

Pumped hydro storage as enabler of energy transition

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Kurzfassung

Pumpspeicherkraftwerke als Baustein der Energiewende

Die strategischen Ziele des Europäischen Klima- und Energiepakets (CEP) werden in den kommenden 30 Jahren zu einer erheblichen Dekarbonisierung des Energiesystems führen. Strom wird sich zur dominierenden Energiequelle entwickeln. Insgesamt werden die hoch intermittierenden Quellen Windkraft und Photovoltaik die Erzeugung aus Kohle- und Kernkraftwerken in erheblichem Umfang ersetzen, während Gaserzeugungskapazitäten und KWK (fossil und Biomasse) als wesentliche Ergänzung bestehen bleiben. Der Wandel erfolgt auf allen Stufen der Wertschöpfungskette, gleichzeitig, mit hoher Geschwindigkeit und mit zunehmend fehlender Systematik.

Die ehrgeizigen Ziele werden zu einer enormen Dynamik des österreichischen Stromversorgungssystems und einer Erhöhung des Flexibilitätsbedarfs in allen Zeiträumen führen.

Die vorliegende Analyse beantwortet folgende Fragen:

- Wie entwickeln sich die österreichischen Residuallastparameter unter sehr hohen Anteilen an intermittierender erneuerbaren Anteilen?
- Können dezentrale Speicher zur Systemstabilität beitragen?
- Wie profitiert das System von der Wasserkraft?

The strategic targets of the European Climate and Energy Package (CEP) will cause a substantial decarbonisation of the energy system within the coming 30 years. Electricity is about to become the dominating energy source. In an overall context, the highly intermittent sources wind power and photovoltaics will substitute generation from coal and nuclear power plants to a significant extent, while gas generation capacities and CHP (fossil and biomass) remain an essential complement. The modification takes place at all stages of the value chain, at the same time, at high speed and in an increasingly uncoordinated manner.

The improvement of electricity infrastructure and system relevant stabilising elements cannot keep up with the rest of transition. The amount of reserves stepwise overrules the given physical reality. As long as calculable thermal units have dominated generation within the EU, system adequacy was calculated by deterministic methodologies. Calculation was reliable. However, the high proportion of feature dependent power generation (e.g. wind power, PV, ...) together with an increasingly dynamised load made stochastic methodologies necessary (ENTSO-E 2015). The determination of security of supply therefore can no longer be done at the desired level of precision. Additionally, massive corrections and adjustments of energy policy targets of key players (e.g. German coal phase out, ...) without any known fall back strategies are overruling previous planning assumptions fundamentally. In Central Europe, during the first two quarters of 2019 there were at least four critical system situations observed. Finally, national energy regulators repeatedly give black out warnings.

Energy transition is about to develop as a large scale experiment with an uncertain outcome.

This mix of increasing uncertainties more than ever demands for reliable flexibility solutions. To reduce imported flexibility risk, Art. 22 lit. d) of Reg. (EU) 2018/1999 requires, that every country has to increase the flexibility of the national system in particular by means of deploying domestic energy sources, demand response and energy

storage, while critics of power plant projects claim for flexibility procurement mainly based on cross-border-exchange.

From the beginning, Austria has decided upon generation preferably from renewables. Hydropower is the backbone. Today, with a RESE share of appr. 72%, Austria is top ranking within the EU28. Supporting EU's CEP targets, in 2018 Austria decided to have an electricity system in 2030 based on 100% renewable electricity (balanced p. a.) meaning, that within the coming 10 years appr. 30 TWh of additional RESE has to be installed (#mission 2030). While biomass is lacking potential, hydropower (plus 6 to 8 TWh), wind power (plus 10 to 12 TWh) and PV (plus 10 to 12 TWh) are expected to match the game. In a longer run, Austria's full hydropower potential of in total 11 TWh is ready for use (Pöyry 2017). This ambitious target will result in an enormous dynamisation of the Austrian system and an increase of flexibility demand in all time frames.

The given analysis responds to the following questions:

- How do Austria's residual load parameters develop under extreme shares of intermittent RESE?
- Can decentralised storage contribute to system stability?
- How does the system benefit from hydropower?

Key findings

For the given Austrian energy strategy targets, already from 2025 on disproportionate growth for all residual load parameters is expected. Negative residual load will increase more than the positive. Peaks (PRLmax) come up to at least -6 GW and gradients (Δ PRL) of more than 3 GW/h with frequent changes of sign (+/-) are expected (Table 1). Large daily lifts of the residual load of more than 9 GW are likely. From 2030 on, the seasonal energy flexibility need of at least appr. 7 TWh in addition to existing storage capacities is evident.

Choosing the proper generation portfolio, to a certain extent run of river plants damp intermittency effects of PV and wind power on the residual load. However, the greatest

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Tab. 1. Changes of residual load characteristics caused by the nation energy strategy #mission2030.

#mission2030		2020	2025	2030	2040	2050
ERLpos	[TWh]	28,6	23,7	20,4	23,4	28,2
ERLneg	[TWh]	-1,1	-3,2	-6,8	-10,5	-12,4
of which seasonal shift	[TWh]	-1	-3	-6	-9	-10
PRLmax	[GW60]	10,3	10,6	11,0	12,9	15,4
PRLmin	[GW60]	-4,4	-6,1	-9,6	-14,3	-17,7
Jahresmax(PRLmax(d) - PRLmin(d))	[GW/d]	7,9	9,5	11,2	15,9	20,2
ΔPRLmax pos	[GW/Std]	2,4	2,8	3,1	4,1	5,3
ΔPRLmax neg	[GW/Std]	-2,4	-3,3	-4,1	-4,9	-6,5

effect for increased flexibility in all time frames including seasonal flexibility is given by hydro storage and pumped hydro storage power plants. Additionally, they reduce the costly dynamic electricity generation and CO₂-emissions of thermal plants, avoid the power reduction at wind- and PV-generation sites and improve big scale RESE integration to the system. This also applies cross-border. Last but not least, from the Austrian point of view, net imports and thus dependence on fossil and non-fossil energy imports can be reduced (TUW 2017).

In order to guarantee policy success, in the sense of a sustainable Austrian long-term strategy it is suggested to consider and accept the role for the new construction and/or the extension of domestic hydropower and in particular the alpine (pumped) hydro storage using the available potential. Appropriate operational framework (in particular for the surge/sunk question) should be provided for the optimised development of the flexibility effect of hydropower. System stability, security of supply as well as the large-scale integration of wind power and PV in Austria can thus be guaranteed also in future.

The enormous challenges are imminent. The speedy handling of permit proceedings is necessary.

The use of additional options (gas CHP and CHP, biomass plants, P2X, decentralised solutions such as battery storage and DSM, cross-border exchange, ...) will contribute to success. Decentralised solutions like batteries, DSM, P2H, etc. ... are expected to be preferably used by optimised, customer driven energy management solutions for buildings and/or industries as well as for distribution grids and will have a minor support for system needs. Moreover it may be assumed, that decentralised solutions – caused by these customer driven optimization – may also have negative system effects (peaks caused by price signals, etc. ...).

A polarising discussion on the choice of solutions is not expedient. At the same time, the import of security of supply should be kept at a reasonable level. This is especially true for periods with lacking wind and sun (“Dunkelflaute”).

Stability and security of supply

The energy transition of the coming years is characterised by the following scarce goods: acceptance, affordability as well as availability of energy for the individual and the economy at any time. The premise of the availability of basic services at any time, especially electricity, as a basis for a prosperous European economy directly influences public acceptance. So far, the energy transition has preferably succeeded in the electricity system. This success has mainly been enabled by reserves of grids, thermal power plants and their flexibility as well as hydropower storage and pumped storage. The reserves of available capacities are used up or are rapidly fading in particular by the thermal phase-out in key regions.

A cardiological remote diagnosis for the future European system may find moderate to strong arrhythmias (grid frequency) or even standstills (blackout), if it is not possible – apart from the grid expansion – to replace timely fossil facilities that have provided ancillary services and other flexibility measures to a large extent up to now. Hydro power plants with storage and/or pumped storage functions have fulfilled these tasks emission free, cost-effective, reliable and, above all, predictable for decades, thus contributing today and even more in future as a substantial enabler for the system-wide large scale integration of intermittent RESE-generation – essentially wind power and photovoltaics.

Residual load analysis

Compared to other grid-based energy systems (gas, oil, district heating), the electrical power system is extremely sensitive. The balance between load and generation at any time is the necessary prerequisite for maintaining system stability and thus security of supply. Frequency and voltage are the central parameters for grid stability. Therefore, the mechanisms for maintaining system stability must already start in the seconds range and in the special case of the instantaneous reserve (inertia) even subtransient.

The mere focus on a balanced annual or at most seasonal energy balance by no means

meets these requirements. The ability of a system to respond to changes in generation and / or load is called system flexibility (ENTSO-E 2015). Compared to a decentralised or a distribution grid situation, at the system level, this is essentially given by a performance-oriented short-term flexibility (time range up to one hour). To keep up security of supply, it is also necessary to ensure a balanced energy supply. Even more in future, long-term flexibilisation based on energy storage is of key importance. In Austria, it is targeted for 2030 to cover the electricity supply by 100% from renewable sources (RESE). Additional generation by the highly intermittent and seasonally available wind power and PV sources (approx. 12 TWh each by 2030), supplemented by the seasonal fluctuating run of river power (approx. 6 to 8 TWh out of a total of 11 TWh potential) will be the backbone.

Controllable RESE, such as biomass, have a complementary effect but have only minimal growth potential. Gas-based CHP plants will continue to play an important role, not at least to cover the heat demand of large cities as well as industrial needs. Likewise, the trade-based cross border exchange of renewable energy, which, however, can only be limitedly available for wind power and PV generation due to the simultaneous given wide area meteorological effects. The residual load (PRL) is determined at system level in an hourly resolution as the power difference of the concurrent load of the public grid (LastÖN(t)) and the variable feed-in to the public grid RESEvol(t):

$$PRL(t) = Last\ddot{O}N(t) - \sum RESEvol(t).$$

Residual load is, without further action, the random result of the multicausal relationship between the simultaneous occurrence of (intermittent) generation and load. It is an indicator for the effort given to maintain the balance respectively how much power has to be withdrawn from the system or fed into the system at any time. In the course of an year, PRL(t) can mean positive (the volatile generation is not able to cover the load at the same time, power or energy deficit) as well as negative values (temporary power or energy surplus). Intermittent generation and load only have limited predictable values or correlations in all timeframes.

The use and characteristic of flexibility tools are determined by the steady state characteristics but also significantly by the dynamic characteristics of the residual load, such as its gradient ΔPRL. Compensation must be given by proper flexibility solutions like hydro storage and pumped hydro storage systems, thermal generation, P2X applications, and to a certain extent also by decentralised solutions, such as DSM, battery storage, etc..

Within the framework of the Integrated Climate and Energy Strategy (#mission2030),

Austria aims to cover 100% its electricity demand by renewables (RESE) in 2030, while industrial self-consumption, reserve balancing and balance energy should be covered also by thermal generation in future. From 2025 on, the projected high increase of intermittent capacity (wind: + approx. 4.5 GW, PV: + approx. 10.5 GW) will cause an enormous stress level for Austria's power system in the May to September period, that in relation may even exceed the respective figures of Germany. In particular, the summer surplus (seasonal flexibility) must be highly efficient shifted to winter time.

In the following, the effects of 100% RESE with a high share of intermittent RESE are estimated for Austria's residual load¹⁾. In order to minimise the need for flexibility a priori, a coordinated architecture of the generation mix of PV and wind together with run of river shall be pursued. The correlation of PV generation characteristic is slightly negative (-0.12) compared to wind. The annual simultaneity factor

$$y_{inst} = \frac{\max(PWind(t) + PPV(t))}{PWind_{inst} + PPV_{inst}}$$

of the simultaneous infeed maximums related to the sum of installed capacities is approx. 50%. This temporarily causes moderate compensation effects. Starting at average load conditions, PV infeed significantly decreases and is negligible at times of peak load. This effect will also have to be mitigated by proper central and decentral flexibility measures. Under the given as-

¹⁾ The objective estimate serves to detect trends and the magnitudes of the relevant parameters. To illustrate the bandwidth, the analysis has to be rounded off on the basis of several weather years and scenarios for generation mix and load profile. According to the IKES convention, the gross electricity consumption is reduced by the industrial self-consumption and the control reserve call.

The Austrian hydropower expansion potential amounts to a total of 11 TWh (Pöyry 2018). All data - unless otherwise stated - apply to unaffected generation or load.

sumptions, the characteristics of the Austrian electricity system will change fundamentally within the coming 10 years (see Figure 10). In 2016, a seasonal characteristic is apparent for the total of generation from run-of-river power, wind and PV²⁾, as well as for load, even if recognised in opposite directions. Generation tips are already characteristic today, but they exceed load only in a few hours. Today, a seasonal energy shift is not required by this reason. The infeed tips essentially are determined by wind power. Residual load is overall positive, while already partially with high positive and negative gradients. The gradient of the simultaneous infeed of wind and PV related to the simultaneous load (how much does the intermittent infeed change per hour related to load at the same time?) is moderate.

In 2030 however, the seasonal characteristics of both, the total of infeed and the load of the public grid, will be increased (Figures 5 to 7). While peak loads (load dynamics together with a general increase of annual consumption) increase significantly, the summer load of the public grid increases only moderately, because prosumers are assumed to have an increased self consumption at these times. However, the infeed peaks increase substantially throughout the year and are characterised by a high infeed of wind power and PV in their extremes. Overall, the picture is characterised by a pronounced roughness. Frequently the infeed significantly exceeds the simultaneous load.

There is also a significant need for a seasonal energy shift (seasonal flexibility). The gradient of the simultaneous PV and wind infeed related to the simultaneous load achieves high values throughout the year. The distinctive morning and evening ramps of the residual load are supplemented during the late morning and early afternoon hours with partly steep ramps. Sign changes of the residual load gradients are frequently given.

In the following the results for the most important parameters are summarised for the years of reference until 2050. Unless otherwise stated, the illustrations correspond to a coordinated development of run of river, wind and PV and with equal generation shares extrapolated for the reference years 2040 and 2050 (solid lines). In order to test the limits, hypothetical scenarios based on wind only or PV only or the combination of both are shown as dashed lines.

One of the usual benchmarks for residual load is the RES Load Penetration Index RLPI

$$RLPI = \max\left(\frac{P_{Wind}(t) + P_{PV}(t)}{Last\ddot{O}N(t)}\right)$$

as the annual maximum of the ratio of simultaneous total infeed from wind and PV related to the simultaneous load of the public grid (ENTSO-E 2015). This index provides information about the maximum hourly coverage of the load using wind and PV within one year. Already in 2025, for Austria this index is expected at least 130% with a rapid increase and reaching levels of up to 260% by 2050 (Figure 1).

The phenomenon of a high infeed gradient – load ratio is evident throughout the year. In addition to the residual load gradient, it is an indicator of how quickly the flexibility solutions have to control their infeed or outfeed in order to be able to balance the system at any time. In both energy directions, values of more than 20% and, in some cases, up to 40% are expected by 2030 (Figure 2).

Under the given assumptions, the characteristics of the positive as well as the negative residual load increase disproportionate, while the increase of the negative residual load for both, the energy and the peak power, is much stronger. The cumulative energy content of all hours with a negative residual load may increase from

²⁾ PV infeed to the public grid (PVÖN) by PV directly coupled (PVnonHH(t)) and surplus infeed by prosumers (PVHHÜE(t)).

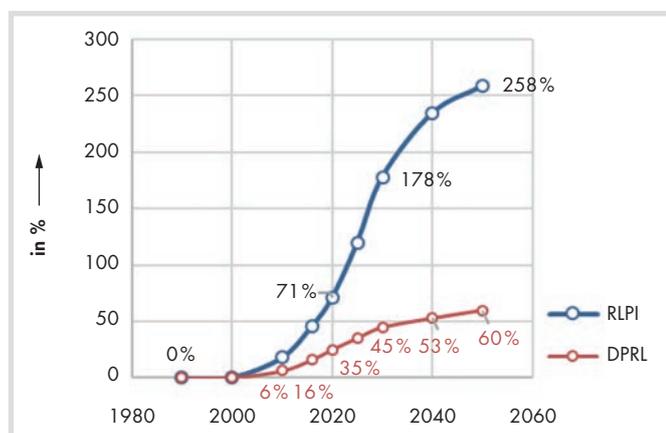


Fig. 1. RES-Load-Penetration Index RLPI and Infeed ratio.

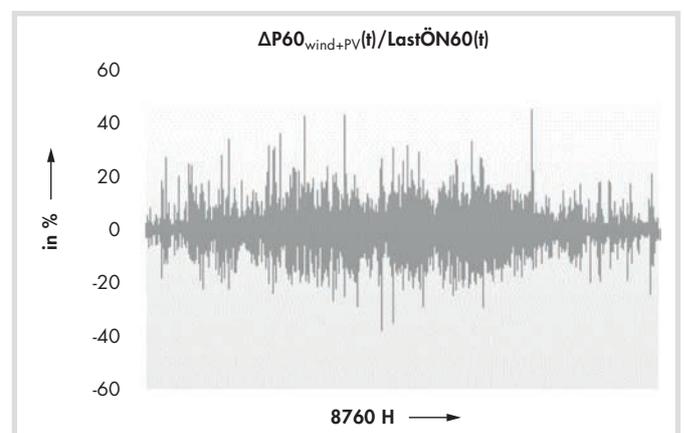


Fig. 2. Already in 2030, the hourly gradient of the simultaneous wind and PV infeed can exceed 40% of the net load in both energy directions for several times.

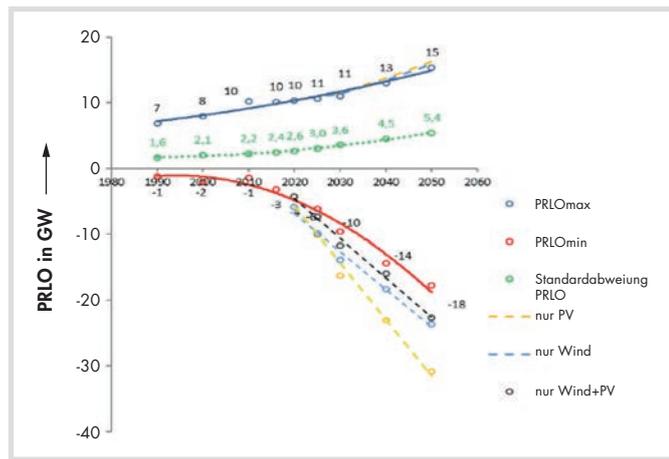


Fig. 3. Residual load peaks (GW60) together with standard deviation 1990 to 2050.

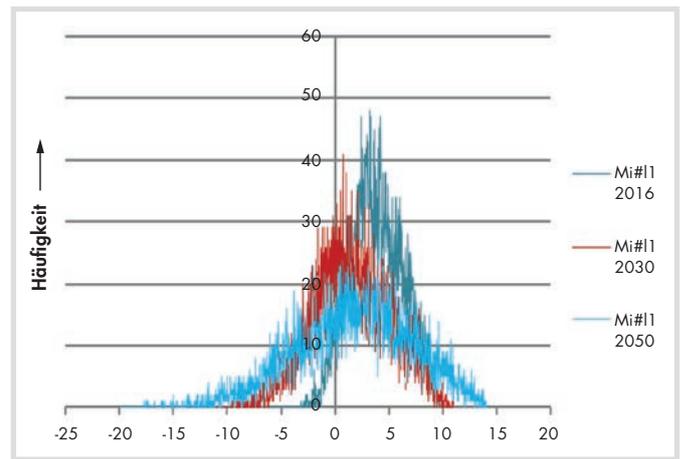


Fig. 4. PRL-Frequency distribution (GW60) for the reference years 2016, 2030 and 2050.

currently approx. -0.4 TWh/a to at least -3 TWh/a by 2025 and to approx. -6.8 TWh/a by 2030. By 2050, -12 TWh/a are foreseeable.

The negative peak PRLmin will double from -3 GW60 today to -6 GW60 by 2025 and reach to -9 GW60 in 2030. Values around -17 GW60 are expected by 2050 (Figure 3). Power peaks of the negative residual load can occur from May to September. From medium classes of its frequency on an increase is expected (Figure 4). If, from 2016 on, additional generation would only be done by wind or PV or a combination of both, the residual load peaks will increase even more in both directions (Figure 3, dashed lines). While for Austrian generation characteristics the combination of wind and PV may have moderate damping effects, the coordinated combination with run of river improves this damping effect significantly.

Essentially negative (energy surplus), strongly intermittent residual load with distinctive gradients and frequent sign changes.

The energy content of residual load and thus the storage requirements for (seasonal) flexibility solutions and to a moderate extent cross border flexibility exchange, will increase stronger than capacity requirement in a further perspective. The energy content of all hours with positive residual load (generation gap from intermittent sources) is approx. 20 TWh in 2030 and approx. 30 TWh by 2050. About 10 GW60 peak remains roughly unchanged until 2030 and will increase to approx. 15 GW60 by 2050 (Figure 4). The block duration of the negative residual load with maximum energy content increases from approx. 16 h (-0.02 TWh) to 117 h (-0.6 TWh) in 2030. It's counterpart for the positive residual load reduces from approx. 2.460 h (12 TWh) to 430 h (3 TWh) in 2030. The number of blocks with positive or negative residual load increases in each case from approx. 110 events/a in 2016 to approx. 340 events/a in 2030.

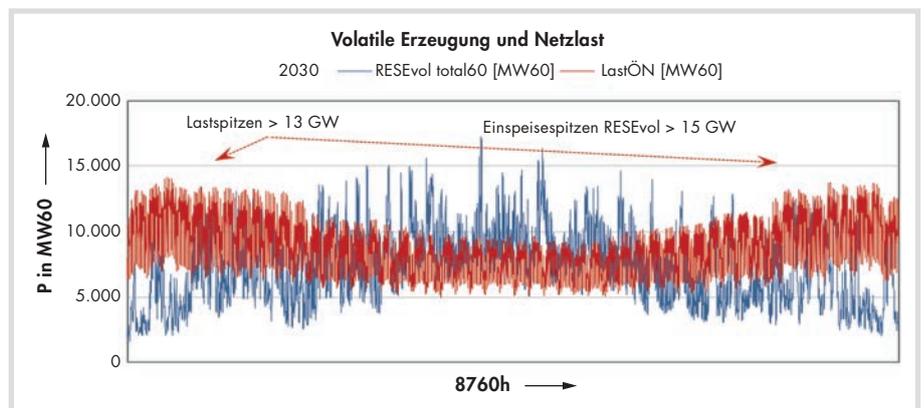


Fig. 5. Estimation of the load of the public grid (LastÖN) and generation from RESEvol (wind + PV + running water). In the summer months there is a pronounced overlap, in the winter months a shortage of the load. Time series 2016 scales for 2030.

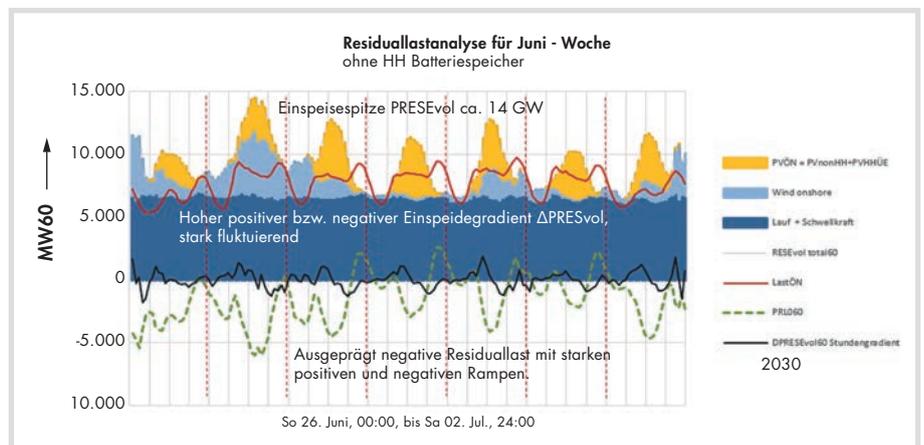


Fig. 6. Random sample for a June week in 2030. Largely constant infeed from run of river combined with more or less strong daily infeed from wind power and PV with partially high infeed peaks, high intermittence and ramps in both directions.

A similar picture emerges for the hourly gradients of the residual load ΔPRL (see Figure 8 and 9). The smoothing effect of the run of river on the residual load gradient is even more evident than for the residual load peaks. In both directions, there is a disproportionate increase of the maximum values from approx. +/- 2 GW/h today to approx. +/- 4 GW/h in 2030 or +/- 6 GW/h in 2050. The frequency of small gradients will decrease in the future, while it will increase for higher ranges in both directions.

The evolution of residual load peak power and gradients significantly increase the need for highly flexible short-term flexibility solutions. 2016 – as typical for the current generation mix – faced only minimal energy surpluses in the summer (Figure 10). The planned Austrian generation mix will cause an estimated seasonal flexibility need of approx. 2.8 TWh already in 2025 (11 % of intermittent summer generation) and at least 7 TWh in 2030 (appr. 18 % of the intermittent summer

Correlations in the Alpine Region

In Europe, as well as in the alpine regions, renewables development will be determined by wind power, PV and hydro.

In the summer months, the daily generation characteristics will be dominated by PV, underpinned by the temporary purchase of wind (Figure 11), whereas in the winter months wind characteristics are decisive. Load, intermittent generation and residual load of Austria is highly correlated with those of other countries of the alpine region (Figure 12). That means, that an area wide generation deficit (positive residual load) or a generation surplus (negative residual load) probably may occur at the same time. This fact is a basic precondition for the definition of a national flexibility strategy and the assess-

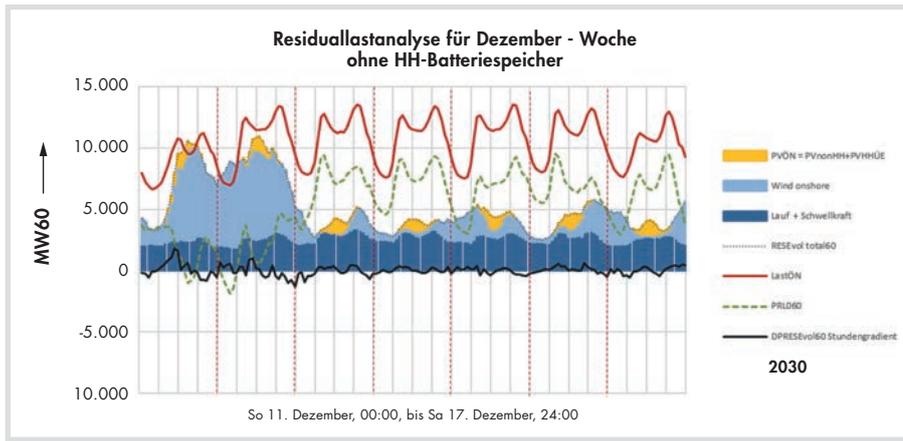


Fig. 7. Random sample for a December week in 2030. Consistently strong wind infeed at the beginning of the week, temporarily supported by moderate PV infeed. High load with distinctive morning and evening peaks. Moderate to strongly intermittent infeed gradient. Strongly intermittent, essentially positive residual load (energy deficit) with high ramps in both directions.

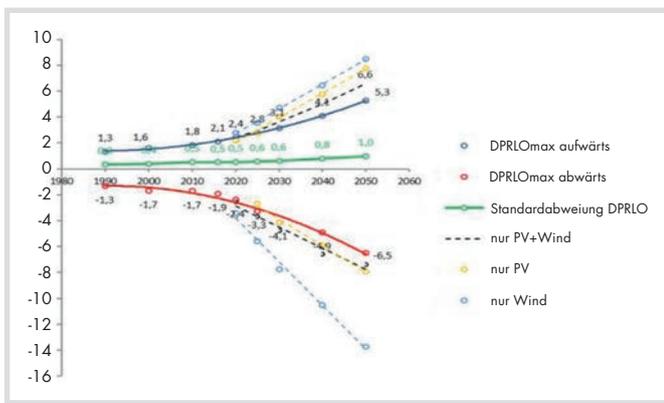


Fig. 8. Hourly residual load gradient $\Delta PRL60$ together with standard deviation, 1990 to 2050.

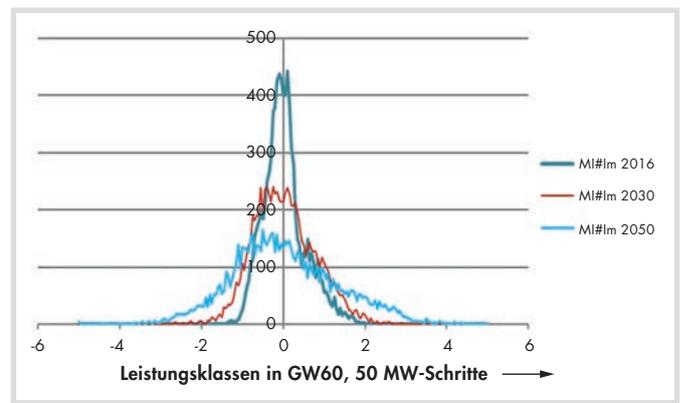


Fig. 9. Frequency distribution of the hourly residual load gradient $\Delta PRL60$ for reference years 2016, 2030, 2050.

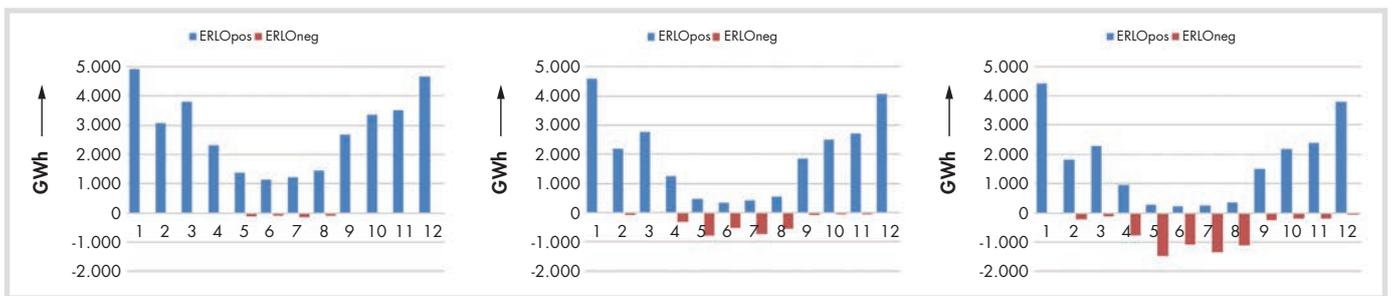


Fig. 10. Monthly accumulated energy content of the positive or negative residual load for 2016, 2025 and 2030.

generation). Compared to other countries, for Austria the issue of seasonal flexibility is of major concern from the mid-2020s on. Hand in hand with the increase of residual load peaks, the annual maximum of daily residual load power increments:

$$\vartheta = \max(PRL_{max}(d) - PRL_{min}(d))$$

experiences disproportionate growth as well, reaching at least 9 GW in 2025 and increasing to at least 20 GW by 2050.

Forced PV and/or wind power expansion cause considerable an increase of these values. The dynamic sampling of the power system due to the emerging wind and PV generation shares has already caused to a

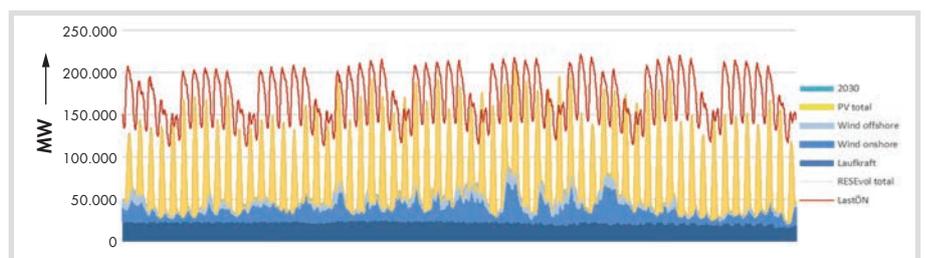


Fig. 11. Cumulative infeed from RESEvol and load in the alpine region (AT, CH, DE, FR, IT, Slo), sample Jun - Jul, 2030.

significantly increased interplay of (pump) storage use in the past. This increase will continue in future.

ment of security of supply, if cross-border flexibility assistance should be taken into account.

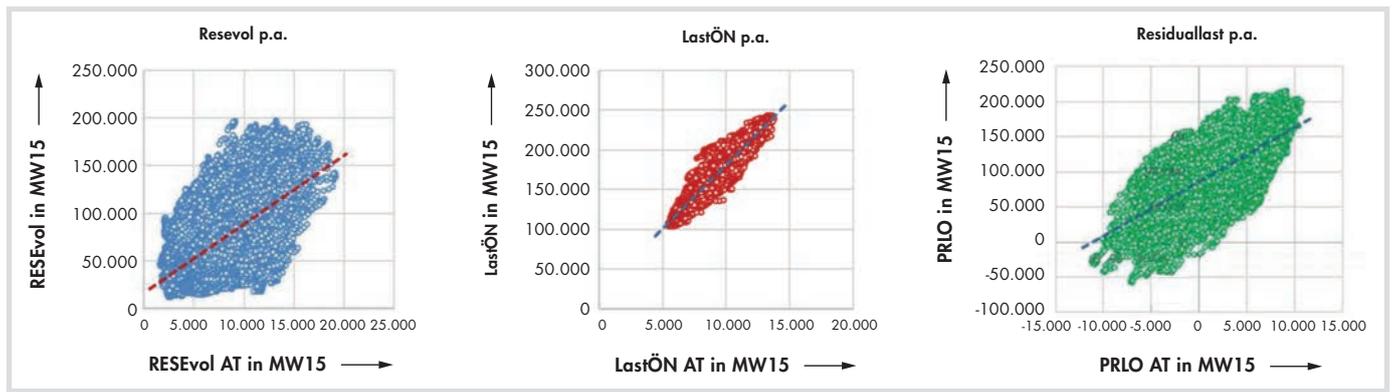


Fig. 12. For 2030 in the Alpine region (AT, CH, DE, FR, IT, Slo) there is a significant correlation of RESE generation (Pearson Coeff. = 0.60), load (Pearson Coeff. = 0.96) and residual load (Pearson Coeff. = 0.67) expected. Data without thermal must-run.

A special phenomenon of concern is a period lacking generation from PV and wind (“Dunkelflaute”) due to wide area meteorological situations. This phenomenon usually occurs in the winter months and has already been observed during the past years by statistics and price signals.

Meanwhile, several publications have analyzed this phenomenon, although it has remained unclear how to define “Dunkelflaute” (minimum intermittence of feed-in, etc.) in a standardised manner. A recent analysis by the TU Dresden (TUD 2019) concludes, that this phenomenon occurs in the medium time range up to 14 days in a significant frequency and is to be mastered especially with hydro storage, when thermal units are expected to be dropped off in future to a significant extent. Further in depth correlation studies for the alpine region remain necessary.

Flexibility options

The overall goal of the energy and climate strategy is the decarbonisation of the energy system in general and of the electricity power system in particular. As a benchmark for success, the RESE generation is related to the gross electricity consumption. The efficiency-first principle (energy and costs) is, additionally to high availability and predictability, the essential precondition for achieving the targets.

As long as the RESE share does not exceed 100%, there will be no electricity surplus in the annual balance. Thus, temporary coverages (negative residual load) from (intermittent) renewable generation must be compensated at the lowest possible costs and be returned to the power system later on. The overall roundtrip efficiency factor of the flexibility process (electricity – electricity) has to be minimised.

According to the architecture of the further renewable generation portfolio in addition to existing electricity hydro power storage capacity Austria needs a flexibility solution with an additional fictitious storage capacity in the amount of Figure 13. To avoid dumped energy, this solution has to cover residual load peaks as given by Figure 3 and gradients according to Figure 8. If further RESE development is preferably based on wind and / or PV, this can cause a doubling of the fictitious storage requirement. Thus, a coordinated mix of suitable RESE technologies together with a moderate cross-border-flexibility exchange to cover short-, middle- and long-term needs should be chosen. For the overall strategic conception of the future Austrian flexibility system the following cornerstones are necessary:

- non-discriminatory, market-oriented use of flexibility assets with full freedom of action with regard to their market use or application alternatives,
- consideration of development of energy policies in neighboring countries, preferably Germany (coal drop off) and availability of grid transfer capacity as well as flexibility capacity for Austrian needs,
- technical characteristics of flexibility assets including operational readiness, system compatibility and climate relevance,
- technical and operational availability and calculability for planning,
- planning period for the system concept versus technical lifetime of the options (capitalised production costs of the services as a basis for an objective comparison of options), level playing field for options,
- energy and cost efficiency.

Regarding these preconditions, the mere addition of statistically listed flexibility capacities of all categories is not useful. The assessment of national flexibility needs, including a moderate cross border exchange, will require a careful monitoring in the future. Wind and PV will continue to have similar characteristics system wide – in particular in the case of “Dunkelflaute”. While Germany’s further change to a net electric-

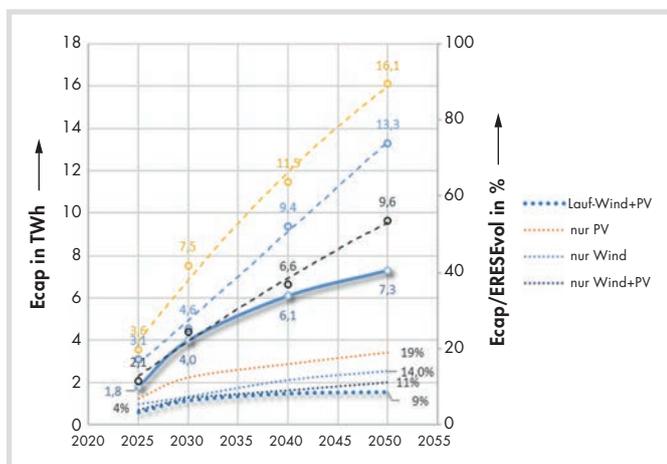


Fig. 13. Fictitious minimum storage capacity requirements for the AT-flex pool depending on RESE scenarios. Existing storage capacities are to be added.

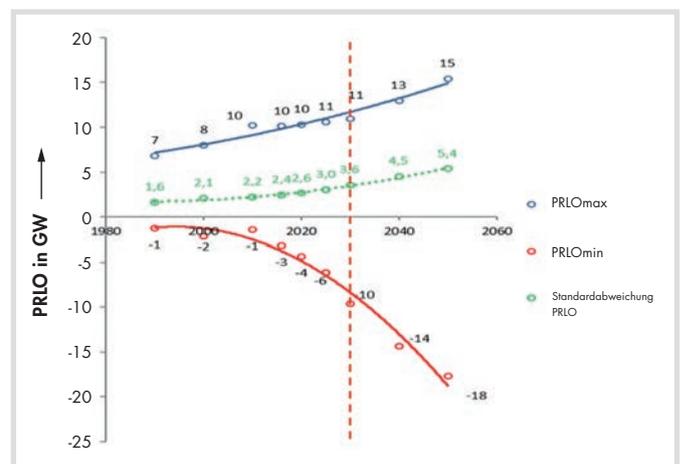


Fig. 14. Extrema of the residual load.

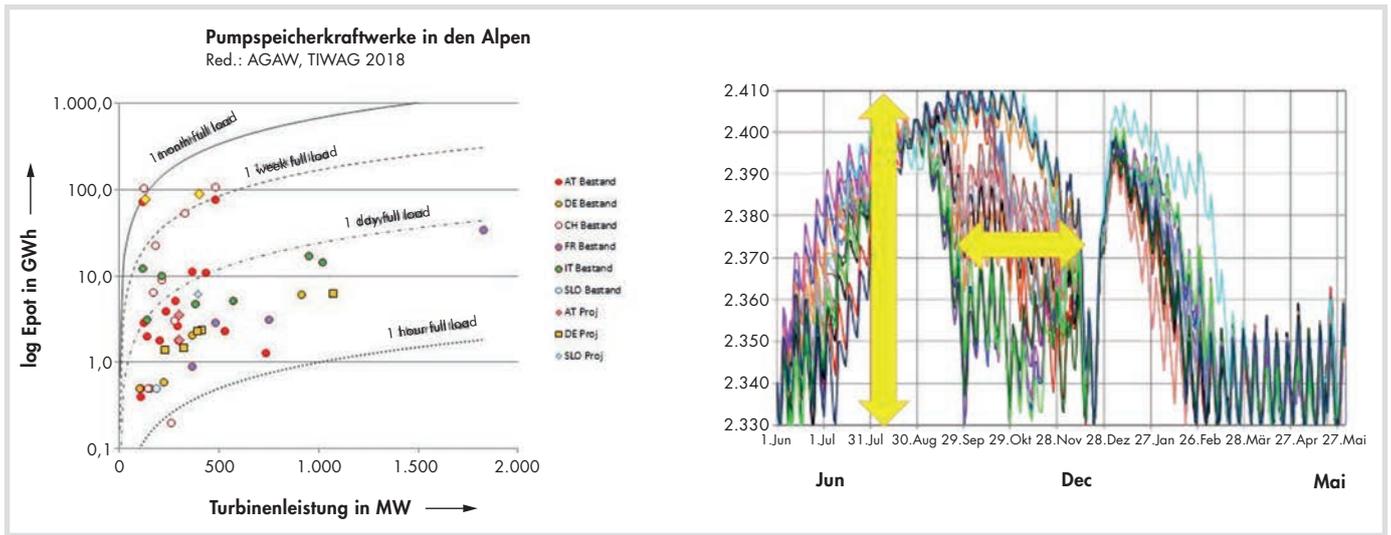


Fig. 15. Alpine (pump) storage is a multi-utility toolbox for the system requirements of the 21st century and differs from typical central European pumped storage solutions with medium drop height and small basins that are usually used for short term flexibility. Additionally, alpine storage solutions store energy from natural inflow from June to October, provide flex-products and ancillary services at all time scales characterised by maximum availability and flexibility (TIWAG 2018).

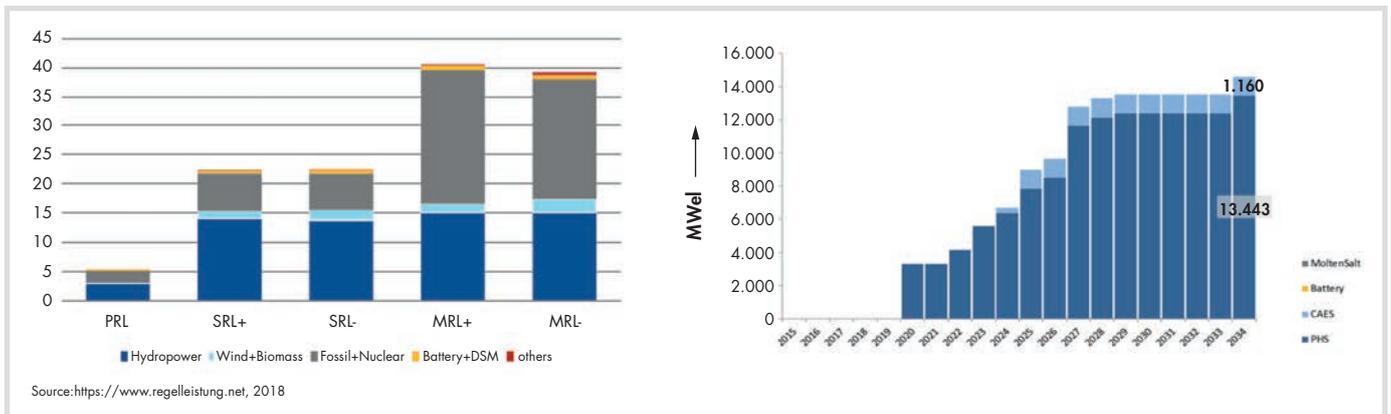


Fig. 16. Prequalified reserve capacities (GW) for Germany by generation type (left). Also in the long run, pumped storage technology remains the leading flexibility option for the Pan-European Energy System (ENTSO-E, TYNDP 2018, Project Fact Sheet).

ity importer was already fixed by the given national plan from 2030 onwards, today the extent, timing and type of replacement for decommissioned coal-fired power plants expands this import dependency on electricity. It's dimension is unknown. Also in future, France and Belgium will be confronted with a high degree of planned non availability of nuclear generation caused by maintenance, even while cold periods. The generation-side assessment of security of supply (system adequacy) has so far been carried out deterministically on the basis of predictable assets, mainly thermal power stations and (pumped) hydro storage facilities. With the significant intermittent renewable share there is a lack of calculable dimension. Meanwhile, it has been necessary to switch to probability-based methodologies (ENTSO-E SOAF). The upcoming challenges of residual load development will require to use all options of flexibility to safeguard system stability.

A polarising debate in favor of a particular technology therefore is not a priori expedient. A given level playing field is a key factor for further success.

Hydropower storage and pumped hydro storage

Today, hydropower plants represent 96 % of world's operational electricity storage capacity. Also for Austria, the expansion of existing assets as well as new constructions are mandatory to maintain system stability and security of supply. Scale effects also apply here. Large, compact solutions provide energy- and cost-efficiency.

In a longer run, power to gas may be expected to act as a complementary solution. Presumed, that this technology proceeds commercially for large-scale use and its efficiency will be improved significantly.

Compared to typical storage facilities in low mountain ranges, alpine (pumped) hydro storage power plants with their enormous storage volumes combined with large drop heights and huge machine capacities together with the use of natural inflow provides all flexibility needs of the 21st century. New plant concepts also focus on seasonal storage requirements (Figure 15 left). The use of natural inflow is an integral part of the plant design expands

the range of flexibility applications (Figure 15, right). This combination is a unique feature of alpine hydropower. During the period from June to October, melting snow and rainfall fill the reservoirs and thus ensure seasonal flexibility (Figure 15 right, envelope curve).

This seasonal storage of primary energy is unique. In this case, the potential energy of water is stored, not electricity. Therefore, this form of seasonal storage is lossless. At the same time, the need for short-term flexibility in both energy directions is met. The generation of renewable energy from the use of natural inflow is a by-product and inherent in the concept. The use of the natural inflow has always been common for pump storage concepts in the alps and may accounts for a significant share of green electricity production up to 8% of a country's annual RESE generation.

³ The term storage facilities in this context refers to other storage technologies, such as battery or compressed air storage, etc.

Even in thermally dominated systems, such as Germany, hydropower storage and pumped storage safeguard a sizeable share of system reserves, where installations of the Alps are essential (Figure 16). Efforts to strengthen Europe's energy infrastructure therefore not only include the expansion of transmission capacities, but also the integration of (pump) storage capacities in the Alps and their expansion (ENTSO-E (2017, 2018)). In terms of the Pan-European energy strategy, the cross-border relevance of such installations based on the Energy Infrastructure Regulation (EU) 347/2013 has an European dimension. Highly qualified, large (pumped) storage facilities³ also can achieve the status of Projects of Common Interest (PCI). According to the current planning, more than 13 GW of additional pumped storage capacity is planned for the maintenance of overall system stability, security of supply and large scale renewable energy integration. Austrian projects share not less than 13%. Thus, also in a long run pumped storage technology will be the backbone for system wide stability and security of supply (Figure 16).

Additionally, the rotating mass (inertia) of directly grid connected machine sets of large hydropower units will play an increasingly important role for the transient stability, when thermal plants are successively dropped off, an wind power and PV are indirectly connected to the distribution grid by power electronics. The integration of the so-called "synchronous inertia", in particular of large hydropower at the system level, will play an even more important role for grid stabilization in by instan-

aneous reserve. Solutions with the help of power electronics for wind power, PV and decentralised battery storage systems (synthetic inertia) can be considered only a partially effective replacement for the rapid instantaneous reserve of thermal systems because it's delays by control procedures are relevant (dena 2015).

There is lacking public awareness on the role of alpine hydro storage and pumped storage power plants at all scales to avoid or overcome system instability resulting from anomalies of load and/or generation. Over the past 20 years, repeatedly there have been critical events that caused or were close to widespread major disruptions. The most well-known was the one from 2006 and most recently the one at the turn of the year 2018/2019. As a rule, where possible and being part of a well organised grid restoration concept, (pumped) hydro storage assets (black start and islanding operation capability) are a fixed solution to restore grids to islanding grids after black outs, keep the operation of islanded grids stable and finally help to reconnect islanded grids to a system. In such events, they significantly contribute to minimise or even avoid enormous economic damage.

Therefore it has to be recommended that both, repowering and new construction of hydropower assets and in particular all sorts of hydropower storages are given the appropriate role in the upcoming years of energy transition. Moreover, regulatory conditions shall safeguard its full operational functionality and thus its full system benefit.

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Interaction of Conformity Assessment and Industrial Safety in Hydropower Plants

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In this context, hydropower generation bears some specifics in terms of technology, operational conditions, regulatory framework and external influences.

VGB PowerTech and experts from various companies agreed to develop a practical guideline to this complex matter for hydropower operating companies and manufacturers.

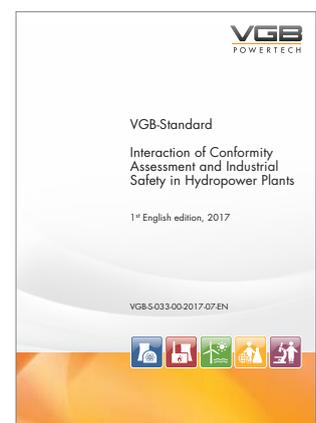
This first English edition is based on the second German edition, which includes the outcomes of a comprehensive review performed by the original authors.

This document is intended to support the involved parties in achieving compliance for all regulatory requirements and to foster a cooperative project realization.

The guidance provided in this document assumes the correct technical characteristics for all components of a product.

Chapter 4 provides a general overview on hydropower generation, which allows a first introduction into this complex matter, while the remaining chapters are essential.

In Chapter 11, practical hydropower examples are described.



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