ENTSO-E Position Paper

Assessment of Future Flexibility Needs

September 2021

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The 42 member TSOs, representing 35 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to use its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility.**

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its **legally mandated tasks**, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

Executive Summary

The ENTSO-E TYNDP (Ten-Year Network Development Plan) and other papers and analyses are underlying the strong increase use of Variable Renewable Energy Sources (V-RES) like wind and solar energy to achieve Europe's 2050 climate neutrality goals. The European Commission "Fit-for-55" proposal requires an acceleration to this trend during the decade 2020-2030.

Flexibility is thus increasingly needed for maintaining the balance of demand and production on all time horizons in the face of increasing scale and frequency of fluctuations in the load net of variable RES (also known as "residual load"). It is also increasingly needed for balancing forecast errors on intraday and balancing markets for transfer capacities, voltage, and power quality.

In many cases, EU power system planning methods already assess flexibility needs and the availability of solutions and products to cover flexibility gaps. For instance, these needs are addressed in the European Resource Adequacy Assessment, the System Operation, Capacity Allocation and Congestions Management and Electricity Balancing Guidelines, and the Electricity Regulation. For example, ENTSO-E's TYNDP has in recent years forecast decreasing inertia levels due to converter and thus asynchronously connected PV, wind and battery resources become dominant. Together with increasing rates of change of frequency (RoCoF) due to the rising size in MW of sudden disturbances, this can lead to a new need for fast frequency response capacities. Indicators such as inertia, RoCoF, Area Control Error (ACE) or Frequency Restoration Control Error (FRCE) quality need to be investigated. EirGrid, NGESO and ERCOT provide examples of how fast frequency response challenges can be met, while Elia's adequacy and flexibility assessment study provides examples of flexibility metrics that address unexpected generation and demand variations after the day-ahead time frame. Moreover, there are R&I projects (e. g., MIGRATE) that have successfully investigated systems with high penetration of power electronics.

One key question for TSOs therefore is which additional flexibilities may be needed at what time in the future and in which European regions, driven by increases in variable RES and converter-connected generation, and what negative effects on the system a flexibility gap could have. ENTSO-E has therefore begun investigations on likely future flexibility needs, and has categorized future needs which are not already addressed through current markets, ancillary service products or evaluation methods into two groups: first, flexibility needs related to the system, i.e., to adequacy, stable frequency, and reliability, and second, other needs related to the grid, i.e. those related to congestion management and voltage stability.

The scope of this paper is limited only to the assessment of future flexibility needs related to adequacy in the day-ahead time frame, i.e. to flexibility needs arising from increasing variability in the balance of generation, demand and storage. Along with assessments of potential future new flexibility needs related to stable frequency (inertia, RoCoF, fast frequency response), congestion management and voltage stability, also needs related to the actual day-ahead, intraday and real-time operational management of the balance of demand and supply are equally important and must be investigated further.

This paper thus proposes metrics specifically for ramping and scarcity period flexibility needs only, which a Transmission System Operator (TSO) and ENTSO-E can apply to determine whether and when in the future a particular new flexibility gap might occur. The proposed flexibility metrics build on the output of chronological simulation studies by exploiting well-known metrics such as Expected Energy Not Served (EENS) which considers the unavailability of flexible resources in different timescales under different scenarios. If and when a TSO identifies, using metrics such as those proposed in this paper, a possible future flexibility gap which endangers the secure and efficient operation of energy systems and markets, the ensuing questions are no less challenging; that is, which measures, market products or investments may be able to cover the flexibility gap most securely and efficiently. Although such product design questions lie in the future for most flexibility needs and most TSOs and fine-tuning and applying new metrics may take several years, beginning this process early will help ensure that the metrics are stable and useful when flexibility gaps begin to have a serious impact on the adequacy and network planning, as well as when TSOs may need to define new measures to address these impacts.

Approach

The two flexibility needs described in this paper, ramping and scarcity periods, along with the proposed metrics, are based on the results of a survey of currently used assessment approaches for future flexibility needs identified by TSOs (22 responses), and on international examples of flexibility needs assessments, metrics and products.

The installed capacities of variable RES are forecasted in TYNDP to keep increasing over the next few decades until they reach multiples of peak loads, likely accompanied by strong decreases in fossil-fuel-fired capacities. This will increase certain challenges related to flexibility, adequacy, inertia and other risks, which can be further elaborated by exploiting the main results of the current European Resource Adequacy Assessment (ERAA)[1] or by using the TYNDP cost-benefit analysis (CBA) methodology. Therefore, in the coming years, ENTSO-E is planning to develop several additional flexibility need assessment methods, along with associated metrics, thus aiming to ensure that flexibility gaps and the use of flexibility from neighbouring countries are captured in assessments of reliability and the evaluation of new interconnection or storage projects in the TYNDP. Once developed, ENTSO-E may directly apply or recommend to its Member TSOs (possibly grouped by synchronous area) a fine-tuning and application of these methods, metrics, and indicators on a national, regional and/or pan-European basis. The remainder of this paper outlines the assessment methods and metrics which ENTSO-E's Research, Development & Innovation Committee (RDIC) considers the most mature, based on an analysis performed together with the consultancy company Guidehouse.

Why are power system flexibility needs increasing?

Power system flexibility needs originate from deviations in the power system due to variability and uncertain availability of generation, demand and grid capacity over all time horizons. For instance, the March 2021 ENTSO-E Discussion Paper "Options for the Design of European Electricity Markets in 2030" points out, that flexibility needs increase with progress towards 2050 climate neutrality and 2030 GHG reductions targets of 55 % due to increases in variability and uncertainty in various aspects:

- In demand, due to electrification of heating, transport (e. g. lack of smart charging in electric vehicles, EVs) and industries (larger electric loads subject to temperature variations, difficult-to-forecast customer preferences and uncertain price responsiveness increase not only variability but also uncertainty).
- In generation, due to increased use of variable renewable energy (VRE) and less dispatchable generation (more generation dependent on wind and sunshine conditions increases not only variability but also, at least in absolute terms, the dependence of energy production in MWh on weather uncertainties).
- In grids, due to VRE, distributed energy resources (DER), inverters (less predictable flows, inertia).

1 See ACER, Methodology for the European resource adequacy assessment, 2 Oct. 2020. This paper refers to simulations such as those performed by ERAA as a source of data and not as a methodology that evolves in a pragmatic stepwise approach based on a legal framework.

As described above, this paper focuses on changing flexibility needs due to the increasing variability of demand and generation, while flexibility needs due to increasing short-term uncertainties and to the grids will be addressed separately in the ENTSO-E. In particular, increasing variability of the predicted demand and generation profile in the day-ahead timeframe can lead to two new flexibility challenges:

- First, the decreasing amount of weather-independent generation may need to ramp up or down faster and over wider overall MW ranges than in the past, especially if steeper load increases coincide with steeper decreases in VRE generation than before (and vice versa for load decreases and VRE generation increases). Load increases could, for example, become steeper due to increasing penetration of heat pumps and EVs, while the MW scale of VRE generation decreases (e. g., during sunset) grows with higher VRE penetration.

- Second, the decreasing amount of weather-independent generation may become insufficient to cover the demand during extended scarcity periods with very low VRE generation, such as windless winter weeks.

The hourly results and annual averages from the chronological simulations show the severity of ramping and scarcity period flexibility gaps, while residual load analysis helps to further focus on times with the highest specific risks regarding ramping capabilities of the portfolio at all hours, whether with and without adequacy concerns.

To illustrate how flexibility needs for ramping and scarcity periods could evolve by 2025 and 2030, we consider the example of Germany, which is both one of Europe's largest countries and has one of the highest VRE penetration rates, based on ENTSO-E's Mid-term Adequacy Forecast (MAF) 2020 data. Note that the German system displays sufficient system adequacy in these MAF analyses, both for 2025 and 2030. However, its high installed wind and solar capacities, relative to both peak loads and installed dispatchable capacities, nonetheless illustrate challenges that are beginning to be visible on ramping and scarcity periods. This is particularly true, if one examines situations beyond the 30 climate years simulated in the MAF, extreme weather situations (e. g., in climate year 1985 for a windless winter week and in climate year 2009 for steep ramps). Further, note that the graphs are based on MAF 19 data and include virtual reserves. In up-to-date load estimates (MAF 21 data), peaks are up to 10 % lower.

The illustrative graphs below are based on residual loads, that is, hourly loads net of fluctuating onshore and offshore wind, PV and run-of-river hydropower generation, which will need to be covered by dispatchable generation, imports or exports, and the use of different kinds of storage. Figure 1 shows the 2025 and 2030 maximum ramps in the residual load over 1, 3 and 8-hour timesteps, which reach a substantial

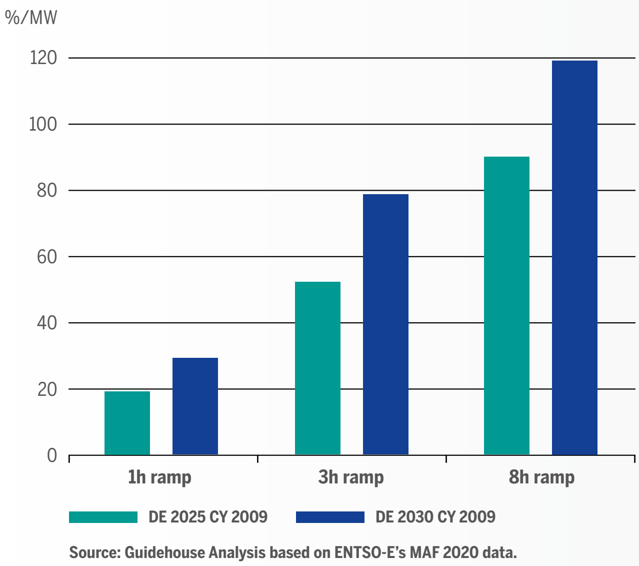

Figure 1: German max residual load ramps

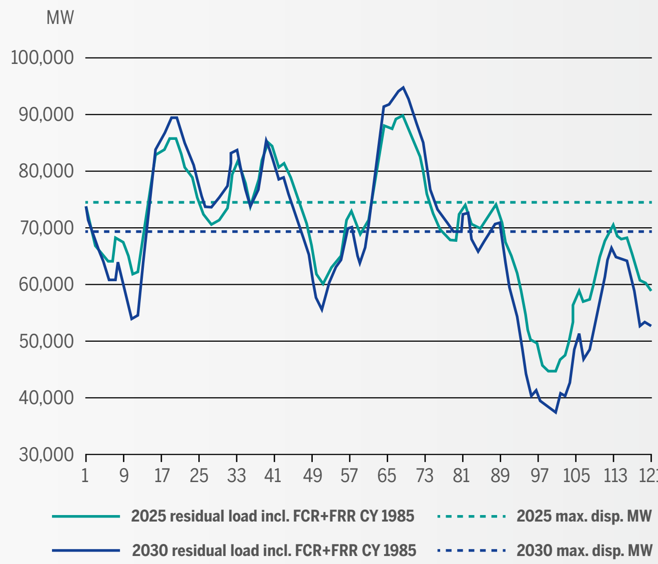

Figure 2: Germany sustained high net loads

fraction of the total dispatchable capacity or even exceed it. In interpreting the residual loads, it is important to keep in mind that they do not account for imports and exports, which strongly contribute to overall system adequacy, especially for strongly interconnected countries such as Germany. Also note that dispatchable capacities, which in any case only provide a very rough reference for the interpretation of residual loads, are adjusted (derated) to account for forced outage rates of coal, gas, pumped-storage hydropower generation and other capacities, but also include the MAF data for demand-side response.

Figure 1 relates the 1-,3- and 8-hour steepest ramps in the 2025 and 2030 residual load data to the dispatchable capacities. It indicates a serious ramping-flexibility challenge, especially for the 2030 data, as dispatchable capacity or other flexibilities would need to be imported from neighbouring countries, or RES would need to be curtailed in a well-coordinated and anticipated manner to cover such ramps. Figure 2 shows a windless winter week where residual loads are almost as high as the loads themselves as a result of minimal VRE contributions. The annual maximum of the 120-hour or 5-day average residual load, plus necessary frequency containment and restoration reserves (FCR+FRR), amounts to 96 % of maximum dispatchable capacities for 2025 and 102 % for 2030. In the example 5-day period in January, many of the 120 hours far exceed dispatchable capacities which include demand response capacities, further indicating dependence on support from neighbouring countries.

However, a simple analysis of residual loads cannot and must not replace the more complete and more realistic chronological simulation of system adequacy, which includes the stochastic effects of forced outages and different climate years, as well as simulating imports and exports based on market price equilibria. Therefore, below we propose metrics which combine the strengths of detailed hourly results from chronological probabilistic simulations with insights gained from the simple residual load analysis focused on two variability challenges found particularly relevant in the literature and international experience.

Possible metrics for flexibility needs

The following methodological approaches and metrics are proposed for the determination of ramping and scarcity period flexibility needs and are suggested to be the basis for ENTSO-E's further development, improvement, and fine-tuning; note that although the metrics build on the outputs of chronological simulation studies, they do not suggest or require any adjustment to the simulations themselves as they might be used for MAF, ERAA or TYNDP

› **1. Ramping flexibility needs:** These metrics measure large daily residual load gradients, for example, at sunset in regions with large PV generation capacities. The approach is partly based on experiences from CAISO and EirGrid. Residual load is the load left after subtracting VRE generation such as wind, PV and run-of-river hydro from the demand. Explicit and implicit demand flexibility was considered as part of the dispatchable capacity, and not in the residual load calculation. The treatment of these capacities in the methodology could be further improved.

_ a) As illustrated in Figure 1, the **highest annual residual load MW ramps**, calculated as the differences between residual loads 1, 3 and 8 hours apart (or more as necessary for managing the uncertainty in a materially weather dependent system), can be easily compared between all market zones and years if they are normalised to the market zone's dispatchable capacity, accounting for demand response and for forced outage derations.

_ b) The metrics **percent of loss of load expectation LOLE, expected energy not served EENS, and curtailed surplus energy during the 5 % highest ramp periods** indicate how the ramping issue can also pose an adequacy and economic problem. They will be assessed separately for positive and negative residual load ramps and for 1-, 3- and 8-hour ramps (or more as necessary for managing the uncertainty in a materially weather dependent system) as well as the corresponding prior hours for potential pre-emptive curtailment. Hourly values for LOLE, EENS and curtailed energy are among the outputs of chronological probabilistic market simulations used for adequacy and TYNDP studies. The necessary fine-tuning of this indicator will not only address the 5 % threshold but also involve examining how ramping capabilities of all resources are modelled in market simulations, especially demand response and VRE curtailment.

›

› **2. Scarcity period flexibility needs:** These are metrics focused on contiguous-day EENS (expected energy not served) problems during scarcity periods, when Variable Renewable Energy (VRE) resources are not available for extended and continuous periods such as windless winter weeks in Northern Europe.

_ a) If the **maximum annual value of 120-hour residual load rolling averages**, including Frequency Containment and Frequency Restoration Reserves (FCR and FRR) requirements and normalised to the market zone's derated dispatchable capacity, including demand response, is near 100 %, as in Figure 2, short-term flexibility resources such as batteries or DSR are unlikely to cover power needs. But as in the case of ramping, this metric can indicate small sets of hours in a given year when flexibility challenges are especially strong, while market simulations can show quantified reliability risks from detailed simulations of dispatchable capacity, demand response, battery use, and mutual support between countries, as well as weather and outage probabilities.

_ b) Therefore, as in 1b, the **LOLE and EENS percentages over the maximum 120-hour average residual load periods** indicate what fraction of overall adequacy concerns stem from seasonal scarcities involving extended periods of high residual load and low VRE generation. For further interpretation of scarcity periods, it can also be useful to also examine the climate years with high LOLE and EENS contributions during the identified 120-hour scarcity periods in market simulations, and the average generation as a percentage of the installed capacities of all VRE resources during these periods. These will help understand which climatic conditions can lead to scarcity periods. Part of the necessary fine-tuning of this indicator will not only address the focus on the single worst 5-day period, but also involve examining how the availabilities of flexibility resources during scarcity periods are modelled in market simulations, especially implicit demand response and sector coupling resources such as vehicle-to-grid, or seasonal thermal or hydrogen storage.

Sector coupling contributions

Given the extent of the flexibility challenge posed by a climate-neutral energy system, participation by every potential flexibility provider should be encouraged. Sector coupling has the potential to promote additional strong and, in some cases, cost-effective contributions to address flexibility gaps.

For example, power-to-heat with thermal storage and electrolysers using clean electricity combined with gas storage appear promising for mitigating scarcity period flexibilities (especially for countries with high VRE shares), while power-to-gas, power-to-heat, smart electrolysers, vehicle-to-grid or smart EV charging can provide fast response flexibility and ramping flexibility - both before and during the steep evening ramp of the residual load.

Sector coupling, along with other flexibilities such as batteries and demand-side management, involves loads that are connected at the distribution level. This means that their usage for the overall system requires close cooperation between TSOs and DSOs, such as coordination between flexibility usage for system ramps versus for local distribution congestion management. In order to promote this cooperation, joint assessment of flexibility needs for different use cases at the transmission and distribution level should be developed. In addition, the fast and secure exchange of data must be expanded in order to enable the monitoring of power flows and the impact of these control actions and to obtain practical knowledge about the activated measures.

Conclusions

The transition (including sector coupling and other related changes and measures) to an integrated energy system will increase contributions from fluctuating renewables, bringing increasing uncertainty and increasing the need for flexible resources.

To ensure sufficient availability of flexible resources when required by system operations, flexibility-need assessments should be integrated into the TSOs' – and likely also the DSOs' – planning toolboxes soon, especially considering that the metrics suggested previously still require fine-tuning. ENTSO-E and TSOs could use and fine-tune the methods and metrics for the flexibility needs described in this paper in the coming years to determine when ramping and scarcity period flexibility gaps might occur, and how these might affect adequacy studies or the future cost-benefit analysis of TYNDP projects. In parallel, the other additional flexibility needs related to stable frequency (inertia, RoCoF, fast frequency response), congestion management, voltage stability and uncertain variations or forecast errors after the day-ahead frames, will be further investigated. The goal is that based on such a growing set of flexibility metrics, TSOs and ENTSO-E will be able to identify possible flexibility gaps sufficiently early to enable them to define measures or products, conduct stakeholder consultations and if needed seek regulatory approval beforehand to ensure that sufficient flexibility resources will be available to cover the gaps identified.

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