ISSN 1831-9424

European Commission

What results should Flexibility Needs Assessments in the power sector produce?

Output indicators that meet the objectives of the Electricity Market Design reform

By Thomaßen, G. and Landeka, J.

2024

Joint Research Centre

EUR 40070

Contact information
Name: Georg Thomaßen
Email: georg.thomassen@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC139027

EUR 40070

PDF ISBN 978-92-68-20978-3 ISSN 1831-9424 doi:10.2760/9174552 KJ-01-24-074-EN-N

Luxembourg: Publications Office of the European Union, 2024

How to cite this report: European Commission, Joint Research Centre, Thomassen, G. and Landeka, J., *What results should Flexibility Needs Assessments in the power sector produce*, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/9174552, JRC139027.

Contents

Abstract

The recently adopted Electricity Market Design (EMD) reform includes provisions for the creation of Flexibility Needs Assessments (FNAs) on the national and European level. The reform sets a focus on advancing decarbonization while maintaining a high level of supply security. The FNAs should further enable Member States to set up mechanisms to procure additional flexibility to meet any identified inefficiencies that are due to an insufficiently inflexible system. Against this background, the JRC reviewed existing flexibility assessments in the literature and the outcomes they produce. Based on this review, we propose that FNAs in Europe should assess three key areas: renewable integration, ramping needs and reserve requirements. We further propose concrete indicators, which allow to derive net flexibility needs – taking into consideration the capabilities already present in the system – and enable Member States to procure any missing volumes of flexibility.

Acknowledgements

We would like to thank our colleagues at ACER for the fruitful discussions and exchanges.

Authors

Georg Thomaßen and Josipa Landeka

Executive summary

Policy context

The European Electricity Market Design (EMD) reform was adopted in July 2024. The reform includes provisions for the creation of Flexibility Needs Assessments on a national and European level. These assessments shall evaluate whether sufficient amounts of flexible resources are present in the power system to meet decarbonisation goals, by effectively integrating electricity from renewable sources, and maintaining a high level of supply security. Where sufficient flexibility is lacking to meet these goals, Member States can then procure the missing volumes.

As a next step, ENTSO-E and the EU DSO entity are charged with developing a methodology, based on which the national assessments shall be conducted. After the proposal is finalized, ACER will have the option to amend and/or accept the methodology.

Key conclusions

— **Flexibility Needs Assessments (FNAs) shall identify concrete needs in the system to enable Member States to swiftly procure any missing volumes of flexibility.** To do so, FNAs must identify concrete shortfalls in the system and quantify the amount of flexibility needed to counter these. The EMD mandates that flexibility needs shall be quantified so that goals with respect to decarbonization *and* supply security can be met.

— **To assess the flexibility needed for decarbonization, two steps are necessary to quantify the amount of flexibility required for sufficient renewable integration.** First, a benchmark needs to be set or derived that defines how much renewable generation should be integrated into the system, or how much renewable curtailment remains acceptable. FNAs can then quantify the necessary volumes of flexibility to achieve this benchmark by a better matching of electricity demand and renewable supply – directly through demand response or through storage as an intermediary.

— **Whether sufficient amounts of flexibility are present in the system to maintain a high level of supply security can be evaluated by assessing the system's capability to deal with *ramps* on the generation and the demand side, and by its ability to provide the necessary volumes of *reserves*.** The relevance of these aspects will grow over the next decades with the decommissioning of large parts of the conventional power plant fleet in Europe and the advent of variable renewable generation.

Main findings

This report proposes a set of outputs that FNAs in Europe should produce to fulfil the criteria set out by the EMD. To this aim, we examined several flexibility assessments in the literature based on the aspects they investigated and the indicators they produced. These assessments typically present two types of indicators: (1) diagnostic indicators which indicate whether a concrete shortfall in the system occurred. And (2) descriptive indicators, which depict characteristics of the system, which do not directly indicate a malfunction in the system, but rather add to the description of the system (and how it changes). These must be seen as part of the bigger picture and in the context with other indicators.

Across the investigated works, we further identified four key areas that present diagnostic indicators: Renewable integration, ramping flexibility, reserve requirements and resource adequacy. The European Resource Adequacy Assessment (ERAA) and National Resource Adequacy Assessments (NRAAs) already assess resource adequacy on a European and on the national levels. The EMD further calls for FNAs to be aligned with ERAA and the NRAAs. We therefore propose that FNAs should focus on the three other areas to be complementary to the RAAs.

To meet the requirements from the EMD, indicators should tackle both, decarbonization and security of supply issues. For the first aspect, FNAs should evaluate the level of renewable integration. This requires a target against which the performance of the system can be assessed. Such a target can be set with regard to the total amount of renewables to be integrated, or with regard to the maximum amount of curtailment that is still deemed acceptable. Where sufficient national targets are lacking to calibrate such a renewable integration target, least-cost optimization could be used to determine the most economic level of curtailment.

A desired level of renewable integration can then be achieved by increasing the correlation between electricity demand and renewable supply – either directly through demand response or with the help of storage as an intermediary. The additional amount of flexibility needed can be determined by adding energy shifting capability to the system, with energy shifting capability being a placeholder technology for either demand shifting or storage operation.

The supply security aspect of FNAs can further be covered by evaluating ramping needs and operational reserve requirements. Both can be determined based on unit commitment model runs. If a load shedding event occurred due to insufficient ramping capability in the system (in contrast to insufficient generation capacity), it would signify a need in this area. Similarly, a unit commitment run could produce time periods in which the model could not provide reserve levels in line with the European grid codes. Both cases are expected to grow in relevance with large volumes of decommissioning foreseen, for example, with regard to coal power plants.

To avoid overprocurement, it is essential to avoid double counting when combining the needs from the three areas. It should therefore be evaluated whether filling the need, for example, for renewable integration would take care of (some of) the needs identified in the two other areas.

Related and future JRC work

The JRC is consulting ACER on the implementation of national and the European FNAs in line with the EMD reform. The JRC has further consulted ACER on the implementation of ERAA since the start of the assessment, and is continuing to do so in the context of the new requirements set out by the EMD.

Quick guide

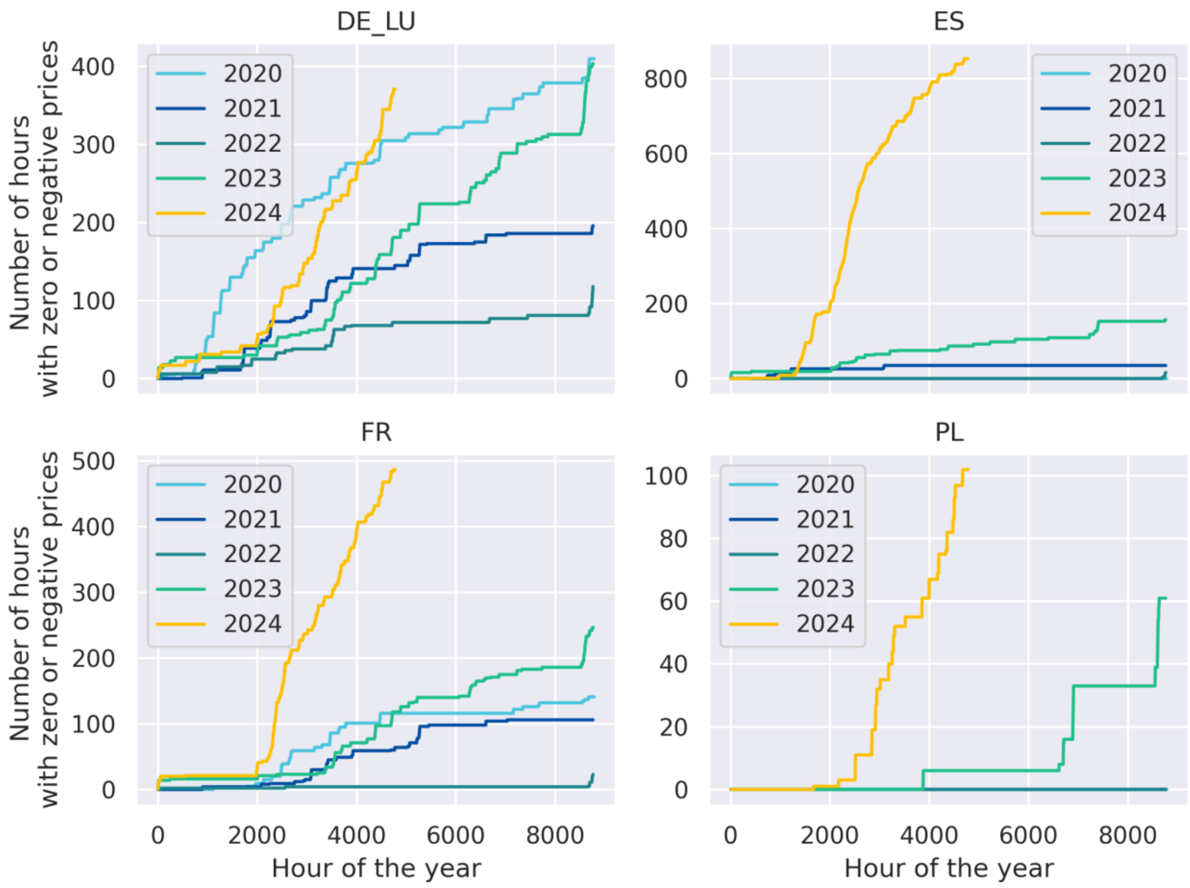
Section 1 introduces the issue, by discussing the requirements that the EMD reform sets out for FNAs, and the overall relevance of flexibility in the current context of the European power system. Section 2 features a review of flexibility assessments in the literature, distinguishing key focus areas and evaluating the indicators presented in these works. Section 3 then features a set of suitable indicators, which would allow national and European FNAs to meet the requirements of the EMD, while section 4 concludes.

1 Introduction

The flexibility of the European power system has become a topic front and centre in the energy policy debate in recent years. This development started during the European gas crisis, where an obligation to reduce electricity demand during peak hours contributed to maintaining a secure supply (European Commission, 2022). Accordingly, the European Electricity Market Design (EMD) reform – drafted in the wake of the crisis – sets a strong focus on improving the flexibility of the power system to increase security of supply and advance its decarbonization.

Recent market outcomes in the EU demonstrate the need for this. Here, the number of hours with zero or negative prices has been increasing massively in recent years, as shown in **Figure 1** for several key markets. The year 2024 appears to mark a new chapter in this context, as the number of hours in July is already matching or exceeding the number of hours that occurred during the entire year in previous years.

Figure 1: Evolution of the cumulative number of hours with zero or negative prices in Germany and Luxembourg, Spain, France and Poland for the years 2020 to 2024.



Source: JRC analysis based on ENTSO-E Transparency Platform.

Zero and negative prices indicate a lack of flexibility in the system. They occur when generators are willing to produce without compensation, or even pay for producing electricity. These situations arise if:

(1) Generation from sources with zero marginal costs supply the entire demand (usually variable renewables);

(2) Generation capacity is insufficiently flexible to shut down in times when high volumes of renewable electricity is being produced.

(3) Capacity has to stay on-line to provide system services.

(4) Or if generation is remunerated on secondary markets – for example through renewable remuneration schemes.

Accordingly, negative prices indicate an insufficient ability to accommodate renewables in the system. Either due to slow ramping capabilities, the inability to provide system services without conventional generators, or due to an inability to bring forward sufficient demand to store or consume the electricity when it is being produced.

The primary instruments for fostering flexibility in the power system featured in the EMD are the removal of market barriers and the introduction of support mechanisms for carbon-neutral flexibility. Member States are supposed to design support mechanisms based on the need for additional flexibility, which shall be determined based on *Flexibility Needs Assessments* (FNAs) on the national level. In addition, ACER will conduct a European-wide FNA in order to assess flexibility needs at the EU level.

These assessments are highly relevant, as they determine the volumes of additional flexibility that Member States can then procure. This report discusses the way FNAs on the national and European level can determine a need for additional flexibility in the power system. To enable addressing inflexibility swiftly, the results should directly enable Member States to dimension support mechanisms that fill any identified gaps. In this way, FNAs distinguish themselves from more general flexibility assessments, as they quantify the need, instead of just identifying shortfalls.

The EMD foresees that ENTSO-E and the EU DSO entity draft the methodology for national FNAs within 9 months after the EMD went into force (July of 2024). The proposal is then submitted to ACER, who can amend or accept the methodology, based on which the national FNAs will be performed. This report has to be seen in the context of this currently ongoing process. We aim to contribute to the discussion by outlining suitable indicators that meet the requirements arising from the EMD.

2 Flexibility indicators in the literature

There exist different works in the literature that assess whether there is sufficient flexibility available in a power system. Some works feature as many as 20 indicators (Parker, 2017). Not all of these indicators directly describe a technical issue, such as a shortfall, but rather convey descriptively how the system changes. We can thus differentiate further between diagnostic indicators, which identify a concrete lack of a certain capability inside the system, and descriptive indicators, which describe characteristics of the system that do not directly identify a malfunction. As an example, lost load would describe a diagnostic parameter, while the number of zero or negative prices would be descriptive, as their occurrence does not directly pose an issue to the operation of the system – even though they might pose challenges to market participants and might signal that renewable electricity is wasted during the respective time periods.

To align FNAs, both on a national and a European level, with the purposes set out by the EMD, the focus should lie on diagnostic indicators, as these assessments have the purpose of identifying a *concrete need* for flexible capacity. Descriptive indicators can help to complement the picture, for example by presenting market indicators, yet should be considered as a secondary priority. To differentiate between diagnostic and descriptive indicators, we can have a look at three system services: The provision of clean electricity, the provision of electricity in general, as well as the provision of sufficient reserves to safeguard the operation of the system. Malfunctions identified in these three areas describe a direct need for more flexibility. Descriptive indicators, like the occurrence of negative prices, indicate a need for flexibility yet do not in itself prove it. If we assume, as a hypothetical, that the addition of flexibility would decrease the number of hours with negative prices, but lead to higher system costs and emissions, this addition would not be rectified. Indicators such as negative prices can therefore be an important indication of a lack of flexibility, yet they do not suffice on their own to determine a need.

To identify suitable indicators that describe concrete shortcomings in the system associated with insufficient amounts of flexibility, the JRC analysed several related works (AESO, 2022; Chondrogiannis et al., 2021; Edmunds et al., 2017; Elia, 2023; Parker, 2017), and screened for diagnostic indicators.

In this context, we identified four key areas:

1. Renewable integration
2. Ramping flexibility
3. Reserve requirements
4. Resource adequacy

The fact that resource adequacy is included in this list reflects that it is often – and ideally – evaluated together with flexibility[1]. It reflects that supply shortfalls can occur due to insufficient production capacity (i.e. total amount of capacity) in the system, or because the flexibility of said capacity was

[1] As a working definition, we assume that adequacy events occur if demand exceeds the available generation capacities. Flexibility-related load shedding events, on the other hand, can occur if there is capacity available in the system that could produce, but it is not possible to make it available in time meet demand, for example due to too long start-up times or low ramp rates.

insufficient to make it available in time. In addition, improving resource adequacy can simultaneously improve the system's flexibility and vice versa.

In the European legislation, there is, however, a clear separation of roles: The European Resource Adequacy Assessment (ERAA) is evaluating the level of resource adequacy in the European system, while National Resource Adequacy Assessments (NRAAs) have the same function on a national level. FNAs should further be in line with the ERAA and NRAAs according to the EMD. This can be achieved by taking power plant capacities from ERAA as a starting point, as a best guess of how the system will look like, and excluding resource adequacy from the scope of FNAs. The remaining three areas in conjunction can deliver a comprehensive picture of whether sufficient flexibility is available. An overview on their presence in the assessed works is given in **Table 1**. The assessments evaluated in this work focus on identifying malfunctions in the system. While this is a necessary precondition to determine the system's needs, FNAs should extend beyond this point to quantify the capabilities Member States need to procure to meet the identified shortfalls.

Table 1: Overview of featured indicators in the assessed literature. Coloured cell implies presence of indicator type.

		(AESO, 2022)	**(Chondrogiannis et al., 2021)**	**(Edmunds et al., 2017)**	**(Parker, 2017)**	**(Elia, 2023)**
Renewable integration	Diagnostic					
	Descriptive					
Ramping flexibility	Diagnostic		(As part of resource adequacy)			(As part of resource adequacy
	Descriptive					
Reserve requirements	Diagnostic					
	Descriptive					
Markets	Descriptive					

Source: JRC analysis

In addition to the areas presented above, one could further assess the contribution of flexibility to resolving congestion. Besides the fact that this aspect was not considered in any of the assessments reviewed for this work, including congestion in FNAs is rather tricky, due to different reasons. From a feasibility point of view, it would take large grid modelling exercises – down to the distribution level – to capture the role of flexibility in managing congestion. More importantly, however, the provisions in the EMD are not necessarily suitable to resolve congestion by procuring additional flexibility through the Member States: Let us assume that a FNA found a need for more flexible resources in the system to manage congestion better. If these resources were to be procured through a general mechanism by the Member State in question, there would be no guarantee that they would be operated in a way that relieves congestion. If they were to be placed on the wrong side of a bottleneck, they could well increase congestion further.

2.1 Renewable integration

A lack of flexibility in the system can lead to lower levels of renewable integration, as the system is insufficiently capable to either store renewable generation with the purpose of making it available at a later point in time, or to shift demand to timeframes when unused renewable energy is still available. Accordingly, several assessments evaluate the level of renewable curtailment (AESO, 2022; Chondrogiannis et al., 2021; Edmunds et al., 2017; Parker, 2017). In addition, assessments feature other descriptive indicators, such as the penetration level of renewable generation (Chondrogiannis et al., 2021), the increase in forecast errors (AESO, 2022) or the volatility of renewable infeed (Parker, 2017).

There are, however, two issues with taking renewable curtailment as the final output indicator measuring renewable integration. Firstly, one would need to define how much curtailment is still acceptable as otherwise no shortfall can be identified. Some curtailment will always be part of the most economical solution – instead of investing in flexibility until the last MWh of renewable generation was integrated. Similar to a LOLE target for resource adequacy assessments, a renewable integration target would therefore need to be defined. The FNA would then identify a need if this target was not met.

The second issue is that an unmet renewable integration target does not contain information on how much flexibility is needed to meet the target. To allow for a fast procurement process, FNAs would therefore need to identify how much flexibility is needed to reduce curtailment below a pre-defined level.

2.2 Ramping flexibility

Insufficiently flexible power systems can further produce situations in which the system operator has to order load shedding – even though generation capacity is available in the system and generally functional. In these cases, free capacity is not able to ramp up in time to meet demand due to ramping limitations. Ramping flexibility includes as well limitations when power plants cannot be ramped up in time after a period of downtime.

These situations can occur when extreme ramps on the demand side occur, for example due to the electrification of heating, which can produce high winter peaks (Thomaßen et al., 2021). Renewable ramps would likely be less of a concern: The market algorithm would curtail renewable generation to maintain enough dispatchable capacity in the system to safeguard operation, as this solution would produce lower costs than shedding load. Exits of conventional generator can further increase the relevance of assessing whether sufficient ramping capacity will be present in the system.

Accordingly, ramping needs are at the core of the assessed works, being considered as an element of security of supply (Chondrogiannis et al., 2021; Edmunds et al., 2017; Elia, 2023; Parker, 2017), while (AESO, 2022) features a descriptive depiction of the magnitude of ramps that occur in the system.

(Edmunds et al., 2017; Parker, 2017) further identified those periods where demand was not met due to insufficient ramping resources, distinguishing them from general adequacy events. We recommend to follow these two examples to allow for sufficient distinction between adequacy and flexibility related events, and thereby sufficient distinction between ERAA/NRAAs and FNAs.

2.3 Reserve requirements

Lastly, insufficient flexibility in the system can trigger events when the system operator is not capable of procuring sufficient amounts of operating reserves to meet reserve targets. This concerns the ability of TSOs to procure and maintain a sufficiently sized reserve *before* imbalances are settled in the balancing market.

Similar indicators have been reported by (Chondrogiannis et al., 2021; Edmunds et al., 2017; Parker, 2017). Providing reserves does not only require free, non-producing capacity, but as well the capability to make this capacity available within a certain time window. If capacity is insufficiently flexible, time periods can occur, during which the market cannot offer sufficient reserve volumes to fulfil the target set by the system operator, resulting in a shortage of reserves.

Flexibility assessments can further assess whether the demand for balancing services will increase, and therefore, whether said reserve would need to increase in size. In this way, (Elia, 2023) assesses the expected imbalances, such as forecast errors, and whether this would create a need to procure larger volumes of reserves in the future.

2.4 Descriptive market indicators

In addition to the three areas above, several assessments feature descriptive market indicators, such as the number of hours with negative prices or positive price spikes that are expected (Edmunds et al., 2017; Parker, 2017), as well as the general level of volatility (Chondrogiannis et al., 2021; Parker, 2017). These indicators can be helpful for market participants, as they give an outlook on how prices might change in the future. As argued above, they should be seen as an important but secondary output of FNAs, as the system's needs cannot be directly derived from these.

3 FNA output indicators in line with the EMD

In this section, we propose a set of output indicators, which consider best practices in the literature (summarized in the previous section), as well as the needs that result from the EMD reform.

The EMD mandates that the focus of FNAs shall be the need for flexible resources to achieve both, security of supply and decarbonization, as outlined in Article 19 c):

> *[…] the regulatory authority, or another authority or entity designated by a Member State, shall adopt a report on the **estimated needs for flexibility** for a period of at least the next 5 to 10 years at national level, in view of the need to cost effectively achieve **security and reliability of supply** and **decarbonise the electricity system** […]*
>
> (Emphasis added by the authors.)

It is therefore the primary purpose of the FNA Methodology to identify in which situations inefficiencies can occur, which are related to a lack of flexibility in the system, and estimate *how much* additional flexibility is needed. The focus shall furthermore lie on inefficiencies that undermine the security of supply, or decarbonization efforts, which aligns well with the three areas identified in section 2: renewable integration, ramping needs and reserve requirements.

In the following, we present three indicators that describe these areas of priority. In conjunction, they deliver a consistent and holistic picture of the inefficiencies present in a given power system that arise due to insufficient flexibility, and which have an impact on decarbonization and the security of supply. They should be determined with the help of a unit commitment model, respecting start-up and shut-down times, ramp rates, among others, as to deliver an accurate picture of the (in)flexibilities present in the power system. In distinction to gross flexibility needs derived with residual load curve analyses (see for example (Artelys, 2023)), all indicators presented here describe *net* flexibility needs, i.e. take into consideration the capabilities already present in the system.

3.1 Renewable integration needs

Instead of simply reporting renewable curtailment, we propose to identify the flexibility needs associated with a reduction in curtailment below a certain target. The need for such an indicator can be directly derived from Article 19 c), mandating that the report shall

> *[…] evaluate the different **types of needs** for flexibility, at least on a seasonal, daily and hourly basis, **to integrate electricity generated from renewable sources** in the electricity system.[…]*
>
> (Emphasis by the authors.)

Broadly, there are two ways of integrating more renewable electricity into the system: By increasing transmission and by improving the correlation of renewable supply and demand. A full-scale grid modelling exercise is likely out of scope of the assessment. Transmission planning is further subject to the Ten Year Network Development Plan (TYNDP) and the national Network Development Plans (NDPs). If FNAs were to assess transmission needs as well, there is a risk that they would interfere with these processes, adding unnecessary complexity to transmission planning while blurring responsibilities and competencies.

The way to increase the share of renewable electricity in the grid within the jurisdiction of FNAs is therefore to increase the correlation between supply and demand. With renewable production potential being driven by weather conditions, there broadly exist two options: To move consumption to times when renewable electricity is available, or to store renewable electricity with the purpose of making it available when sufficient demand for it is present. Leaving aside transmission expansion, additional renewable integration can therefore only be achieved by additional energy shifting – demand *or* supply.

The respective section in the EMD further mandates that the needs shall be split up into at least hourly, daily and seasonal flexibility needs. While those indicators related to the security of supply produce primarily hourly and sub-hourly flexibility needs, renewable integration needs arise along all time scales, up to seasonal or even inter-annual horizons[2].

3.1.1 Renewable integration target

A precondition for determining the energy shifting need of a system is that there exists a target with regard to how much renewable electricity shall be integrated into the system. This target can, for example, be formulated as a renewable share with regard to consumption, or as a curtailment standard, mandating how much renewable curtailment should occur at maximum. Here, it has to be noted that it is likely not reasonable to set a common curtailment standard, as the system-optimal level of curtailment will differ between a country with high shares of variable renewables and one which has just started deploying these technologies. It will further differ in time, as higher curtailment rates will be system optimal with larger deployed volumes of variable renewable generation. Each Member State therefore has to define what level of renewable curtailment is acceptable at what point in time.

One option to derive such a target would be to interpret national targets, where these are defined in sufficient detail. A renewable integration target could be derived, for example, if these describe the deployed renewable capacity and the share of renewable electricity in the electricity mix. The renewable integration target would be achieved if sufficient flexibility were present in the system to integrate the renewable energy volumes foreseen by the national targets.

A second option, for example where similar information is lacking, would be that Member States rely on modelling approaches to identify how much renewable integration is system optimal.

3.1.2 Calculation from model outputs

The starting point to determine a renewable integration need would be a unit-commitment model run, which resulted in insufficient amounts of renewable electricity being integrated into the system. As outlined above, a renewable integration need would be equivalent to a need for more energy shifting to increase utilization.

To determine the energy shifting needs, an energy-shifting technology (EST) can be added to the system until the renewable integration target was met (see Box 1). The correct capacity of this EST could be determined with the help of an investment model, either iterative or in one run. Alternatively,

[2] Inter-annual fluctuations in renewable energy supply can be relevant with regard to hydro production, or – potentially at higher levels of decarbonization – with regard to the production of hydrogen.

even capacity additions by hand would be a feasible, yet cumbersome solution, similar to ENTSO-E's approach for the Capacity Market scenario in ERAA 2021 (ENTSO-E, 2021).

Box 1: Energy shifting technology

An energy shifting technology (EST) can act as a placeholder for flexibility with energy shifting capabilities – such as demand response and storage – and should be modelled as a dummy storage technology. It is suitable as well to depict demand shifting, as the shifting process is often modelled through the use of some kind of storage (virtual or actual[3]). This allows depicting the impact of additional capabilities to transfer electricity in time, which is a precondition for increasing the utilization of renewable generation (compare section 3.1). Adding EST capacity (measured in MWh) until a renewable integration target is met therefore describes the need, without any assumption to how this need is ultimately satisfied.

To remain technology agnostic, the EST should therefore be parametrized as a storage technology without losses, which is primarily defined through its energy content. Restrictions with regard to charging and discharging capacity should not apply, to enforce that shifting energy is the only purpose of capacity additions by the model. These limitations, together with loss rates, should rather be taken into consideration during the procurement process[4] – as they are technology specific – instead of being considered within the procurement volume, which should be technology agnostic.

Splitting up the renewable integration needs into the different time horizons (hourly/daily/seasonal) would then require an analysis of the time series, which describes the EST energy content. To this aim, a similar methodology to the one presented by (Artelys, 2023) could be used[5]. Instead, however, of deriving flexibility needs from the residual demand curve – which would yield gross needs – it could be used to split up the energy shifting needs determined by the model, representing necessary *additions* to the existing capabilities (net needs).

This can be achieved by taking the energy content curve of the EST and splitting it up by subtracting the mean over the corresponding time interval. For daily energy shifting needs, it would be the daily mean, while the weekly mean would be the relevant value for weekly energy shifting and so forth. As an example, the daily flexibility needs produced by each hour could be calculated as:

$$E(h, d) - E_{mean}(d)$$

With $E(h, d)$ being the energy content stored inside the EST during a given hour of the day h on a given day d, and $E_{mean}(d)$ being the mean energy content of the same day.

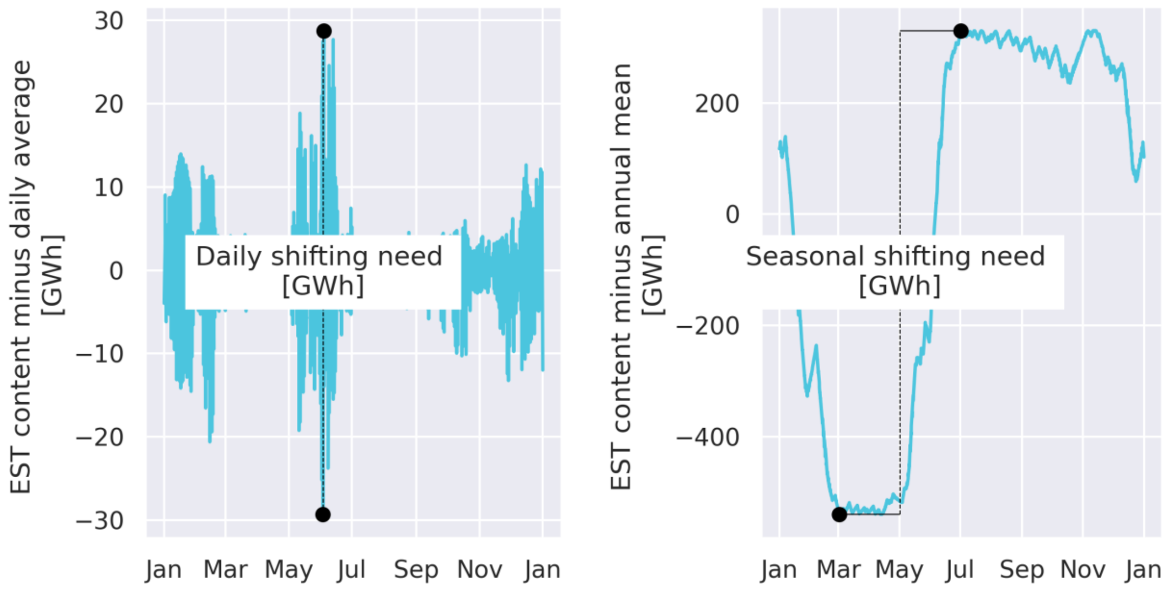
The difference between the maximum and the minimum value over the full study horizon then corresponds to the renewable integration need, expressed as an energy shifting capacity (in MWh), which could be satisfied by storage and demand shifting with the corresponding capabilities (see **Figure 2**).

[3] For example in the case of heat pumps (thermal storage) or electric vehicles (considering charging strategies).

[4] For example through derating factors, similar to capacity credits in a capacity market.

[5] As an alternative, Fourier transformation could be used to disaggregate into different time horizons.

Figure 2: Determination of daily (left) and seasonal (right) energy shifting needs based on an evaluation of the EST's energy content curve (exemplary representation)



Source: JRC analysis

3.2 Ramping needs

This indicator describes flexibility needs that are related to ramping, i.e. the inability to supply load due to insufficient ramping capacity inside the power system. Ramping needs distinguish themselves from adequacy indicators, as derived in ERAA, as they describe occurrences in which sufficient generation capacity was in principle still available, yet it could not be committed or ramped up in time to meet demand. These needs are therefore a result of (1) limited capability to ramp up a committed generator from one production level during one hour to a higher (or lower) one in the next, or (2) of ramping up a generator that was previously not committed. Start-up and minimum down time requirements being the limiting factor in the second case.

The need to consider ramping needs can be derived from the EMD's requirement to consider security of supply when assessing the flexibility needs within a power system, as load shedding events that are unrelated to adequacy are usually related to insufficient ramping capabilities.

Ramps that describe the transitions from one market time interval to another fall under the category of hourly flexibility needs, or even sub-hourly, if the model resolution is increased to 15 minutes. These correspond to the short-term flexibility definition used by (Elia, 2023). Limitations with regard to commitment decisions – activating a generator that was previously down – can further relate to longer time horizons.

Capturing limitations with regard to commitment decisions would require the modelling of at least two separate market sessions – one real time or several intraday sessions in addition to one day ahead. If forecasts for load or renewables deviate from the real-time outcome, it can require the commitment of additional capacity. If this capacity cannot be committed, due to long start up times, it can force the system operator to order load shedding. These inefficiencies only reveal themselves if a market session *after* the day ahead is modelled – when some final commitment decisions were already made.

3.2.1 Calculation from model outputs

The calculation of ramping needs is rather straightforward. As a first step, the hours during which load shedding occurred are identified. In a second step, a check is performed whether all available capacity inside the respective zone was operating, i.e. generating power or providing balancing services.

If all capacity was operating, but it was still not possible to meet demand, the event has to be classified as an adequacy event, and therefore should not be reported in the flexibility indicators. If, however, there was sufficient capacity available in the respective zone, the load shedding event has to be seen in the context of insufficiently flexible power plants, as it was not possible to ramp up the free capacity in time.

The needed amount of fast-ramping capacity can be determined by considering the maximum load shedding capacity that occurred due to ramping constraints. The additional flexibility need due to ramping could therefore be described as a ramping capacity (in MW/MTU). This flexibility could be provided by very different means, such as storage, demand response, but also the flexibilization of existing generators and the addition of quick-start units. The final need further needs to take into consideration the reliability standard set by the Member State in question. In an otherwise highly adequate system, the occurrence of some load shedding events due to ramping limitations might still remain within acceptable limits.

3.3 Reserve needs

Similar to the ramping needs, a reserve shortage indicator describes insufficient power system flexibility to safeguard the security of supply. In addition to shortfalls in making generation capacity available to the market – which are subject to section 3.2 – insufficient flexibility can show itself in the model's inability to meet the level of reserves which should be withheld during every trading interval. As described in section 2.3, this describes the TSO's ability to withhold sufficient reserves *before* balancing markets are settled close to real time. Reduced reserve levels, in turn, can lead to load shedding events, as the risk increases that the balancing demand exceeds the available supply.

Reserve shortages require additional flexibility at a sub-hourly timescale, as the delivery periods for all reserve products but replacement reserves are usually up to 12.5 minutes.

3.3.1 Calculation from model outputs

It is common to add a reserve constraint to unit commitment models to ensure that sufficient reserves are withheld during every trading interval. This constraint can be formulated as

$$\sum_{u} Reserve_{u,h} + LostReserve = ReserveTarget$$

With $Reserve_{u,h}$ as the level of reserves provided by each unit u during hour h, and $ReserveTarget$ being the amount of reserves procured by the TSO for the relevant reserve segment. The $LostReserve$ variable describes a slack generator, which is only drawn in cases when the model cannot fulfil the balance in any other way. TSOs would always aim to preserve the reserve levels necessary to safeguard the system's operation, even ordering load shedding to maintain adequate levels of reserves. The $LostReserve$ variable would therefore be penalized with a high penalty factor in the objective function.

Lost reserves can therefore be directly extracted from the modelling results. The amount of capacity needed to compensate a lost reserve event can be determined by considering the maximum amount of capacity that was missing. Procuring the missing capacity in a flexibility auction then requires taking into consideration the prequalification criteria that exist for the respective reserve product where a need was identified.

3.4 Deriving the overall needs

To limit the procurement of additional flexibility to what is actually needed, double counting should be avoided. To do so, one should start with the area that usually produces flexibility needs with the longest time horizon – renewable integration. The reason is that it is possible that additional flexibility for renewable integration will decrease the needs for additional flexibility for ramping and reserve purposes as well. Similarly, ramping needs, can produce hourly and multi-hourly flexibility needs and should therefore be considered before reserve needs.

4 Concluding remarks

As set out in the EMD reform, FNAs should address both security of supply and decarbonization objectives. They should further enable Member States to dimension support schemes for flexibility that procure sufficient volumes to address any existing gaps. To this aim, this work analyses existing assessments of power system flexibility in the literature before proposing suitable outcome indicators that fulfil these purposes.

We find that flexibility assessments commonly focus on four key areas: renewable integration, ramping flexibility, reserve requirements and resource adequacy. As resource adequacy is subject to ERAA and NRAAs, we propose to focus on the three remaining areas in the upcoming methodology for FNAs.

While the reviewed assessments provide already suitable indicators on aspects regarding the security of supply – ramping needs and reserve shortages – they usually evaluate renewable integration based on curtailment levels. This indicator can indeed be the starting point to judge whether sufficient resources are available to integrate renewables, yet there are two challenges: On the one hand, a renewable integration target would need to be defined, in comparison to which it can be determined whether renewable curtailment exceeds acceptable levels or not. Further, to meet the requirements set out by the EMD, it needs to be derived *how much* flexibility needs to be procured at the different time scales to meet a renewable integration target that would otherwise not be met.

We thus propose three output indicators that align with the three identified areas of key interest: (1) *renewable integration needs*, (2) *ramping needs*, as well as *reserve needs* (3).

With regard to (1), it appears necessary that Member States define a renewable integration target. Wherever sufficient information is available, this target could be derived from national renewable targets. Alternatively, modelling exercises could be used determine system-optimal levels of curtailment.

In those cases where the target has not been met, renewable integration needs could be determined by adding energy-shifting capacity to the model until sufficient amounts of renewable generation were integrated. We further outlined how these needs for additional energy shifting could be separated into the different time horizons.

Ramping needs (2) can furthermore be derived directly from unit-commitment model runs. To this aim, load shedding events can be evaluated. Events with insufficient ramping capacity need further to be distinguished from adequacy events, to avoid overlaps with ERAA/NRAAs. This can be achieved by considering the utilization rate of the available capacity.

Lastly, it should be evaluated whether reserve shortages occur during the model runs. In these cases, we can quantify reserve needs (3), which describe the need for additional flexibility at a sub-hourly time horizon. These needs arise when there is insufficient capacity available for system operators to procure the targeted volumes for each reserve segment.

To avoid over procurement, synergies between the three areas of interest need to be taken into consideration. It needs therefore careful assessment whether capacity procured for one purpose might as well resolve flexibility shortages in other areas. Generally, needs with the largest time horizon should therefore be determined first, as filling these can already supply some of the needs at shorter time horizons.

References

AESO, 2022. System-Flexibility-Assessment.

Artelys, 2023. Power System Flexibility in the Penta-region - Current State and Challenges for a Future Decarbonised Energy System.

Chondrogiannis, S., Poncela-Blanco, M., Marinopoulos, A., Marneris, I., Ntomaris, A., Biskas, P., Bakirtzis, A., 2021. Power system flexibility: A methodological analytical framework based on unit commitment and economic dispatch modelling, in: Mathematical Modelling of Contemporary Electricity Markets. Elsevier, pp. 127–156. https://doi.org/10.1016/B978-0-12-821838-9.00008-6

Edmunds, T., Alzaabi, O., Mills, A., 2017. Flexibility Metrics to Support Grid Planning and Operations.

Elia, 2023. Adequacy & Flexibility Study for Belgium (2024-2034).

ENTSO-E, 2021. ERAA 2021: Annex 3 Methodology.

European Commission, 2022. State of the Union 2022. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_5489

Parker, M.J., 2017. Grid Modernization: Metrics Analysis (GMLC1.1).

Thomaßen, G., Kavvadias, K., Jiménez Navarro, J.P., 2021. The decarbonisation of the EU heating sector through electrification: A parametric analysis. Energy Policy 148, 111929. https://doi.org/10.1016/j.enpol.2020.111929

List of abbreviations and definitions

Abbreviations	Definitions
ACER	Agency for the Cooperation of Energy Regulators
EMD	Electricity Market Design
ENTSO-E	European Network of Transmission System Operators for Electricity
ERAA	European Resource Adequacy Assessment
EU DSO	European Distribution System Operators
FNA	Flexibility Needs Assessment
MWh	Megawatthour
MTU	Market time unit
NDP	Network Development Plan
NRAA	National Resource Adequacy Assessment
RAA	Resource Adequacy Assessment
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan

List of figures

List of tables

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
Joint-research-centre.ec.europa.eu

Publications Office of the European Union