Hydro Storage as Enabler of Energy Transition

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Abt. Energiestrategie und Energieeffizienz

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Abstract: Energy transition is speeding up. Europe's economy is about to be decarbonized until 2040. Carbonless electricity generation is expected to have large shares of energy procurement, while endenergy consumption will be provided by electricity directly and sector coupling products as well. Thanks to hydropower, Austria starts from a 74 % RESE-share today and national energy policy claims a 100 % RESE target until 2030. Hydropower, windpower, PV and to a small extent biomass will have to match the game.

Extreme high shares of highly intermittent generation of windpower and PV will disproportionately increase Austria's flexibility needs in all timeframes up to seasonal dimensions, when system stability and security of supply shall be kept at today's level.

The given study analyses residual load parameters of Austria's electricity system up to 2050, estimates flexibility demand and discusses the central role of highly efficient hydropower to meet these challenges. Furtheron it discusses how reliable imported flexibility could be, when neighbouring countries implement thermal drop off.

With it's ambitious decarbonisation targets Austria develops a field test for flexibility needs at times of highly intermittent RESE shares. Basic conclusions on residual load development as well as the role of hydropower to match ramping needs may be generalised for other regions. The ability of modern hydropower designs in the Alps to provide also seasonal flexibility is underlined.

Keywords: energy transition, hydropower, storage, decentralized storage, pumped hydro, flexibility, system stability, security of supply, residual load, ramping, sector coupling, intermittent renewables, windpower, photovoltaics.

1 Introduction

The strategic targets of the European Climate and Energy Package (CEP) aim to decarbonize the energy system until 2050, while the “Green Deal” shifts this target forward to 2040. 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 stabilizing elements cannot keep up with the rest of the 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 determined by deterministic methodologies. This calculation was reliable. However, the high proportion of feature dependent power generation (e.g. wind power, PV, …) together with an increasingly stimulated load profile 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 at the time given 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 longs for reliable flexibility solutions. To reduce risk from imported flexibility, 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 very beginning, Austria has decided upon generation preferably from renewables. Hydropower is the backbone. Today, with a RESE share of more than 72 %, Austria is top ranking within the EU28. Supporting EU's CEP targets, in 2018 Austria decided to have an electricity system based on 100 % renewable electricity (balanced p. a.) in 2030 meaning, that within the coming 10 years appr. 30 TWh[1] of additional RESE has to be installed (#mission 2030). While biomass is lacking potential, hydropower (plus 5 – 8 TWh), wind power (plus 10 - 12 TWh) and PV (plus 10 - 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 therefore responds to the following questions:

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

2 Key Findings

For the given Austrian energy strategy targets, already from 2025 on disproportionate growth is expected for all residual load parameters. Negative residual load will increase more than the positive. Peaks (PRLmax) come up to at least -6 GW and ramps/gradients (ΔPRL) of more than 3 GW/h with frequent changes of sign (+/-) are expected (Tab. 1). Large daily lifts of the

[1] Rem.: In 2018 first estimations suggested appr. 30 TWh of additional RESE, while the current policy program (2020) fixes this target to appr. 27 TWh.

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 (appr. 4.3 TWh) 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 most effective and efficient influence on 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 power reduction at wind- and PV-generation sites (dumped energy) and improve big scale RESE integration to the system. This also applies cross-border. Last but not least, from the Austrian perspective, net imports and thus dependence on fossil and non-fossil energy imports can be reduced (TUW 2017).

#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

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

In order to guarantee policy success and 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 alpine (pumped) hydro storage using the available potential. Appropriate operational framework (in particular for the surge/sunk question) should be provided for the optimized 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 be guaranteed also in future.

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

The use of additional options (gas and biomass CHP, P2X, decentralized solutions such as battery storage and DSM, cross-border exchange, ...) will contribute to success. Decentralized solutions like batteries, DSM, P2H, etc. … are expected to be preferably used by optimized, 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 decentralized solutions – caused by these customer driven optimization – may also have negative system effects (peaks caused by price signals, etc. …).

A polarizing 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 relevant for periods with lacking generation from windpower and PV („Dunkelflaute“).

3 Stability and Security of Supply

The energy transition of the coming years will be characterized by the following scare 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 precondition for a prosperous European economy directly influences public acceptance of energy transition. So far, the energy transition has preferably succeeded in the electricity system. This success has mainly been enabled by reserves of grid infrastructure, 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 assets that have provided ancillary services and other flexibility measures at a large extent up to now. Hydro power plants with storage and/or pumped storage functions have fulfilled these tasks emission free, cost-effectively, reliably and, above all, predictably 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.

3.1 Residual Load And Flexibility Needs

Compared to other grid-based energy systems (gas, oil, district heating), the electricity 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 key parameters for system stability. Therefore, the mechanisms for it's maintenance 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). At the system level this is given by a performance (power-) -oriented short-term flexibility with a time range up to one hour and may differ from needs from distribution grids. To keep up security of supply, it is also necessary to ensure a balanced energy supply. Even more in future, long-term flexibilization 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 intermittend and seasonally available wind power and PV sources (approx. 12 TWh each by 2030), supplemented by the seasonal fluctuating run of river power (approx. 5 - 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 simultaneously 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 infeed 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. Within 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 characteristics 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/ramp ∆PRL. 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 decentralized solutions, such as DSM, battery storage, etc… .

Within the framework of the Integrated Climate and Energy Strategy (#mission2030), Austria aims to cover 100% of it's electricity demand by renewables (RESE) in 2030, while industrial consumption, reserve balancing and balance energy should be covered also by thermal generation in future. From 2025 on, the projected enormous increase of intermittent capacity will cause an enormous stress level for Autria'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 generation are estimated on Austria's residual load[2]. In order to minimize 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

$$\gamma inst = \frac{\max(PWind(t) + PPV(t))}{PWindinst + PPVinst}$$

of the simultaneous infeed maximums related to the sum of installed capacities is approx. 50%. This causes temporarily 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 centralized and decentralized flexibility measures.

Under the given assumptions, the characteristics of the Austrian electricity system will change fundamentally within the coming 10 years (Fig. 10). In 2016, a seasonal characteristic is apparent for the total of generation from run-of-river power, wind and PV[3], as well as for load,

[2] Note: 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.

[3] Note: PV infeed to the public grid (PVÖN) by PV directly coupled (PVnonHH(t)) and surplus infeed by prosumers (PVHHÜE(t)).

even if recognized in opposite directions. Generation tips are already typical for today, but they exceed load only in a few hours. Today, a seasonal energy shift is not required by this reason. The infeed tips are mainly 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 (Fig. 5-7). 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 characterized by a high infeed of wind power and PV in their extremes. Overall, the picture is characterized 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 ramps are given frequently.

In the following, the results for the most important parameters are summarized 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

$$RLPI = max\left(\frac{PWind(t) + PPV(t)}{Last\ddot{O}N(t)}\right)$$

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 (Fig. 1).

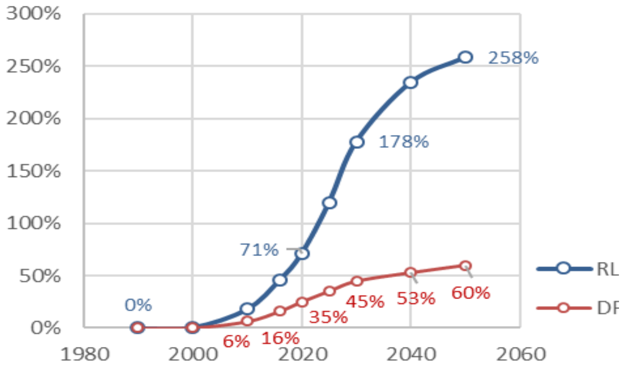

Fig. 1: RES-Load-Penetration Index RLPI and infeed ratio.

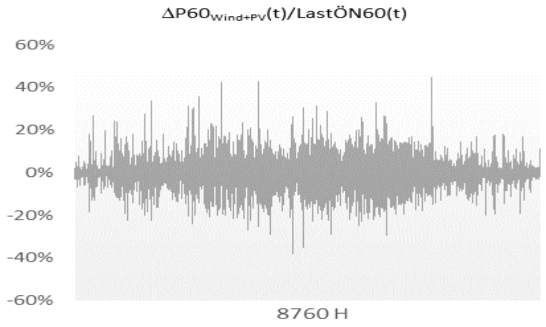

Fig. 2: Already in 2030, the hourly gradient of the simultaneous wind and PV infeed can exceed 40% of the net load in both energy directions for several times.

The phenomenon of a high infeed gradient to load ratio is evident throughout the year. In addition to the residual load ramp, it is an indicator of how quickly the flexibility assets 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 already by 2030 (Fig. 2).

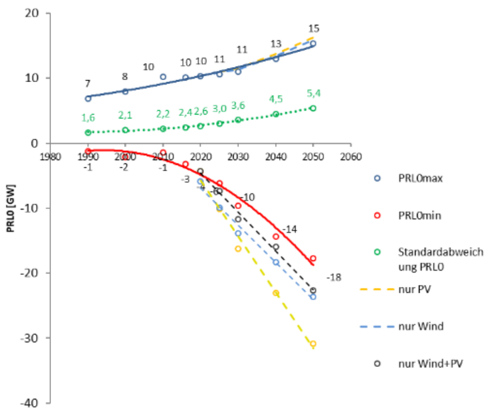

Fig. 3: Residual load peaks (GW60) together with standard deviation 1990 to 2050.

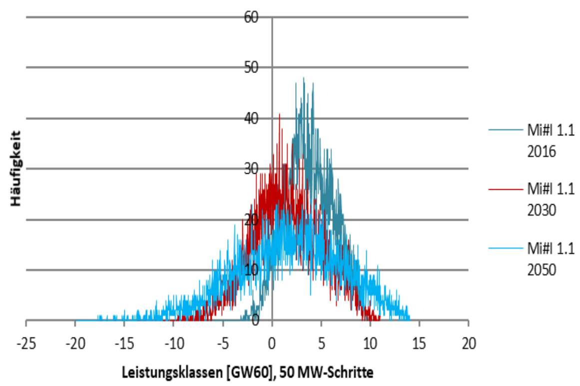

Fig. 4: PRL-Frequency distribution (GW60) for the reference years 2016, 2030 and 2050.

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 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 up to -9 GW60 in 2030. Values around -17 GW60 are expected by 2050 (Fig. 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 (Fig. 4). If, from 2016 on, additional RESE 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 (Fig. 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. The energy content of residual load and thus the storage (TWh) requirements for (seasonal) flexibility solutions will increase stronger than capacity requirements (GW) in a further perspective.

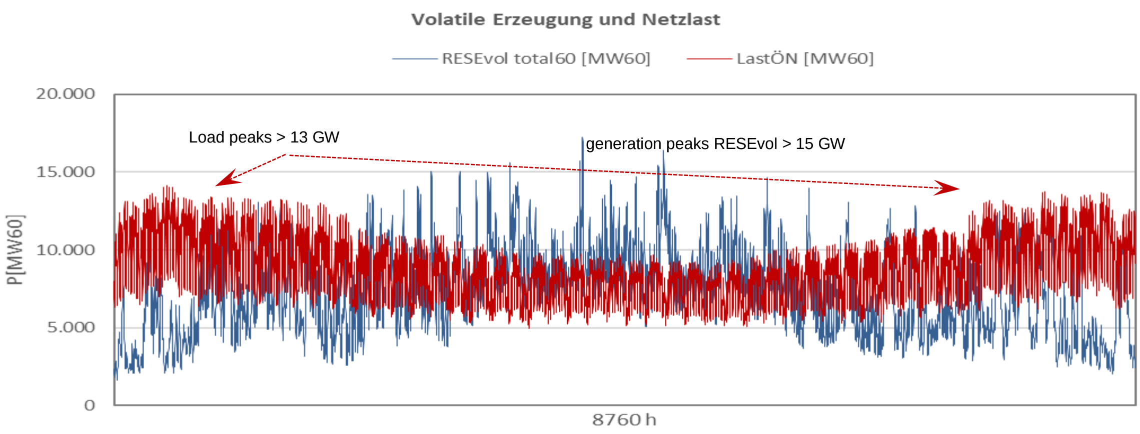

Fig. 5: Estimation of the load of the public grid (LastÖN) and generation from RESEvol (wind + PV + run off river). In the summer months there is a pronounced overlap, in the winter months a shortage of the load. Time series 2016 scaled for 2030.

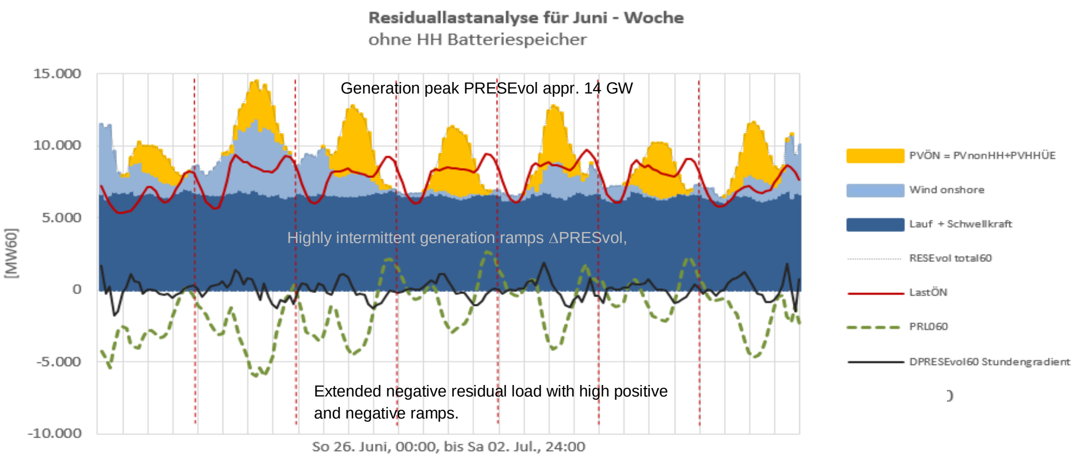

Fig. 6: Random sample for a week in June in 2030. Largely constant infeed from run of river combined with more or less strong daily infeed from wind power an PV with partially high infeed peaks, high intermittence and ramps in both directions. Essentially negative (energy surplus), strongly intermittent residual load with distinctive ramps and frequent sign changes.

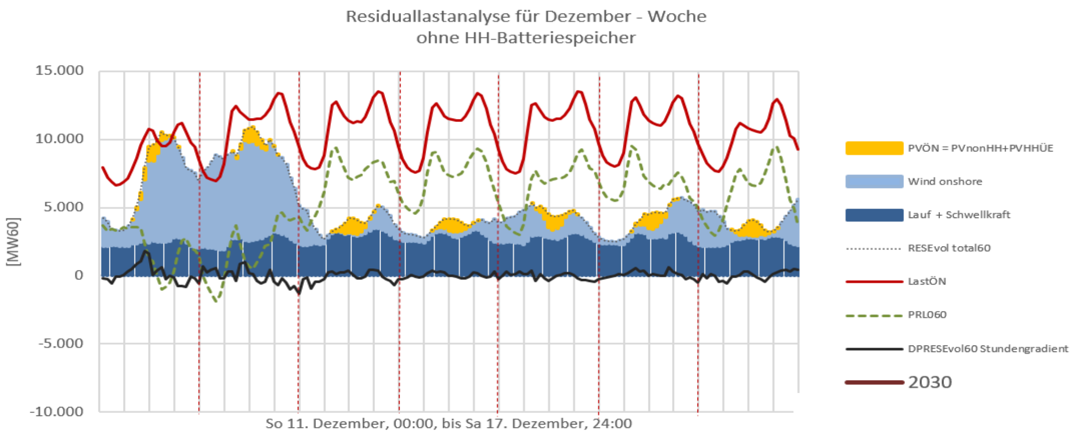

Fig. 7: Random sample for a week in December in 2030. Consistently strong wind infeed at the beginning of the week, temporarily supported by moderate PV infeed. High load with distinctive morning and evening peaks. Moderately to strongly intermittent infeed ramps. Strongly intermittent, essentially positive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

The energy content of all hours with positive residual load (generation gap from intermittent sources) is appr. 20 TWh in 2030 and appr. 30 TWh by 2050. About 10 GW60 peak remains roughly unchanged until 2030 and will increase to appr. 15 GW60 by 2050 (Fig. 4).

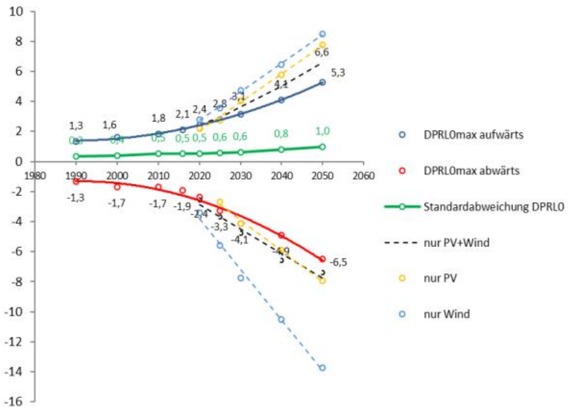

Fig. 8: Hourly residual load ramp ΔPRL60 (GW/h) together with standard deviation, 1990 to 2050.

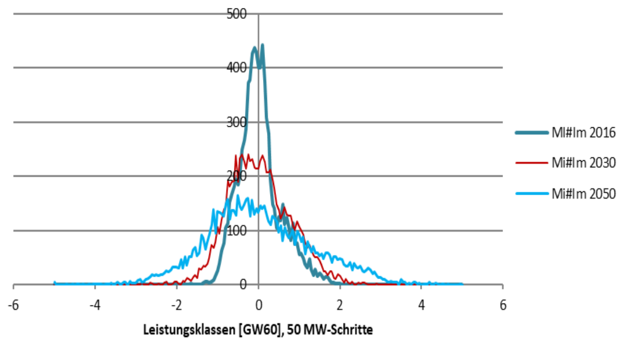

Fig. 9: Frequency distribution of the hourly residual load ramp ΔPRL60 for reference years 2016, 2030, 2050.

The block duration of the negative residual load with maximum energy content increases from appr. 16 h (-0.02 TWh) to 117 h (-0.6 TWh) in 2030. It's counterpart for the positive residual load reduces from appr. 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.

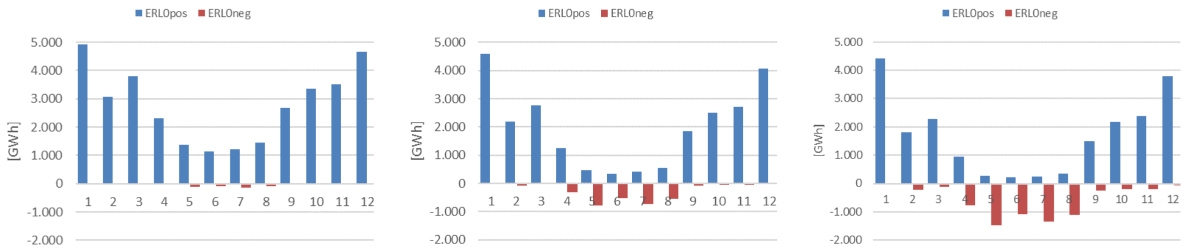

Fig. 10: Monthly accumulated energy content of the positive or negative residual load for 2016, 2025 and 2030.

A similar result emerges for the hourly residual load ramps ΔPRL (Fig. 8 and 9). The smoothing effect of run-of-river on the residual load ramps 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 ramps will decrease in the future, while it will increase for higher ranges in both directions.

The evolution of residual load peak power and ramps 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 (Fig. 10). However, the planned Austrian generation mix will cause an estimated seasonal flexibility need of approx. 2.8 TWh already in

2025 (11% of intermittent generation in summer) and at least 7 TWh in 2030 (appr. 18 % of the intermittent generation in summer). Compared to other countries, for Austria the issue of seasonal flexibility is of major concern from the mid-2020ies on. Hand in hand with the increase of residual load peaks, the annual maximum of daily residual load power increments

$$\vartheta = \max(PRLmax(d) - PRLmin(d))$$

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 a considerable increase of these values. The dynamic sampling of the power system due to the emerging wind and PV generation shares has already caused a significantly increased interplay of (pump) storage use in the past. This increase will continue in future.

3.2 Correlations for the Alpine Region

In Europe, as well as in the alpine regions, RESE 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 (Fig. 11), whereas in the winter months wind characteristics are decisive. Austria's load, intermittent generation and residual is highly correlated with those of other countries of the alpine region (Fig. 12). That means, that an area wide generation deficit (positive residual load) or a generation surplus (negative residual load) propably may occur at the same time. This fact is a basic precondition for the definition of a national flexibility strategy and the assessment of security of supply, if cross-border flexibility assistance should be taken into account.

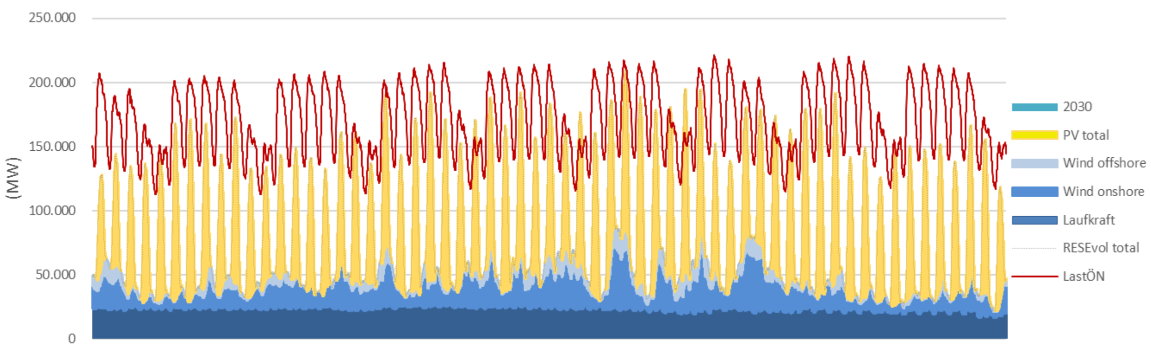

Fig. 11: Cumulative infeed from RESEvol and load in the alpine region (AT, CH, DE, FR, IT, Slo), sample Jun - Jul, 2030

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 to14 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.

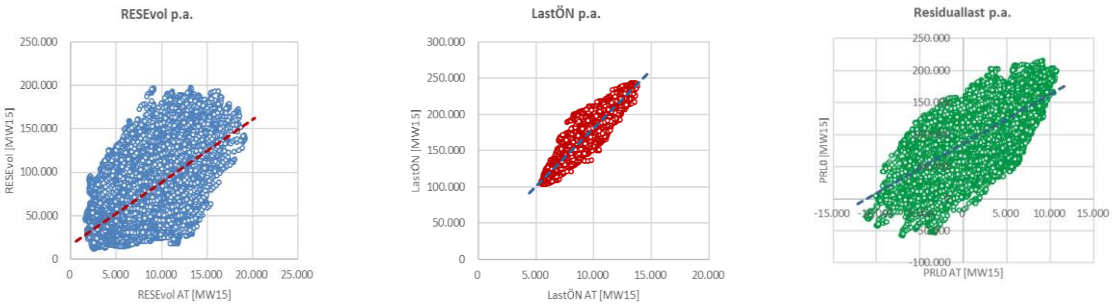

Fig. 12: For 2030 in the Alpine region (AT, CH, DE, FR, IT, Slo) there is a significant correlation of RESE generation (Pearson Coeff. = 0.60), load (Pearson Coeff. = 0.96) and residual load (Pearson Koeff. = 0.67) expected. Data without thermal must-run.

4 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 RESE 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 losses and will be returned to the power system later on. The overall roundtrip efficiency factor of the flexibility process (electricity – electricity) has to be minimized.

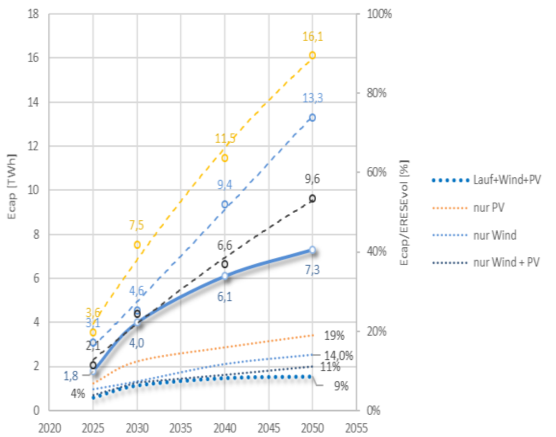

Fig. 13: Fictitious minimum storage capacity requirements for the AT-flex pool depending on RESE scenarios. Existing storage capacities (appr. 4.3 TWh) are to be added.

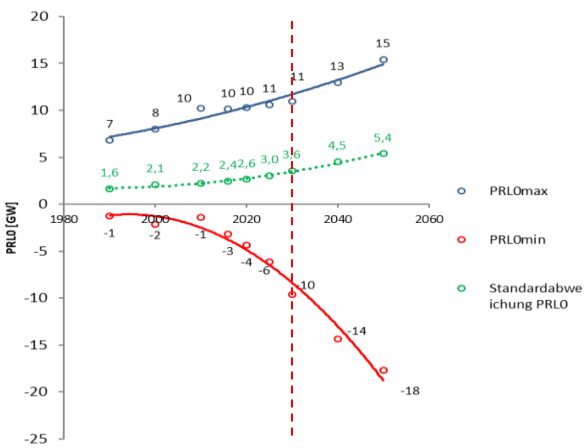

Fig. 14: Extrema of the residual load.

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 Fig. 13. To avoid dumped energy, this solution has to cover residual load peaks as given by Fig. 3 and ramps according to Fig. 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 (capitalized 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 electricity 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 done deterministically on the basis of predictable assets: mainly thermal power stations and (pumped) hydro storage facilities. A significant intermittent renewable share goes hand in hand with a lack of calculable generation capacity. 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 polarizing debate in favor of a particular technology therefore is not a priori expedient. A level playing field is a key factor for further success.

3.1 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 apply also 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 in particular for seasonal flexibility. Presumed, that this technology proceeds commercially for large-scale use and its efficiency will be improved significantly.

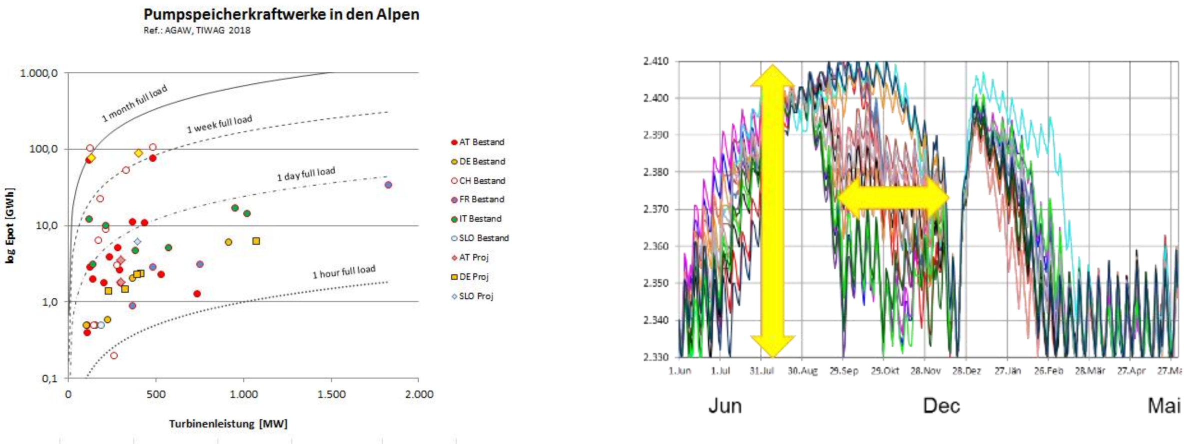

Fig. 15: Alpine (pump) storage is a multi-utility toolbox for the system requirements of the 21st century and differs from typical central European pumped storage solutions with medium drop height and small basins that are usually used for short term flexibility. Additionally, alpine storage solutions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

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 (Fig. 15 left).

The use of natural inflow is an integral part of the plant design and expands the range of flexibility applications (Fig. 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 as well (Fig. 15 right, envelope curve).

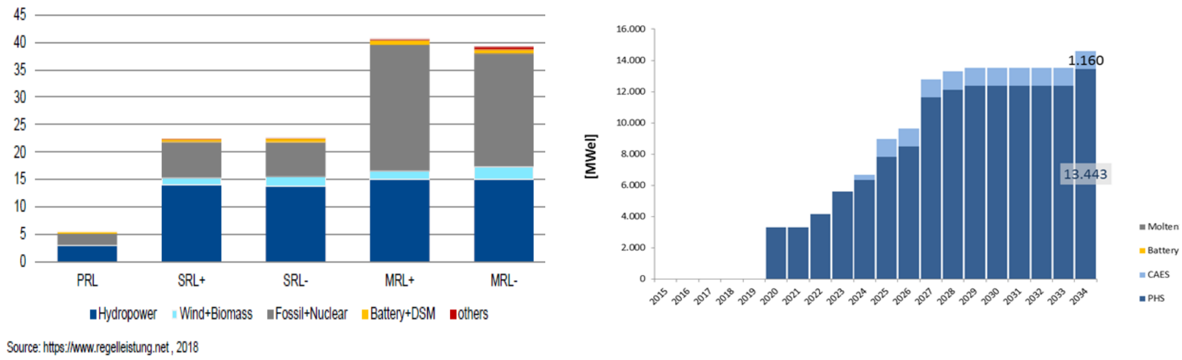

Fig. 16: Prequalified reserve capacities (GW) for Germany by generation type (left). Also in the long run, pumped storage technology remains a leading flexibility option for the Pan-European energy system
(ENTSO-E, TYNDP 2018, Project Fact Sheet).

This seasonal storage of primary energy is unique. In this case, the potential energy of water is stored, and it avoids electricity generation at times not needed. Therefore, this form of seasonal storage is lossless. At the same time, also 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 account for a significant share of green electricity production up to 8 % of a country's annual RESE generation.

Even in thermally dominated systems, such as Germany, hydropower storage and pumped storage safeguard a sizeable share of system reserves, where installations in the Alps are essential (Fig. 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 assets[4] also can achieve the status of Projects of Common Interest (PCI). According to the planning for ENTSOE TYNDP 2018, more than 13 GW of additional pumped storage capacity have been planned for the maintenance of European system stability, security of supply and large scale renewable energy integration. Austrian projects share not less than 13%.

Thus, also in a longer run pumped storage technology will be the backbone for system wide stability and security of supply (Fig. 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, and 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 system level, will play an even more important role for grid stabilization by instantaneous reserve. Solutions with the help of power electronics for wind power, PV and decentralized 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 in 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 organized 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 in a first step, keep the operation of islanded grids stable and finally help to reconnect islanded grids to a system. In such events, they significantly contribute to minimize 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 including all functional units with other hydropower assets 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.

[4] Note: The term "storage facilities" in this context refers to other storage technologies, such as battery or compressed air storage, etc.

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