SHORT REPORT

FLEXIBILITY SUPPLY AND DEMAND IN THE AUSTRIAN ELECTRICITY SYSTEM 2020/2030

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1 INTRODUCTION

The optimal use of flexibility is one of the core aspects of future electricity supply in order to drive the future expansion of renewable energies. As flexibility can be provided by generation as well as by consumption and by storage and affects the different markets and grids, the analysis of flexibility covers a large part of the energy system. The aim of this study is to investigate what flexibility potential is currently (2020) and will be available in the future (2030) in Austria. It should also be estimated for this period how high the demand for flexibility or how much flexibility will be required for the individual flexibility demand options. As flexibility demand options, the energy market with an energy system model, the balancing reserve, redispatch, the distribution grid and short-term portfolio optimisation within a day are considered.

> *Definition of the concept of Flexibility:*
> *Flexibility is the possibility of changing the feed-in or consumption power at a defined grid node of the power system via the prompt change - by an external specification. The specifications can be made externally via aggregators, defined interfaces, or other system requirements, and thus the performing plants can be used in a way that is appropriate for the grid, the market, the customer, and the system.*

2 FLEXIBILITY SUPPLY

One of the objectives of this study is to determine the actual usable flexibility potential of the various generation, consumption, and storage technologies. The first step was to determine the technical potential for each technology. Since there are often limiting hurdles to flexibility, the actual usable potential results from the technical potential, which is restricted by technical, regulatory, economic, and political barriers. In the following the essential core statements per technology are summarised:

Generators: In the analysis of the flexibility potential of generators, a distinction is made between thermal power plants (natural gas, biogas, biomass, waste incineration) and variable renewable generators (run-of-river power, photovoltaics, and wind power (variable renewable generation, VRG)) as well as (pump-)storage (see point below). While many flexibility options are only in their infancy, generators have historically taken a central role in providing the necessary system flexibility and will continue to play an important role in the future. The expected use of the generators for the future (2030) provision of flexibility was determined in this study using energy market modelling. (Pump-)storage power plants currently (2020) provide the greatest potential (positive and negative potential aggregated) and are treated separately below due to their storage character. Among the pure producers in 2020, the greatest negative flexibility potential was in run-of-river and cascading hydropower, followed by wind power. At the same time, natural gas provided the greatest positive potential, which can also be used as negative flexibility. Due to the planned shift to more renewable energies, the highest potentials in 2030 lie with the volatile producers of photovoltaics and wind power, although these are normally only available as negative flexibility via curtailment and when the corresponding resources are available. The potential of controllable producers, on the other hand, will decrease by 2030 due to the planned reduction of fossil fuels.

(Pumped-)Storage Power Plants: In addition to import and export, storage hydropower is already a dominant flexibility option today. Fundamentally, a distinction must be made between pure storage hydropower plants without pumps and pumped-storage power plants. Austria has both types of plants, which can provide flexibility through demand-based generation. In the future an increase in installed capacity and storage capacity is expected. According to the UBA-WAM/NEKP scenario[2] an increase in the turbine capacity of (pumped-)storage power plants from currently (2020) 8.8 GW to 10.8 GW (2030) is planned, as well as an increase in the pumping capacity from 4.2 GW to 5.5 GW. This information is the basis for the modelling carried out as part of this study.

Import & Export: Both today and in the future, cross-border electricity flows represent one of the most important flexibility options for balancing differences in generation and consumption. The prerequisite for cross-border electricity trading is the existence of a corresponding grid infrastructure. Transmission grid capacities with generators, consumers and storages located in other market areas can in principle be used as a flexibility option for the various markets or operations. The marginal net transfer capacities that can be used for trading (NTC) to all neighbouring countries amounted to 9,100 MW (export) and 8,855 MW (import) in 2020[1]. To ensure a safe grid operation, they are significantly smaller than the thermal transmission capacity of the cross-border lines - but even these represent a theoretically available potential. The actual usable potential corresponds to 80% of the technical one since the n-1 security is taken into account. It should be mentioned here that the potential is subject to technical network and system restrictions (e.g. ring flows, consideration of capacities already allocated, simultaneity), which reduce the availability of cross-border capacities. Likewise, the existence of cross-border transport capacities does not mean that the required flexibility can be made available in the neighbouring electricity markets at the specific point in time.

Heat Pumps and Boilers: Due to the efficient coupling of the heat and electricity sectors, heat pumps and electric boilers play an increasingly important role in providing flexibility, both in the household and commercial sectors. Especially for heat pumps, a large flexibility potential can be achieved through the different thermal storage options available (heating storage, hot water storage and buildings). Activations are possible several times a day for several hours (depending on the season and building structure). For both heat pumps and boilers, a strong increase in technical potential is expected by 2030; for heat pumps by more than five times and for boilers by more than seven times. Heat pumps are already participating in the electricity market in some cases; with boilers, this is currently only the case within the framework of research projects.

E-Mobility: Apart from field tests and pilot applications within the framework of research projects, there is still no developed technical and thus no actual usable potential of flexibility of e-cars in 2020. The technical potential of flexibility is significant in 2030, but there are still technical challenges to exploit the flexibility. With the increased options of providing positive and negative flexibility through "vehicle-to-grid" services and "smart charging" in the future, the battery-electric mobility sector will also play a growing role in providing flexibility. However, it must be noted that the flexibility potential of e-cars can only be used in pools and the used flexibility potential usually has to be recharged shortly after the flexibility use or the recharge will take place on the same day.

Industry: The potential of flexibility provision from industrial consumers results mainly from flexible self-generation plants and, to a large extent, also from consumers with large specific electricity consumption. In 2020, industry still offers a lot of unexploited potential, which is why this sector can play an important role in the provision of flexibility in the future. However, a constraint regarding its calculability and reliability is that the production behaviour of industrial companies, depending on the sector, only follows defined patterns to a limited extent and is always heavily dependent on the economic situation and thus on capacity utilisation. While the technical potential will remain almost the same until 2030 due to the long lifespan of industrial process plants, barriers must be removed in this period to be able to exploit the usable potential. For the modelling, only those potentials were explicitly selected that enable load shifting for at least one hour without risking a loss of production.

Commerce: Commercial sectors with high potential for providing flexibility are air conditioning & ventilation, data centres, food refrigeration, wastewater treatment plants and water supply. The greatest potential in terms of power in the commercial sector is air conditioning and ventilation, but here there are the greatest restrictions in terms of the duration and frequency of the calls (max. 1 h, max. 1x / day). The greatest increase in technical potential is expected in data centres. The greatest challenge in the commercial sector are the high-quality requirements for the applications. Here, automatic control must ensure that the requirements of the systems are always fulfilled. Therefore, in all sectors, the actual utilisation of the potential already available is not expected until 2030.

[1] Source: ENTSO-E TYNDP 2018 (https://tyndp.entsoe.eu/maps-data/)

Hydrogen: The production of hydrogen through electrolysis (power-to-gas) offers the electricity system both the flexibility to balance short-term load and generation fluctuations and to shift energy seasonally, since hydrogen, unlike electricity, can be stored over a longer time. A seasonally focussed generation of hydrogen would mean significantly increased installed capacities and investment costs. At the moment, there are no large-scale power-to-gas applications and infrastructure in Austria. For the year 2030, it is assumed that hydrogen will play a larger role in the electricity system. Therefore, the Austrian NEKP (National Energy and Climate Plan) mentions an electricity consumption for hydrogen production (conversion input) of 1.18 TWh[2].

Batteries: In general, we distinguish between home storage systems and large-scale batteries. The development of flexibility supply in this sector depends very much on future economic incentives, but the provision would be technically feasible. In particular, the provision of system services, such as frequency control reserve and possibly faster balancing reserve products in the future, can be attractive for large batteries. Due to the current regulatory framework, large-scale use of battery storage to support the distribution grid is unlikely by 2030. However, they could very well be used in individual niche applications for temporary grid support.

Summary flexibility supply: The results of the flexibility supply analysis for the year 2030 are shown in Figure 1. The graph shows the maximum available flexible capacities in positive and negative direction, with a call duration of 1 h. It should be noted that these maximum potentials are not available over the entire year, but can be reduced by various factors (season, time of day, availability of natural resources, regeneration times, etc.). The technical potential as well as the actual usable potential is shown. One can clearly see the planned shift towards more renewable energies, and thus the highest (negative) potentials for photovoltaics and wind power. Furthermore, by 2030 significantly more potentials will be available in the consumer sector and, above all, they can be actually used. Despite these increases, the flexible potentials from generators as well as imports and exports are still many times higher than the highest potentials from these "new" flexibility sectors.

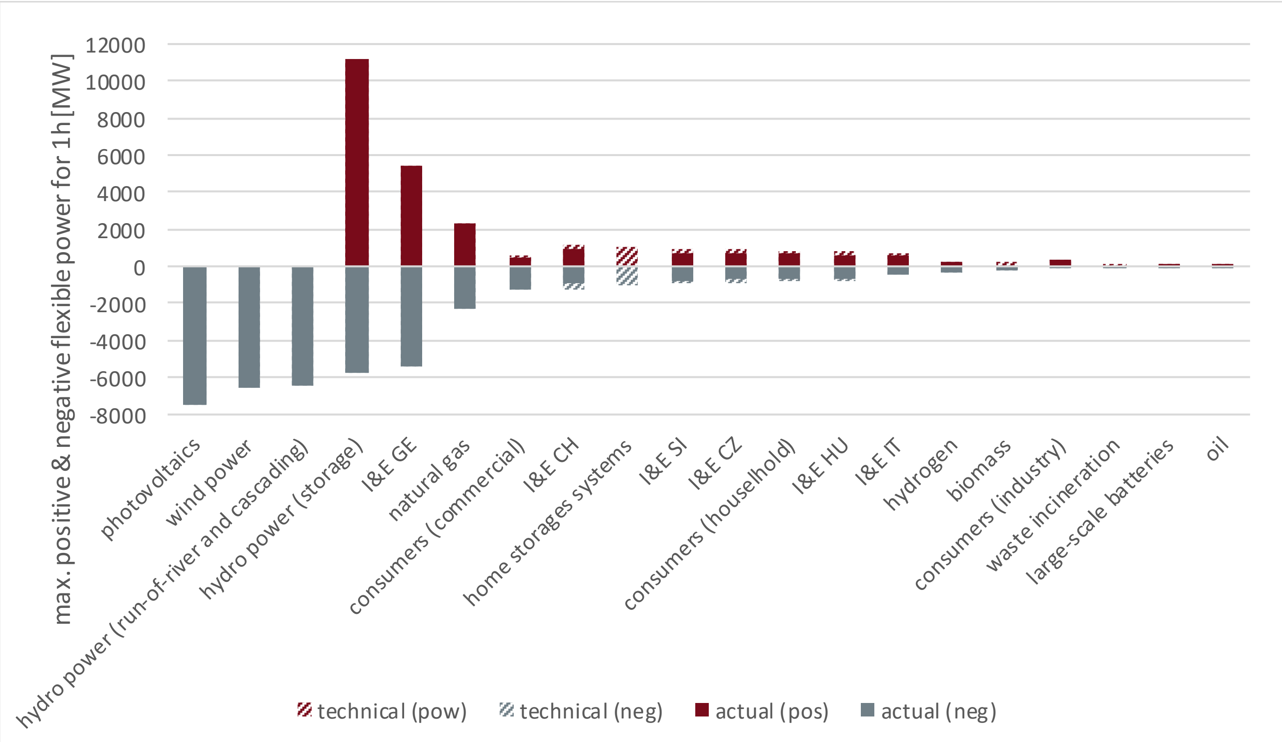

Figure 1: Total overview of the maximum available flexibility potentials for a call duration of 1 h for 2030.

[2] Source: Umweltbundesamt, 2019. *WAM NEKP Scenario.*

3 FLEXIBILITY DEMAND

As another key point, this study also estimated how high the demand for flexibility will be in the future and to what extent flexibility will be required for individual flexibility demand options. The flexibility demand options considered are specifically the energy market, redispatch, distribution grid applications, short-term portfolio optimisation for balancing the schedules of a wind balance group and balancing reserve demand.

Energy market: In particular, short-term energy markets will play a central role in the future regarding the need for flexibility, as they serve to balance supply and demand on the electricity market. Within the scope of this study, an evaluation of the status quo (2020) of the flexibility demand in the Austrian electricity market was carried out based on statistical data. In addition, a comprehensive model-based investigation of the future (2030) flexibility demand was carried out. Its result provides information about the need for flexibility for the short-term energy markets (Day-Ahead, Intraday) in the year 2030, taking into account supra-regional effects (neighbouring countries). To achieve this, the flexibility demand derived from the residual load[3] was placed in the focus of a comparison of scenarios. Different weather influences were considered, specifically a "normal year 2030" scenario and an "extreme year 2030" scenario, accompanied by a sensitivity analysis on the influence of the future CO_2 price and the market availability of large batteries. Furthermore, the modelling shows the coverage of this flexibility using the different flexibility options.
Fehler! Verweisquelle konnte nicht gefunden werden. illustrates the the timeline of the residual load today (2020 - based on electricity market statistics) and tomorrow (2030 - according to modelling), while shows the temporally subdivided flexibility demand (left) comparing the annual balance of the residual load (right).

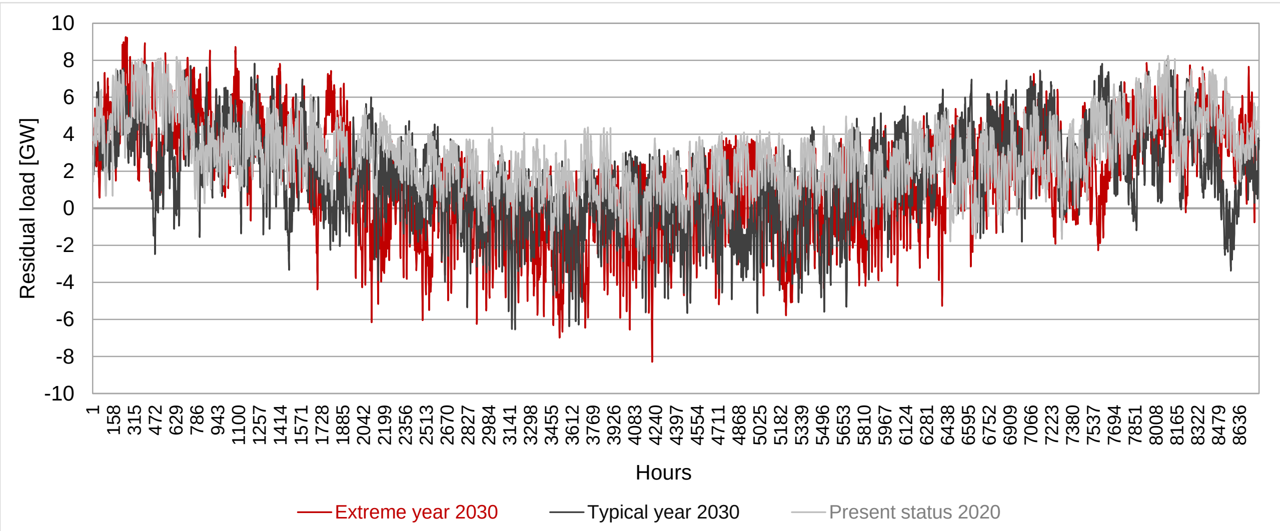

Figure 2: Status quo (2020) and comparison of scenarios (2030) for the temporal development of the residual load [4]

As can be seen from (right), a **comparison of the residual load** today and tomorrow shows a significant decrease in the residual load in the annual balance – von heute 24,4 TWh auf künftig 12,9 bis 14,8 TWh, je nach Szenario. In the case of positive maximums of the residual load, almost no change can be seen, while a clear increase can be observed with regard to negative peaks. Both aspects reflect the anticipated change in the electricity system, i.e., the massive expansion of renewable energies envisaged in the UBA-WAM/NEKP scenario (especially VRG).
Regarding the temporal dynamics of the residual load, 2020 data is showing considerable gradients, both positive and negative. The modelling of the year 2030 provides a restrained picture in this respect - accordingly, a significant decrease in these dynamics would be expected. The main reason for this is the envisaged massive expansion of VRE and the associated decline in residual load.

[3] The value "residual load", which measures the difference between (fixed) load and electricity generation from VRE, describes this relationship in a useful way.
[4] Source: based on ENTSO-E Transparency Platform (https://transparency.entsoe.eu/) and own calculations.

Looking at the identified **flexibility demand**[5] (see) shows in the short term, i.e., in terms of hourly fluctuations compared to the daily mean, an increase of 30 % to 33 % by 2030. The medium term shows a similar pattern, while in the long term a significant increase in flexibility demand can be observed by 37% up to 81% compared to today (2020).
In conclusion it can be stated that the modelling for 2030 shows an increase in the need for flexibility compared to today, specifically regarding the temporal fluctuations of the residual load, while the absolute need for residual load to be covered decreases significantly because of the envisaged expansion of renewables.

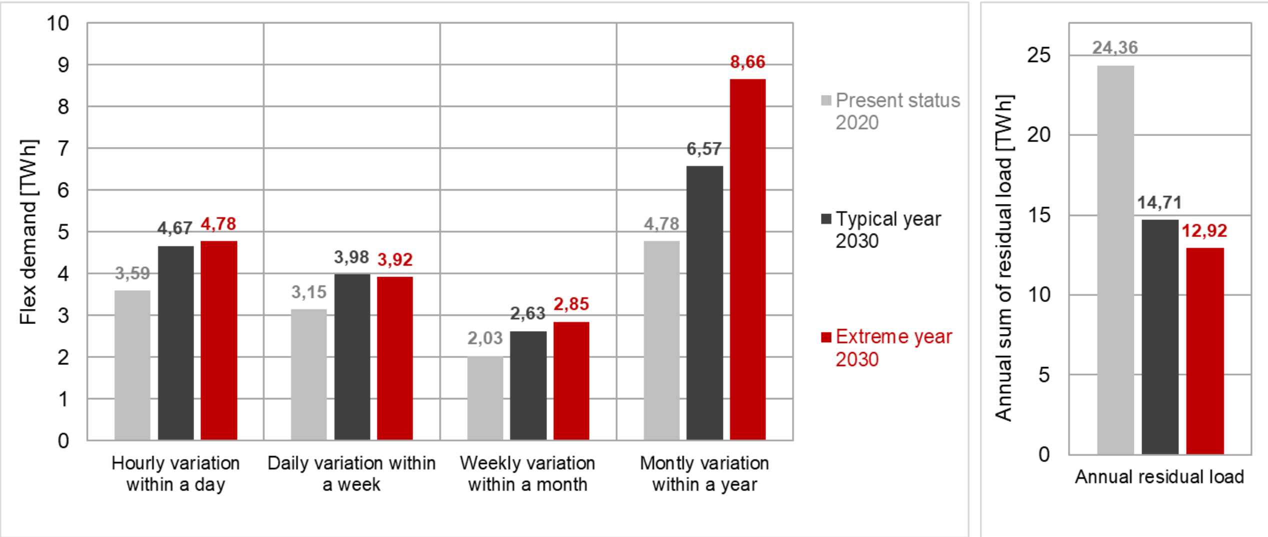

Figure 3: Status quo (2020) and comparison of scenarios (2030) of the temporally subdivided flexibility demand (left) incl. indication of the annual balance of the residual load (right)

There are different flexibility options available to cover the **flexibility demand**. According to the modeling, the following usage pattern emerges:

- Consumer options (load shifting in households, commerce and industry, e-mobility, hydrogen generation, etc.) contribute to balancing short-term fluctuations in the residual load but make (almost) no contribution to seasonal balancing in the long term.
- Large-scale batteries, if available in the 2030 electricity market, would contribute to meeting demand in the short term in a form comparable to flexible consumers.
- Storage and pumped-storage power plants allow flexible use in all time ranges. Based on real deployment patterns, their contribution is usually higher in the short and medium term as well as for covering the residual load over the entire year, i.e., in terms of providing the annual sum of the residual load. In general, it should be noted that (pumped-)storage hydropower is of central importance for meeting the demand for system flexibility in the domestic electricity market today - and this is also expected for tomorrow (2030).
- As a rule, thermal power plants show an opposite pattern to this: their contribution tends to be greatest in the long term, i.e., for the seasonal balancing of monthly fluctuations compared to the annual average, and in the provision of the annual sum of the residual load.
- In the case of power exchange, the contribution to seasonal balancing, i.e., to covering the higher residual load in the winter months, is clearly the greatest, also in comparison to other options. In the short term, i.e., for balancing hourly fluctuations during the day, the opposite is true. Here, Austria exports short-term flexibility to neighbouring countries.

[5] The residual load and consequently also the need for flexibility is characterized by the annual requirement and the fluctuations over time, both in the short term - i.e. the fluctuations in the residual load within a day or a week - and in the long term, where seasonal patterns typically occur within a year are recognizable. In order to differentiate between short-term and long-term flexibility needs, the flexibility needs were broken down into four fluctuation periods and in relation to the annual needs and then evaluated. The short-term level is one day, followed by a week, a month and, at the long-term end, a year. For an exact definition of the terms and parameters used, please refer to the detailed long version of this study.

Redispatch: Based on the hourly results of the energy market modelling also considering the planned grid extensions of the transmission grid until 2030, the flexibility requirement for redispatch was subsequently calculated. For this purpose, percentage line utilisation of the transmission grid was calculated for all installed capacities in Austria - based on the hourly results of the market model - and any overloads that occurred were resolved using an algorithm for calling redispatch. Subsequently, the scenarios already mentioned were compared again. As a result, there were only a few differences in the activation of redispatch and a similar average utilisation on the critical lines of the transmission grid. The investigation of the concrete use of flexibility shows a maximum demand for flexibility of ±1,500 MW (standard year 2030) and ±1,900 MW (extreme year 2030) for redispatch and a total energy demand of around ±880 GWh (1,455 GWh according to APG's Annual Report in 2020). Furthermore, you can usually observe a flexibility requirement of less than 400 MW, while outliers of more than 600 MW only occur in exceptional situations. A comparative simulation without grid expansion showed overloads that are hardly manageable and thus underlines the necessity of the planned new construction and renewal projects.

Distribution Grid Applications: The greatest challenge for distribution grid applications identified in this study is the increasing penetration of decentralised generators and new consumers in the distribution grid, and the associated, increasing operation of this grid level at the technical limits. Regarding the use of flexibility in the distribution grid, the following findings and recommendations can be stated based on national and international experience:

- A measurement-based recording of the real grid situation makes it possible to deviate from worst-case assumptions in grid planning. Through the continuous monitoring of the real grid situations, both expanded reserves/capacities can be made usable and critical grid areas can be pointed out and identified. For the low-voltage grid, the effort for this monitoring is significantly higher due to the greater line lengths, number of resources, customers and nodes.
- Grid topological measures (e.g., switching state, tap changers) are a very efficient solution in the high and medium voltage grid (e.g., temporary, or permanent ring closures). It is expected that this will be increasingly possible in the future, as more and more grid operators also fully integrate the medium-voltage grids into their control systems. With a higher degree of automation and integration into control systems, switchovers in the grid can be carried out more easily. In the low-voltage grid, however, these measures are very difficult to implement, as these are operated as radial systems and the effort for the automating is much higher.
- The studies on innovative grid components, such as controllable local grid transformers and line controllers, show a great potential to increase the absorption capacity of low-voltage grids in a cost-efficient way. For this reason, they must be considered as alternatives in grid planning processes.
- The coordinated operation of consumers (e.g., charging of e-vehicles) and generators (e.g., PV) together with storage systems also has great potential for avoiding generation or load peaks. Whether such measures can be used in grid planning depends on whether they also function reliably in practice and how correct regulation is identified and implemented.
- Measures defined in grid connection requirements or in grid codes (e.g., technical rules for generators in Austria) such as reactive power provision and voltage-controlled active line control are suitable measures for increasing the absorption capacity of existing grid infrastructure. The implementation of a 70 % curtailment (e.g., Germany) should be considered or discussed in Austria. The power is limited to 70%, but this only entails a small energy loss of max. 3%.
- Measures covered by the grid tariff, such as interruptible supply (e.g., heat pump tariff), continue to be a very suitable option for avoiding short-term bottlenecks. Interruptible supply allows load shifting in the event of capacity bottlenecks.
- With the further development of grid control systems, the use of market-based flexibility analogous to existing products in the transmission grid may be possible on the high-voltage level. In the medium and low-voltage grid, market-based flexibility can only be used to a very limited extent, as capacity bottlenecks occur very locally and only a few grid users can be considered as potential flexibility providers.

In general, it must be noted that the economic evaluation of the solutions in the low-voltage grid is very sensitive to the assumptions regarding the running costs (OPEX) of the solutions. The actual operational costs will only become known with the experience gained from a wider deployment of the solutions. Therefore, in network planning, very conservative OPEX assumptions are made for new technologies (i.e. more towards the upper end of the possible costs). In any case, the solutions must be simple and very robust (keyword maintenance effort).

Portfolio Optimisation: During the study, the use of flexibility in intraday portfolio optimisation was examined in more detail, with a focus on the balancing of schedule deviations. In principle, the need for flexibility can be determined by replicating or questioning the balance group, or by analysing the forecast deviations of the individual technologies or the consumption. The focus of the analysis was on the historical forecast deviations concentrating on wind technologies, which was carried out by means of a descriptive statistical analysis for the period January 2020 to February 2021. It was shown that there is already a significant need for flexibility for balancing wind generation in 2020. In addition, an increase in the expected flexibility demand for intraday and balancing energy is shown due to the planned increase in wind generation, with a doubling of the flexibility demand to be expected here.

Balancing reserve demand: The evaluation of the balancing reserve demand was carried out in a different way depending on the type. The current reserve was determined by means of an estimate based on a previous literature search. The determination of demand for FCR (Frequency Containment Reserve) was obtained via expert assessments, based on the demand calculation method for FCR. For the other types of balancing reserves (aFRR – automatic Frequency Restoration Reserve, mFRR – manual Frequency Restoration Reserve) a qualitative/historical approach was used, as a quantitative, probabilistic estimate is not possible regarding the high uncertainty of the relevant influencing factors. It was shown that an increase in the demand for fast control reserve is to be expected in the interconnected grid with the elimination of conventional instantaneous reserve, which can, however, be covered in Austria by the flywheel mass provided by hydropower. No increase in FCR demand is expected. No relevant change in the reference incident is expected by 2030. However, the demand forecast for FCR is subject to a high degree of uncertainty. For example, an increase in FCR demand due to hourly jumps, a change in the power plant outage incidence and caused by the provision from units with limiting energy storage cannot be excluded. For aFRR and mFRR a qualitative view of the relevant influencing factors suggests a slight increase in demand by 2030. Neither an increase in international cooperation, a change in load forecast errors, nor the probability and level of power plant outages are expected to lead to a relevant change in the aFRR/mFRR demand. While the structure of the electricity market and an improvement in the forecasting quality for variable renewables are expected to have a decreasing influence on the aFRR/mFRR demand, it can be assumed that the increasing influence of the expansion of variable renewables will predominate, so that a slight increase in the aFRR/mFRR demand can be expected overall.

Summary flexibility demand: This study shows that the demand for flexibility will continue to increase until 2030 for 4 out of 5 considered flexibility demanders (see Table 1). It could be demonstrated that it is therefore necessary to enable technical potentials and make them available both for the markets and for the distribution grid. It must be considered that only the flexibility that is also available locally on site as well as in the right grid level can be used for the distribution grid. Further open research questions remain, for example regarding how the use of flexibility can still be improved. These include, for example processes for the interaction between transmission grid operators and distribution grid operators, and the regulatory framework for the use of flexibility in the distribution grid.

Table 1: Overview on the development of the flexibility needs of the respective flexibility demanders

	Trend – Demand of short-term flexibility until 2030
Energy market	small to medium increase with regard to short-term fluctuations of the residual load, strong increase with regard to long-term (seasonal) fluctuations
Redispatch	slight decrease[6]
Distribution grid applications	strong increaseg
Short-term wind portfolio optimisation	strong increase
Balancing eserve	neutral - small increase

[6] This is mainly due to the implementation of the transmission grid expansion projects listed in the network development plan ("NEP") until 2030, without whose influence a strong increase in the need for flexibility to avoid congestions could be observed.

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