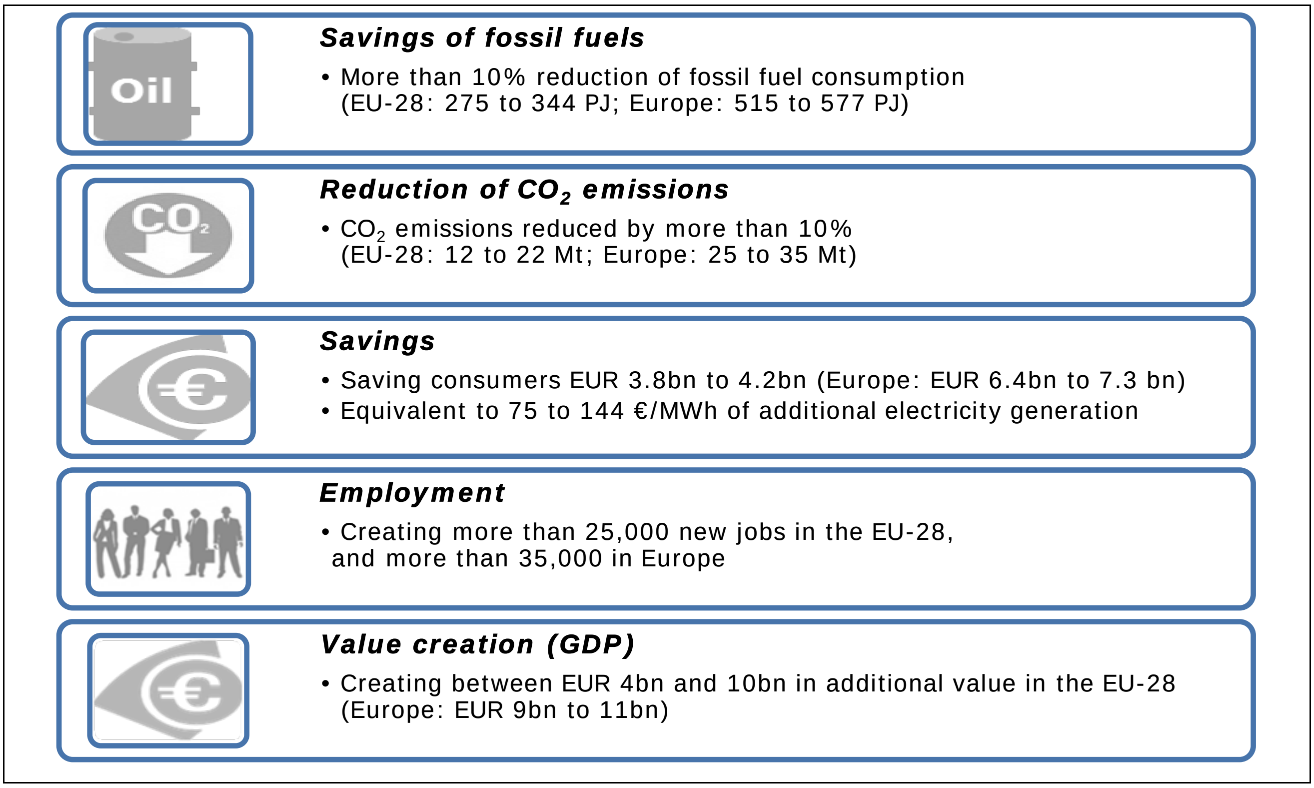



**Figure 3-12: Benefits of an incremental increase of hydropower production in 2030 by 10%**
Sources: DNV GL analysis

# 4 ENABLING THE INTEGRATION OF RENEWABLE ENERGIES

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. One of the cornerstones of this overall policy framework is a commitment by European countries to substantially reduce greenhouse gas emissions over the next decades and to increase the share of renewable energies in Europe's energy supply. For instance in their recent decision on the 2030 climate and energy policy framework[38], 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, most scenarios and forecasts expect that much of the additional capacity will come from variable sources. For illustration, we refer to Figure 3-1 on p. 22 in section 3.1 above, which shows the evolution of the future mix of RES in the two scenarios we have used for the electricity market simulations. Figure 3-1 clearly shows that wind and solar power account for most of the additional capacity from RES and will increasingly dominate the total capacity mix from RES.

Integrating these additional volumes of variable generation from RES will create serious challenges for the European power systems. These challenges are mostly related to the volatile and uncertain generation from wind and solar power over different time horizons, i.e. from a minute-by-minute basis during real time operations to the optimal use of available energy on a seasonal basis and the provision of generation adequacy.

More specifically, and as illustrated by Figure 4-1, the future power system will require the following, in order to successfully deal with the variable nature of wind and solar power:

- ***Flexible generation*** (and demand), in order to accommodate potentially large and unexpected variations in residual demand as well as increasing ramp rates in real time,
- ***Firm capacity*** that can be reliably called upon during situation when there is insufficient output available from wind and solar power,
- ***Storage capability***, in order to balance volatile generation over a timeframe of several weeks or even months.

These developments will greatly increase the value of hydropower as it provides an ideal solution for these challenges. Apart from their flexibility, hydropower plants can contribute to reliability by making power available when so required. Furthermore, hydropower is the only form of electricity storage that is available on a large scale and across different time scales at competitive costs today.

The following sections discuss each of these three areas in more detail and provide relevant evidence and illustrative examples of how hydropower already helps to integrate variable RES into the power system today, and will increasingly play an essential role in this respect in the future.

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

Hydropower provides

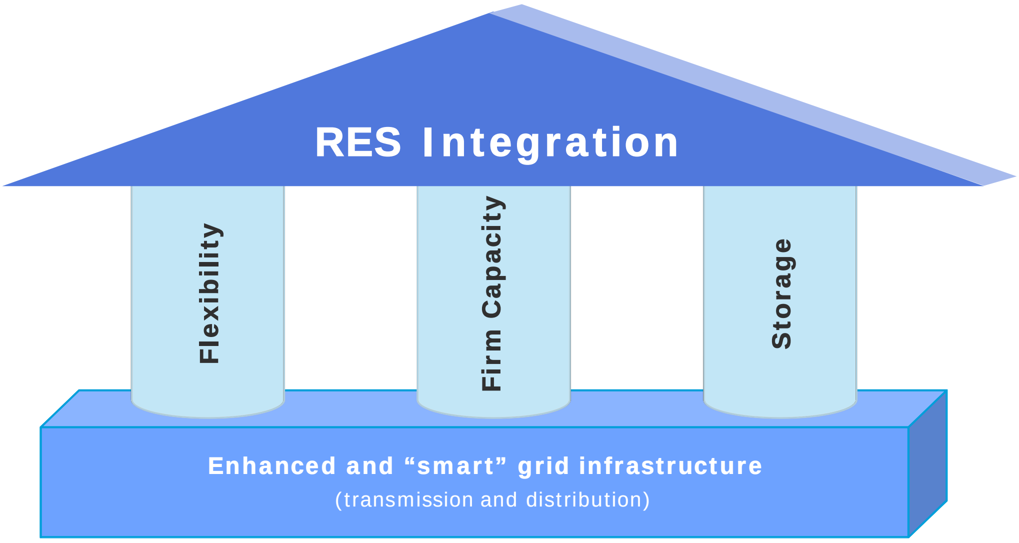



**Figure 4-1: Building blocks of RES integration**
Source: DNV GL

## 4.1 Provision of Flexibility by Hydropower Plants

Wind and solar power are characterised by considerable volatility across different scales and their output cannot be predicted with absolute 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[39] as the generation of wind and solar plants does not always coincide with load, which may lead to temporary periods of 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 within a few minutes and are able to follow even major variations in real time.

### Hourly, daily and weekly flexibility for the Iberian power market

These benefits, which have been extensively described in a large number of studies and reports, are also illustrated by the results of the power market simulations within this project. To start with, Figure 4-2

39 Residual demand is equal to hourly electricity demand net off hourly wind and solar generation.

shows the average hourly residual electricity demand[40] as well as average hourly hydropower generation for two selected months in summer and winter on the Iberian Peninsula, based on the simulation of the scenario Diversified Supply for the year 2030. One can easily see that hydropower generation is generally scheduled in a way to follow the form of the residual demand profile. Hydropower generation is generally higher during periods of high residual electricity demand, for instance due to high load and/or low RES generation. This pattern allows 'flattening' the average generation profile to be provided by other generation technologies, thereby helping to reduce thermal or mechanical stress and to improve the efficiency of operations of such other plants.

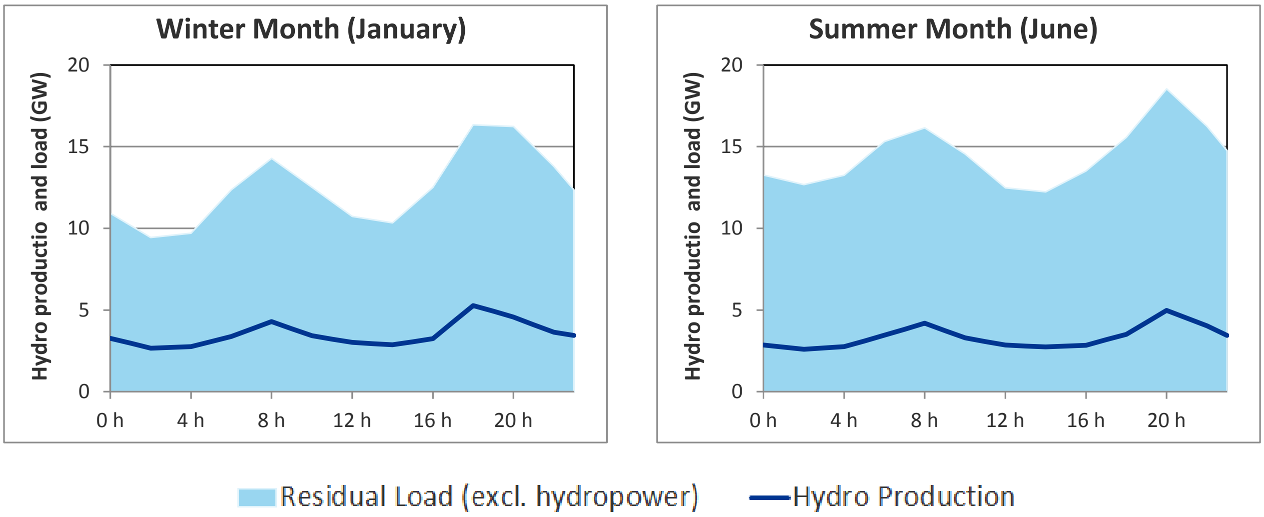



**Figure 4-2: Average daily profile of residual load and hydropower generation in Iberia for two selected months in 2030 ('Diversified Supply' scenario)**
Source: DNV GL

Figure 4-3 shows another example, again based on the example of the Iberian power system. More specifically, the graph presents the hourly generation profile of different types of RES, hydropower and conventional power plants for two exemplary weeks in May and June 2030. This depiction clearly illustrates the role of flexible hydropower for integration of variable RES, particularly wind and PV.

Most importantly, we observe that:

- Hydropower generation is used to compensate diurnal variations of PV generation, i.e. to produce primarily in morning / evening hours and reduce output during the day, when PV generation reaches its peak,
- Hydropower is used to compensate variations of wind power by shifting generation across different days, i.e. by reducing output during periods of high wind generation and shifting generation to periods of low wind generation on other days,
- Pump storage plants use excess electricity (e.g. in periods of high wind generation) for pumping and hence storing electricity, which can be released in other hours,
- Finally, it is worth noting that part of the remaining difference between generation and load is compensated by cross-border exchanges, i.e. exports and imports.

40 Residual electricity demand is calculated as the difference between regional electricity demand and wind / PV production.

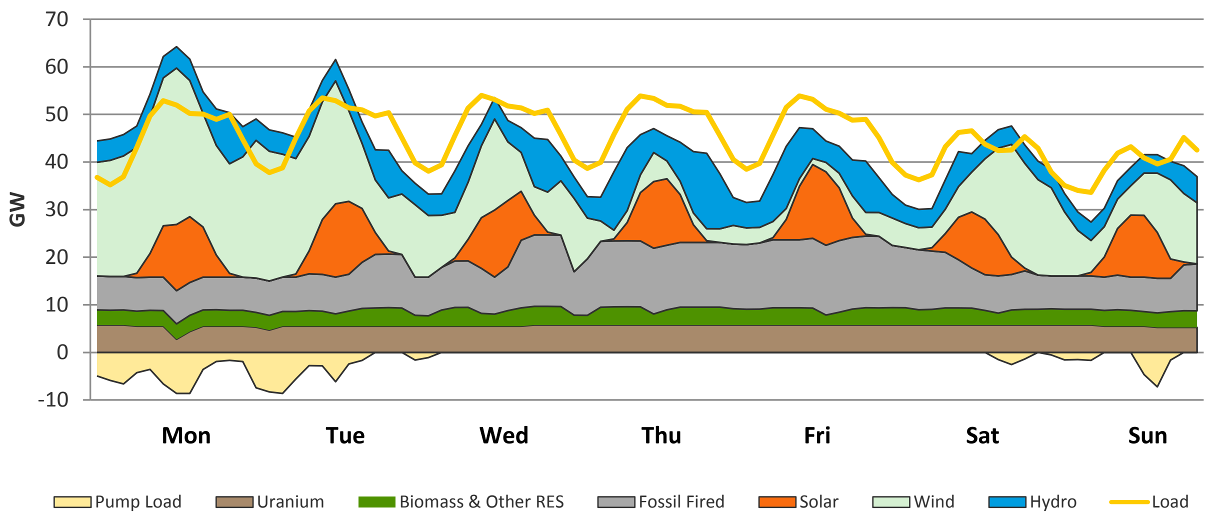



**Figure 4-3: Hourly electricity generation in Iberia for one week in June 2030 ('Diversified Supply' scenario)**
Note: Net electricity exchanges correspond to the difference between electricity demand (plus pump load) and generation
Source: DNV GL

These simplified examples already highlight how flexible hydropower helps to manage the energy balance and compensating for the volatile generation by variable RES. Such operational patterns also help to avoid RES curtailment by providing storage capacity and making it possible to utilise excess generation caused by fluctuating RES generation. Furthermore, ramping requirements of thermal generation are reduced, allowing conventional plants to operate at more efficient dispatch levels, hence saving energy and $CO_2$ emissions.

## Dealing with PV ramp rates in Germany

The examples presented above deal with the need for flexibility, in order to accommodate hourly, daily or weekly variations. In addition, variable RES may also create operational challenges at a much shorter time frame. In particular, generation by solar PV changes very quickly when the set gets up in the morning and, even more importantly, when the sun settles in the afternoon or evening. This may result in very fast changes of residual load, especially when these effects coincide with the underlying change of local demand.

For illustration, Figure 4-4 shows the hypothetical effect, which the solar eclipse in March 2015 could have had on residual electricity demand in Germany on a sunny day[41]. The left part of Figure 4-4 clearly shows how generation by solar PV, with an aggregate installed capacity of some 38 GW, leads to a major decline of residual load during the daylight hours. In addition, one can clearly see the sudden and marked increase of residual load during the time of the solar eclipse (approx. 10:45 h to 12:00 h). During this period, generation by solar PV first declines by up to 272 MW/min and then increases again with a maximum ramp rate of up to 348 MW/min.

A comparison with the overall shape of both the original load profile and the initial residual load profile reveals that this rate of change is considerably larger than the maximum ramp rates, which would otherwise be expected on a sunny day. The solar eclipse can thus be expected to create an extraordinary challenge for operation of the German power system.

41 For further details, see: Weniger et al. (2014)

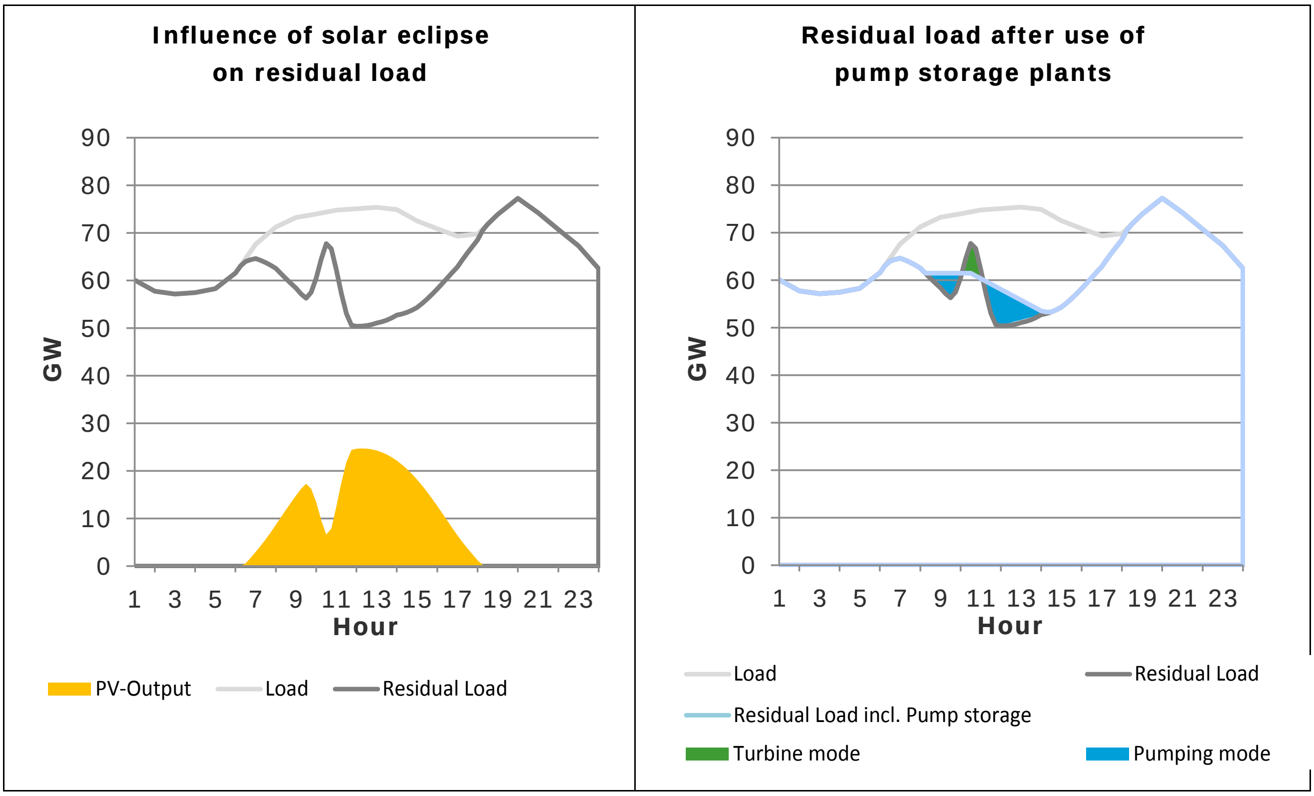



**Figure 4-4: Compensation of PV ramp rates by pump storage plants during solar eclipse in Germany**
Source: DNV GL, based on J. Weniger et al. (2014), p. 28

However, as the right part of Figure 4-4 shows, the situation is less dramatic when also considering the ability of German pump storage plants to mitigate these effects. Indeed, although the installed capacity of pumps storage plants is less than 20% of that of solar PV, they are able to effectively reduce the rate of the remaining change in residual load. 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.

As mentioned above, this example is related to the present situation, with an aggregate installed capacity of some 38 GW of solar PV in Germany. Based on current governmental plans and forecasts, however, Germany expects a significant increase of solar PV, potentially reaching a level of nearly 60 GW in the year 2024 already. The question, therefore, is whether the situation would change in the future, i.e. with a much higher penetration of solar PV?

In this context, it is worth noting that the maximum ramp rate mentioned above (350 MW/min) corresponds to approx. 5% of the installed capacity of storage and pump storage plants in Germany. On first sight, German hydropower plants should thus be able to provide the necessary ramp rate, even after doubling of solar PV capacity. However, as Figure 4-4 indicates, the solar eclipse could potentially result in a temporary loss of some 18.5 GW of generation. In case of a doubling of solar PV capacity, this would equate to more than five times the total installed capacity of German storage and pump storage plants. Hence, whilst German hydropower plants may be able to provide the dynamic response on a minute-by-minute basis, their overall contribution will be limited to the level of installed capacity.

Still, the situation might be further relieved by relying on the flexibility of additional hydropower plants in Austria and Switzerland. Even when accounting for the limited size of cross-border capacity, this would give the German power system access to an additional volume of flexible capacity that is at least as large as the volume of local flexibility from hydropower (7 GW).

These considerations show that flexible hydropower is an important instrument for dealing even with extreme instances of short-term variability of variable RES in the German market. Although hydropower will not be able to resolve all challenges on its own, its superior flexibility appears to be sufficient for dealing with high dynamic requirements, thereby providing sufficient space for resolving the remaining change in residual load by other technologies.

## 4.2 Supporting Generation Adequacy by Provision of 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 firm capacity, which can be called upon when needed. Indeed, practical experience and numerous studies show that there will still remain periods when the aggregate generation from 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 (DNV GL (2014) found that the need for firm capacity in the year 2030 was largely independent of the penetration of wind and solar power.

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

### Case Study: Contribution of hydropower plants to generation adequacy in Southern Germany, Austria and Switzerland in 2030

Section 2.2 (p. 11) presented a case study on the contribution of Alpine pump storage plants to generation adequacy in Southern Germany in the next few years, i.e. based on the current penetration of variable RES and with a considerable number of nuclear plants still being in operation in Southern Germany and Switzerland. However, the remaining nuclear plants in Germany will be switched off by 2022, and Switzerland also intends to reduce nuclear capacity in the future. Against this background, we consider the possible contribution of hydropower plants to generation adequacy in this region. For simplification, this case study is limited to Southern Germany, Austria and Switzerland and the year 2030, whilst we neglect the possible contribution of Italian hydropower.

This additional case study is based on the ‘‘Reference‘ scenario, which has also been considered for the market simulations (see section 3.1 above). Based on the underlying assumptions, we have determined the residual load profile for each of the three countries, as well as for the entire region. As illustrated by Figure 4-5 the resulting profile is characterised by major volatility and ranges between a minimum of almost 0 GW and a maximum of nearly 99 GW. This indicates that other types of generation must be able to supply at least 99 GW on a firm basis, i.e. on demand.

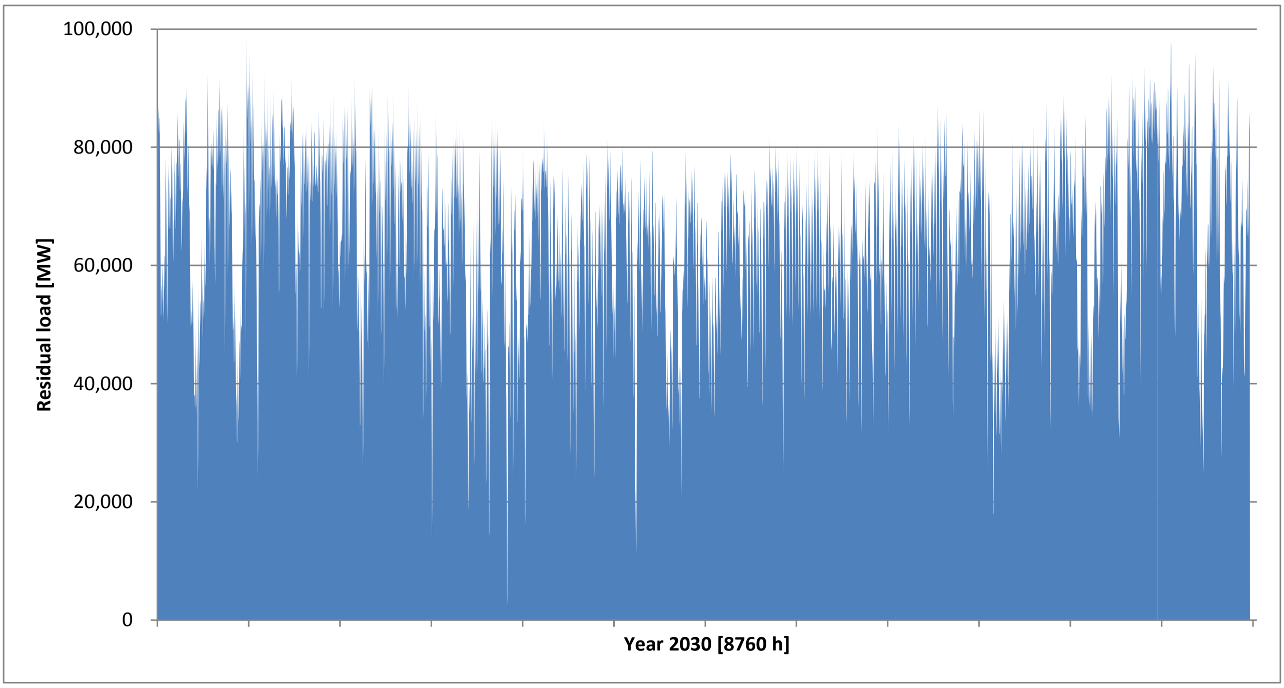



**Figure 4-5: Residual load profile in the region Germany, Austria, Switzerland ('Reference' scenario, 2030)**
Source: DNV GL analysis

Whilst many types of hydropower plants, such as storage and pump storage plants, can flexibly provide capacity when required, their ability to produce electric energy may be constrained by the limited size of their reservoirs. As a consequence, the contribution of hydropower plants to generation adequacy may be limited by energy rather than capacity constraints. Nevertheless, true peak load situations are typically of a limited duration, which means that such energy constraints may not be critical. In other words, hydropower storage is very valuable for dealing with peak load situations, such that only the remaining need for firm capacity has to be covered by other types of generation, such as thermal plants.

In a second step, we have analysed by how much the need for firm capacity can be reduced when using hydropower for covering peak load. More specifically, this involves the following steps:

- First, we have determined the minimum value of residual load that was observed over different time periods during the entire year[42]. This value principally indicates the need for 'residual firm capacity' that has be provided by other plants, assuming that hydropower is able to cover all demand in excess of this value. For instance in the example shown in Figure 4-6, maximum load over a period of 24 h amounts to 86.9 GW, whereas minimum load during the same period is 51.1 GW. Consequently, if it was possible to cover the difference between these two values, i.e. 35.3 GW, by hydropower, other plants would need to cover the remaining 51.5 GW of demand.
- Secondly, we have then calculated the maximum value of 'residual firm capacity' observed during the entire year. This value can be used as a proxy for the amount of firm capacity to be provided by other types of generation to ensure generation adequacy in each hour of the year.

[42] This calculation is similar to calculation of a moving average but focusing on the minimum rather than the average.

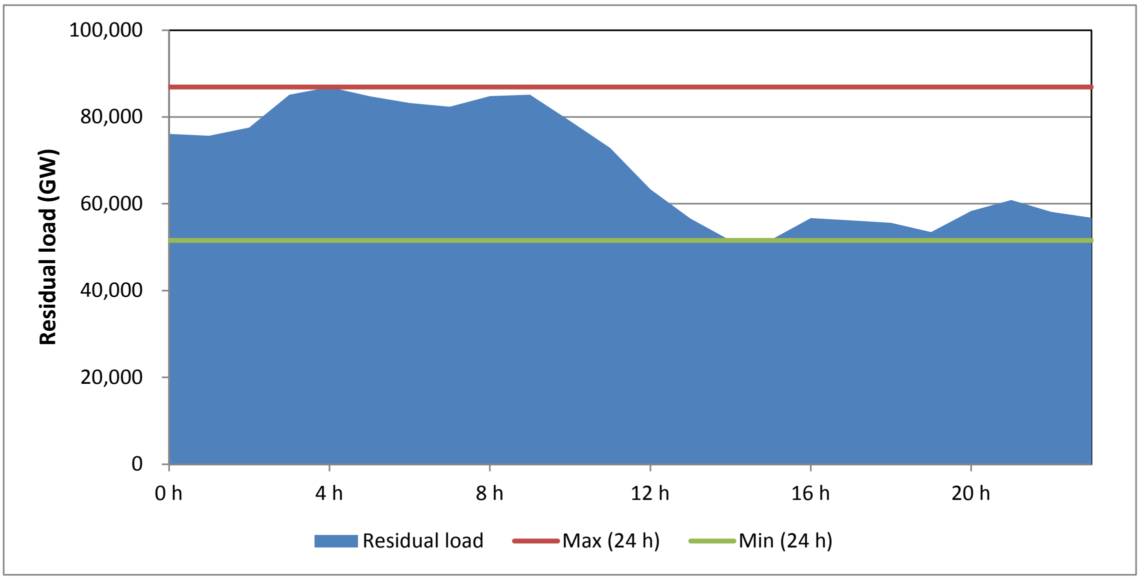



**Figure 4-6: Determination of minimum residual load for a given time period**
Source: DNV GL analysis

Table 4-1 shows the results of the corresponding analysis. For example, the highest residual load that was observed in Germany in the year 2030 amounted to 76,617 MW. Conversely, the need for 'residual firm capacity' for a consecutive period of 8 hours amounts to 70,310 MW only. In other words, from a total requirement of at least 76,617 MW of firm capacity, only 70,310 MW have to be sustained over eight hours or more. In contrast, the difference between these two values, i.e. approx. 6.3 GW, can also be provided by generators, which are able to produce for up to eight hours at one time.

**Table 4-1: Need for 'residual firm capacity' over different time horizons (MW)**

| Time horizon | DE | AT | CH | Entire region |
|---|---|---|---|---|
| **1 h** | 76,617 | 11,242 | 11,202 | 98,802 |
| **8 h** | 70,310 | 10,431 | 10,830 | 90,534 |
| **24 h** | 65,327 | 7,968 | 10,047 | 82,361 |
| **168 h** | 46,869 | 6,149 | 9,118 | 60,404 |

Source: DNV GL analysis

In Table 4-2 below, we further extend this analysis by comparing the system requirements for firm capacity and energy, on the one hand, with the capacity and energy that can be provided by storage and pump storage plants, on the other hand. The required capacity, which is shown in the left of Table 4-2, has been calculated as the difference between the short-term residual load (time horizon 1h) and the values of minimum residual load for the remaining time horizons as shown in Table 4-1. Conversely, the right part of Table 4-2 shows, how much energy had to be supplied by the corresponding capacity in the year 2030. The latter values have been calculated as the sum of hourly residual load in excess of the corresponding capacity values as shown in Table 4-1[43].

Apart from the corresponding requirements, Table 4-2 also shows the volumes of capacity and energy, which are available from storage and pump storage plants. By comparing needs and availability, it is thus possible to assess the ability of storage and pump storage plants to provide the corresponding

43 When considering the entire region, for example, the system needs a minimum volume of 90.5 GW of firm capacity for a consecutive period of 8 hours, which is 8,268 MW less than maximum hourly value observed in the year (98.8 GW). At the same time, the analysis shows that the total energy to be provided in excess of 90.5 GW amounts to 0.2 TWh only, which corresponds to less than 25 equivalent operating hours.

volumes of capacity and energy. For ease of interpretation, (potentially) critical combinations are highlighted by blue shading, with light blue cells indicating potentially critical cases, whereas values in dark blue cells clearly exceed available volumes.

Table 4-2 shows that German hydropower plants are unable to meet even the requirements over a time horizon of 24 hours since the requirements exceed available capacity and energy by 45% and 470%, respectively. Similarly, Austrian hydropower plants face energy constraints for a time horizon of one week but seem to be have sufficient storage to cover shorter periods of up to eight hours. However, there seems to be more than enough capacity and energy in Switzerland in all four cases, noting the difference between annual peak load and the 168-h value in Table 4-2 is far smaller in Switzerland than in the other two countries[44]. Finally, it is clearly visible that the combined fleet of storage and pump storage plants from all three countries is sufficient to cover the 24-h value from Table 4-1, whereas both the capacity and energy needs would be much higher than available volumes for the maximum figures across an entire week.

**Table 4-2: Comparison of capacity and energy requirements against volumes available from storage and pump storage plants**

| Time horizon | Required capacity (MW) | | | | Required energy (TWh) | | | |
|---|---|---|---|---|---|---|---|---|
| | DE | AT | CH | Entire region | DE | AT | CH | Entire region |
| **8 h** | 6,307 | 811 | 372 | 8,268 | 0.2 | 0.0 | 0.0 | 0.2 |
| **24 h** | 11,290 | 3,274 | 1,155 | 16,441 | 1.7 | 1.9 | 0.3 | 2.7 |
| **168 h** | 29,749 | 5,092 | 2,084 | 38,398 | 58.6 | 8.5 | 2.1 | 71.6 |
| **Available volumes** | **Installed capacity (MW)** | | | | **Available energy (TWh, winter)** | | | |
| | 8,632 | 10,342 | 14,268 | 24,364 | 0.3 | 3.2 | 8.6 | 12.1 |

Notes: Available volumes reduced by 10%, in order to account for limited availability of capacity
Shaded cells indicate (potentially) critical combinations, i.e. requirements in excess of available volumes
Source: DNV GL analysis

Although Table 4-2 accounts for energy constraints of hydropower already, it may still result in overly optimistic assumptions. This is illustrated by Figure 4-7, which shows the minimum storage levels in Austria and Switzerland for each month of the year, which have been observed over many years in the past. This figure clearly shows that minimum storage levels late in the winter and in early spring are much lower than the typical volume of energy available in the winter season. Given that generation adequacy requires a high degree of certainty, we therefore take the assumption that the volume of energy available from storage plants is limited to the level of stored energy in February (2.7 TWh).

44 Arguably, this may reflect a more modest penetration of variable RES.

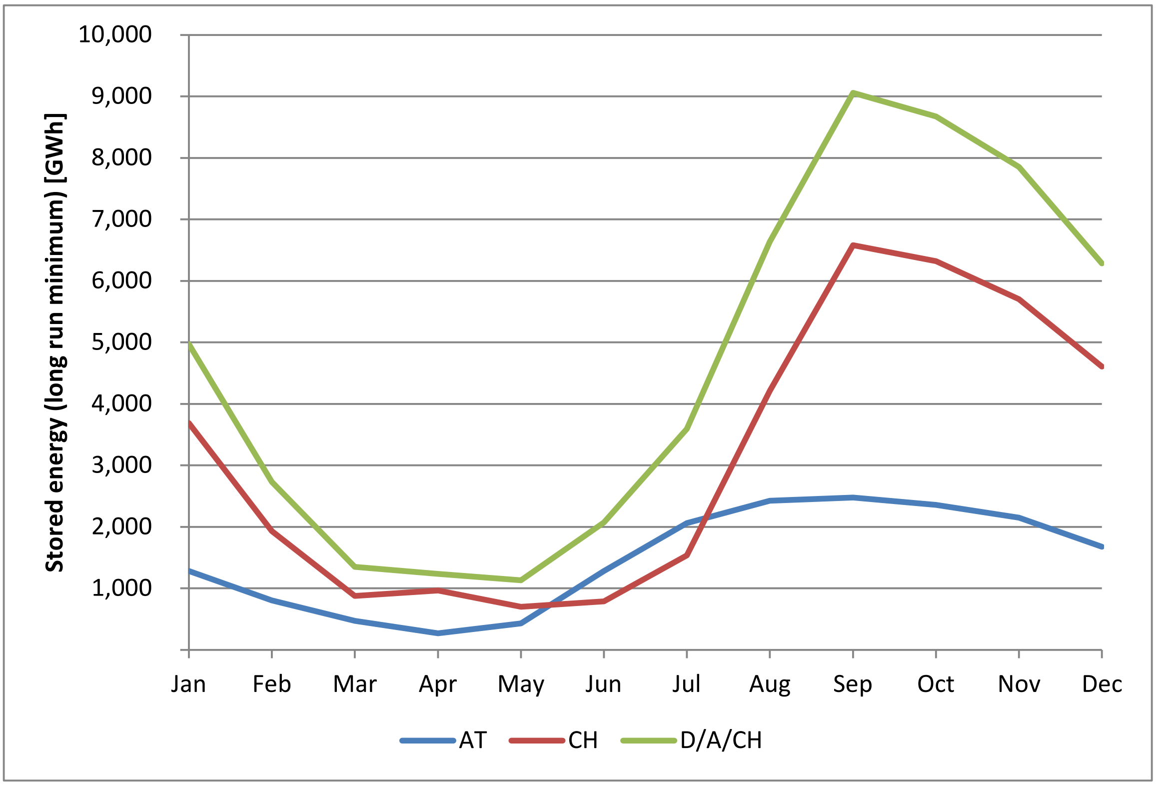



**Figure 4-7: Long run minimum storage levels in Austria and Switzerland by month [GWh]**
Source: DNV GL analysis, based on E-Control, BFE

Based on these considerations, Figure 4-8 shows an indicative comparison of available capacity and energy from hydropower for different levels of firm capacity, as well as the associated need for annual energy from storage. More precisely, the graphs shows the following:

- The dark blue line indicates the need for firm capacity for different time horizons (compare Table 4-2),
- The light blue area indicates capacity and energy available from storage and pump storage plants during the winter (compare Table 4-2),
- In contrast, the dark blue area is limited to consideration of storage plants with natural inflows[45] and the volume of stored energy at the end of the winter, i.e. in February (2.7 TWh).

When taking these additional constraints into consideration, hydropower plants are able to provide about 14.8 GW of firm capacity with an association generation volume of 2.7 TWh. Coincidentally, these values roughly correspond to the capacity and energy needs for the 24-h time horizon. In other words, storage and pump storage plants in Austria, Germany and Switzerland are able to provide some 15 GW of firm capacity to the regional power system. This corresponds to a capacity credit of roughly two thirds of their installed capacity, which is below the typical capacity credit of thermal plants (around 90%) but far higher than the corresponding values for wind and solar power.

45 Pump storage plants have been excluded due to the very limited volume of energy they can provide.

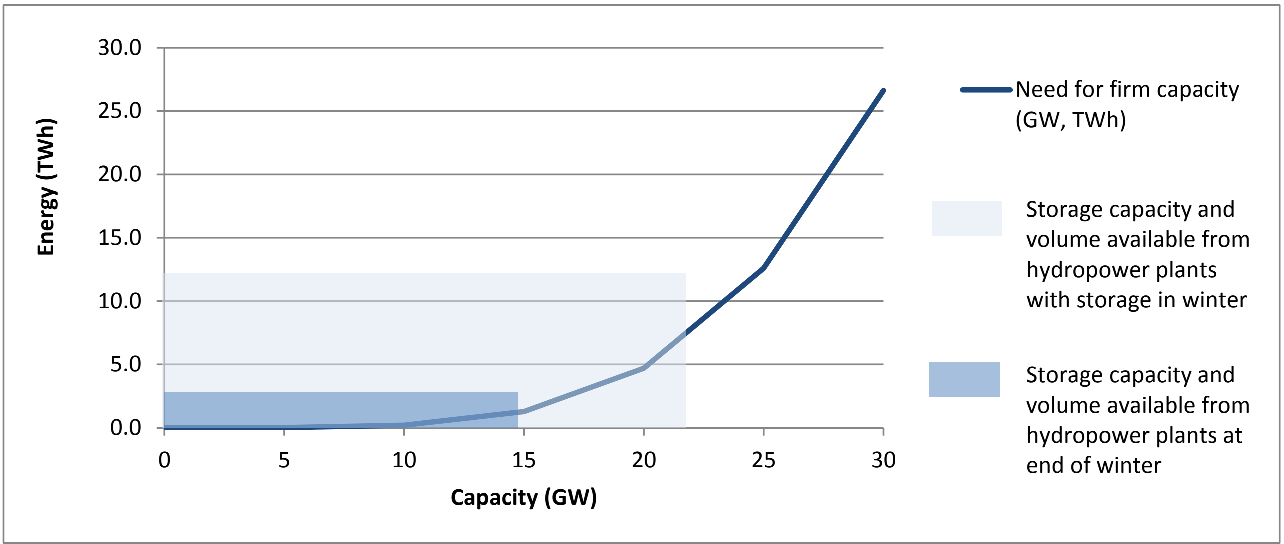



**Figure 4-8: Indicative comparison of energy needs vs. available capacity and energy for different levels of firm capacity**
Source: DNV GL analysis

We emphasise that these calculations have to be interpreted with considerable caution as they do not account for a number of factors, which may either increase or decrease the potential contribution by hydropower[46]. Nevertheless, they do indicate that hydropower plants can deliver an important contribution to generation adequacy. This furthermore has a major monetary value as hydropower plants help to reduce the need for firm capacity that has to be provided by other generation technologies. For instance in comparison against the alternative construction of open-cycle gas turbines with specific investment costs of 300 EUR/kW and a technical lifetime of 25 years, storage and pump storage plants may thus avoid about EUR 0.5bn in annual capital costs[47]. This value is in addition to their main economic benefits as discussed in other sections of this report.

## 4.3 Electric Storage for Optimal Use of Renewable Energies

### Case Study: Balancing Fluctuating Wind Power in Western Denmark by Nordic Hydropower

The storage capabilities of many hydropower plants makes them a perfect instrument for optimising the use of variable RES over longer periods, i.e. for weeks, months or even entire seasons or years. Hydropower plants can stop generation and save water when there is an excess of electricity, and supply the system with high quantities of reliable renewable electricity 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.

46 For example, the risks of dry years or the need for the provision of ancillary services from hydropower, on the one hand, or the possibility of adjusting the annual management of seasonal storage as necessary, on the other hand.

47 Using average capital costs of 9% per annum

The Danish power system is characterised by one of the highest penetrations of wind power in the world. By the end of 2013, wind power amounted to almost 4,800 MW of installed capacity, compared to a peak load of slightly more than 6,100 MW. As a result, Denmark is regularly facing situations in which generation from wind power is equal to or even exceeds local demand. For example: In the morning hours of 1 December 2013, wind generation was at 136% of Danish electricity demand.[48]

These numbers are even more extreme when looking at Western Denmark, i.e. the Jutland peninsula and the island of Funen.[49] As shown in Figure 4-9, close to 4,000 MW of wind power are installed in this area, or roughly 80% of the total. At the same time, Western Denmark accounts for about 60% of total (gross) consumption only, or a peak load of 3,559 MW in 2013. Due to the volatile pattern of wind power, this combination creates substantial challenges for the power system. As also illustrated by Figure 4-9, wind generation may exceed simultaneous electricity consumption by up to 1.5 GW, or more than 40% of peak demand. Simultaneously, wind power leads to a negligible reduction of peak load only.

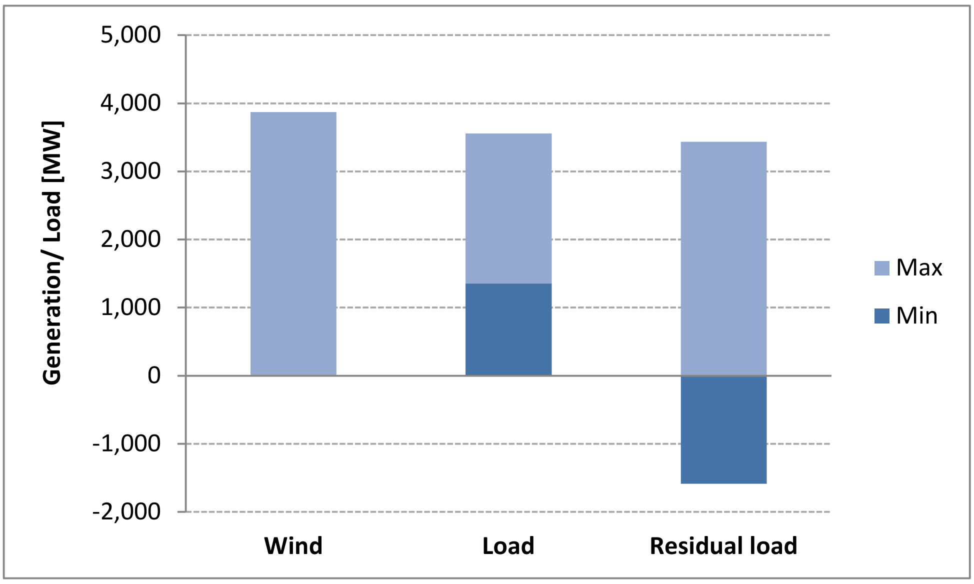



**Figure 4-9: Wind generation vs. load in Western Denmark (2013)**
Source: DNV GL analysis

The occurrence of negative residual load represents a significant challenge for the Danish power system, which does not have access to any pump storage plants (or other significant sources of local storage). As a result, it is impossible for the power system in Western Denmark to absorb excess generation. However, Western Denmark is strongly connected with other areas, including Eastern Denmark, Germany, Norway and Sweden. In total, these interconnections provide for approx. 3,800 MW of exchange capacity, which is comparable to local peak load. Moreover, a considerable share of this number (approx. 1,700 MW) consists of direct links with Norway and Sweden, providing Western Denmark with access to flexible hydropower in those countries.

As presented in Figure 4-10, cross-border exchanges are indeed an essential instrument, which allows the Danish TSO Energinet.dk to deal with the challenges of negative residual load. More specifically, Figure 4-10 shows the extent to which situations with negative residual load occurred, and what the

48 Data provided by Energienet.dk on http://www.energinet.dk/EN/El/Nyheder/Sider/2013-var-et-rekordaar-for-dansk-vindkraft.aspx

49 The electricity systems of Western and Eastern Denmark are only connected by a DC-cable. Western Denmark is part of ENTSO-E's Regional Group (RG) Continental Europe (formerly known as UCTE) and synchronised with the German grid, whereas Eastern Denmark belongs to the RG Northern Europe (formerly known as NORDEL) and is synchronised with the other Nordic countries.

cumulative levels of energy for different levels of excess generation were in the year 2013. It is immediately visible that exchanges with other areas allow the Western Danish power system to resolve or at least reduce the impact of negative residual load by exporting the corresponding volumes. For instance whilst more than 20,000 MWh of excess energy were available in hours with a surplus of between 900 and 950 MW, Energinet.dk was obviously able to export most of this surplus to other countries. As a result, the remaining surplus, which had to be resolved by other means[50], was reduced to about 1,000 MWh, or some 5% of the initial value. Overall, the remaining volume of excess generation decreases from 360 GWh to 38 GWh, i.e. by almost 90%[51].

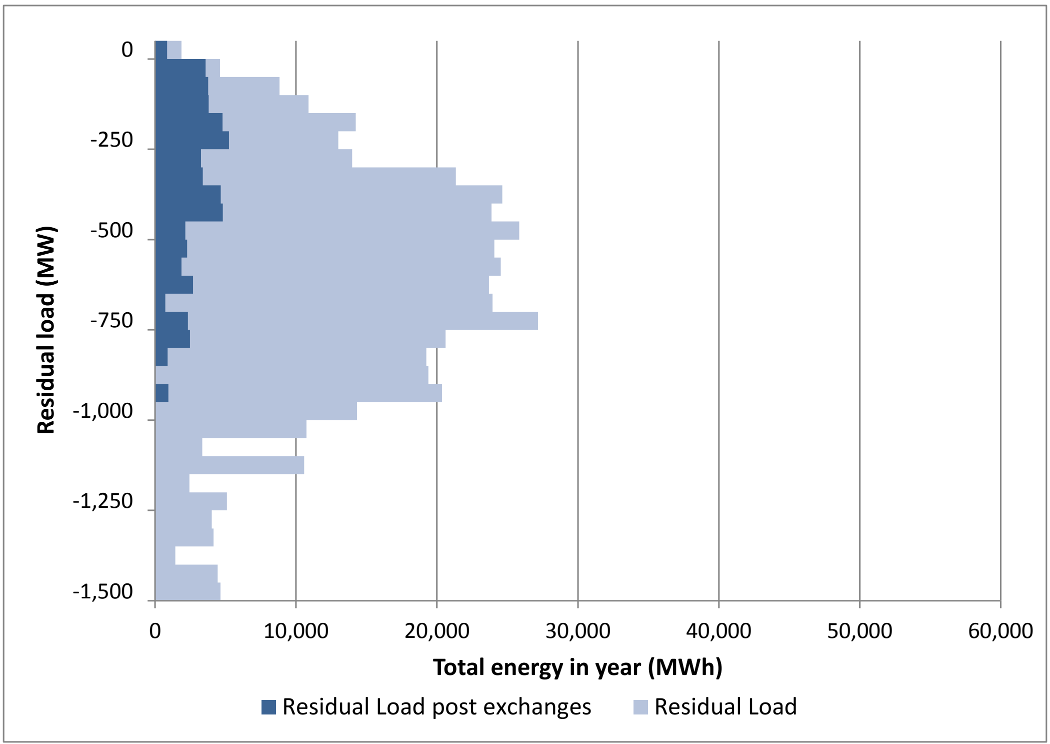



**Figure 4-10: Reduction of negative residual load in Western Denmark by cross-border exchanges (2013)**
Source: DNV GL analysis

With continuing development of renewables in Denmark this situation is expected to become even more severe. Until 2030, Denmark is assumed to increase wind capacity to approximately 8,500 MW in the 'Diversified Supply' scenario, whereas peak demand is expected to only moderately increase to approximately 6,600 MW. Consequently interconnector capacity as well as access to flexibility of the Nordic countries will become even more vital for the Danish power system.

We have analysed the contribution of flexible hydropower from Nordic countries for the integration of wind capacities in Denmark for the year 2030. Figure 4-11 below shows electricity market modelling results for hourly wind generation as well as electricity exchange between Denmark and the hydropower dominated power systems of Norway and Sweden. The analysis shows a clear impact of wind generation on electricity exchanges. In periods of high wind generation, significant amounts of electricity are exported to Norway and Sweden, while in times of low generation, flexible hydropower generation is imported to meet Danish demand for energy and flexibility.

50 Please note that have not analysed how Energinet.dk dealt with remaining excess generation.

51 Alternatively, when considering net consumption, the corresponding numbers amount to 431 and 54 GWh, respectively.

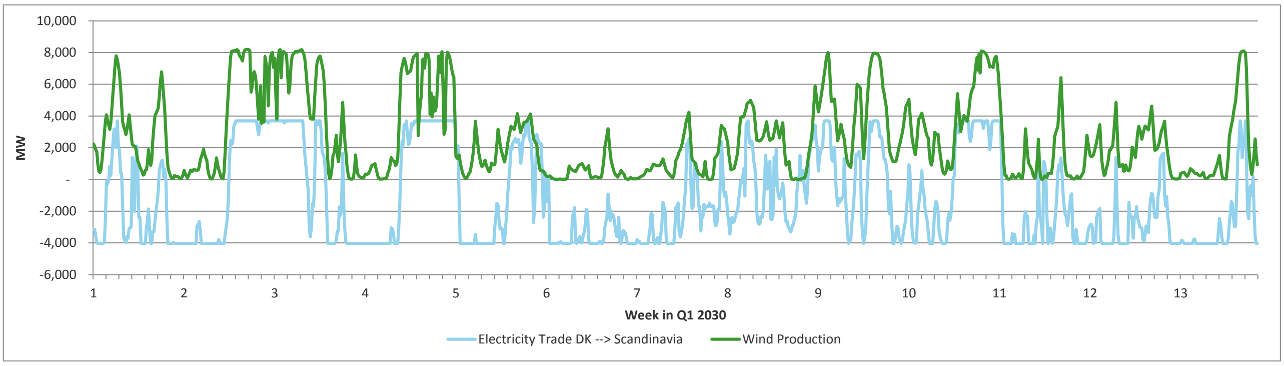



**Figure 4-11: Danish wind generation and electricity exchanges between Denmark and Norway / Sweden in the first Quarter 2030**
Source: DNV GL analysis

To further analyse the benefits of hydropower in the Scandinavian power system on wind integration in Denmark, we have carried out several simulations of our European market model with different levels of interconnector capacity between Denmark, on the one hand, and Norway and Sweden, on the other hand. Results are presented in Figure 4-12 below, based on the 'Diversified Supply' scenario.

Our simulations show that increasing interconnection with the Scandinavian power system allows for a better use of the available wind power. Whereas wind curtailment is as low as 0.4 TWh in the basic scenario, it increases to around 5 TWh in a scenario without any interconnector capacity to the Scandinavian power system. Conversely, wind curtailment almost disappears in case of a significant increase of interconnector capacity.

These observations clearly highlight the importance of Scandinavian hydropower for dealing with excess wind power in Denmark. Indeed, access to flexible hydropower in the Nordic countries is essential for reaching a penetration of variable RES, which otherwise require substantial levels of curtailment.

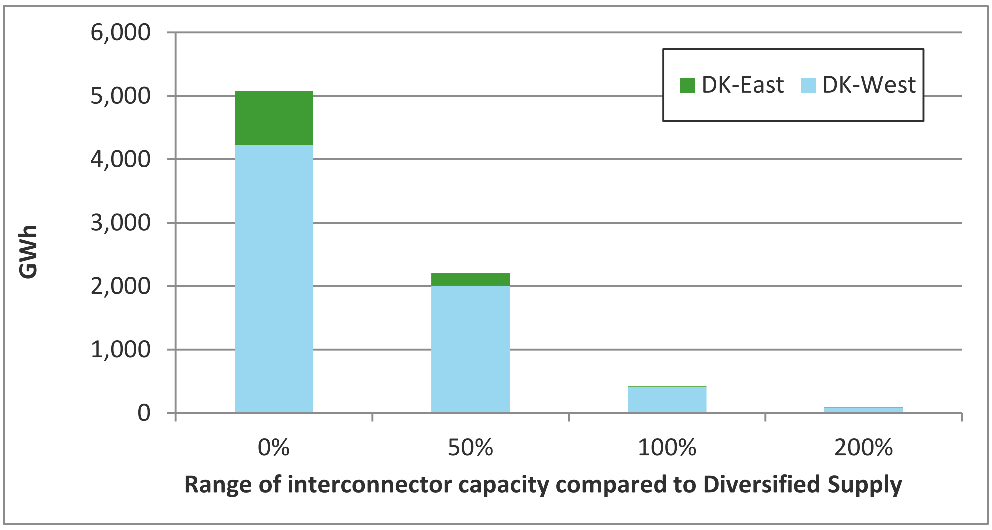



**Figure 4-12: Curtailment of wind generation in Denmark for different levels of interconnection with Scandinavian hydropower in 2030**
Source: DNV GL analysis

In summary, this case study shows that the storage capabilities of many hydropower plants make them a perfect instrument for optimising the use of variable RES. As the example of Western Denmark clearly shows this makes it possible to utilise energy available when there is an excess of electricity, which would otherwise be lost. This feature is particularly important in case of variable RES. Apart from an increasing need for flexibility, variable RES can be produced at negligible variable costs. Consequently, any curtailment of wind and solar power leads to significant additional costs, which can be avoided by storage from flexible hydropower.

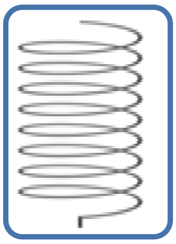
## 4.4 Summary

The analysis in this chapter highlights the value and importance of hydropower for integration of variable RES into the power system. As mentioned RES integration 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, future power systems will depend on flexibility, firm capacity and storage.

Figure 4-13 summarises the main findings of the analysis and the case studies presented in this chapter. The simulations results for the Iberian power market and the analysis related to the recent solar eclipse in Germany clearly illustrate how flexible hydropower makes it possible to deal even with extreme cases of volatility and variable generation from wind and solar power in general. In addition, 175 GW of European hydropower represent a major contribution to generation adequacy in Europe. These benefits are highlighted by another case study on the role of hydropower plants in Austria, Germany and Switzerland for the provision of firm capacity.

Last but not least, hydropower is the only form of electric storage, which is already available at a large scale and at competitive costs today. Europe already benefits from more than 220 TWh of storage capacity from hydropower today. Although hydropower resources are unevenly distributed across Europe, they also facilitate the integration of variable RES in other countries. This is clearly illustrated by the case study from Western Denmark as Scandinavian hydropower has been an essential precondition for enabling Denmark to reach a high penetration of wind power already today.

In summary, the facts and examples highlight that hydropower plants are perfectly suited to facilitate the integration of variable RES into the power system. Indeed, hydropower plants already facilitate the integration of RES today and, in line with an increasing penetration of variable RES in the future, the value of hydropower for successful integration of RES will greatly increase in the future.

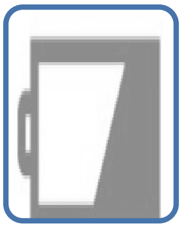


***Flexibility***

- Hydropower plants offer unmatched flexibility at a large scale
- Market simulations show how Iberian hydropower help dealing with variable generation from wind and solar power on different times scales
- German pump storage plants enable the power system to cope even with extreme short-term variability, such as the solar eclipse in March 2015 (resulting in a potential loss of 18.5 of generation)

***Firm capacity***

- 175 GW of reliable and flexible capacity from hydropower plants are a major source of firm capacity for Europe
- Hydropower plants are able to offset the daily variation of residual load and providing 15 GW of firm capacity, or 15% of total requirements in Austria, Germany and Switzerland



***Electricity storage***

- Hydropower storage is a perfect instrument for optimising use of RES
- 220 TWh of storage capacity available from European hydropower
- Equivalent to nearly 25 days of average European consumption
- Access to Scandinavian hydropower allows Western Denmark reducing excess supply of electricity from wind power by more than 90%.

**Figure 4-13: Key benefits of hydropower for integration of variable RES**
Sources: DNV GL analysis

# 5 TECHNOLOGY LEADERSHIP AND INNOVATION

Today, hydropower is a proven and mature technology, and the only large-scale energy storage technology available. Constant innovations and improvements have helped converting hydropower into an indispensable pillar of today's power system. For instance, the overall peak efficiency of hydropower turbines was already high a century ago, but constant design improvements have lifted turbine efficiency to more than 90% today (see Figure 5-1).

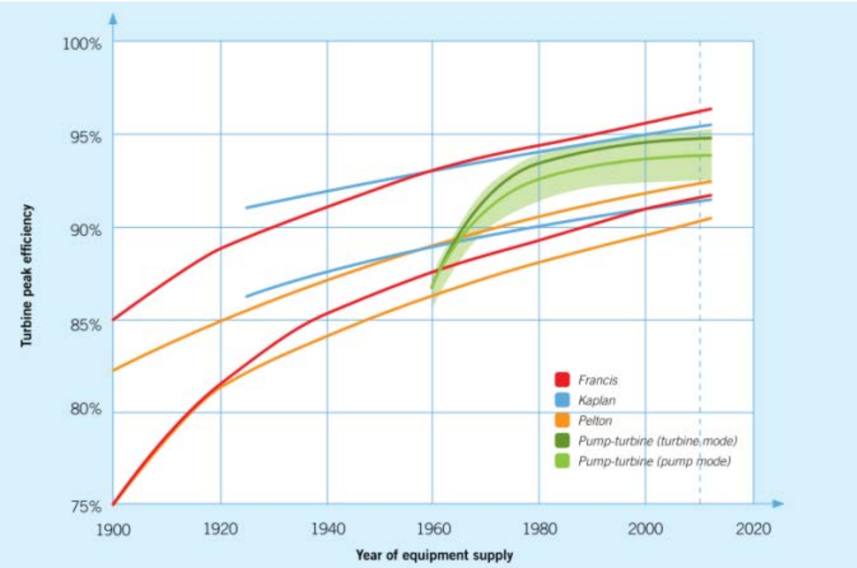



**Figure 5-1: Development of Efficiency**
Source: Hydropower Equipment Association, Hydropower Equipment Technology Roadmap, 2013

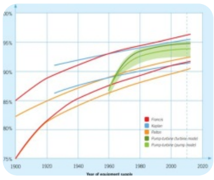
The success of the European hydropower sector is based on its technology leadership and a high level of innovation. As a result, European hydropower equipment manufacturers command an estimated two thirds of the world market. This includes three current global leaders, which account for more than 50% of the worldwide market, as well as a large number of small and medium-sized companies. Many of them serve the global market and have set up subsidiaries in other parts of the world, including Asia, North and South America.

This success is built on close cooperation between generation companies, equipment manufacturers as well as academic and research institutions. Each hydropower plant is unique and requires expertise from various disciplines, such as hydrology and water management, geology, rock engineering, hydraulic engineering, structural engineering, electro-mechanical engineering. Hence, innovative concepts for hydropower plants are often the outcome of interdisciplinary approaches. In addition to in-house development, many hydropower manufacturers and hydropower generation companies are engaged in cooperation with universities as well as academic and research organisations. This cooperation leads to unique innovations with regards to generators, turbines, pumps and other electro-mechanical components of hydropower plants. Europe counts on a large number of leading research centres, with a focus on hydraulic and electro-technical engineering as well as interdisciplinary issues of hydropower plants. They trigger innovation, facilitate information exchange and contribute to technological progress[52].

In order to maintain its leading position and to be prepared for dealing with the challenges of the transition to future power systems dominated by variable RES, the European hydropower industry is continuously investing into research and development and innovative technologies. European manufacturers alone spend more than 5% of annual turnover on R&D, which is more than twice the European average.

Despite the maturity of their technology, hydropower 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, as also illustrated by Figure 5-2. It aims at preparing the European hydropower sector for the challenges of a future power system dominated by variable RES, while maintaining global technology leadership.

52 Including, amongst others, Eidgenössische Technische Hochschule Zürich (ETH), University of Technology Graz, Vienna University of Technology, Technical University Munich, (TUM), University of Stuttgart, Ecole Polytechnique Fédérale de Lausanne (EPFL), University of Innsbruck, Norwegian University of Science and Technology Trondheim (NTNU).



### Cost reduction and increased output

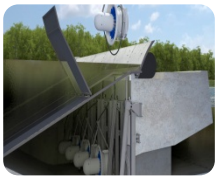
• Technical & managerial improvements
• Standardisation of equipment

### Flexibility

• Increased development of pump storage plants
• Dispatchable power from small hydropower
• Technological progress, e.g. hydraulic short circuit

### Environmental-friendly development

•Mitigation of hydro- and thermo-peaking
•ensuring water quality
•providing for landscape integration and river habitat friendly design
•New concepts for small hydropower plants



### Complex site conditions

•Use-tailored design of low-head and kinetic flow turbines (in canals, pipes, rivers)
•More comlex site conditions/design constraints
•New applications/environments: wave and tidal hydropower

### Adaptation to climate change

•Predicition of magnitude of changes
•Availability of water ressources
•Sediment management

**Figure 5-2: Focus area for innovation in the European hydropower sector**
Source: DNV GL, HEA, EPFL, 'Schwall/Sunk Sanierung in der Hasliaare – Phase 2b: Ökologische Bewertung von künftigen Zuständen', Steffen Schweizer et al. ,Wasser Energie Luft , edition 4-2013.

## Improving operational efficiency and cost reductions

Increasingly tight market conditions reinforce the need for efficient and smart plant design and operation. Innovations are oriented at increasing efficiency, reliability and availability. Novel technologies serve to maximise operational availability and output. New construction methods lead to an increase of total energy efficiency through a significant decrease of hydraulic losses during operation. Other technologies aim at extending the lifetime of turbines and increasing the number of operating cycles of rotor parts. Online monitoring and diagnostic systems help to better anticipate the total asset life time when operating at variable / small loads, in order to optimise maintenance intervals, minimise outages and shorten the duration of rehabilitation work.[53] The use of standardised equipment[54] leads to cost reductions and allows for the use hydropower even at sites that could not be economically used before.

**Figure 5-3: *Abandoned canal locks from the 19th century, equipped with five innovative generating modules with a capacity totalling 1.35 MW without compromising its discharge capability.***

Source: Hydropower Equipment Association

## Reducing the ecological impact is at the heart of modern hydropower installations

New hydropower projects often face intense public participation and higher environmental standards than ever. Concerns not only relate to the construction but also to the operation phase. For instance, more flexible operation leads to higher but not necessarily natural variability of flow releases. This phenomenon is known as hydropower- and thermopeaking and may negatively impact wildlife downstream of a hydropower plant.

A substantial share of innovation, therefore, aims at addressing environmental and public concerns around the construction and operation of hydropower plants. For instance, innovative design concepts are applied, which use compensations basins as multipurpose schemes for flood protection, energy generation, biotope restoration, ecological flow regulation and leisure activities.

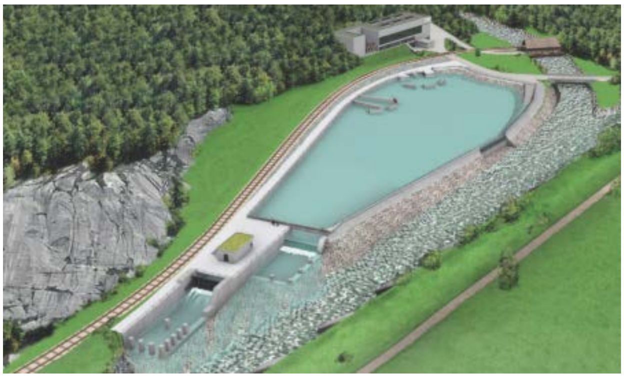


**Figure 5-4: Compensation basin to reduce hydropower-peaking at power plant Innertkirchen, Switzerland**

Source: 'Schwall/Sunk Sanierung in der Hasliaare – Phase 2b: Ökologische Bewertung von künftigen Zuständen', Steffen Schweizer et al. ,Wasser Energie Luft , edition 4-2013.

Innovation also focuses on maximizing environmental-friendly development and outflow control. Sustainable development includes river habitat friendly design (e.g. low speed turbines, fish ladders,

53 For instance, for high head power plants new designs of the layout of waterway systems with deep alignments and vertical shafts have been developed. These allow for omitting very expensive steel lining of high pressure tunnels and shafts.

54 See e.g. HYDROMATRIX®, developed by ANDRITZ HYDROPOWER, consisting of a 'grid' of modules containing small propeller turbine-generator units and Voith's StreamDiver®, a new compact, low-maintenance and eco-friendly propeller turbine with modular design.

fish-friendly turbine design), landscape integration[55], use of environment-friendly materials, and reduction of visual impact and acoustic noise.

Outflow control attempts to minimise negative impacts on wildlife during plant operation, comprising mitigation of hydropower- and thermopeaking and water quality control and improvement, e.g. through water aeration in the turbine draft tube and use of water- or bio-degradable oil lubrication, etc.

**Figure 5-5: Adapted Kaplan turbine design (left) for increasing the fish survival rate by minimising the gap between the runner and the hub (compare to image on the right).**
Source: Hydropower Equipment Association

## Enabling access to increasingly complex and constrained sites

Hydropower development in Europe has attained a relatively mature stage and most easily accessible resources have been exploited to a considerable extent. New hydropower schemes often face more challenging design constraints in terms of topographical, geological and access difficulties, which may add to environmental constraints mentioned before. Example of new technologies include ocean/tidal/stream power, offshore storage hydropower plants or the development of pump turbines with very high heads for the use of hydropower plants in caverns (e.g. from former salt, gas or mining caverns). All of these examples aim at providing for tailored solutions for hydropower in in arduous circumstances.

**Figure 5-6: Largest cable lift systems in the world, installed for the pump storage power plant project 'Linthal 2015', Switzerland**
Source: www.freyag-stans.ch

## Developing solutions to minimise the consequences from climate change and best adapt to changing climate conditions.

While it is often argued the natural hydropower potential has been exploited to a large extent, climate change poses new chances and risks to hydropower. It will have an influence on the availability of water resources in time and space, providing for instance for more intense precipitation in some areas. It also increases the risk of natural hazards and increased sediment yields. However, glacier retreat, a direct impact of climate change, may be the source for new hydropower plants. In the light of climate change,

55 E.g. completely underground plants

current research focuses on predicting the magnitude of changes. The hydropower sector not only tries to anticipate such changes and its impacts by adjusted projections of water inflow patterns. It also prepares itself for such changes, by improving spillway design, sediment management and introduction of abrasion resistant hydropower equipment.

For instance, Alpine glaciers are rapidly shrinking. A considerable number of new lakes will form existing lakes will increase in size. A recent research project[56] investigated where and when new lakes are likely to form in the Swiss Alps and what their characteristics (depth, volume, moraine or bedrock) are likely to be. Looking also into, how the related risks and chances can be assessed and managed in an integrative way, the study suggests a potential use is, apart from tourism and flood protection, also energy generation.

## Novel concepts and technical solutions for increasing operational flexibility and facilitating the integration of variable renewable energies into the future power system.

Hydropower provides for significant benefits and advantages for the future power system, which is increasingly dominated by volatile renewable energy sources. System integration of increasing scales of variable RES (wind and solar) requires the need for short-term flexibility. On the one hand, this creates additional revenue potential for flexible hydropower. On the other hand, it puts a strain on hydropower (and other technologies) in terms of operational flexibility articulated by grid-operators[57]. Due to the innovative strength to increase its flexibility even more, hydropower may cope with these new challenges and promote the power system integration of other volatile renewable sources. Dedicated innovations mainly aim at increasing technical-operational flexibility in terms of peak electricity and possibility to provide system services. They are associated with increasing hydropower plants' capability to provide power reserves and ancillary services[58] as well as an increase of operational ranges[59].

56 NELAK, 2013

57 E.g having pumping & storage HPP running in 'synchronous mode' for voltage control, simultaneous operation of units in pumping and generation mode for ensuring max promptness to load changes

58 Through implementation of technical concepts like hydraulic short circuits , variable speed modes (especially important for provision of such services in pumping mode) power electronics and converter technology improvement to deliver voltage range, as well as constructional adjustments like heightening of existing dams, and provision of ancillary services also by small hydropower plants

59 Including increased hydraulic stability at lower loads or even no load

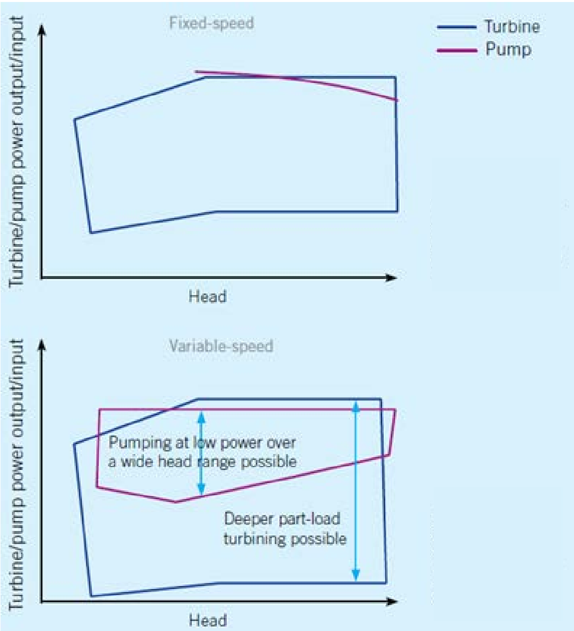



**Figure 5-7: Comparison of fixed-speed and variable-speed operation.**
Source: Hydropower Equipment Technology Roadmap, Hydropower Equipment Association, 2013

**Figure 5-8: Powerhouse cavern of the pump storage scheme Kopswerk II (Austria), allowing for simultaneous operation of the storage pumps and turbines and switching from non-operation into pump or turbine operation within seconds.**
Source: www.kopswerk2.at

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# 7 APPENDIX: METHODOLOGY AND DATA SOURCES

## 7.1 Data Collection

The data used in this study was mostly collected from public sources, including the following:

- Statistics from official statistical offices, among them Eurostat, Statistisches Bundesamt (Germany), Bundesanstalt für Statistik (Austria), Instituto Nacional de Estadística (Spain), Bundesamt Stastik (Switzerland) and IStat (Italy)
- Hydropower generation and capacity data collected from ENTSO-E, national statistical offices, national TSOs and hydropower generation companies
- Studies published by the European Commission and European research institutes
- Company reports by publicly listed companies

A number of hydropower specific topics could not, however, be covered by data from public sources, so we conducted three surveys[60] among stakeholders in our target countries:

- a survey on key technical and economic indicators of electricity generation from hydropower, focusing on individual countries and/or companies,
- a survey on key economic indicators for hydropower equipment manufacturing,
- a survey on the role and contribution of different multipurpose benefits associated with the use of hydropower in individual countries.

The first survey focussed on data on employment, taxation and investment in hydropower generation. Some respondents answered the questions for their individual company, some for a whole country. The second survey among manufactures of hydropower equipment was conducted to cover roughly the same economic variables for this sector, i.e. value creation, employment and investment. Our data set covers more than 50% of the world market sales. The third survey on multipurpose benefits was combined with interviews and aimed at capturing the industry's views on the importance of different multipurpose benefits, and gathering additional information on relevant literature, data sources and examples. In the survey, we asked respondents about their subjective assessment of the importance of potential multipurpose benefits. Corresponding survey results were matched with information from global database on large dams (ICOLD).

In order to complete information on the generation sector, the answers to the first questionnaire were complemented by information from company reports or official studies where necessary. In addition, we used extrapolation to obtain a complete picture; for some variables we used an indirect derivation of the results, relying on publicly available data and basic economic relations characterizing them.

For extrapolation, either installed hydropower capacity or hydropower generation can be used. Figure 7-1 shows a scatter diagram with generation and capacity for our country selection (for 2010). We observe that the relation is almost linear, i.e. the quotient of generated electricity and installed capacity is very similar for all countries in the selection. This suggests that the choice of the

60 The respondents were assured confidentiality: if a variable is derived directly from the answers in the survey, it is presented as a European aggregate or by way of an anonymized country list.

extrapolation basis does not matter much: extrapolation by either variable will produce very similar results.

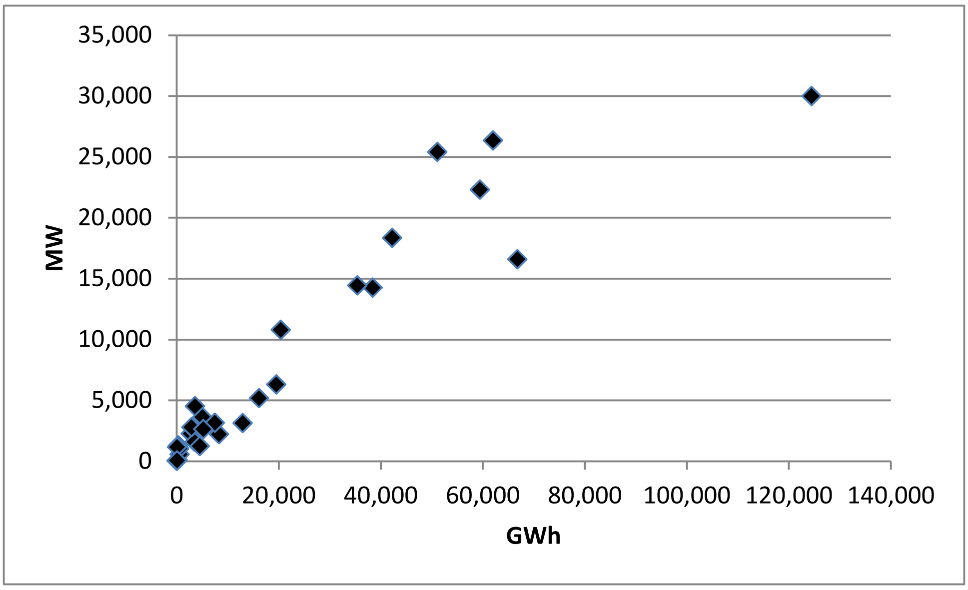


**Figure 7-1: Relation between generation and installed capacity per country (2010)**
Source: DNV GL analysis

In practice, we have largely used installed capacity for extrapolating our results to a country and/or European level. Figure 7-2 shows electricity generation from hydropower assets for our country selection for the year 2010, both individually for each country and cumulatively from left to right; the column at the right side shows total generation for all 31 countries of our selection. We observe that the twelve countries in the figure cover 94% of generation. Consequently, extrapolation from the subset of the most important countries (in terms of generation) can be expected to produce a satisfactory picture of economic variables for the whole region under study.

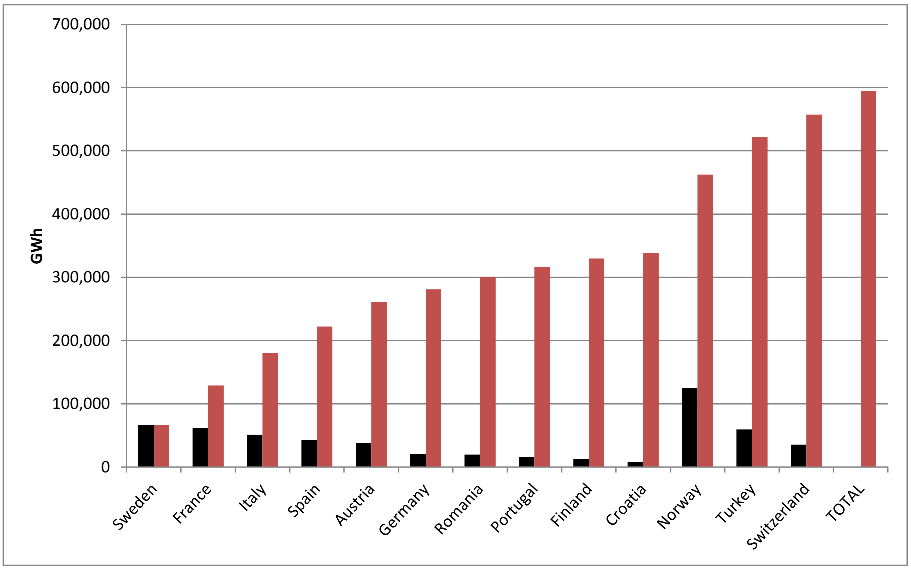


**Figure 7-2: Generation hydropower – Country-wide and cumulative value for country selection (2010)**
Source: DNV GL analysis

## 7.2 Power Market Modelling

For analysing the long-term developments of the future European power system, DNV GL has applied scenario-based, quantitative market simulations. The geographical scope of the modelling exercise covers Europe as well as the remaining countries on the Western Balkan.

The incremental benefits of hydropower have been assessed by varying the share of hydropower in the market simulations. For this purpose we have created and simulated additional hydropower sensitivities around the basic scenarios, in which we:

- Increased the share of hydropower in line with actual hydropower potentials ('High' Sensitivity);
- Decreased the share of hydropower compared to the basic scenario ('Low' Sensitivity).

On this basis we have performed an analysis of the incremental benefits of hydropower, including its impact on electricity prices, fuel consumption and CO2 emissions. Furthermore we have assessed the role of hydropower in enabling the energy transition by supporting the integration of intermittent RES.

### 7.2.1 Brief Description of Power Market Model

DNV GL has applied its European electricity market model for the quantitative power sector analysis for the period until 2050. Our market model optimizes the addition of generation, transmission and back-up infrastructure as well as hourly electricity generation and reserve provision. The model uses an integrated approach for determining the optimal expansion of generation and transmission infrastructure as well as simulating the electricity market outcomes. We have simulated the chronological development of variable RES, electricity demand and operating reserves on an hourly basis. In the simulations we have considered several types of hydropower plants, including Run of River, Pondage, Storage and Pump Storage to achieve a realistic representation of hydropower flexibility across Europe. Based on actual electricity generation figures, we have created generation profiles for each hydropower type. Pump storage plants are endogenously optimized by our power market model.

Our European market model applies an integrated approach for capacity expansion as well as simulating market outcomes as illustrated in Figure 7-3.

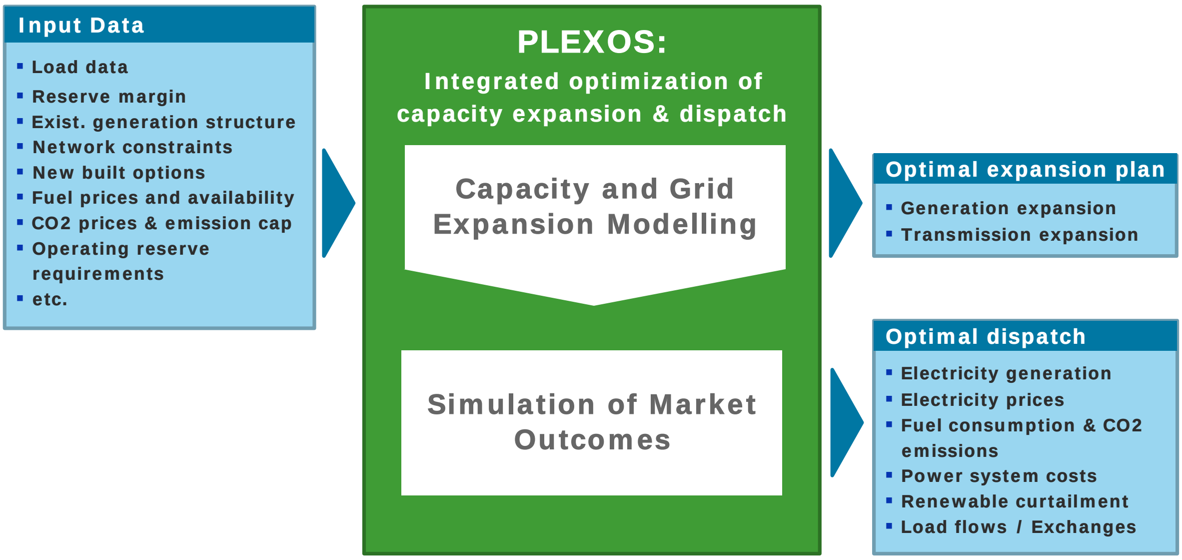


**Figure 7-3: Set-up of our market models**
Source: DNV GL

## Step 1: Capacity and Grid Expansion Modelling

Using input data such as assumptions on the regional distribution of RES, load, commodity and carbon prices/constraints, reserve requirements as well as grid topology, the model endogenously builds (conventional) generation and transmission capacity in order to meet demand at least cost. Within the optimization, our model commissions new thermal generation capacity, including the following technologies:

- Coal-fired steam turbines, with or without Carbon Capture and Storage ('CCS');
- Combined-cycle gas turbines (CCGT), with or without CCS; and
- Open-cycle gas turbines (as back-up capacity).

For the optimal expansion of the transmission grid, the model is allowed to expand existing lines as well as building new interconnectors with specified cost per MW/km. Due to the long lead times of such transmission projects the model incorporates the assumptions of the ENTSO-E's system development plan until 2023 for the development of transmission infrastructure.

Within the optimization, trade-offs between the costs of additional generating capacity, additional transmission infrastructure, renewables curtailment and transmission congestion are taken into account. In addition, constraints on the maximum allowed carbon emissions ensure a development of generation infrastructure in line with political decarbonisation targets. Consequently, new generation and transmission capacity (of a given type) is built only if it represents the least-cost solution over the entire time horizon of the study, taking into account decarbonisation constraints.

Although the target year of the analysis is 2030, the capacity expansion modelling was undertaken for the period until 2050 to properly take into account the impact of long-term decarbonisation requirements and RES expansion on the development pathway of the power system.

### Step 2: Simulation of Market Outcomes

Our simulations of the electricity wholesale markets at an hourly resolution take into account a detailed representation of the generation side (including thermal and renewable generators) as well as storage and operating reserve requirements.

Our model simulates the hourly system operation of a selected time period by taking into account the capacity and grid expansion from Step 1. The model simulates ‘real-world’ hourly dispatch, following the least cost principle under consideration of dynamic unit constraints and available interconnection capacity. Generators are dispatched in each hour according to their short-run marginal cost (‘cheapest generators first’). However, hourly generation is subject to individual flexibility constraints like ramp rates, minimum stable level, start costs, scheduled maintenance and random outages, minimum up- and down-times. Furthermore, individual resource constraints like water availability of hydropower plants or minimum generation levels of combined heat and power plants are properly accommodated in the optimization.

## 7.2.2 Market Modelling Assumptions

### Scenario Framework based on DG ENER Analysis

The analysis in this study is based on the following two scenarios that take different assumptions on the success of the EU decarbonisation policy[61]:

- ‘**Diversified Supply**’, i.e. the ‘Diversified Supply Technologies’ scenario from the European Commission’s ‘Energy Roadmap 2050’ (see European Commission (2011)) ,
- ‘**‘Reference’ scenario**’, i.e. the ‘‘Reference’ scenario 2013’ from the Commission’s ‘Trends to 2050’ study (see European Commission (2013)).

The ‘Diversified Supply’ scenario follows the EU’s long-term decarbonisation pathway and uses a mix of different technologies, including RES. It achieves a significant reduction of carbon emissions in the power sector (> 95% by 2050) and assumes a strong growth of RES, mainly wind power. In contrast, the ‘Reference’ scenario reflects a more conservative development scenario that fails to meet the ambitions carbon reduction targets by 2050. Implicitly, this scenario framework also includes variations in terms of RES shares as the level of decarbonisation is a significant driver for the development of (variable) RES.

61 While the ‘Reference’ scenario contains detailed assumptions on an individual member state level, the ‘Diversified Supply’ scenario only provides information for EU-27. We have therefore applied national assumptions from DG ENER’s ‘Reference’ scenario 2013 and ECF’s Energy Roadmap and Power Perspective studies to allocate European values to individual countries. Furthermore, the DG ENER studies do not include assumptions for Norway and Switzerland. To derive assumptions for these countries, we have used the development scenarios from the mentioned ECF studies to complement our datasets. The same source has been used for the Balkan countries. For Turkey we have established relevant assumptions with support of our Turkish project partner involving relevant policy and industry stakeholders.

In our modelling, we have based the development assumptions for RES and nuclear power on the two EU scenarios. Figure 3-1 below compares the RES assumptions for the reference region (Europe) in both scenarios. The 'Diversified Supply' scenario has significantly higher installed RES capacities in the long-run with 1,300 GW compared to 1,050 GW in the 'Reference' scenario in 2050. However, in both scenarios, RES development is mainly driven by wind generation (both on and offshore) with a limited contribution by solar PV only. The overall generation of hydropower (net of pump storage generation) is at comparable levels in both scenarios. While hydropower development in Europe sees only moderate growth, significant development is expected for Turkey, which is assumed to increase hydropower generation by a factor of approximately 2.7 between 2010 and 2050.

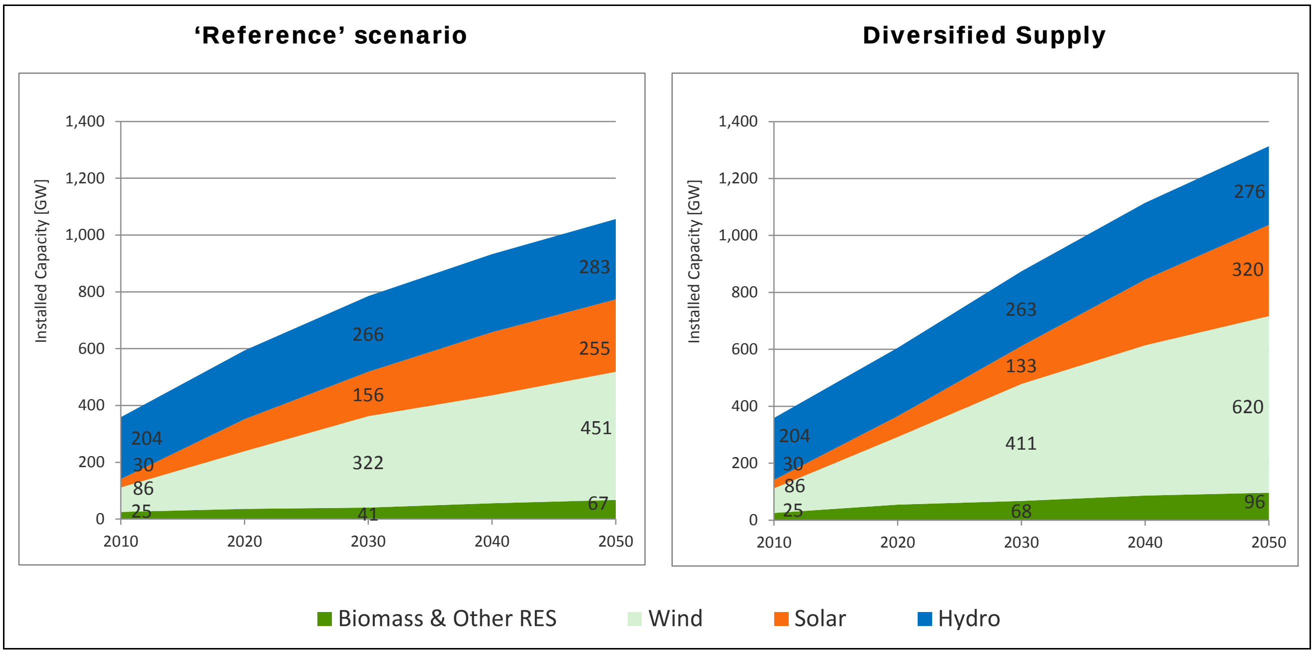


**Figure 7-4: Mix of RES capacities in the two basic scenarios (Europe)**
Note: Other RES include geothermal, wave, tidal generation technologies
Source: DG ENER, DNV GL analysis

Fuel and $CO_2$ prices are a major driver for wholesale electricity prices. The underlying scenario assumptions for gas and coal as well as $CO_2$ prices until 2050 are illustrated in Figure 7-5. Compared to historic price levels for 2010, fuel prices are expected to significantly increase in both scenarios until 2030. However, commodity prices follow very different development pathways in the two DG ENER scenarios. When comparing the two scenarios, we note that fuel prices, in particular gas prices, are substantially higher in the 'Reference' scenario compared to Diversified Supply. In the latter scenario, fuel prices increase due to strong world demand for fossil fuels in the medium term. In the long-term, however, demand and consequently prices for fuels decrease due to increasing global decarbonisation efforts.

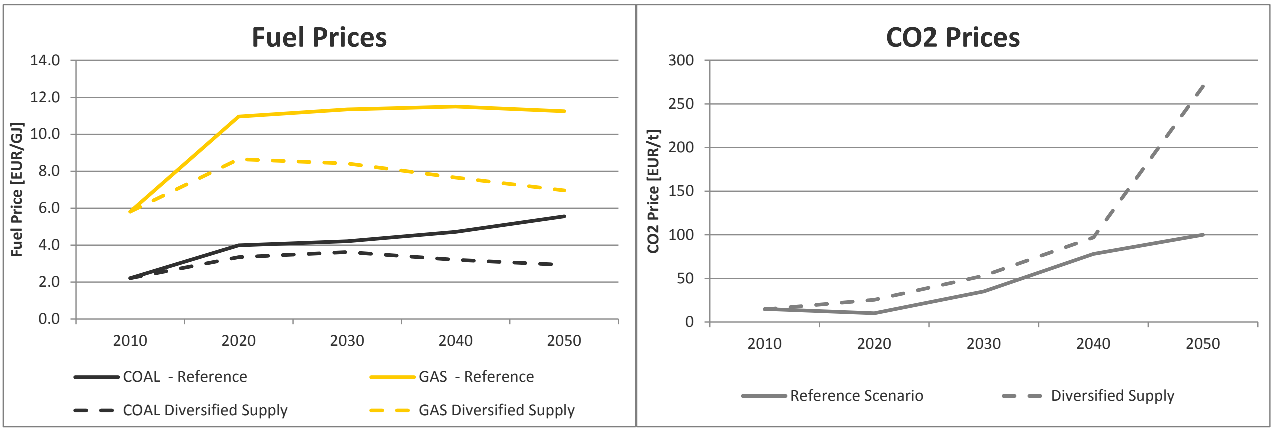


**Figure 7-5: Development of commodity prices in the two basic scenarios**
Source: DNV GL analysis, based on European Commission (2011)

The 'Diversified Supply' scenario requires almost full power sector decarbonisation in the EU-28 countries by 2050. Due to this requirement, $CO_2$ prices increase significantly and reach approximately 53 EUR/t in 2030 and 270 EUR/t in 2050. In this scenario, we assume other European countries to decrease carbon emissions substantially as well, although at a lower rate than EU Member States. For Turkey, we have assumed a limited increase of carbon emissions in line with the overall power sector development until 2020. However, after 2020 we have imposed the requirement to limit carbon emissions at the 2020 level. Our analysis is furthermore based on the assumption that all countries covered in the modelling will introduce a carbon pricing mechanism, for which we have applied the EU-28 $CO_2$ prices.

Due to lower decarbonisation requirements in the 'Reference' scenario, $CO_2$ prices for Europe and Turkey remain at moderate price levels for 2030, but increase by 2050. Again, we have applied EU-28 $CO_2$ prices for all countries covered in the analysis. In general, decarbonisation requirements follow the EU scenarios. However, for Turkey we have not applied a binding decarbonisation target.

## Country Specific Hydropower Assumptions

In our modelling we have used the hydropower assumptions as presented in Table 7-1 below.

**Table 7-1: Scenario specific hydropower assumptions**

| Country | Actual | | Reference Scenario | | | | Diversified Supply Scenario | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Capacity (MW) | Generation (GWh) | Capacity (MW) | | Generation (GWh) | | Capacity (MW) | | Generation (GWh) | |
| | 2013 | 2013 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| *Austria* | 13,427 | 40,957 | 20,285 | 20,899 | 45,467 | 47,669 | 19,926 | 20,297 | 43,721 | 45,193 |
| *Belgium* | 1,430 | 1,672 | 1,350 | 1,360 | 534 | 563 | 1,344 | 1,350 | 513 | 534 |
| *Bulgaria* | 3,184 | 4,616 | 3,683 | 3,683 | 4,631 | 4,810 | 3,613 | 3,571 | 4,453 | 4,560 |
| *Croatia* | 2,110 | 8,046 | 2,495 | 2,637 | 7,853 | 8,744 | 2,495 | 2,637 | 7,853 | 8,744 |
| *Czech Republic* | 2,230 | 3,707 | 2,369 | 2,505 | 3,446 | 4,138 | 2,332 | 2,440 | 3,314 | 3,923 |
| *Denmark* | 9 | 14 | 12 | 12 | 23 | 22 | 12 | 11 | 22 | 21 |
| *Estonia* | 7 | 25 | 28 | 34 | 118 | 140 | 27 | 32 | 113 | 133 |
| *Finland* | 3,168 | 12,672 | 3,441 | 3,796 | 14,157 | 15,874 | 3,335 | 3,610 | 13,613 | 15,050 |
| *France* | 25,434 | 75,518 | 28,100 | 33,673 | 67,806 | 78,887 | 27,429 | 32,481 | 65,202 | 74,790 |
| *Germany* | 10,780 | 24,438 | 13,948 | 15,393 | 25,917 | 29,086 | 13,771 | 15,041 | 24,922 | 27,575 |
| *Greece* | 3,237 | 5,163 | 3,891 | 3,891 | 9,012 | 10,059 | 3,793 | 3,735 | 8,666 | 9,537 |
| *Hungary* | 56 | 207 | 64 | 64 | 258 | 258 | 62 | 61 | 248 | 245 |
| *Ireland* | 530 | 891 | 604 | 746 | 1,025 | 1,471 | 594 | 724 | 986 | 1,395 |
| *Italy* | 22,009 | 52,842 | 26,729 | 27,185 | 50,983 | 50,713 | 26,138 | 26,223 | 49,025 | 48,079 |
| *Latvia* | 1,578 | 2,893 | 1,733 | 1,733 | 3,342 | 3,339 | 1,680 | 1,648 | 3,214 | 3,166 |
| *Lithuania* | 1,026 | 1,058 | 1,056 | 1,106 | 614 | 800 | 1,051 | 1,096 | 590 | 758 |
| *Luxembourg* | 1,134 | 1,149 | 1,343 | 1,347 | 140 | 150 | 1,342 | 1,345 | 135 | 142 |
| *Netherlands* | 38 | 0 | 37 | 37 | 106 | 106 | 36 | 35 | 102 | 100 |
| *Norway* | 30,753 | 129,025 | 32,705 | 34,736 | 140,000 | 150,000 | 32,705 | 34,736 | 140,000 | 150,000 |
| *Poland* | 2,349 | 2,957 | 3,224 | 3,438 | 4,812 | 5,707 | 3,179 | 3,356 | 4,627 | 5,411 |
| *Portugal* | 5,652 | 14,639 | 7,293 | 8,168 | 11,898 | 13,318 | 7,147 | 7,893 | 11,441 | 12,626 |
| *Romania* | 6,227 | 14,877 | 7,268 | 7,836 | 22,413 | 25,169 | 7,044 | 7,452 | 21,552 | 23,862 |
| *Slovakia* | 2,531 | 5,000 | 2,883 | 3,127 | 6,144 | 7,135 | 2,826 | 3,024 | 5,908 | 6,764 |
| *Slovenia* | 1,129 | 4,479 | 1,497 | 1,497 | 4,621 | 4,617 | 1,456 | 1,432 | 4,444 | 4,377 |
| *Spain* | 19,382 | 40,557 | 21,143 | 22,202 | 35,967 | 37,031 | 20,678 | 21,411 | 34,586 | 35,108 |
| *Sweden* | 16,150 | 60,817 | 18,319 | 18,828 | 69,694 | 70,018 | 17,754 | 17,905 | 67,018 | 66,381 |
| *Switzerland* | 13,805 | 39,572 | 18,600 | 18,871 | 36,565 | 37,330 | 18,600 | 18,871 | 36,565 | 37,330 |
| *United Kingdom* | 3,969 | 5,746 | 4,522 | 4,669 | 5,392 | 5,389 | 4,472 | 4,582 | 5,185 | 5,109 |
| *Turkey* | 22,289 | 59,000 | 37,815 | 39,467 | 134,000 | 140,208 | 37,815 | 39,467 | 134,000 | 140,208 |
| *EU-28* | 148,776 | 384,940 | 177,317 | 189,866 | 396,373 | 425,213 | 173,535 | 183,392 | 381,455 | 403,583 |
| *Europe* | 215,623 | 612,537 | 266,437 | 282,940 | 706,938 | 752,751 | 262,655 | 276,466 | 692,020 | 731,120 |

Note: 2030 & 2050 generation figures for the 'Reference' and 'Diversified Supply' Scenarios exclude electricity generation in pump storage plants due to pumping activity, which is optimized by our electricity market model
Source: DNV GL analysis, based on ENTSO-E; TEIAS; DG ENER

## Sensitivity Analysis

As mentioned in section 3.1, we have analysed two sensitivities for each basic scenario. These sensitivities assume a variation of electricity generation from hydropower as follows:

- 'High' sensitivity, with increased hydropower generation (compared to the basic scenarios), assuming an improved environment for hydropower,
- 'Low' sensitivity, with decreased hydropower generation /compared to the basic scenario), assuming deteriorating framework conditions for hydropower.

The rationale and main parameters of the hydropower sensitivities are presented in Table 7-2.

**Table 7-2: Rationale and approach of hydropower sensitivities**

| | High Sensitivity | Low Sensitivity |
|---|---|---|
| Rationale | • Increasing the share of hydropower (capacity & generation) in line with actual hydropower potentials due to:<br>- improved licensing procedures,<br>- increased public acceptance,<br>- better financial viability, etc. | • Decreasing the share of hydropower in electricity generation as a consequence of:<br>- difficult licensing procedures,<br>- lack of public acceptance,<br>- lack of profitability<br>- more stringent environmental constraints (e.g. increased residual flow requirements and/or limited diurnal variation due to Water Framework Directive) |
| Approach | • Assessment of actual hydropower potentials to reflect a realistic distribution of additional hydropower capacities.<br>• Based on data provided by 'Hydropower World Atlas 2013'[62] and 'STREAMMAP' [63] followed by a review by selected country representatives.<br>• Turkey: assumption that development of hydropower will continue and the country will reach its economic potential in 2030 already. | • Same development of hydropower capacities as in the basic scenarios, however, keeping hydropower generation at a constant level after 2020.<br>• Turkey: growth until 2020 does only take into account plants currently under construction (8.5GW or 26TWh according to IHA[64]). Afterwards delayed development of hydropower. |

Source: DNV GL analysis

The overall development electricity generation for the two development scenarios and the respective High and Low sensitivities is presented in Figure 7-6. The development of hydropower in the sensitivities of the 'Reference' scenario is similar to the 'Diversified Supply' scenario, although at a slightly higher level. In 2030, the differences between the Low and High sensitivity are 91 and 85 TWh in the Reference and 'Diversified Supply' scenario, respectively.

62 International Journal on Hydropower & Dams (2013) 'Hydropower'

63 ESHA (2014)

64 IHA (2014) **Error! Hyperlink reference not valid.**

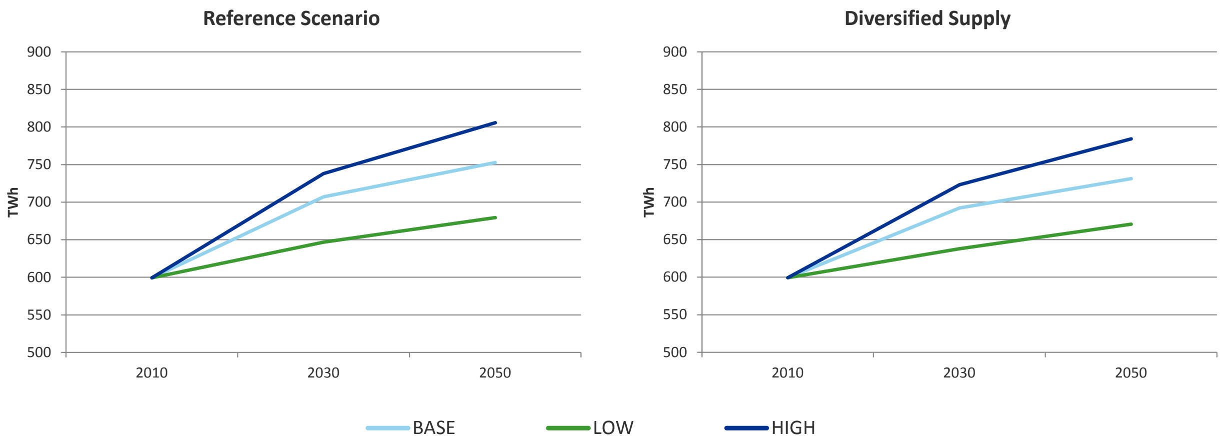


**Figure 7-6: Development of electricity generation in High and Low sensitivities of the 'Reference' scenario**
Note: Generation figures exclude generation from pump storage
Source: DG ENER analysis

### 7.2.3 Market Modelling Results

## Installed Capacities and Electricity Generation

In the period until 2050, investments into RES and conventional plants are required in order to meet increasing electricity demand and replace decommissioned generation capacity. While the development of RES and nuclear is taken from the EU studies, we have derived the development of conventional generation capacities from our European long-term capacity expansion model. In addition to technical and economic power plant parameters, the optimisation takes into account the scenario-specific carbon emission targets as well as other parameters, such as fuel and $CO_2$ prices, electricity demand and interconnector capacities.

Figure 7-7 below shows the evolution of installed generation capacity in both scenarios for Europe during the period 2010 – 2050. In both scenarios, intermittent RES are expected to have the largest shares of electricity generation capacity in 2030 already. Residual electricity demand is satisfied by a mix of fossil gas and coal fired technologies. As commodity prices as well as decarbonisation requirements have a major impact on the expected capacity portfolio, we see substantial amounts of gas fired capacity being built in the 'Diversified Supply' scenario. Due to the strong decarbonisation requirements in this scenario, Carbon Capture and Storage ('CCS') enters the system after 2030 to meet carbon reduction targets. In the 'Reference' scenario, a mix of coal and gas fired capacities is commissioned to provide base load and mid-merit capacity. Some CCS enters the system after 2030. However, due to lower decarbonisation requirements, the total amount of capacity is lower compared to the 'Diversified Supply' scenario. In both scenarios, significant amounts of gas turbine backup capacity are required to compensate for increasing shares of intermittent RES capacities. The share of hydropower of installed capacity in 2030 is 17% and 19% for Diversified Supply and 'Reference' scenario, decreasing to 12% and 14% in 2050 respectively.

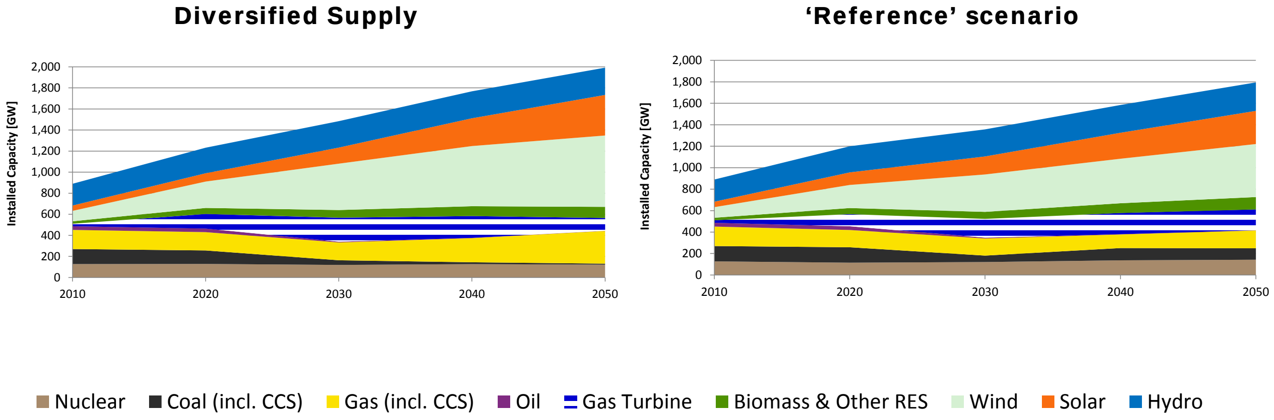


**Figure 7-7: Development of installed capacity in the Diversified Supply and 'Reference' scenario**

Source: DNV GL analysis, based on European Commission (2011)

Based on the development of generation capacities and the underlying assumptions on electricity demand, commodity prices, etc. we have simulated the hourly dispatch of the European power system. These detailed chronological simulations have taken into account the impact of intermittent RES generation as well as the requirements for and provision of operating reserves (both spinning and non-spinning).

Figure 7-8 below presents the forecasted evolution of electricity generation in Europe for the two basic scenarios in the year 2030 as well as 2013. As already indicated in the results for the capacity expansion, we observe that commodity prices have significant impact on the generation mix of conventional generation. In both scenarios, we observe a fuel shift from coal to gas fired technologies over time. In the 'Diversified Supply' scenario, gas fired technologies produce the largest amount of conventional generation due to moderate gas prices, but higher CO2 prices. In the 'Reference' scenario, coal technologies meet base load demand, while gas fired technologies operate with mid-merit capacity factors. The contribution of hydropower to total annual generation is 17% in the 'Diversified Supply' scenario and 18% in the 'Reference' scenario.

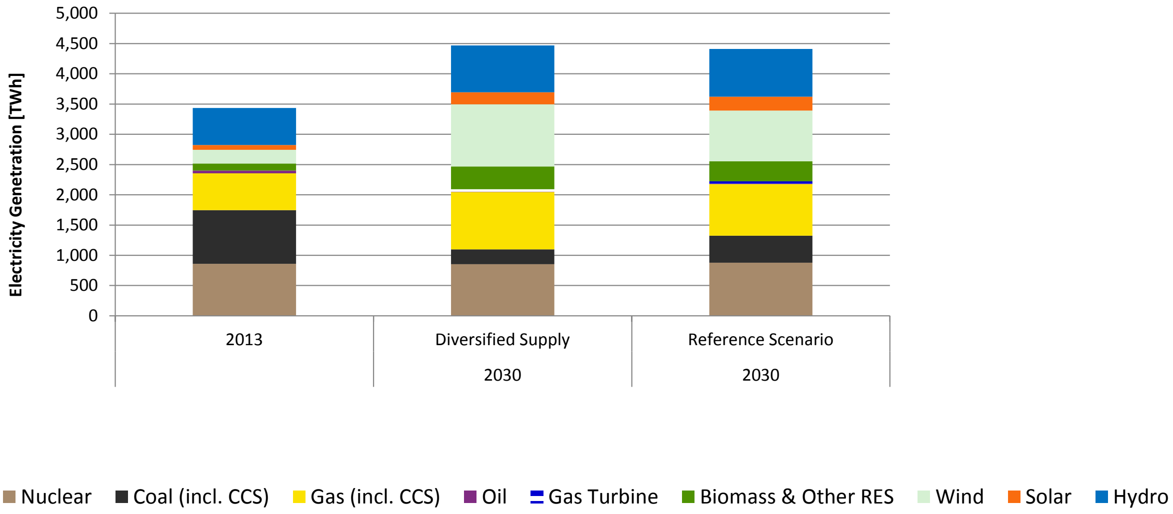


**Figure 7-8: Development of electricity generation in 2030**[65]
Source: DG ENER, DNV GL analysis

## Wholesale Electricity Prices

Our European market model has been applied to project the development of wholesale electricity prices for the year 2030 for each modelling scenario. The model projects hourly and region specific electricity prices on the basis of short-run marginal costs of individual generation technologies, accounting for no-load and generator start costs. Figure 7-9 below presents the resulting average wholesale electricity prices for the year 2030 in both scenarios. The figure shows national electricity prices as well as European average prices.

In general, wholesale electricity prices reflect the development of underlying commodity and CO2 prices, subject to the evolution of the generation and transmission infrastructure. Due to generally higher fuel prices in the 'Reference' scenario, wholesale electricity prices are higher (101 EUR/MWh) compared to the 'Diversified Supply' scenario (85 EUR/MWh). Furthermore we observe regional variations in wholesale electricity prices, which are caused by the impact of different RES shares and distributions across Europe. In particular, prices in the Nordic countries are generally lower as a result of higher shares of RES compared to other European countries. In contrast, regions which continue to rely on fossil fuel fired generation reveal highest wholesale electricity prices (e.g. Bulgaria).

In addition we observe the impact of (increasing) interconnector capacities between regions & countries, i.e. convergence of electricity prices across geographies and time. In particular price effects are exported from regions with high RES generation to neighbouring power systems, e.g. Scandinavia with a high share of hydropower to the Baltic region. Despite a conventional based generation infrastructure, the Baltic region enjoys relatively low electricity prices compared to regions with similar generation infrastructure.

65 Including grid losses

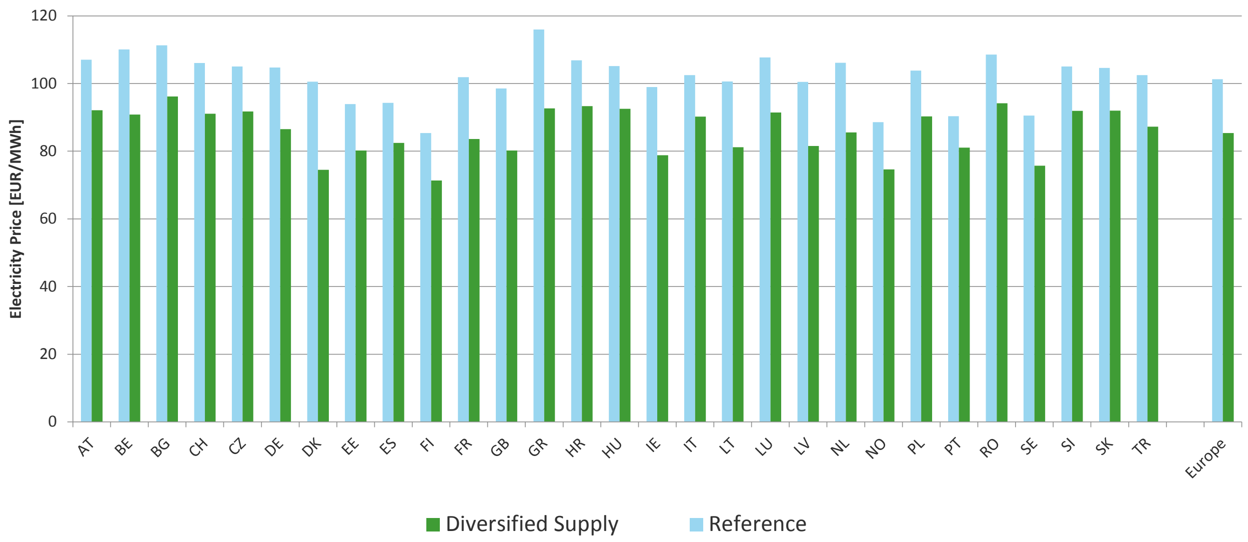


**Figure 7-9: Average annual wholesale electricity prices in 2030**
Source: DNV GL analysis

When analysing the incremental impact of hydropower on electricity prices we observe that flexible hydropower generation is generally used for peak shaving (i.e. avoiding electricity price spikes). In addition run-of river and pondage generation provides low cost base load energy to the market and due to its merit-order effect, reduces electricity prices.

As expected, electricity prices are therefore generally lower in the High sensitivity compared to the Low sensitivity. The results of our analysis are presented in Figure 7-10 below. On average the wholesale price differential between High and Low sensitivity is

- 2.53 EUR/MWh in the Diversified Supply and
- 2.06 EUR/MWh in the ‘Reference’ scenario.

However, the analysis reveals significant regional differences in average electricity prices, particularly when comparing the Nordic region to other European countries. As Norway and Sweden are expected to increase their hydropower generation in the High sensitivity by approximately 8 TWh in 2030 compared to the basic scenario, leading to a structural surplus, the largest price effects can be observed in this region. It should be noted that countries without significant shares of hydropower generation (e.g. Denmark or the Netherlands) also benefit from the price decreasing effects of hydropower. As these countries are physically interconnected to countries with higher shares of hydropower, imports of flexibility and cheap electricity help to reduce the general price level.

Alpine countries, which are also assumed to notably increase their hydropower generation, do not show significant price variations. As the Alpine region is well interconnected to the neighbouring power systems, electricity exchanges support the regional distribution of the price decreasing impact of hydropower.

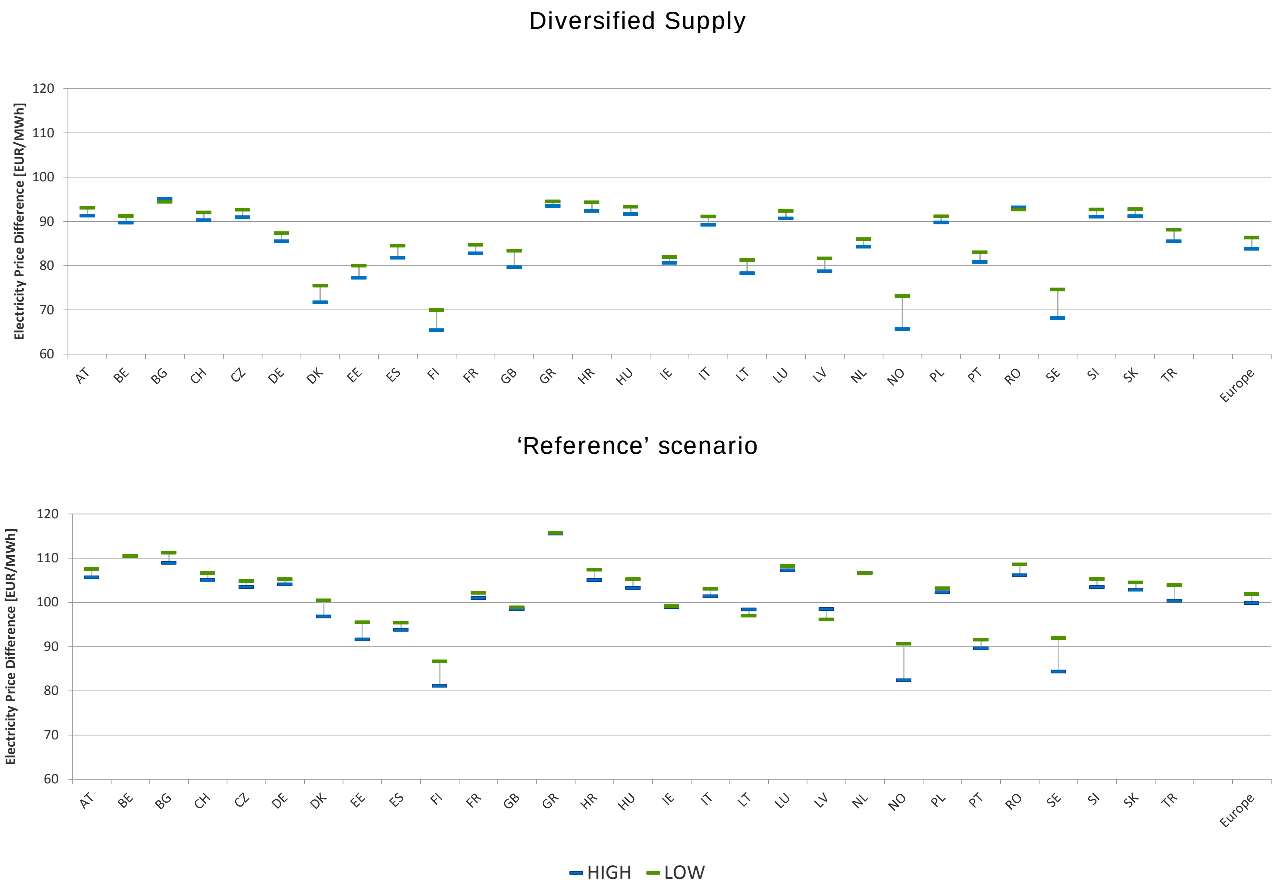


**Figure 7-10: Average annual electricity prices in the hydropower sensitivities in 2030**
Source: DNV GL analysis

## Fossil Fuel Consumption and CO2 Emissions

On the basis of the detailed dispatch modelling for the year 2030, we have analysed fossil fuel consumption as well as total carbon emissions. The assessment of fuel consumption includes coal, natural gas and oil.

Table 7-3 shows the effects of varying the share of hydropower by comparing the fuel savings between the High and Low sensitivities. Due to the smaller share of RES in total electricity generation, overall primary energy consumption in the power sector is higher in the 'Reference' scenario compared to the 'Diversified Supply' scenario. Varying the share of hydropower results in notable savings in fossil fuel consumption. We note that:

- Notable savings of 514 to 577 PJ (EUR 4.5bn to 6.5bn) for Europe and 275 to 344 PJ (EUR 2.6bn to 3.8bn) for the EU-28. However, actual cost savings significantly depend on underlying fuel cost assumptions;
- Each MWh of additional hydropower generation saves between 1.6 to 2.9 MWh of fuel, which makes hydropower a very efficient options to reduce fossil fuel consumption;
- Depending on the commodity price scenario, the incremental value of hydropower in terms of fuel cost saving is between 50 and almost 100 EUR/MWh.

**Table 7-3: Impact of hydropower sensitivities on fuel consumption and costs in 2030**

| Scenario | Region | Hydropower variation TWh | Savings | | | |
|---|---|---|---|---|---|---|
| | | | Fossil Fuel PJ | Fuel costs EUR mn | $MWh_{fuel}$ / $MWh_{hydro}$ | EUR / MWh |
| Diversified | Europe | 85 | 577 | 4,572 | 1.9 | 54 |
| Supply | EU-28 | 33 | 344 | 2,616 | 2.9 | 79 |
| 'Reference' | Europe | 91 | 514 | 6,452 | 1.6 | 71 |
| scenario | EU-28 | 39 | 275 | 3,765 | 1.9 | 96 |

Source: DNV GL analysis

In terms of carbon emissions, we observe lower emissions in the Diversified Supply compared to the 'Reference' scenario due to the higher share of RES and more gas fired generation. The results of our sensitivity analysis are presented in Table 7-4 below. By varying the generation of hydropower in the sensitivity analysis, we realize significant annual savings. However, it should be noted that a significant share of savings is realized in Turkey, which remains reliant on fossil fuels (and particularly coal) in the year 2030.

Table 7-4 also compares $CO_2$ emissions and related costs savings for each sensitivity. Cost savings have been calculated by weighting $CO_2$ savings with the $CO_2$ prices taken from the DG ENER modelling and respective scenarios. We note that:

- Notable savings of 25 to 35 Mt (EUR 900mn to 1,900mn) for Europe and 12 to 22 Mt (EUR 400mn to 1,200mn) for the EU-28. However, actual cost savings significantly depend on underlying carbon price assumptions, which vary significantly between both scenarios;
- Each MWh of additional hydropower generation saves between 0.3 to 0.7 t of $CO_2$;
- Depending on the carbon price scenario, the incremental value of hydropower in terms of $CO_2$ cost saving is between 10 and almost 35 EUR/MWh.

**Table 7-4: Impact of hydropower sensitivities on carbon emissions and costs in 2030**

| Scenario | Region | Hydropower variation TWh | Savings | | | |
|---|---|---|---|---|---|---|
| | | | Emissions Mt | Emission costs [EUR mn] | $t_{CO2}$ / MWh | EUR / MWh |
| Diversified | Europe | 85 | 35 | 1,855 | 0.4 | 21.7 |
| Supply | EU-28 | 33 | 22 | 1,157 | 0.7 | 34.8 |
| 'Reference' | Europe | 91 | 25 | 886 | 0.3 | 9.7 |
| scenario | EU-28 | 39 | 12 | 408 | 0.3 | 10.4 |

Source: DNV GL analysis

When combining cost savings from fossil fuel and $CO_2$ we note that overall savings of 75 EUR/MWh and 114 EUR/MWh can be realized, depending on the respective region as well as underlying carbon and fuel price assumptions.

## 7.3 Macroeconomic Analysis

The direct macroeconomic effects of hydropower generation considered encompass turnover (i.e. gross value creation), employment, investment and taxation. In addition, hydropower induces positive effects in other sectors of the European economy, i.e. through price effects. Finally, many hydropower installations provide multipurpose benefits.

In this section we describe the data and assumptions in their derivation, as well as further details of the calculation where required. The data were also used as the basis for our projection for the future development of the hydropower sector that is described in an additional subsection. A last subsection describes the input-output analysis that is used to describe the marginal effect of future hydropower investments on electricity prices, value creation and employment.

Multipurpose benefits are separately dealt with in section 7.4 below.

### Value Creation

Turnover of a company or sector can essentially be characterized by total revenues of the company resp. sector, gross value creation by turnover plus VAT. In this study we present turnover from hydropower generation, and from sales of hydropower equipment. In the latter case, we can present selective empirical evidence from the survey, showing the aggregate turnover of large hydropower equipment manufacturers. As for hydropower generation, we had to derive turnover figures from publicly available data since raw data were not available. We have derived the numbers from generation and wholesale prices, accounting for subsidies for small hydropower generation in the following way:

- Small hydropower generation values are taken from a study[66] on European renewable energy, alongside the subsidized remuneration (counting as turnover).
- Hydropower generation is divided into generation by run-of-river and pondage plants and by storage plants; small hydropower generation is subtracted from the first category[67].
- The remaining generation from run-of-river and pondage plants is valued at average wholesale market prices in each country, based on prices reported by power exchanges[68];
- A similar approach is taken for generation from storage generation, but subject to a mark-up, to reflect the possibility of shifting generation to peak hours.
- Pump storage generation is valued at the difference between peak and base prices.
- Total turnover is calculated as the sum of all categories, including subsidies for small hydropower.

Please note that the valuation of hydropower considers revenues from wholesale energy markets only. In contrast, the numbers reported in this study do not account for possible additional income from ancillary services and balancing markets.

### Employment

The figures on employment both in hydropower generation and equipment manufacturers stem to a large extent from the respective surveys. In the former case we asked for full-time equivalents (FTE)

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66 ‘The State of Renewable Energies in Europe – Edition 2013’, 13th ObservEr Report, Paris

67 Assuming that this category is more representative of small hydropower.

68 For the exact list of Power Exchanges look at reference section and ‘Energy Markets in the European Union 2011’, European Commission, 2012

employed directly in hydropower operations and maintenance and generation processes. Moreover, we have completed the results by extracts from company reports, and ultimately extrapolate the data to obtain a complete picture. Additionally, we asked the correspondents for an estimation of employment induced in service providers, also in terms of FTE; the answers were also extrapolated.

## Investment

The information on investments by hydropower producers and equipment manufacturers is primarily based on the responses from our surveys. In addition to the information from the questionnaires the results on investments in hydropower were based on other sources of data such as company reports.

In order to analyse the investments in hydropower it is important, when possible, to distinguish between two main types of investment:

- Refurbishment/maintenance investments: all investments related to replacement of aged (technically or economically) equipment and maintenance;
- New investments: all investments needed for meeting the change of load and generation patterns.

## Taxation

One of the sections of the questionnaire for company/ country representatives was devised to collect data on taxes, levies and royalties related to the hydropower operations. Therefore, the results of the analysis were primarily based on the data collected through the questionnaire that was distributed to the participating companies and associations.

Table 7-5 provides an overview of possible elements of taxation and indicates which ones have been considered in this study. This summary shows that the analysis principally considers three components: Taxes, levies and surcharges that are specifically charged on hydropower, VAT, and income tax on employee salaries. Conversely, corporate taxes (i.e. levied on profit) were not considered due to lack of information on company profits. Similarly, VAT in the equipment manufacturing sector was not accounted for: if it accrues from domestic use, it is included in the VAT paid for by hydropower producers, and if it accrues in countries outside Europe that import European kit, it is accounted for in national accounts of the importing countries.

**Table 7-5: Relevant taxes for hydropower producers and equipment manufacturers**

| Generation sector | Equipment manufacturing |
|---|---|
| • Hydropower specific taxes, levies and surcharges<br>• Value added tax from electricity sales (VAT)<br>• Income tax on employees' salary<br>• Corporate tax (not considered) | • VAT (not considered)<br>• Income tax on employees' salary<br>• Corporate tax (not considered |

Source: DNV GL analysis

The volume of specific taxes on hydropower was based on responses from the questionnaires. VAT tax revenues were calculated based on revenues from electricity generation (see p. 74 above) and national VAT rates (EU Commission (2014)).

Tax revenues from income taxes (i.e. taxes on employees' salary) were determined using a country-wise extrapolation of employment figures. The reported values on tax revenues are based on responses to FTE question and values from company reports /studies. The figures on annual salaries are taken from national sector statistics (average for electricity & gas sector) where available. For all other countries (where information was not directly available), the salary was calculated by a mark-up on the average income for the country (using Eurostat data). The mark-up was calculated as an average of the respective mark-ups in the countries where annual salaries were available. The total labour income in the hydropower sector was calculated for each country and applied the average income tax rates from Eurostat employment statistics.

## Projection of Future Development

In chapter 3.3 we present a projection of future value creation and employment in the hydropower sector for 2030. This is essentially based on the power market simulation. For the two scenarios, turnover is calculated as the product of future hydropower generation and electricity prices on a country-by-country basis. Value creation is then extrapolated on the basis of turnover by including VAT. A for hydropower equipment manufacturing, we assume the same level of value creation as before. The projection of future employment in the hydropower sector is derived by extrapolating 2013 employment based on capacity, as projected in the two scenarios. The share of indirect employment (in maintenance, engineering, consulting etc.) is set be fixed at 100% of direct employment. As for employment in hydropower equipment manufacturing, we assume that the number of employees in unaltered, in line with the flat projection of value creation.

## Input-Output-Analysis

Input-output analysis in this study is used to calculate indirect economic effects: More precisely the economic impact of a potential future increase in hydropower use. The method was originally developed by Wassily Leontief in the 1930s, allows for an analysis of the changes in one sector on all other sectors. An input-output -table summarizes inputs and outputs for a standardized set of sectors of a national or regional economy for a given point in time; the standardized tables used for this study are provided by the OECD statistical database.

We use a cost-push analysis to calculate the economic impact of electricity price changes[69] on prices in different sectors of the economy. As for the input into the cost-push analysis –the electricity price changes- we build on the power market simulation described in Appendix 7.2: More precisely, we use the hydropower sensitivities for the two scenarios to determine percentage changes in national electricity market prices. The sensitivities allow for a ceteris-paribus analysis: only hydropower capacity is varied, all other factors remain constant. Following the method employed by Lim & Yoo (2013) we determine the sectorial price changes induced by the electricity price changes. The sectorial division is based on the OECD standard, the input-output tables stem from the OECD statistical library[70]. From the sectorial price changes we derive ranges of changes in turnover by way of sectorial price elasticities: in line with the

69 Cf. Blair & Miller (2009), 'Input-Output analysis – foundations and extensions', Cambridge; compare also Ngyen (2008), 'Impacts of a rise of electricity tariff on prices of other products in Vietnam', Energy Policy 36; Lim & Yoo (2013), 'The impact of electricity price changes on industrial prices and the general price level in Korea', Energy Policy 61

70 Cf. http://stats.oecd.org/. We use the latest version of the input-output-tables from the mid-2000 years.

macroeconomic literature we assume elasticities between -0.2 and -0.5, that are used to determine the sectorial output changes, based on OECD output data and corresponding to the price changes. These output changes highlight first order effects of an increased hydropower employment.

The employment effects are derived from the output effects. We use capital/labour shares to determine the labour cost of the output. We use average wages for the countries analysed in this study to deduce the corresponding number of employees (FTE).

Generally, we limit the calculation to twelve countries out of our sample with notable price changes: Austria, Switzerland, Germany, Spain, Finland, France, Italy, Norway, Portugal, Romania, Sweden and Turkey.

## 7.4 Analysis of Multipurpose Benefits

To narrow down the scope of our analysis, we have, in a first step, conducted a survey, enhanced by interviews, among European hydropower operators and associations, in order to collect the industry's views on the importance of different multipurpose benefits. In the survey, we asked respondents about their subjective assessment of the importance of potential multipurpose benefits, based on a qualitative assessment between 1 (low importance) and 5 (high importance). Figure 7-11 presents the results of this survey, which clearly indicate that certain multipurpose benefit are obviously deemed to be more important than others, as well as certain regional differences between different parts of Europe.

These observations broadly correspond with the results of a supplementary analysis of a global database on large dams (ICOLD)[71]. Besides other information, this database also registers information on the purposes of each dam, which we have used to identify multipurpose installations as well as the frequency and regional distribution of different functions that are provided in combination with hydropower. In addition, we have also validated the responses to the questionnaires against other publicly available sources, in order to assess the value and importance of difference effects.

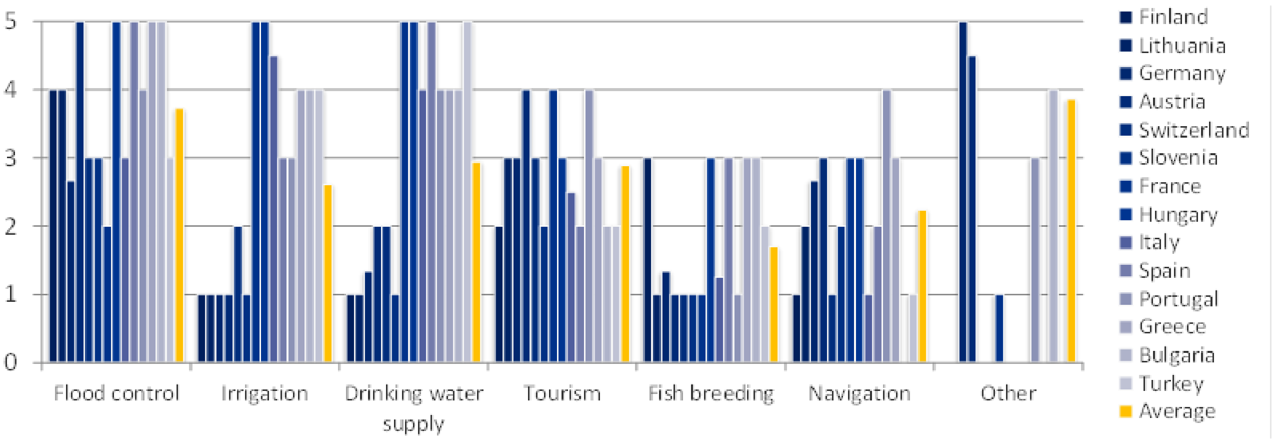


**Figure 7-11: Results of country survey on multipurpose benefits[72]**
Source: DNV GL analysis

71 The database of the International Commission on Large Dams (ICOLD) provides a basic overview on large dams and reservoirs all over the globe. It currently covers more than 6000 large dams which are in operation and with a defined purpose (power generation, or any other).

72 Please note that for some countries and multipurpose benefits various responses may be available whereas for some others the number of responses may be small.

The main results of the internal survey and the supplementary analysis can be summarised as follows:

- **Flood control** is often considered as one of the most important multipurpose benefits. This effect covers the ability of dams and reservoirs to mitigate the impact of (major) floods by retaining water during critical situations, thereby reducing downstream water levels. In addition, this ability can be used to strategically release water in advance and store additional volumes during the flood event, therefore avoiding for instance a concurrence of peak water levels from upstream rivers at a certain point and reducing the impact for more downstream residents.

- **Water supply** for irrigation, as drinking water and for industrial purposes represents an important multipurpose benefit especially in Southern European countries (incl. Turkey). Water reservoirs allow for a more stable supply of water, making it possible to compensate the changing availability of water resources throughout the year. Moreover, they may help reducing differences between regions with different natural water resources, provided that water can be transported from a reservoir to other regions with more scarce water resources. This function is by far the most common purpose of dams and reservoirs in some of these countries, i.e. hydropower often represents a 'by-product' rather than the primary purpose of such dams in many cases. In many cases, water supply from reservoirs is considered as a key enabler of local economic growth, for instance where agriculture is a major source of economic wealth.

- Various respondents across Europe also consider the promotion of **tourism** as an important multipurpose benefit, even though it is generally considered as less important as the previous functions. Hydropower reservoirs may enlarge the spectrum of available tourist activities, or even provide the basis of it, for instance in the form of water sports.

- In certain regions, dams serve the dual purpose of hydropower and enabling or facilitating **inland navigation** on river system. Compared with other transport means, inland navigation by ships allows for relatively cheap hauling of mass and heavy goods.

- In addition to these four major functions, respondents have also mentioned several other multipurpose benefits. However, these functions have generally been found to either be of limited importance or to be confined to isolated areas. Examples include:

  - In some parts of Southern Europe, like Italy or Portugal, hydropower reservoirs also facilitate **firefighting**, i.e. by providing (additional) places where firefighting planes can load water. Similar to flood control, the main value of this function relates to avoided damages.
  - Operators of hydropower plants often are responsible for **garbage collection and removal**, i.e.to collect and dispose of materials floating on rivers and collected upstream of hydropower plants. For instance in Germany, operators annually remove approx. 15,000 t (90,000 $m^3$) of waste, and considerable numbers have been reported from Italy as well.
  - Some operators also reported fishing in the proximity of hydropower plants as a potential multipurpose benefit. However, publicly available data and statistics show a very limited role of commercial fishery[73] and a limited link between hydropower and aquaculture[74], such that we assume the value of this function to be very limited.

Based on these considerations, we subsequently focus on the first four multipurpose benefits, which our preliminary analysis revealed as being potentially most relevant.

73 Catch limited to EUR 10mn even in larger countries

74 Mainly due to requirements on sewage water treatment

# 7.4.1 Flood Control

Flooding is the most common natural disaster in Europe and is, along with winter storms, the most important natural hazard in Europe in terms of economic losses. Between 1998 and 2009, 213 flood events occurred in Europe, causing 1126 fatalities, millions of people affected, and damages worth more than EUR 52bn.[75] Recent examples of floods include the 2014 Southeast Europe flood affecting Bosnia-Herzegovina, Serbia and neighbouring countries, the 2014 Bulgarian flood and the 2013 floods along the Danube and Elbe rivers and their tributaries.

Floods represent a significant risk to human health, property, the environment and cultural heritage. Possible consequences are summarized and categorized in the table below.[76]

**Table 7-6: Consequences of floods**

| | Tangible | Intangible |
|---|---|---|
| Direct effects | • Damage to buildings | • Loss of life |
| | • Damage to infrastructures | • Physical and mental health effects |
| | • Damage to crops | • Loss of memorabilia and cultural heritage |
| | • Damage to inventories and customer goods | • Disruption or loss of ecosystems |
| Indirect efects | • Generation and income losses | • Increased vulnerability of people and companies |
| | • Clean-up costs | • Disruption of community |
| | • Costs of evacuation | • Inconvenience caused by evacuation or disruption of services |
| | • Increased travel costs | |

Source: DNV GL

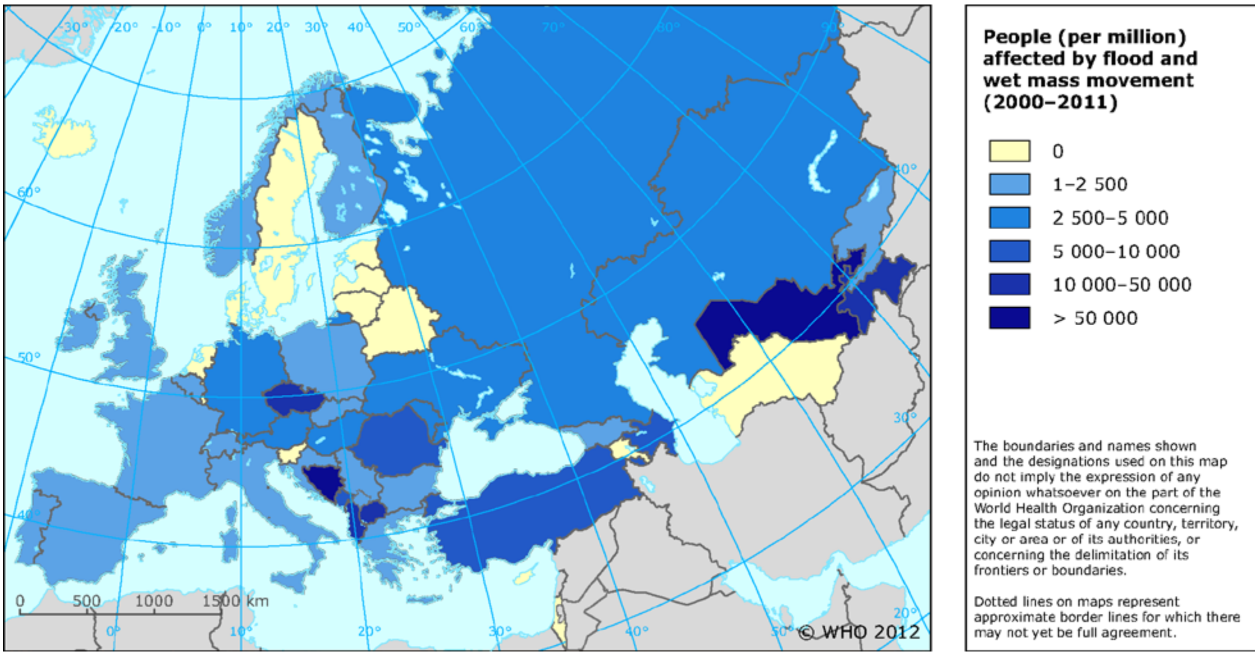


**Figure 7-12: People affected by flood and wet mass movement**
Source: WHO

[75] EEA: Mapping the impacts of natural hazards and technological accidents in Europe. An overview of the last decade. Technical report No 13/2010

[76] A Working Group Floods (CIS) resource document 'Flood Risk Management, Economics and Decision Making Support, October 2012

The following examples illustrate selected historical flood events and how hydropower reservoirs and have contributed through watercourse management and hydropower operation to contain flood damages in specific instances.

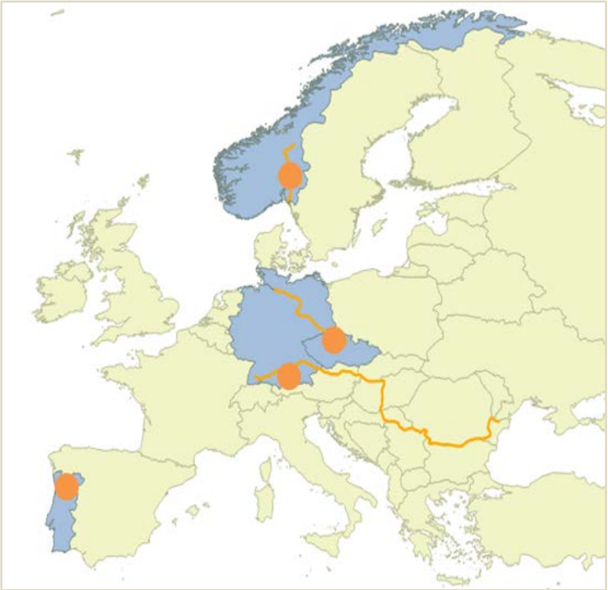

**Figure 7-13: Examples on floods in regulated river system (north to south): Glomma (Norway), Elbe (Germany / Czech Republic), Lech (Danube tributary), and Lima River (Portugal)**
Source: DNV GL

## Elbe / Labe River (Germany / Czech Republic)

The Elbe (Labe in Czech) is one of Europe's largest rivers, running 1165 km from the Riesengebirge mountains (Czech Republic) to the North Sea at Cuxhaven (Germany). Important cities along the riverbank include Dresden, Magdeburg and Hamburg. Areas along the Elbe have experienced several large floods during the past decades, including major floods in 2002 and 2013, and a smaller flood in 2006, all caused by periods of intense and long lasting rain.

Analyses of historic events have shown that downstream parts of the Elbe benefit from upstream flood control. Hydropower reservoirs in the Czech Republic play a major role in reducing floods, also in the German part of the river further down streams. River flow in the city of Dresden was diminished by approximately 750 and 890 $m^3/s$ for the floods in 2006 and 2002 respectively. Peak water level was reduced by approximately 70 cm in each event. The relative impact of the reservoirs was larger for the 2006 flood than for the 2002 flood (see Figure 7-14). In the 2002 flood, the water reached the famous Dresden historical area, and without the impact of the upstream reservoirs, the flood damages here would have been much more devastating.[77]

77 Report from EU project "LABEL - Adaptation of flood risk in the Elbe catchment area. "Bewertung von Einflüssen tschechischer und thüringer Talsperren auf Hochwasser an Moldau und Elbe in Tschechien und Deutschlandmittels Einsatz mathematischer Abflussmodelle. BfG-1725 report (2012) (in German)

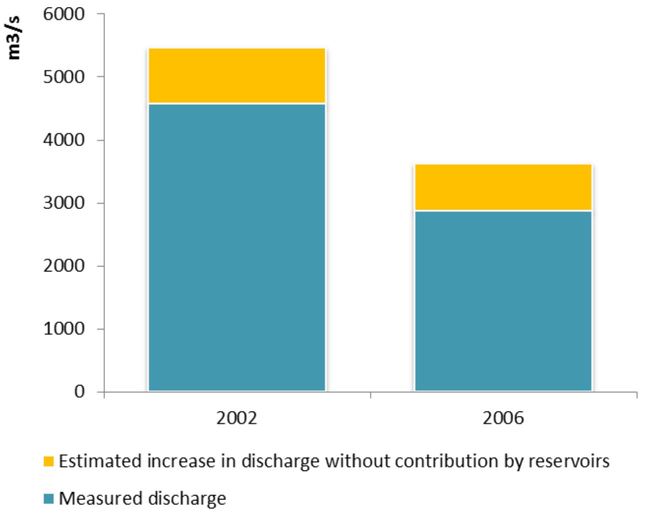


**Figure 7-14: Effect of hydropower reservoirs for the 2002 and 2006 flood in Dresden (Elbe), Germany**
Source: Busch et al. (2012), BfG-1725

## The Lech River – Alpine Tributaries to the Danube

At Lech river, a tributary to the Danube, E.ON operates the large Forggensee dam and several hydropower stations. The reservoir reduces the risk of flooding in the downstream areas, both during snow melt and / or periods with heavy rain.

In August 2005, the northern part of the Alpine region was affected by severe floods caused by heavy rain. The damages downstream from the Forggensee dam were limited as the Forggensee reservoir retained large amounts of water. When heavy precipitation was forecasted the water level at Forggensee was lowered to create more retention volume, thus decreasing the culmination level downstream.

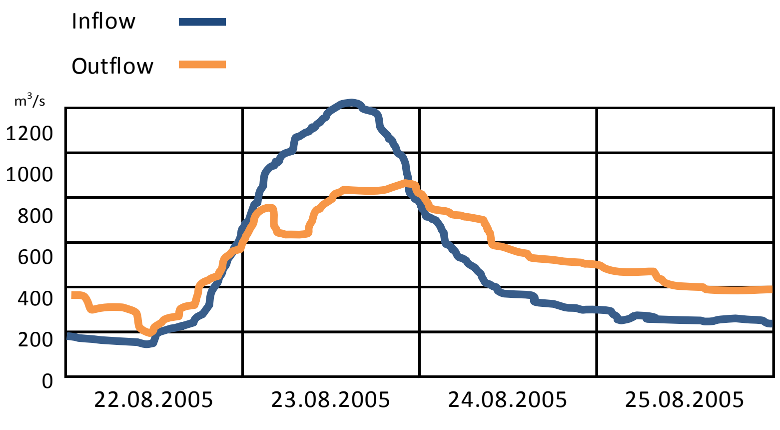


**Figure 7-15: Inflow and outflow (m3/s) from the Forggensee reservoir during the 2005 flood**
Source: Berga et al. (2006)

Historic floods have revealed the importance of an accurate prediction of precipitation and improved methods for forecasting. In the Bavarian region, an efficient cooperation exists between the hydropower operator E.ON and the regional water resource agency (LFU - Landesamt für Umweltschutz). The cooperation includes a proficient data exchange where precipitation and flow forecasts are supplied by

LFU, and E.ON reports actual operational figures. This has proved to be especially helpful in flood situations to ensure that correct actions are taken in due time.

## Glomma River System (Norway)

The Glomma river system represents more than 11.5 TWh of hydropower generation, and the regulating capacity from its 22 reservoir plays an important role in flood control in Eastern Norway.

Figure 1-4 shows the Glomma river system and its catchment area. Unregulated (natural) and regulated water flow are shown for selected locations. Typical natural inflow profiles for this part of Europe have low winter flow, and a high spring /summer peak. Reservoirs and water management help to control variations between seasons, securing higher winter flow and controlling the inflow peaks.

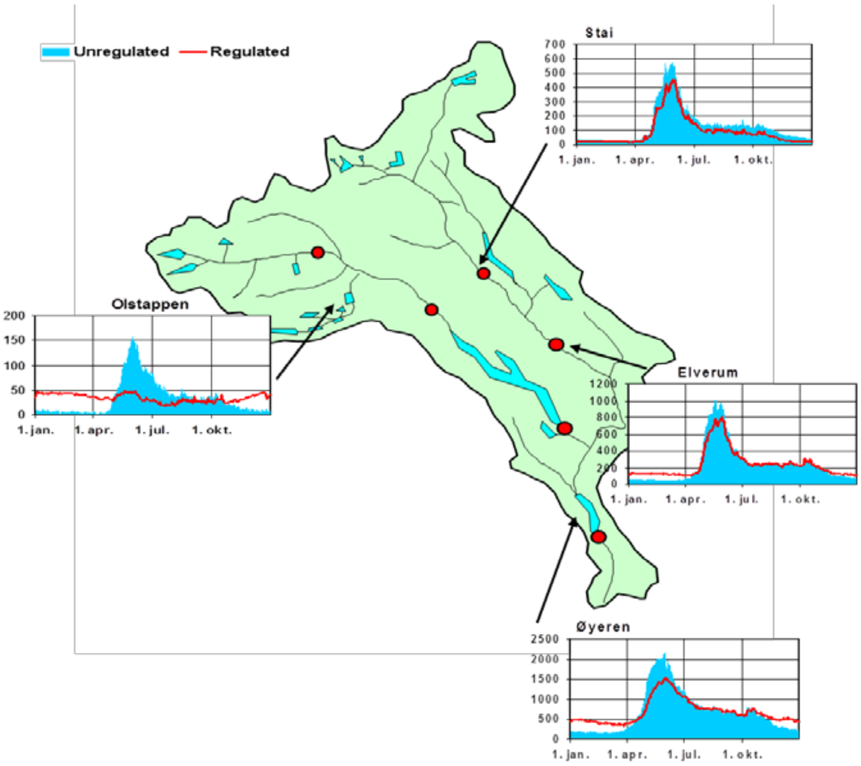


**Figure 7-16: Glomma River (courtesy GLB) including average inflow over the year (m3/s)**
Source: Glommens og Laagens Brukseierforening (GLB)

In 1995 a large flood occurred in the Glomma river system, causing 1 casualty, the evacuation of 7,000 people and reported damage to more than 1,800 farms. Many of those affected during the flood could not return to their homes for several months while the houses dried up and the damage was repaired. Damages were estimated to be approximately EUR 225mn.

The cause of the flood was a combination of larger snow reservoirs than normal and delayed and rapid snow melting coinciding with heavy rainfall. Several reservoirs were cleared to make room for the expected water, thus limiting the flooding downstream. Nevertheless, large areas were flooded, and at Elverum in Glomma the water flow was the largest measured since 1789.

Figure 7-17 shows the peak flow at the city Elverum. The flood culminated at approx. 3500 $m^3$/s, and it is estimated that the reservoirs diminished the flood by approximately 800 $m^3$/s or 90 cm, thus preventing larger areas from flooding.

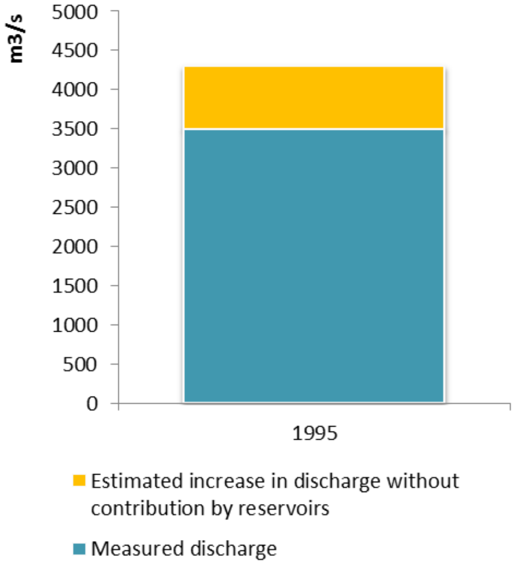


**Figure 7-17: Effect of hydropower reservoirs for the 1995 flood at Elverum (Glomma, Norway)**
Source: Glommens og Laagens Brukseierforening (GLB)

The importance of the reservoirs in Glomma to limit floods was also apparent in 2011 and 2013, when floods culminated on the door steps of one of the region's largest shopping centres (Lillehammer). Without the effect of the reservoirs, it is estimated that the water level would have been 1 metre higher. In 2014 the water level was somewhat lower, but still caused infrastructure challenges. In this case the reservoirs limited the peak water level by approximately 0.5 metre.

Observations from recent years seem to indicate a trend towards more frequent and intense rainfall which threatens households and infrastructure in this area, suggesting that the flood limiting effect of the hydropower reservoirs will be even more important in the future.

## Summary

Apart from the loss of human lives, the tangible damage from flood events may be tremendous in economic terms. Studies and past experience show that hydropower operation may play a considerable role in flood control and mitigation of corresponding events, especially during small to medium size floods. Although the material damage is hard to assess in numbers even with scientific instruments, there are examples where hydropower storage installations have clearly reduced the impact of floods. Based on the examples cited above, the contribution of hydropower to flood mitigation may easily reach several hundred million Euros on regular basis.

In many areas, floods and related damage risk are even expected to increase for different reasons. It is often argued that the number of people and economic value of the assets located in flood risk area augments. Moreover, phenomena like climate change, increase of soil impermeability or deforestation most likely increase the likelihood of floods and resulting damages.[78] Flood events caused by heavy

[78] dito.

precipitation are likely to become more frequent in many regions in Europe.[79] Consequently, the contribution of hydropower in terms of avoided damages to homes and businesses will be no less relevant in the future than it is today.

### 7.4.2 Water Supply

Water supply to the business and private sector, especially agriculture and as drinking water, is a primary function of water reservoirs in various countries. Especially in Southern Europe precipitation and ground water sources are often unable to meet the water demand in regions with high population density or a strong agricultural sector. Moreover, water resources may be unevenly distributed among various locations and have a limited availability during some periods. The construction of dams and reservoirs thus enables a more stable and balanced supply of water.

The extent to which reservoirs (with or without hydropower plants) are involved in ensuring availability of water resources strongly depends on the local / regional situation. Similarly, the type and value of economic activities that are associated with water supply may vary depending on the location and the value of goods produced. As a consequence, publicly available information on the role and value of water supply is largely limited to individual projects or regions. In line with that, we rely on selected examples, in order to illustrate the potential value of water supply for different Southern European countries, based on literature review and simplified estimations.

#### Value of Water Supply in Spain

In Spain, hydropower reservoirs mostly serve for water supply. According to ICOLD data, for approx. 700 out of a total of 1,000 larger Spanish dams, water supply is the dominant application. Moreover, half of these dams are single-purpose constructions that serve water supply (incl. drinking water and irrigation) only. In contrast, only 25% of all dams are related to hydropower, including approx. 160 dams with multipurpose schemes, again including water supply as the dominant form.

A major share of the stored water is dedicated to irrigation. Irrigation represents almost 80% of the total demand for consumptive uses, and about 50% total of the consumptive and non-consumptive demands (including hydropower generation). In order to provide further insights, we have analysed several studies on the water footprint[80] of water use in Spain, with a regional and national scope.

- In a regional study[81] for the Guadiana River Basin in South Eastern Spain, which is dominated by agriculture, a water footprint hydrologic and economic analysis was carried out. While taking different water consumers (private and business) into account, data reveals that especially in the Middle Guadiana basin large surface water reservoirs serve for water supply.
  Overall, the study suggests the internal[82] water footprint of the Guadiana basin to be no less than EUR 3bn per year. Half of this value is attributed to the industrial sector, due to the relatively high

79 For instance, WHO and HPA estimate that, in the absence of adaptation to climate change, river flooding is estimated to affect 250,000 to 400,000 additional people per year in Europe by the 2080s; see Floods: Health effects and prevention in the WHO European Region, WHO Regional Office for Europe, 2013

80 The water footprint of a country is defined as the total volume of water used, directly or indirectly, to produce the goods and services consumed by the inhabitants of that country.

81 Water Footprint Analysis (Hydrologic and Economic) of the Guadania River Basin, Aldaya et al., 2008

82 Defined as the volume of water used from domestic water resources to produce the goods and services consumed by the inhabitants of the region, and calculated as the sum of the total water volume used from the domestic water resources in the national economy minus the volume of virtual water export to other countries insofar as it's related to the export of domestically produced products.

economic values of products and services produced and despite its fairly low water consumption. Another 30% of total gross value added, i.e. EUR 1bn, comes from agriculture, whereas another 10% are attributed to livestock. About 20% of the total gross value added of agriculture, i.e. EUR 200mn per annum may be attributed to surface water (compare Figure 7-18), assuming an average year of water resources availability.

- An aggregate evaluation for all sectors and the entire territory of Spain[83] suggests the economic value of reservoir water is about EUR 25bn, or about 5% in terms of contribution to the gross added value at the market value. The total value distributes among water for industrial uses (EUR 11.5bn), irrigation and drinking water (EUR 5bn), and refrigeration and other uses (EUR 3bn).
- Another study for entire Spain finds a total gross value added of irrigated agriculture of slightly above EUR 9bn, without tracing back the source of irrigation water to large reservoirs (with / without hydropower) or others.[84] Nevertheless, when applying the results produced by the aforementioned Guadiana study, one may conclude that 20% of the total value, or roughly EUR 2bn, can be attributed to water supply from hydropower schemes.

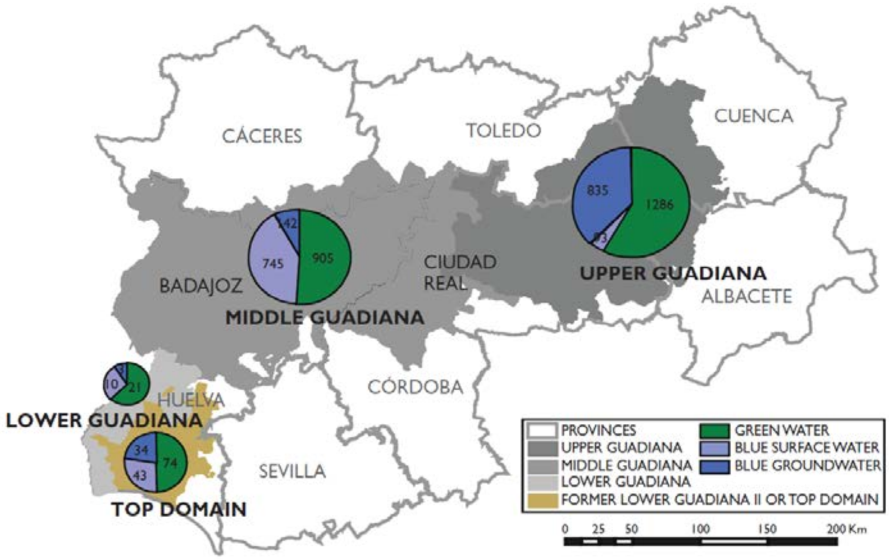


**Figure 7-18: Agricultural use of water resources in the Guadiana river basis ($hm^3$/year, 2001)**

Source: Water Footprint Analysis (Hydrologic and Economic) of the Guadania River Basin, Aldaya et al., 2008

In total, these considerations suggest that the gross value added of water supply by hydropower reservoirs to agriculture may be in the range of EUR 2-5bn. Conversely, the total value of water supply may amount to some to EUR 20bn.

However, as pointed out above, it seems that only a certain share of this value can be attributed to multipurpose schemes including hydropower generation. As stated above, multipurpose schemes where hydropower generation is involved represent about 16% of all Spanish dams only. We therefore estimate that only about EUR 0.3bn to 0.8bn of gross value added generated in the agriculture sector may be linked to water provision from multipurpose hydropower schemes, and another EUR 3.2bn for water supply to other sectors. The total benefit may thus be in the range of EUR 4bn annually.

83 Berga (2008)

84 'Water footprint and virtual water trade in Spain', Aldaya et al., p.52f, 2010.

## Value of Water Supply in other Countries

Water supply by dams for irrigation and drinking water is not only relevant in Spain, but also in other countries of Southern Europe, like Portugal, Italy, Turkey, Romania and France:

- In **Turkey**, 52,800 km$^2$ out of a total of 280,000 km$^2$ of arable land were irrigated in 2009[85]. According to ICOLD data, hydropower schemes supplied water to a total area of 26,000 km², i.e. about 50% of the total irrigated area or 9.3% of the total surface used by agriculture[86]. Taking into account that Turkey's GDP is about EUR 900bn and agriculture contributes by about 9%, one may estimate that about EUR 7.5bn of the country's GDP are associated with water supply from large hydropower installations.
- Some Turkish water reservoirs are also relevant for stable drinking water provision. For instance, the dams of Çatalan, Güldürcek and Kartalkaya[87] account for 260mn m$^3$ of drinking water, or about 3% of total domestic water consumption of 7bn m$^3$ in 2008.[88]
- The value of hydropower plants for water supply has been confirmed also for **France**. Water for irrigation is especially important in in the Rhône and Durance rivers and in the Pyrenees region in Southern France. Similarly, hydropower reservoirs are the primary sources of water supply for the South East of France, with a total population of some 3 million inhabitants.
- In **Italy**, water supply from artificial reservoirs is very common in the central and Southern parts of the country. There, reservoirs were in several cases built for drinking / irrigation purposes and only very recently their exploitation has been extended to power generation. In fact, the use of water for irrigation and drinking purposes prevails (and thus has a priority) over power generation under the current Italian legislative framework.[89]
- Examples of water supply for irrigation from hydropower plants may also be found in **Portugal**. For instance, next to the aforementioned Guadiana area in Spain, there is the Alqueva dam on Portuguese territory. It has enabled enlarging the agricultural area in the Alentejo region by more than 1000 km$^2$.

### 7.4.3 Tourism

Many large water reservoirs provide not only good conditions for electricity generation but also have been the catalyst for a flourishing tourism sector. Reservoirs may enlarge the spectrum of tourist activities, or become a major destination themselves. However, such benefits are not a general feature of hydropower reservoirs but are subject to specific local conditions. In the following, we therefore present a limited number of selected examples of multipurpose schemes with a relevant impact on tourism. More specifically, these include examples from Austria (lake Achen), Germany (Lake Eder) Hungary (lake Tisza). The economic impacts have been estimated based on a simplified set of assumptions, from estimating the potential economic value of tourism in the proximity of hydropower.

85 General Directorate of State Hydraulic Works. Turkey Water Report 2009, 2009,; compared to that estimates the land use by agriculture at 400,000km2

86 ICOLD data

87 Information provided by Turkish company Teias.

88 Turkey Water Report 2009, 2009, General Directorate of State Hydraulic Works

89 This principle is also enshrined in the provision for granting hydroelectric power generation permits, which, in some cases, provide for a mixed use (volumes of water and / or periods). This means in case of exceptional periods of drought, such as the 2003 and 2005 summer season in the northern, hydropower producers are required to release water downstream.

## Lake Achen (Austria)

Built in 1927, the reservoir with a length of 10 km provides the basis for energy generation at the nearby 79-MW storage power plant operated by TIWAG. Lake Achen is embedded in the Austrian region Tyrol, which accumulates one third of all over-night stays in Austria, 43 million. About one third of tourists' expenses in Tyrol are dedicated to accommodation, followed by restaurants, and retail and services (each about 22%) and transportation (17%). Total direct tourist expenses amount to some EUR 9bn. About 70% of the inputs for accommodation and restaurant services are provided locally, while another 20% stems from other parts from Austria and only 10% are procured from abroad.[90]

The two municipalities next to lake Achen (Eben am Achensee and Achenkirch) account for more than 1.5 million guest nights. One of them, Eben am Achensee, is among the top touristic destinations in Austria, both in winter and summer season. To account for the role of alternative offerings (especially winter sports), we only consider the potential role of the lake for tourism in the summer, which represents 850,000 guest nights.[91] Taking this number as a basis for estimating the value of the lake for local economy, the turnover of tourist activities at the lake may be estimated to a maximum of EUR 200mn per year.[92] Although the lake is probably not the only reason why people spend their time there and also other activities, like hiking, aviation or other activities, are attractive, it may be assumed that the lake, directly or indirectly, induces large economic benefits to the region.

## Lake Eder (Germany)

The county of Waldeck-Frankenberg where Lake Eder is located at accounts for around 250,000 guests and more than 3 million overnight stays per year. Looking at the nearer vicinity of the lake, three municipalities (Vöhl, Waldeck, Edertal) combine more than 400,000 overnight stays. [93] Another 1.5 million stays are registered in Bad Wildungen, which is about 5 km away from the lake. It provides for the principal place where to reside and start off for day trips to the two main regional biospheres, lake Eder and national park Kellerwald. In this context, it seems reasonable to assume that both destinations complement each other rather than competing for the same tourists, since most tourists come in summer and mainly resort to the area where they may enjoy both at the same time.[94]

90 'Tourismus in Tirol - Herzstück der Tiroler Wirtschaft', Chamber of Commmerce of Tyrol

91 Tiroler Wirtschafts- Und Arbeitsmarktbericht 2011, Amt Der Tiroler Landesregierung, 2011

92 Share of 850,000 guests nights, compared to 43 million resulting in a gross value added of 4 billion EUR.

93 Municipal Statistics 2013, Regional statistical office of the Land Hessen.

94 'Regional Development Concept for the Kellerwald-Edersee Region', Region Kellerwald-Edersee e.V., 2007.

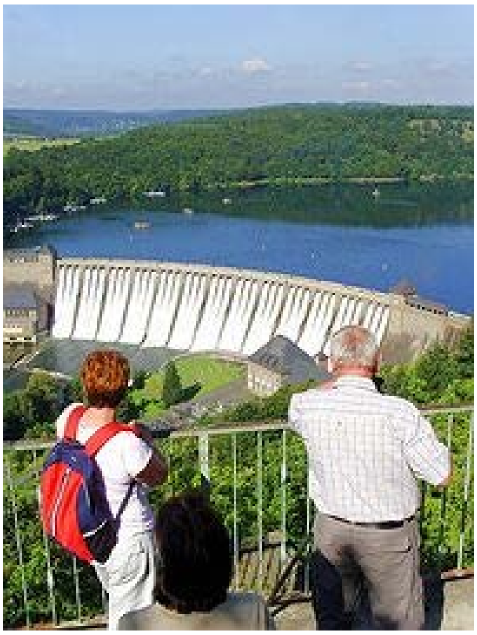


**Figure 7-19: View of lake Eder and the geographical area around the lake**
Source: left picture - Edersee Touristic GmbH, M. Latzel; right figure: 'Regional Development Concept for the Kellerwald-Edersee Region', Region Kellerwald-Edersee e.V., 2007.

When only considering a total of 0.4 to 1.9 million overnight stays in the nearer proximity of the lake and assuming average tourist expenses of EUR 115 per day[95], the total economic value of lake Eder for the local economy can be estimated at some EUR 46mn to 218 mn in terms of turnover.

## Lake Tisza (Hungary)

The lake Tisza is an artificial reservoir developed in the floodplain of Tisza with an area of 127 square kilometres. Its development became possible through the barrage in Kisköre. The hydropower plant in Kisköre forms part of the facilities of the barrage in Kisköre which also includes the reservoir in the floodplain.

Apart from its excellent multipurpose characteristics Lake Tisza may serve as a blue print for the development of touristic and leisure time activities in the surroundings of a hydropower plant. In fact, the lake is famous for rural, active and eco-tourism rather than for beach holidays. Award-winner due to its broad menu of service offerings, Tisza one of the smallest, however one of the fastest growing touristic destination in the country. In 2012, 85,000 guests spent in total 250 thousand overnight stays, including many foreign tourists mainly from Germany, Romania and Slovakia. Based on average figures for tourism in Hungary[96], the annual turnover and the value added may be estimated at EUR 20mn to 33mn.

95 „Tourismus in Nordhessen und regionale Betroffenheit durch den Klimawandel', Ulf Hahne et al., 2012.

96 Based on a total number of 23 million overnight stays, the turnover generated by tourism for whole Hungary is reported to be around EUR 3bn, while the value added is estimated to EUR 1.8bn.

### Summary

The examples presented above illustrate that hydropower reservoirs may promote regional development by supporting tourism in the proximity of the reservoir. Relevant examples exist at different places across Europe.

We are aware that not all benefits may be entirely linked to the presence of the reservoir and may therefore not fully be associated with the hydropower installation, as tourism may also develop in the absence of the reservoir. However, the examples indicate that reservoirs enlarge the spectrum of tourist activities and suggest that, in the absence of the reservoir, the level of tourism would otherwise be lower. Overall, the examples presented above thus indicate that the corresponding benefits for the local economy may be substantial. This is especially relevant in regions with limited scope for economic growth, job opportunities and income sources. In this sense, Lake Tisza is a remarkable show case because the reservoir has a catalyst function for economic growth for a region formerly underdeveloped in terms of tourism. Similarly, lake Eder, located in an economically less developed region of Germany, also proves additional benefits from the symbiotic co-existence of different touristic offers, including the reservoir and the national park next to it.

## 7.4.4 Navigation

Besides the generation of electricity from hydropower, many dams at European rivers serve to facilitate or even enable inland water navigation. Figure 7-20 shows the main water bodies used for freight transport by inland navigation. Although many European rivers serve as route for waterway transportation, the highest transportation density can be found on a limited number of waterways.[97] Waterways in Central-Western European countries account for the major part of freight volumes, while other waterways are far less used. This suggests that the benefits for navigation have a clear regional focus.

97 'The power of inland navigation - The future of freight transport and inland navigation in Europe 2013-2014', the Blue Road, 2014

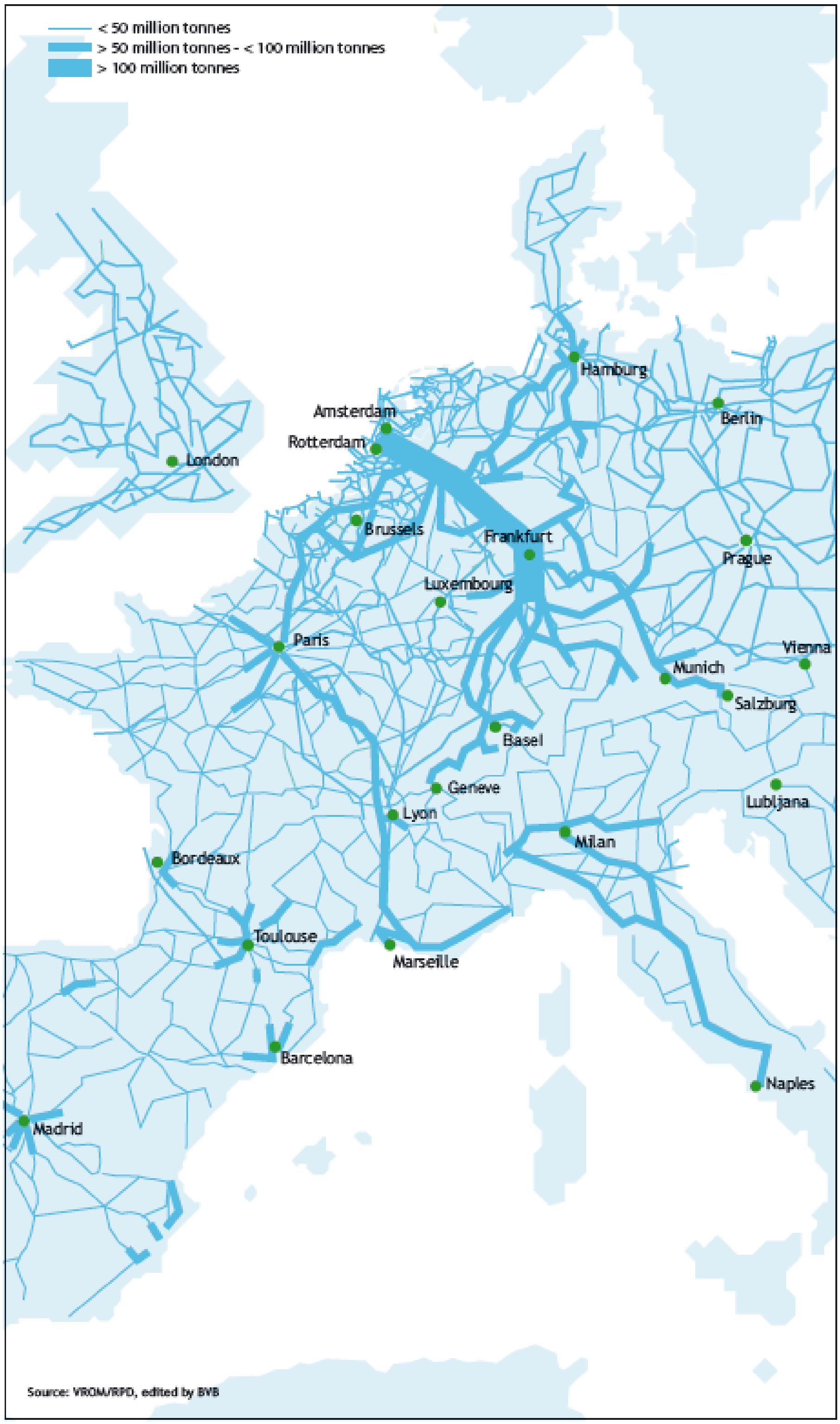


**Figure 7-20: Main ship transportation routes in Europe**

Source: The power of inland navigation - The future of freight transport and inland navigation in Europe, The Blue road, 2014.

Moreover, it is important to note that the analysis in this study limited to multipurpose benefits of hydropower. Consequently, the analysis has to be limited to those (parts of) river systems where the water flow is regulated by dams, which also provide hydropower. Taking into account these constraints, we therefore limit the analysis in this section to the following rivers and river sections:

- Upper Rhine and its contributories, incl. Main, Neckar, Saar (Germany), Mosel (Germany and France),
- Upper Danube (German and Austrian parts),
- Rhone / Saone (France),
- Maas (Belgium).

## Methodological Approach and Assumptions

In order to quantify the economic value of inland water navigation, we consider the comparative advantage of freight shipping compared to cargo transportation via motorway and railway. As most of the main waterways cross the border between two countries at one point or another, we hereafter analyse benefits of waterway transportation on the basis of rivers and not on a country-basis.

Our estimates rely on total transport volumes for the main waterways that are valued at the specific costs of transportation. The costs of different transport means are derived from different external and transport costs studies. The benefit which may be attributed to hydropower corresponds to the net costs saving of water borne transport compared to transport via other means.

## Transportation Volumes and Distances by River

The basis for our calculations is the total transport intensity (tons * km) on rivers with considerable freight volumes and that are regulated by dams, which also comprise of hydropower generation facilities.[98,99,100,101] In a strict sense, one may thus argue that the analysis should be limited to only those river sections, which are directly regulated my multipurpose dams that include hydropower. However, this may underestimate the true benefits of hydropower as a single river may contain sections with and without hydropower. Moreover, it seems unreasonable to consider isolated river sections only since this may under-estimate the cost of re-loading cargo. For example, it may be argued that water level regulation at an upstream section may also increase transport volumes on other downstream sections, whereas it may otherwise be uneconomic to use water navigation for the downstream sections only.

For these reasons, we have used three different approaches for estimating transport distances:

1. A lower estimate, which considers only those rivers sections that are directly regulated by hydropower plants, i.e. total transport intensity is reduced in proportion to the ratio between the transportation distance that is regulated by hydropower and total waterway length.[102]
2. An intermediate estimate, which considers the entire length of a major river section, provided that at least part of the waterway is regulated by hydropower plants; this is equivalent to the assumptions that all rivers with hydropower plants are supporting navigation and that the full benefits can be attributed to hydropower,
3. A high estimate, which additionally takes into account benefits of navigation on adjacent waterway, e.g. on the rivers Rhine and Danube where hydropower installations are located upstream, but navigation volumes are considerably larger downstream[103].

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98 Data from data from the Federal Administration for Water and Navigation (Wasser- und Schifffahrtsverwaltung des Bundes, www.wsv.de)

99 « Trafics fluviaux 2013 », Voies navigables de France

100 http://edfluminus.edf.com/fichiers/fckeditor/Commun/EDFLuminus/pdf/2013_Brochure_centrales_hydro-electriques.pdf

101 http://www.binnenvaart.be/nl/waterwegen/kaarten/index.html

102 For instance, at influxes into Rhine river in Germany navigation control accounts for 70-95% of the entire distance from upstream to estuary. Different to that, at Rhine river, shared for transportation to French, German or Swiss destinations, hydropower plants are only present at upstream sections between Basel and Iffezheim, corresponding to a total length of around 200 km.

103 For simplicity, we assume that 50% of transport volumes on the Upper Rhine are also transport on the Middle Rhine, whereas 10% are also assumed to be transported on the Lower Rhine.

Moreover, we assume that distances of waterborne transportation are generally longer than for road or rail transport. Based on a limited check of selected transport corridors, we assume that road and rail transport distances are 25% shorter than for shipping.

Table 7-7 provides an overview of the resulting assumptions for all relevant river systems.

**Table 7-7: Summary of assumptions and input data for inland navigation**

| Country | River | Total length of transportation system<br>km | Share with regulation by hydropower<br>km | Transportation volume<br>In million tkm |
|---|---|---|---|---|
| Germany | Neckar | 203 | 188 | 970 |
| Germany | Main | 387 | 370 | 2835 |
| Germany | Saar | 94 | 74 | 269 |
| Germany / France | Mosel | 519 | 260 | 3552 |
| Germany/ France | Upper Rhine | 214 | 148 | 2412 |
| (considered partially) | Middle Rhine | | | 13688 |
| (considered partially) | Lower Rhine | | | 22035 |
| France | Rhone-Saone | 550 | 500 | 1254 |
| Belgium | Maas | 114 | 70 | 696 |
| Germany / Austria/ Slovakia | Upper Danube | 562 | 410 | 4227 |
| | Lower Danube | | | 3740 |

Source: DNV GL analysis

## Costs of Transportation Means

To estimate the advantages of inland water navigation which may be assigned to hydropower, we compare it with alternative transportation via truck and train. For this purpose we rely on external studies quantifying the (external) costs of different transportation means, as shown in Figure 7-21. Initially, we focus on the difference in transportation costs only, while in an extended analysis we also take external costs into account, like noise, air pollution, accidents, loss in biodiversity, nature and landscape, and traffic congestion. [104]

We note that, for simplicity, external costs are treated as a whole without differentiation. In addition we hereafter neglect methodological differences.[105,106]

104 Moreover, for road transport we have selected only data which corresponds to heavy trucks due to the distance, weight and structure of goods to be transported.

105 including a different data basis and reference years

106 Delft (2011) is a EU-27 study limited to external costs. Infras (2014) estimates external cost specifically for Switzerland.

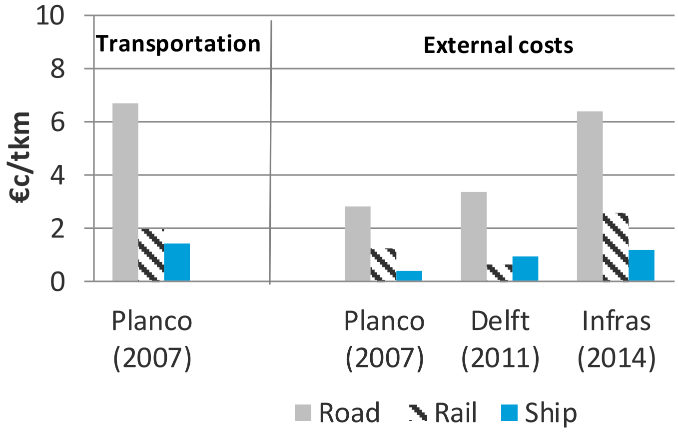


**Figure 7-21: Comparison of transportation and external costs of different transport means**
Source: DNV GL

Apart from the studies mentioned above, scientific analysis suggests that there are also other effects that should be taken into account, in particular costs from traffic congestion. A 2008 study[107] estimates marginal traffic congestion costs for different road types (motorways, main roads and other roads for metropolitan, urban and rural areas) and densities of traffic. Based on that, we estimate traffic costs to be at 0.4 EUR/tkm.[108]

Combining the cost estimations from the different studies cited above, our comparison of net benefits between the three carriers relies on the following assumptions and combines the costs of transportation, external effects, and traffic congestion.

**Table 7-8: Assumptions on transport costs (cEUR/tkm)**

| Cost basis | Transport medium | | |
|---|---|---|---|
| | Road | Rail | Waterway |
| Transportation only | 6.66 | 2.02 | 1.39 |
| Including costs of external effects and congestion | | | |
| Source 1 (Planco) | 9.44 | 3.32 | 1.78 |
| Source 2 (Delft) | 10.00 | 2.69 | 2.34 |
| Source 3 (Infras) | 13.04 | 4.66 | 2.58 |

Source: DNV GL analysis

## Results

Based on the methodology and assumptions explained above, Figure 7-22 shows the resulting net benefits of inland water navigation on relevant river systems. There is a clear cost advantage of shipping over road. When considering transportation costs only and using the low estimate of relevant river sections, the net benefit is about EUR 0.5bn. It increases to approx. EUR 1bn when using the upper estimate of relevant transport distances, i.e. when partially including transport volumes on the Middle / Lower Rhine and the Middle Danube. When also considering the external costs of transport, the corresponding numbers range between EUR 0.7bn and 2.1bn.

107 Handbook on estimation of external costs in the transport sector (IMPACT), CE Delft/Infras/ISI, 2008

108 As costs are stated on vehicle km basis, they need to be transferred into tkm. We therefore assume that transportation via truck will involve mainly the use of heavy trucks on motorways and main roads at a split of 80%/20% to replace waterborne transport between ports. Moreover, we assume a split of 80%/15%/5% between free flowing, high density of traffic and congested sections, and the use of trucks loaded at 30 tons.

In contrast, the net benefits of shipping compared to rail transport are small or may even become negative, depending on the underlying assumption on external costs. At a maximum, the net benefits of river vs. rail transport for the relevant river sections amount to approx. EUR 250mn only.

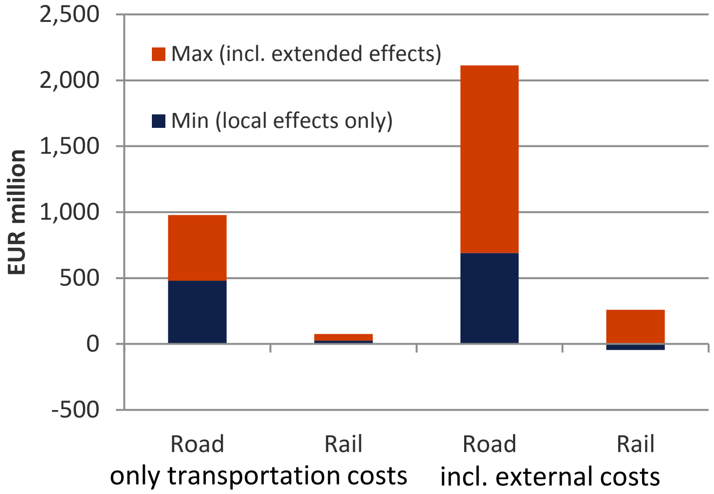


**Figure 7-22: Net benefits of hydropower induced inland navigation compared to road and rail transport with transportation cost (upper graph) and without (lower graph)**
Source: DNV GL analysis

In summary, these estimates show that the net benefits strongly depend on the reference for comparison (road, rail) as well as on the definition of relevant river sections. From a conservative point of view, the net benefits of shipping over other transport means are not more than 200mEUR, while a more optimistic interpretation may reach be up EUR 2bn annually. In this context, it is worth noting that bulk and hazardous goods, which represent a large share of total transport volumes on inland waterways, are typically transported either by rail or by ship. Hence, shipping seems to be more comparable to rail than to road transport.

When interpreting these results, it should furthermore be noted that many of the corresponding multipurpose installations were originally built with the aim of regulating water flows and promoting inland navigation, while hydropower generation often represented an additional benefit only and has sometimes been implemented ex post only. Hence, it may be argued that the benefits of navigation may not be attributed to hydropower installations, but vice versa. This favours a more conservative interpretation of numbers.

## 7.5 Fact Sheets

### 7.5.1 Development of the hydropower sector

**Europe**

| Category | 2013 | 2030 Ref Low | 2030 Ref Base | 2030 Ref High | 2030 DST Low | 2030 DST Base | 2030 DST High |
|---|---|---|---|---|---|---|---|
| Hydropower | | | | | | | |
| Installed capacity - GW | 216 | 262 | 266 | 276 | 258 | 263 | 273 |
| Annual generation - TWh | 613 | 647 | 707 | 737 | 638 | 692 | 722 |
| Production share - % | 18% | 15% | 16% | 17% | 15% | 16% | 17% |
| RES production share - % | 59% | 32% | 34% | 35% | 29% | 30% | 34% |

| Category | 2010 | 2030 Ref Low | 2030 Ref Base | 2030 Ref High | 2030 DST Low | 2030 DST Base | 2030 DST High |
|---|---|---|---|---|---|---|---|
| Fossil Fuel Consumption & CO2 Emissions | | | | | | | |
| Total fossil fuel consumption - PJ | 16,788 | 9,659 | 9,311 | 9,145 | 8,638 | 8,327 | 8,061 |
| Fossil fuel costs - m€ | 71,968 | 80,221 | 76,228 | 73,770 | 60,327 | 57,830 | 55,755 |
| CO2 emissions - Mio. t | 1,334 | 704 | 685 | 679 | 579 | 560 | 544 |
| CO2 costs - m€ | 20,009 | 24,655 | 23,982 | 23,769 | 30,665 | 29,674 | 28,810 |

**EU-28**

| Category | 2013 | 2030 Ref Low | 2030 Ref Base | 2030 Ref High | 2030 DST Low | 2030 DST Base | 2030 DST High |
|---|---|---|---|---|---|---|---|
| Hydropower | | | | | | | |
| Installed capacity - GW | 149 | 177 | 177 | 184 | 174 | 174 | 181 |
| Annual generation - TWh | 385 | 374 | 396 | 413 | 365 | 381 | 398 |
| Production share - % | 13% | 11% | 11% | 12% | 10% | 11% | 11% |
| RES production share - % | 48% | 23% | 24% | 24% | 20% | 21% | 24% |

| Category | 2010 | 2030 Ref Low | 2030 Ref Base | 2030 Ref High | 2030 DST Low | 2030 DST Base | 2030 DST High |
|---|---|---|---|---|---|---|---|
| Fossil Fuel Consumption & CO2 Emissions | | | | | | | |
| Total fossil fuel consumption - PJ | 15,326 | 7,539 | 7,388 | 7,264 | 6,721 | 6,597 | 6,378 |
| Fossil fuel costs - m€ | 65,786 | 62,191 | 60,382 | 58,425 | 48,259 | 47,371 | 45,643 |
| CO2 emissions - Mio. t | 1,226 | 554 | 546 | 542 | 441 | 432 | 419 |
| CO2 costs - m€ | 18,389 | 19,381 | 19,105 | 18,973 | 23,349 | 22,902 | 22,192 |

### 7.5.2 Direct and indirect macroeconomic effects of hydropower

**Europe**

| Category | 2013 | 2030 Ref Low | 2030 Ref Base | 2030 Ref High | 2030 DST Low | 2030 DST Base | 2030 DST High |
|---|---|---|---|---|---|---|---|
| Employment | | | | | | | |
| Total direct employment - FTE | 63,232 | 75,605 | 76,835 | 79,475 | 74,612 | 75,851 | 78,482 |
| Indirect employment - FTE | 56,357 | 68,730 | 69,960 | 72,600 | 67,737 | 68,967 | 71,607 |
| Value creation | | | | | | | |
| Value creation (generation only) - m€ | 31,767 | 67,515 | 72,693 | 73,457 | 57,106 | 60,634 | 61,446 |
| Investments | | | | | | | |
| Maintenance/refurbishment (p.a.) - m€ | 3,268 | 3,985 | 4,057 | 4,210 | 3,928 | 3,999 | 4,152 |
| New investments (cumulative from 2013) - m€ | 3,441 | 84,915 | 94,315 | 114,836 | 79,800 | 80,740 | 109,618 |
| Taxes | | | | | | | |
| Total taxes - mn | 14,578 | 28,366 | 30,501 | 30,841 | 24,090 | 25,549 | 25,908 |

**EU-28**

| Category | 2013 | 2030 Ref Low | 2030 Ref Base | 2030 Ref High | 2030 DST Low | 2030 DST Base | 2030 DST High |
|---|---|---|---|---|---|---|---|
| Employment | | | | | | | |
| Total direct employment - FTE | 48,764 | 50,176 | 50,171 | 51,312 | 49,353 | 49,268 | 50,487 |
| Indirect employment - FTE | 41,889 | 43,301 | 43,296 | 44,437 | 42,478 | 42,393 | 43,612 |
| Value creation | | | | | | | |
| Value creation (generation only) - mn | 20,143 | 41,159 | 43,086 | 43,791 | 35,137 | 36,085 | 36,718 |
| Investments | | | | | | | |
| Maintenance/refurbishment (p.a.) - mn | 2,239 | 2,935 | 2,935 | 2,999 | 2,913 | 2,893 | 2,976 |
| New investments (cumulative from 2013) - mn | 509 | 49,408 | 49,439 | 63,835 | 44,292 | 39,926 | 58,617 |
| Taxes | | | | | | | |
| Total taxes - mn | 8,500 | 15,200 | 15,893 | 16,157 | 13,028 | 13,368 | 13,607 |

### 7.5.3 Macroeconomic effects induced by hydropower (12 countries)

**Europe**

| Induced Effects | High-low sensitivity - Reference scenario | High-low sensitivity - Diversified supply |
|---|---|---|
| Value Creation | | |
| Lower bound - m€ | 566 | 805 |
| Upper bound - m€ | 1416 | 2012 |
| Employment | | |
| Lower bound - FTE | 8.258 | 11.575 |
| Upper bound - FTE | 20.647 | 28.936 |

**EU-28**

| Induced Effects | High-low sensitivity - Reference scenario | High-low sensitivity - Diversified supply |
|---|---|---|
| Value Creation | | |
| Lower bound - m€ | 488 | 721 |
| Upper bound - m€ | 1.222 | 1.804 |
| Employment | | |
| Lower bound - FTE | 7.246 | 10.964 |
| Upper bound - FTE | 18.115 | 27.409 |

## About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.