ACER

European Union Agency for the Cooperation of Energy Regulators

Preparing for the European flexibility needs assessment

Facilitating transparent analysis using open-source modelling

5 November 2026



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Executive summary

The European power system is undergoing significant changes. The European Union (EU) aims to reduce its dependency on imported fossil fuels, improve the competitiveness of its economy and meet its climate objectives. To this end, the EU is deploying large volumes of renewable energy sources (RES) while pursuing the electrification of the transport, heating and industry sectors.

Delivering this transition will increase the relevance of and need for a flexible power system that can better adapt to changes in generation and demand by shifting consumption, storing energy and using networks to deliver electricity where and when needed.

Recognising the growing importance of flexibility, the European Union (EU) has established a new framework for assessing the flexibility needs at both national and Union level: the Flexibility Needs Assessment, or FNA. This assessment identifies where additional flexibility may be required and informs policy decisions at both national and European level.

As part of this framework, ACER[1] must carry an EU-wide FNA, with the first assessment due in July 2027. This assessment will provide unique insights into the challenges the EU's power system faces, and the opportunities its Member States can leverage to meet them. Its results can help both national and European policy makers in developing effective policies to support the flexibility of the European power system.

With the support of the Joint Research Centre (JRC) and Open Energy Transition (OET), ACER has developed an open-source modelling tool to deliver its new mandate: the EU-Flex model. The model is designed to assess flexibility needs across Europe in a transparent and replicable way, using in principle public data to support robust policy making and business decisions.

This paper outlines the EU-Flex model and its main features. It provides stakeholders with an early view of the analytical approach being developed through an illustrative test case. Additionally, ACER is releasing both a preliminary version of the EU-Flex model and its underlying methodology.

By making this information publicly available, ACER aims to:

- Improve transparency and support evidence-based decision making.
- Enable decision-makers, stakeholders and researchers to scrutinise the modelling approach, familiarise with the model and use it, as well as contribute to its further development.
- Gather feedback by interested parties that can help improve the EU-Flex model.

[1] In this document, 'ACER' and 'the Agency' are used interchangeably.

1. Introduction

1.1. Purpose and scope of this paper

ACER aims to foster the transparency of the EU-wide FNA assessments, ensure the credibility of the analysis conducted and incentivise cooperation with stakeholders. For these reasons, this paper launches the public release of a preliminary version of the EU-Flex model and its underpinning methodology, allowing stakeholders to scrutinise the model, reuse and improve it as they see fit.

It is important to note that this document does not constitute the ACER's EU-wide FNA report nor should it be considered an analysis of recently published national FNAs. The analysis presented in this document is purely illustrative in nature. It should not, therefore, be construed as representing official findings or policy recommendations.

The content of this document is structured as follow:

- Chapter 2 outlines the FNA process, ACER's role within it and the work it has undertaken to deliver its new mandate, as per Article 19e(7)(b) of the Electricity Regulation[2].
- Chapter 3 introduces the EU-Flex model that will be used to carry out ACER's EU-wide FNA, describing its overall architecture and main features.
- Chapter 4 presents the results of an illustrative test case, showcasing the model's capabilities.

Alongside this paper, the Agency is also publishing:

- The source code of the EU-Flex model itself, available in ACER's GitHub repository. There, stakeholders will also find a user manual explaining how to download, install and use the model.
- The test case used for the analysis presented in this paper, also available in ACER's GitHub repository.
- The modelling specification underpinning the model itself, available both on in ACER's public consultation page and ACER's GitHub repository.

1.2. How to provide your feedback and next steps

The Agency is seeking from stakeholders:

- High-level feedback on the methodology underpinning the model itself to identify areas for improvement for future iterations. This can be provided through the EU Survey to be found in ACER's public consultation page, alongside any feedback on the content of this paper.
- User feedback on the EU-Flex model to help ensure that it works as intended. This can be provided directly in the GitHub repository, where you can find detailed instructions on how to submit your comments.

ACER will:

- Collect feedback until 17 December 2026.
- Include a summary of the feedback received in the formal EU FNA report in 2027.

Pleae note that only identified critical issues in the model or the methodology for ACER's EU-wide FNA will be addressed before July 2027.

Please also note that this feedback collection does not substitute the formal public consultation process that ACER intends to launch when the EU-wide FNA will be published in July 2027.

[2] Regulation (EU) 2019/943 (recast).

2. The need to assess flexibility across the EU

2.1. A changing European power system

The energy transition is radically changing how power systems operate. To improve its energy security, enhance competitiveness and decarbonise its economy,[3] the EU has been gradually phasing out polluting conventional power plants whilst deploying significant volumes of RES. At the same time, the EU is promoting the electrification of sectors that traditionally relied on fossil fuels (e.g. transport and heating) to limit its reliance on energy imports and to reduce costs to consumers.[4]

These processes are transforming how electricity is produced and consumed. Historically, power systems were mainly centralised, with large conventional power plants providing controllable generation to meet a largely inflexible demand. Today, power systems are gradually becoming more decentralised, with a growing share of RES generation that depends on weather conditions and a more controllable demand. These changes make managing the power system more challenging but also increase the range of resources available to meet changing system needs.

RES generation may not always be available when electricity is needed, while periods of high renewable output may lead to increased curtailment (i.e. turning down renewable energy when the system cannot absorb it). As the EU deploys more RES and gradually phases out conventional fossil fuel-based power generation, the need for flexibility is expected to grow.[5]

Flexibility is the ability of a power system to adjust to the variability of generation and consumption patterns and to grid availability, across relevant market timeframes.[6] It can be provided by a variety of resources such as storage, demand response, flexible generation and the electricity network.

A flexible system can shift supply by storing the renewable electricity generated during periods of excess (e.g. during the day, or a sunny weekend) and releasing it during times of high demand (e.g. in the evening around dinnertime, or the working week). It can also shift generation to times when renewables are less abundant. Similarly, flexible demand can be adjusted to better match the available supply, for example by shifting it during times when renewables are plentiful.[7] Interconnected grids can also improve the overall flexibility of the power system by enabling market participants to benefit from complementary generation sources and demand patterns between Member States.

In other words, a flexible power system can support delivering the energy transition by better integrating RES and managing the power system in a cost-effective way. This in turn may mitigate the need for additional investments and lower consumer bills. Therefore, flexibility has emerged as a critical component of recent EU's energy policy.

2.2. The flexibility needs assessment process

In the aftermath of the Russian invasion of Ukraine, the European Commission adopted a series of new policy initiatives to improve EU's energy security and affordability.

Among these, the Electricity Market Design (EMD) reform put a renewed focus on the need to better integrate the growing share of RES to reap the benefits of low-cost electricity generation, and on flexibility as a key enabler of the transition.

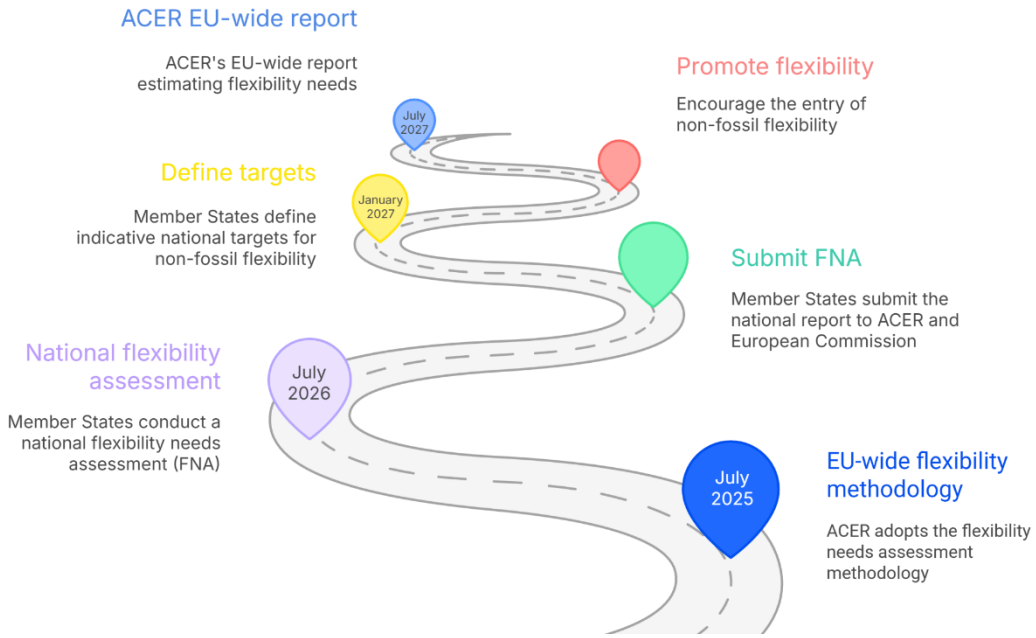
The reform mandates Member States to perform, every two years, a FNA to identify how much flexibility is needed for a period of at least the next 5 to 10 years. Member States are specifically required to consider the role that non-fossil flexibility sources can play in meeting those needs and to assess

[3] See, for example, the 2030 Climate & Energy Framework (2014) Clean Energy Package (2019), the European Green Deal (2019) and the Fit for 55 legislative package (2021).
[4] Important initiatives in this regard are, for example, the REPowerEU plan (2022) and the AccelerateEU initiative (2026).
[5] EEA/ACER Report 09/2023 - Flexibility solutions to support a decarbonised and secure EU electricity system.
[6] Regulation (EU) 2019/943, Article 2.
[7] Cost-efficient levels of RES curtailment or demand disconnection are also considered sources of flexibility.

whether there are barriers preventing their deployment in the market, as well as the contributions of digitalisation.

Based on this assessment, Member States are then required to define indicative national targets for non-fossil flexibility. Member States can promote the deployment of non-fossil flexibility via the removal of barriers, and as a last resort, consider the introduction of support mechanisms to facilitate the development of carbon free flexibility sources.

Figure 1: Description of the key steps in the newly established flexibility monitoring process



Source: ACER

ACER plays a fundamental role in this process. The EMD reform mandates [8] the Agency to:

- Amend or approve the methodology underpinning the national FNAs (the FNA methodology) developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European entity for the cooperation of Distribution System Operators (DSO Entity). [9] This process was concluded in July 2025.
- Review and analyse the national assessments, providing recommendations on issues of cross-border relevance and the removal of barriers to non-fossil flexibility identified by Member States.[10]
- Estimate the flexibility needs at European Union's level.

To deliver its mandate, the Agency has decided to develop an open-source modelling tool: **the EU-Flex model.** The model has been developed with the support of the European Commission's Joint Research Centre (JRC), Open Energy Transition (OET) and a dedicated group[11] of 30 experts.

With this model, ACER will run its first-of-its-kind assessment in line with the FNA methodology. ACER's FNA has an EU-wide, rather than national, focus, providing unique insights into the challenges facing the European power system as a whole and the cross-border synergies its Member States can leverage to address them. This EU-wide FNA can support national and European policy makers in developing effective policies and strategies to improve system flexibility.

[8] Electricity Regulation (EU) 2019/943, Article 19(e).
[9] ACER Decision No 05/2025 on the type and format of data and the methodology for TSOs' and DSOs' flexibility needs analysis
[10] Please note that these tasks sit outside the scope of this document. Nonetheless, they will be an integral part of ACER's publication planned for July 2027.
[11] For more information on the Expert Group, please visit this page.

The EU-Flex model is developed using Python for Power System Analysis (PyPSA)[12], an open-source Python toolbox designed to simulate and optimise modern power and energy systems. The Agency will publish the final version of EU-Flex model used for the EU-wide FNA due in July 2027, including the model source code and all non-confidential input data.

[12] For more information on PyPSA, please visit this page.

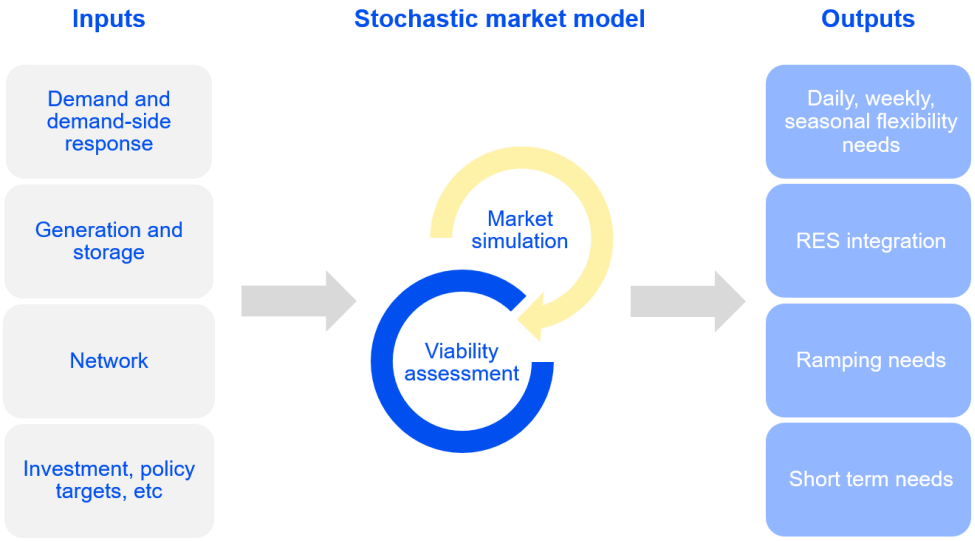
3. An overview of the EU-Flex model

This chapter provides an overview of the model's key features. More details can be found in the modelling specification document published alongside this document.

The EU-Flex is a model that simulates the European power market. It is designed to assess flexibility needs across Europe in a transparent and replicable way.

The model considers two market timeframes, allowing for a more granular representation of the operation of the power system and a better assessment of the revenues streams that assets can obtain from the market. Based on these revenues, it simulates how the European resource mix could evolve over time. The model then computes flexibility indicators included in the FNA methodology, the contributions to flexibility needs per technology, including cross-border interconnectors, and other market indicators.

Figure 2: Overview of the EU-Flex model's architecture



Source: ACER

3.1. General set up

The EU-Flex model simulates power markets on an hourly basis, and its geographical scope encompasses all Member States and key neighbouring countries connected to the European power network.[13] To represent European power markets, the EU-Flex model considers Member States at a bidding zone level.[14]

The EU-Flex model can handle interconnection capacities defined as net transfer capacities (NTC) and flow-based domains (FBMC). This means that the model can fully simulate exchanges across bidding zones, accounting for network constraints between them.[15] On the other hand, the model does not model internal networks, nor the electricity flows within a given bidding zone.

[13] The geographical scope and the representation of peripheral countries will follow the modelling of the European Resource Adequacy Assessment (ERAA). Neighbouring countries include Norway, the United Kingdom and the Balkan nations. The model also considers peripheral countries such Morocco and Tunisia in a simplified manner.
[14] A bidding zone is a geographical area within which electricity can be traded without considering internal transmission constraints. They are generally defined around national borders (e.g. France, Poland, Greece), although some countries can contain multiple bidding zones (e.g. Italy and Sweden), or there can be cross-border bidding zones (e.g. Germany/Luxembourg).
[15] Electricity flows are calculated using either the National Electricity Transmission System (NETs) or the Flow-Based Market Coupling (FMBC) method, where applicable.

The input data relating to each Member State (e.g. generation mixes, demand, interconnection capacities) will be collected from the national FNAs submitted to ACER.

To account for the impacts of weather variability on the power system, the EU-Flex model uses weather assumptions from the Pan-European Climate Database (PECD), provided by the Copernicus Climate Change Service and co-developed by ENTSO-E.[16] The model can also consider planned and unplanned outages of energy assets.

3.2. Granular representation of short-term markets to better capture high-renewable systems dynamics

At the core of the EU-Flex model lies a simulation of the European electricity market, based on a unit commitment economic dispatch model (UCED). This model allows to determine how different resources are scheduled and dispatched to meet demand, whilst ensuring the cost-efficient operation of the power system. This is done through a two-step market simulation composed of a day-ahead and an intraday-balancing timeframe.

- **Day-Ahead Unit Commitment and Economic Dispatch (DA-UCED):** It aims to represent the day-ahead energy market and the procurement of balancing reserve capacities. The model determines the commitment of generators for the following day, and how different resources (i.e., generation, storage and demand response) are dispatched to meet demand at the lowest possible cost.

  The DA-UCED also determines the allocation of balancing reserves such as Frequency Containment Reserve (FCR) and Frequency Restoration Reserve (FRR), based on the reserve requirements defined for each bidding zone[17].

  The DA-UCED step considers forecasted timeseries of demand and RES generation, and planned outages of energy assets. The forecasted demand and RES generation potential values are derived by a separate machine-learning model developed by JRC and validated by ACER.

- **Intraday-Balancing Economic Dispatch (IDB-UCED):** It aims to replicate the adjustments made by market participants after the day-ahead market closure until real-time, when electricity is delivered. In this timeframe, market participants adjust their positions in response to possible errors in forecasts affecting RES generation and demand, and the occurrence of unplanned (or 'forced') outages.

  In this step, the model considers 'actual' (as opposed to forecasted) demand, RES availability, and forced outages to update the decisions made in the DA-UCED timeframe, taking into account the commitments of units and capacity reserves. The model assumes that only certain technologies can fully respond to forecast errors (e.g. storage, gas power plants), whilst other are considered slow units (e.g. coal, nuclear) and have limited capability to change their scheduling due to technical limitations and running costs.[18]

The EU-Flex performs a Monte Carlo assessment to simulate various weather and outage patterns (i.e., periods of planned or unplanned unavailability of units). Weather patterns define demand, renewables potential and hydrological conditions and are based on the PECD as input data. Outage patterns can be generated by the EU-Flex model based on historical data of forced unavailability of power plants. The market models for each combination of weather and outage patterns are run independently.

While this modelling approach does not replicate the full complexity of real-world electricity markets, it focuses on the most relevant dynamics introduced by variable RES, particularly the need for flexible resources. As such the EU-Flex model provides a clear view of flexibility requirements and the revenue

[16] For more information, please visit this page.
[17] Technically, the model co-optimises the DA energy and the FCR and FRR reserves. However, the use of co-optimisation in the model and its modelling design does not represent ACER's views on the actual implementation of co-optimisation in the internal energy market and is limited to the EU-Flex modelling exercise only.
[18] Slow units cannot change their *commitment* (on/off status) but can change their *dispatch* (production level) if it lies within their technical operation (minimum and maximum technical limits, ramping constraints). See the Modelling document for further details.

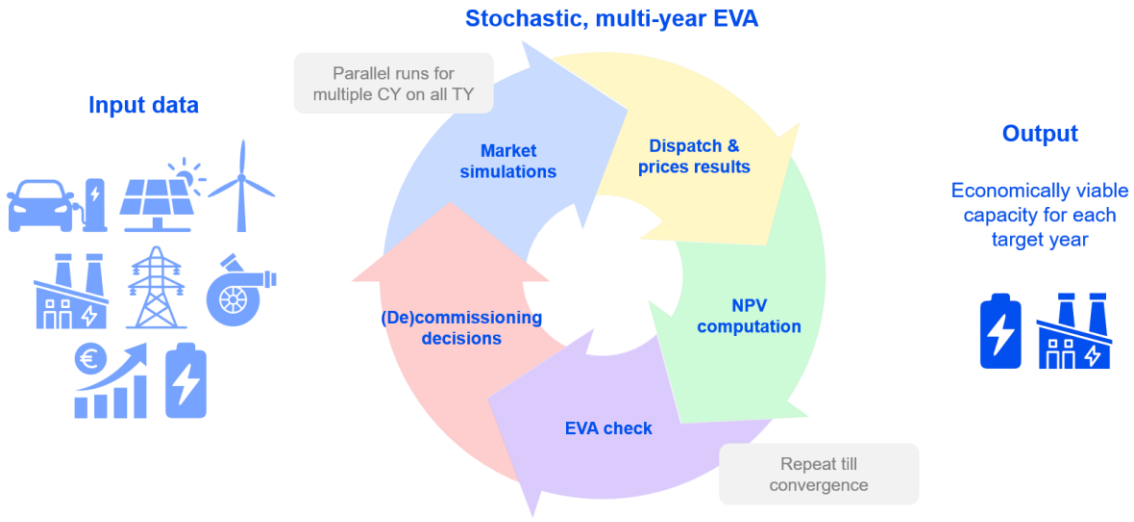
streams available to different technologies. These are critical factors to assess the profitability and viability of assets in systems with high shares of renewable energy.

3.3. An investor perspective to assess the evolution of the power mix

The EU-Flex model assesses the evolution of the resource mix through an economic viability assessment (EVA).[19] Under this approach, the model determines the resource mix of each bidding zone from an investor's perspective. The decision is based on the profitability of an asset, i.e., by comparing its expected revenues with its costs.

The revenue-based EVA evaluates the profitability of assets and iteratively adjusts their capacities until a market equilibrium is reached, at which point economically viable assets remain or enter the market and uneconomical ones exit the market, permanently or temporarily (i.e., mothballed). This process is illustrated in Figure 3.

Figure 3: Overview of the economic viability assessment process



Source: ACER

The EVA uses the market simulations results (prices and dispatch results) to estimate revenues and costs for a number of target years**.** Based on costs and revenues, and investment-related parameters[20] the model computes the net present value (NPV)[21] to assess the economic viability of candidate units.

Finally, the model updates the capacities of the system (by either increasing, reducing or maintaining capacities in the system), based on the estimated NPV, technical or policy limitations for development, and expected decommissioning date of existing assets.

ACER has selected this approach as it provides several benefits, including:

- A better representation of what capacities will be in the system based on market forces.
- A better representation of the European power markets through the day-ahead and intraday-balancing timeframes, which allows to account for multiple revenue streams.

[19] The revenue-based EVA has been implemented by a number of system operators in the context of adequacy assessments, including Elia, TERNA, REE and ENTSO-E.
[20] The revenues considered in the EVA are those earned from selling electricity in the day-ahead and intraday market timeframes, and for providing balancing capacity. Costs include variable operational costs (i.e. fuel, start-up and shut-down costs), fixed operational and maintenance costs, and investment costs. Investment related parameters include economic lifetime of an asset, interest rates and risk premium.
[21] The net present value (NPV) of an asset is the total value of future cash inflows minus the present value of cash outflows over time.

- A revenue-based EVA allows for a better consideration of stochasticity (i.e. combination of weather and outage assumptions) to be analysed through smaller problems across the time horizon of the study, rather than as one large optimisation problem. These smaller problems can be solved more efficiently.
- More robust results. Having smaller problems allows to increase the number of combinations of weather and outage assumptions for each target year modelled, better capturing their impact on the power system.

3.4. Flexibility indicators for understanding the challenges of high-renewable systems

The EU-Flex model quantifies flexibility needs across different dimensions, providing a comprehensive assessment of where and when additional flexibility is required. The flexibility needs computed by the EU-Flex model are the ones defined in the FNA methodology. Therefore, the indicators have been adopted in both national FNAs and the EU-Flex model, ensuring consistency across the assessments.

As per the FNA methodology, flexibility needs are divided into two groups: system needs and network needs.

3.4.1. System flexibility needs

System flexibility needs reflect the power system's ability to match generation and demand in real time. As RES penetration increases, the system must manage greater variability, requiring resources that can adjust their output or consumption.

The EU-Flex model assesses the three key types of system flexibility needs:

- **RES integration needs** measure the flexibility required to reduce the curtailment of renewable generation to meet RES integration targets.

  In the national FNA process, Member States are responsible for defining integration targets for RES, e.g. in terms of maximum allowed curtailment or, alternatively, minimum RES generation.[22]

  The EU-Flex model evaluates RES integration needs by analysing the level of RES dispatch observed in the market model simulations and comparing it with the RES integration targets. The model estimates the additional flexibility capacity needed to increase the RES generated to acceptable levels, using a technology-neutral approach. For this process, ACER developed a dummy storage module within the EU-Flex model (see Box 1 below).

[22] These targets are mostly derived from the integrated National Energy and Climate Plans (NECPs) that each Members States produces.

Dummy storage module

The dummy storage module is a tool within the EU-Flex model designed to estimate how much flexibility is needed to integrate renewable energy into the power system according to the RES Integration Targets set in the national FNAs. It helps answering a key question: "How much flexible capacity would be required to reduce renewable energy curtailment and meet Europe's renewable energy targets?"

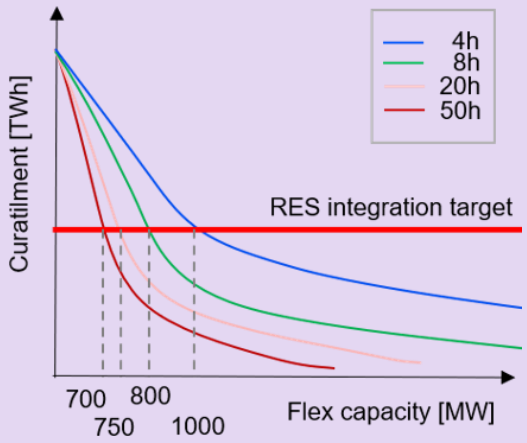
The module follows a technology-neutral approach. Instead of modelling real non-fossil flexible resources in detail, the module uses a generic system that can store or shift energy use (thereafter called "dummy storage") to determine the minimum flexibility capacity needed to reduce renewable energy curtailment up to the RES integration target. It also provides a benchmark for policymakers and system operators to understand where and how much flexibility is lacking. The dummy storage can represent different non-fossil flexible resources, including batteries, long-duration storage technologies, demand response or any other non-fossil technology that can offer the flexibility needed in the relevant timeframe considered.

The starting point for the calculations is the results from the market models. The module works by gradually introducing dummy storage capacities, considering that this generic storage can discharge when the residual load is positive, and charge when there is RES curtailment. This is done gradually, and for different energy-to-power ratios, resulting in different curves of installed capacity of dummy storage as shown in Figure 4 below. This is not a full Economic Dispatch, however, but an illustration of the effect of the dummy storage on the curtailment levels of RES generation.

In the EU-Flex model, an important component of the dummy storage analysis is the importance of interconnections when fulfilling flexibility needs. The EU-Flex model considers the available interconnection capacity and can compute dummy storage expansion with and without utilising cross-border exchanges, highlighting the benefits of an interconnected system.

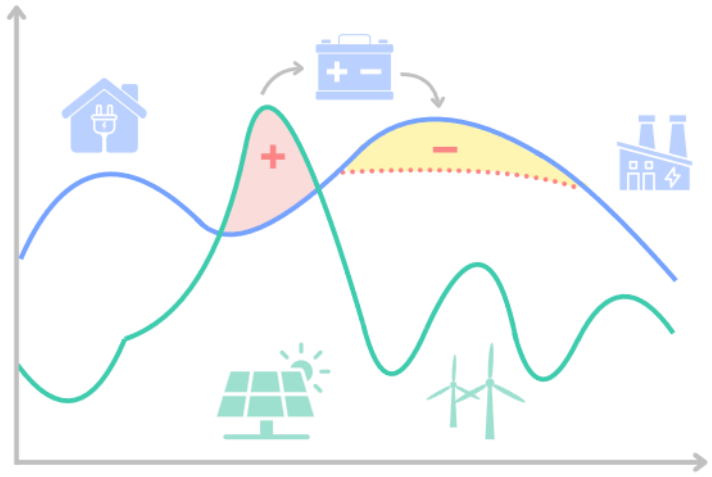
In the illustrative example below, 700 MW of 50h-batteries (or 1000 MW of 4h batteries, or the other intermediate configurations) would be needed to achieve the RES integration target.

Figure 4: Illustrative example of the additional flexibility capacity needed to meet a hypothetical RES integration target



Source: ACER

Figure 5: Illustrative example of RES integration needs, indicating what is the flexibility needed to integrate more RES



Source: ACER

- **Ramping needs** capture the flexibility required to manage rapid changes in the residual load, i.e. the difference between total demand and non-dispatchable generation (e.g. wind and solar). These needs are particularly important in systems with high-RES penetration, where sudden changes in renewable output or spikes in demand require fast-acting resources to maintain balance.

  The EU-Flex model assesses ramping needs by identifying periods where the system struggles to follow rapid changes in the system's output or consumption. This is done by means of analysing results from the market models with and without ramping constraints.

Figure 6: Illustrative example of ramping needs indicating what is the flexibility needed to cope with new ramping needs



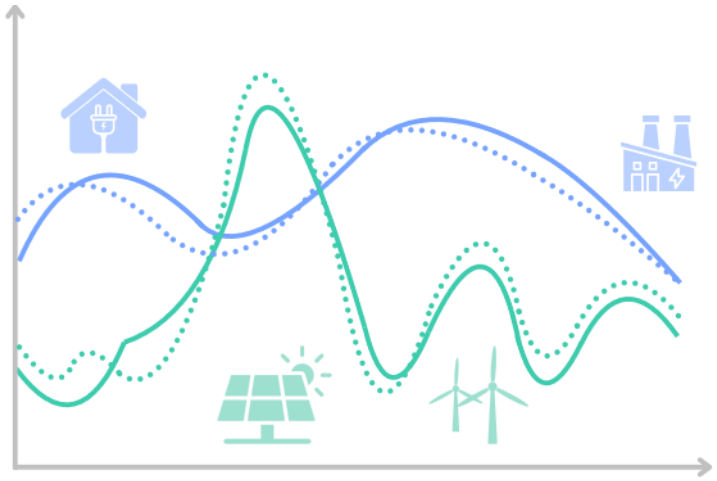
Source: ACER

- **Short-term flexibility needs** relate to unexpected variations in demand, renewable generation (e.g. forecast errors) or unplanned outages of power plants and transmission lines. These needs are inherently uncertain and may require the system to respond quickly to maintain balance.

  The EU-Flex model evaluates short-term flexibility needs by simulating adjustments from the day-ahead to the intraday-balancing market timeframe, as described in section 3.2. These adjustments represent the flexibility needed to cope with the uncertainties between the day-ahead to real-time. The short-term flexibility needs represent the flexibility needed in a broader sense, including

adjustments in intraday markets and balancing markets. As such, this should not be confused with balancing reserves.

Figure 7: Illustrative example of short-term needs indicating what is the flexibility needed to cope with RES and demand forecast errors



Source: ACER

3.4.2. Network needs

While system flexibility needs are assessed at the bidding zone level, network flexibility needs arise from local congestion or voltage issues within transmission and distribution grids. For this reason, in the national FNAs, TSOs and DSOs may report the network flexibility needs they foresee for the next 5 to 10 years.

The EU-Flex model has the capability to incorporate these network flexibility needs as exogenous inputs to be used in the calculation of system flexibility needs. This process is called “fine-tuning” in the FNA methodology and is also applied in the EU-Flex.[23] Through fine-tuning, additional RES curtailment observed exclusively due to conditions in the network are integrated in the calculation of RES integration needs. Network needs are not considered in the market models but only used in the dummy storage model.

3.4.3. Breaking down flexibility needs to different timescales

Not all flexibility needs are created equally. For instance, the flexibility that a 2h battery provides is most effective for short daily bursts, while a large hydropower plant can store energy during the spring and summer and generate in winter. To capture the daily, weekly and seasonal patterns of flexibility requirements, the EU-Flex model decomposes needs across multiple timeframes, in line with the requirements in the Electricity Regulation.

Daily flexibility needs capture intra-day variability, including the well-known "duck curve" effect, where residual load peaks in the morning and evening, while it drops considerably around midday day due to solar generation. High daily flexibility needs suggest that the system requires resources capable of quickly adjusting their output to follow rapid changes in output or consumption.

Weekly flexibility needs account for recurring patterns, such as lower demand on weekends or variations in industrial activity. For instance, if demand consistently drops on weekends, storage resources can be scheduled to charge during low-demand periods and discharge during weekdays when demand rises. Similarly, certain types of demand response could profit from the lower prices during the weekend.

[23] Type and format of data and the methodology for TSOs’ and DSOs’ flexibility needs analysis, Article 14.

Seasonal flexibility needs reflect long-term variations in renewable generation and demand. For example, wind generation is typically higher in winter, while solar output peaks in summer. Demand also varies seasonally, with higher heating demand in winter and cooling demand in summer. The model aggregates flexibility needs by month to identify periods of structural surplus or deficit.

3.4.4. Contributions of flexibility resources

The EU-Flex model will also assess the contributions of different flexibility technologies to meeting system needs. This analysis helps identify which resources are most prominent in addressing specific flexibility challenges.

The model evaluates contributions to daily, weekly and seasonal needs, as well as to ramping and short-term needs. It computes contributions for all generation, storage, and demand response technologies, as well as for cross-border interconnectors.

3.5. Known limitations of the EU-Flex model

Like all modelling tools, the EU-Flex model necessarily involves simplifications to balance the level of detail with computational complexity, retaining the key features needed for the analysis whilst obtaining modelling outputs within reasonable timeframe. Some key limitations are listed below:

- **Simplified market representation.** Although the EU-Flex model simulates two distinct market timeframes, it cannot capture all the complexities of day-ahead and intraday market coupling in Europe, such as portfolio bidding, sequential balancing capacity and energy markets, or several intraday auctions, among others. It also does not model all possible revenue streams explicitly, such as capacity mechanisms or non-frequency ancillary services.[24]
- **Simplified assessment of entry/exit.** The EU-Flex model's economic viability assessment considers each candidate technology independently. As such, it does not capture potential economies of scale or portfolio strategies, such as seeing in co-location of RES and storage, among others.
- **Hourly resolution**. Electricity is traded and scheduled in 15-minute intervals in the day-ahead and intraday markets in at the European Union's level. Using a 15-minute resolution in the EU-flex model would better capture the economic value that flexible resources can bring to the market, as it would better reflect closer-to-real-time variations in RES generation and electricity demand. However, the model uses an hourly resolution due to unavailability of input datasets in 15-minute resolution, and additional computational costs.
- **Local electricity networks are not modelled.** This means that internal transmission constraints and electricity flow within bidding zones are not captured. As a result, the model does not identify where flexibility may be needed within a bidding zone.

ACER intends to explore possible ways to address these limitations after the first iteration of the EU-wide FNA. The Agency welcomes any constructive feedback from stakeholders to that end.

[24] Additional revenue streams from capacity mechanism revenues or other support schemes are considered implicitly by excluding assets receiving such revenues from the EVA. This is to reflect that these assets are expected to be profitable thanks to these additional revenues.

4. Key insights from the EU-Flex model

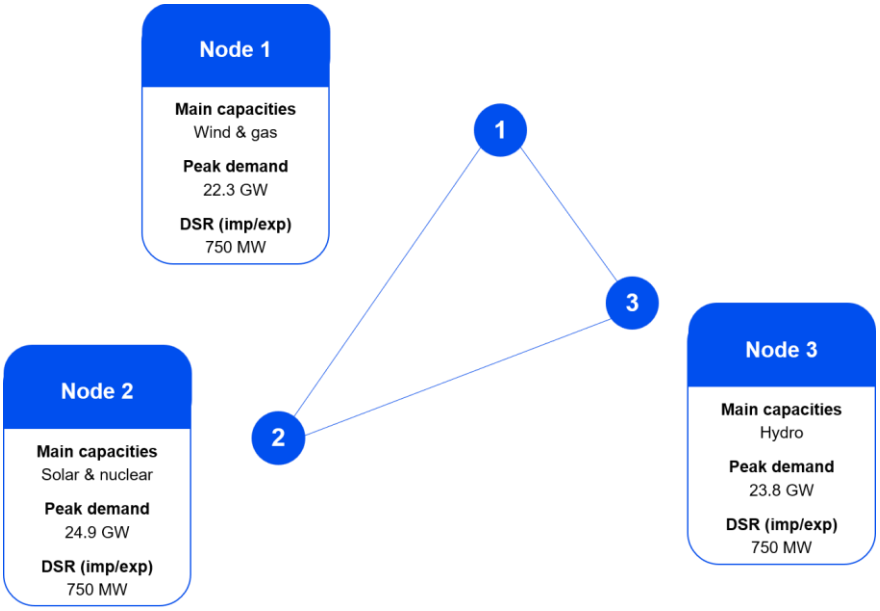
This chapter presents an illustrative test case using the EU-Flex model. Its purpose is to demonstrate key features, metrics and outputs of the EU-Flex model, and to illustrate the main dynamics that arise in the operation and evolution of high-renewable systems. This analysis is not aimed at determining the flexibility needs of any specific European country, nor replicating the actual EU-wide FNA by ACER planned for July 2027.

Those interested in familiarising with the EU-Flex model can find both input and output datasets of this analysis on ACER's GitHub repository to be used alongside the model's source code to test it. Users are also given the possibility to modify the inputs of the test case to observe how the model behaves under different assumptions, as explained in the model manual.

4.1. An illustrative test case

The test case represents a simplified three-node system, with each node reflecting a different resource mix and demand profile. Each node represents one bidding zone with similar demand (around 15 GW on average across the three nodes). The nodes are interconnected and the cross-zonal capacity is the same across all nodes (4 GW), representing roughly 40% of a node's peak demand. The test case covers one full year, with hourly resolution while using a single representative weather scenario.

Figure 8: Graphic representation of the test case assumptions

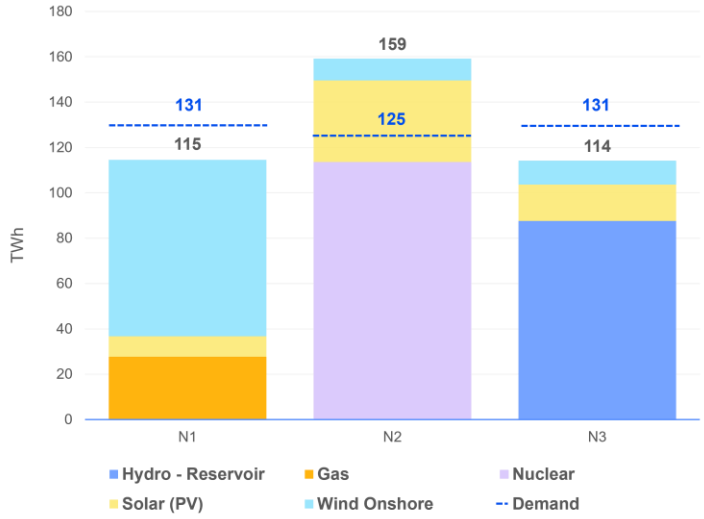


Source: ACER

N1 has a large share of wind capacity, complemented by gas generation, solar and a small battery capacity (100 MW/200 MWh). N2 has large solar and nuclear capacities, complemented by wind, and N3 relies mostly on hydro, with smaller capacities of wind and solar. Demand side response is assumed at 1.5 GW in total in each node, split equally between explicit (peak shaving) and implicit (demand shifting).

The generation mix resulting from the test case is shown in Figure *9*. N1 and N3 are net importers, with the rest of their demand covered mostly by wind and gas in N1 and Hydro in N3. On the other hand, N2 is a net exporter, thanks to the low-cost nuclear generation and significant solar generation.

Figure 9: Total demand and generation per technology for the three nodes in the test case



Source: ACER calculations

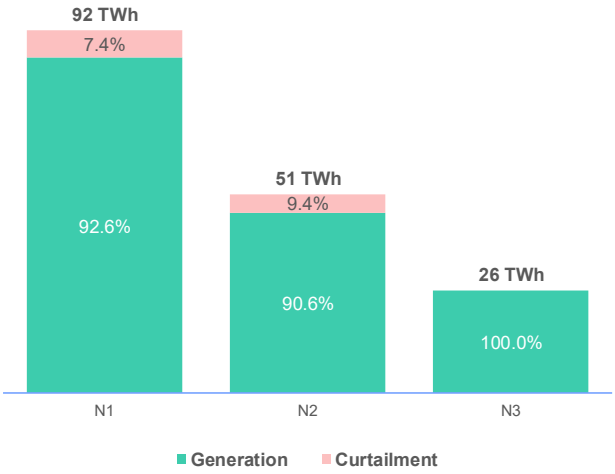
4.2. Performing a flexibility needs assessment with the EU-Flex model

The EU-Flex model computes all indicators required to perform the FNA as per the approved methodology.[25] These are listed below.

4.2.1. RES integration needs

The EU-Flex model computes curtailment levels of variable renewables. Figure *10* shows the curtailment levels for the test case for solar and wind generation. Higher curtailment levels are observed in nodes N1 and N2, due to higher wind and solar capacities respectively. Curtailment is slightly higher in N2, driven by limits in the flexibility that can be provided by nuclear technology. N3 sees no curtailment, due to lower RES generation capacities and flexible hydro generation.

Figure 10: RES generation and curtailment levels in the test case



Source: ACER calculations

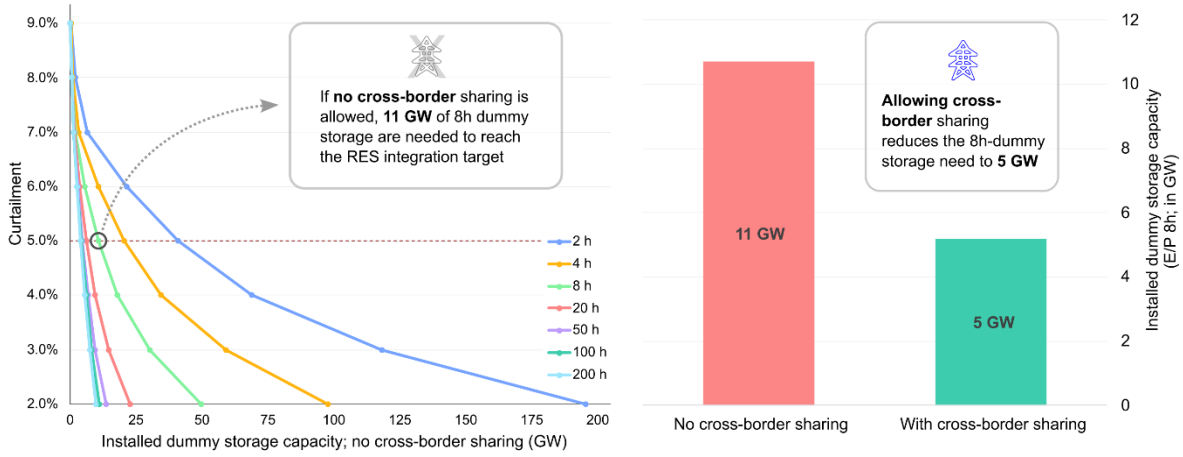
[25] ACER Decision 05/2025 Articles 8, 9 and 10.

For illustrative purposes we consider that all three nodes have a RES integration target of 5% of maximum allowed curtailment[26]. Based on the results we can evaluate the amount of uncovered RES integration needs (i.e., excess curtailment) for each node. N1 and N2 do not meet their RES integration targets, having excess curtailment levels above 5%, whereas N3 would meet its RES integration target.

To identify the additional flexibility needed to reach the RES integration target for different energy-to-power ratios, the dummy storage module is used. Different energy-to-power ratios are simulated separately, in accordance with the FNA methodology[27], as illustrated in Figure 11.

The dummy storage module is also computed in two different configurations: with and without the possibility of accessing spare interconnection capacity. The latter assumes that the cross-border exchanges from the market models are fixed throughout the expansion of dummy storage. The former allows the model to change the cross-border exchanges while minimising the dummy storage deployed. Figure 11 displays aggregated values for the three nodes considered in the case study.

Figure 11: Total curtailment per dummy storage capacity without cross-border sharing (left) and comparison with cross-border sharing (right)



Source: ACER calculations

Two main conclusions arise from the dummy storage computation. Firstly, interconnection capacity plays a significant role in decreasing the overall amount of flexibility needed to meet the individual RES integration targets. This highlights the benefits that additional flexibility capacity in one node can have on the rest of the region. Secondly, reaching lower levels of curtailment is progressively more difficult, especially for low energy-to-power ratios. This shows that aiming for curtailment levels close to 0% can require excessive amounts of flexibility.[28]

4.2.2. Ramping needs

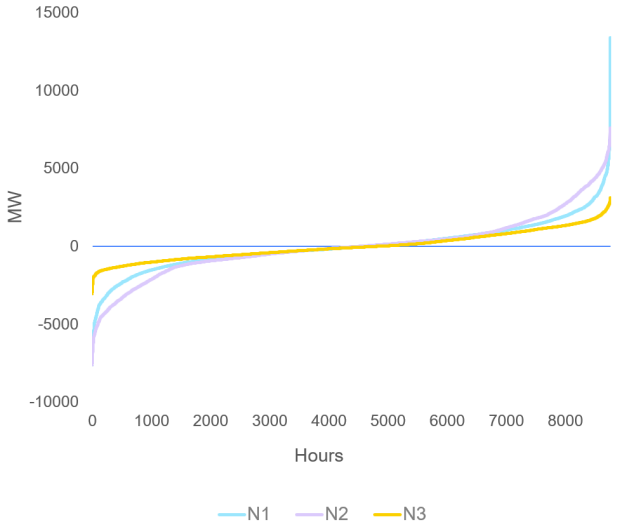
The EU-Flex model can compute the relevant indicators for assessing ramping needs. As mentioned in Section 3.4.1, ramping needs are computed from the residual load changes from one hour to the next, and since the EU-Flex model already accounts for ramping limits in the formulation, uncovered ramping needs.

Figure *12* below shows the distribution of ramping needs for the test case. The same as short-term needs, extreme ramping needs are concentrated in a few hours. Upwards ramping needs are larger than downwards ramping needs, as they often occur in the evening when an increase in demand, as

[26] The RES integration targets need to be derived from the National Energy and Climate Plans (NECP) targets, as per the FNA Methodology.
[27] Article 8(10) of the FNA Methodology.
[28] In other words, a zero RES curtailment target would expectedly be cost-inefficient, in a similar way that authorities do not plan the power network to eliminate all congestions.

people come back from work, coincides with the reduction of solar generation as the sun sets. In the test case, N1 and N2 see the highest ramping needs as they both have higher RES capacities. N2, which has the highest solar capacity, sees a larger number of high-ramp hours. This is because ramping needs can occur almost every day during seasons with high solar generation.

Figure 12: Ramping needs duration curve

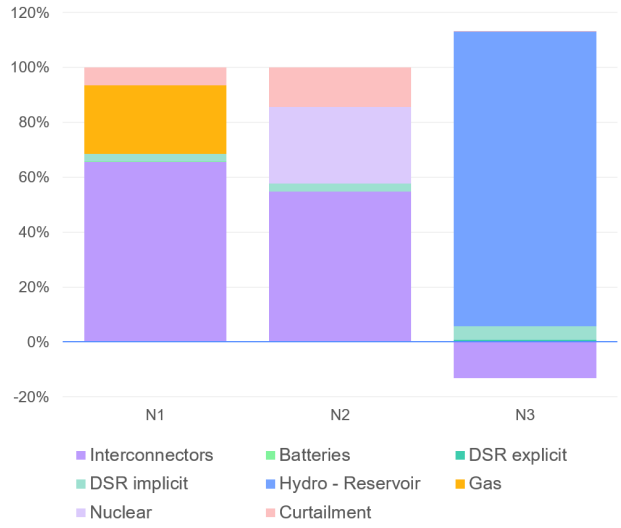


Source: ACER calculations

The EU-Flex model computes the uncovered upwards and downwards ramping needs. Since the technologies in the test case do not have binding ramp limits, there are no identified uncovered ramping needs.

As with short-term needs, the EU-flex model also allows to assess which technologies contribute to the ramping needs. Average contributions for the 25 most extreme ramping needs in each node are shown in Figure *13* below. For N1 and N2, over 50% of the contribution to the most extreme ramping needs come from neighbouring nodes through interconnections, while the remaining coming mostly from the conventional generation technologies (gas and nuclear). In N3, the ramping needs are almost exclusively covered by Hydro, which also contributes to solving ramping needs in other zones that happen simultaneously, thus *exporting* ramping flexibility to their neighbours.

Figure 13: Contribution per technology to the worst 25 ramping events per node

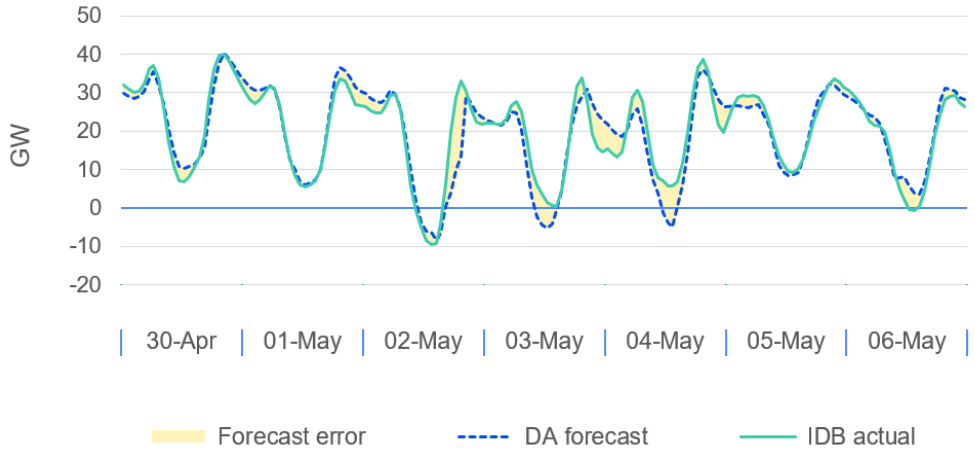


Source: ACER calculations

4.2.3. Short-term needs

The EU-Flex model can compute the relevant indicators for assessing short-term needs, which arise from forecast errors of demand and generation. As mentioned in Section 3.4.1, short-term needs are computed directly from the model results, as the difference between the DA and IDB timeframes. Figure *14* shows the residual load of the day-ahead and intraday-balancing timeframes for one illustrative week.

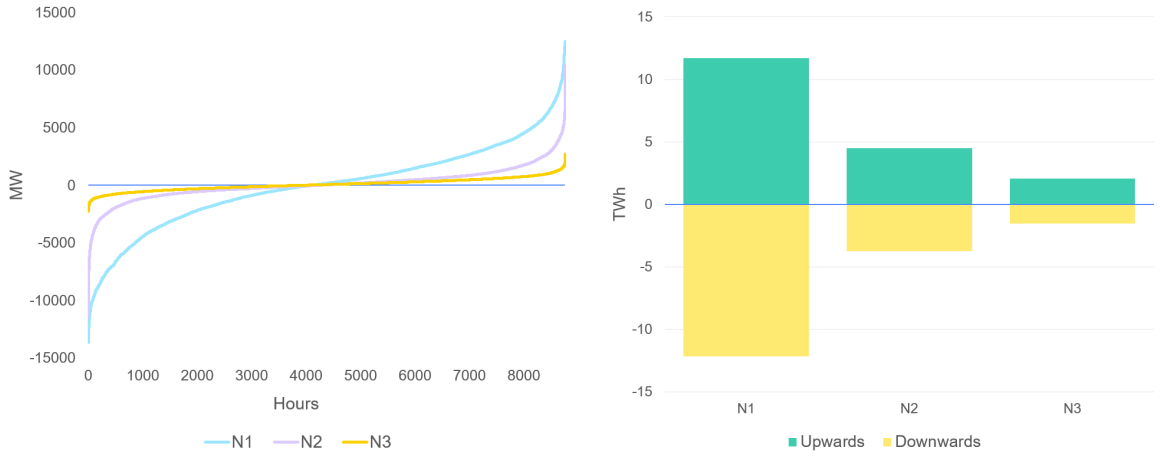
Figure 14: Residual load in the day ahead (DA) and intraday-balancing (IDB) market timeframes



Source: ACER calculations

Figure *15* Figure *15*shows the short-term needs' duration curve and the total volume of short-term needs for each node[29]. N1 has the largest short-term need, driven by the largest wind and solar capacity overall. N2 and N3 present lower short-term needs, as the lower solar and wind capacities in those nodes make them less susceptible to the impacts of forecast errors.

Figure 15: Short-term needs duration curve (left) and total short-term needs energy per node (right)



Source: ACER calculations

Based on the results of the EU-Flex model, we can evaluate the uncovered short-term needs. Upwards short-term needs represent upwards forecast errors that create additional energy not served, whereas downwards short-term needs represent errors that create additional RES curtailment. Detailed values can be found in the Annex.

[29] The impact of unplanned (forced) outages is not reflected in the short-term need indicator. However, forced outages are included in the simulation and computation of uncovered short-term needs.

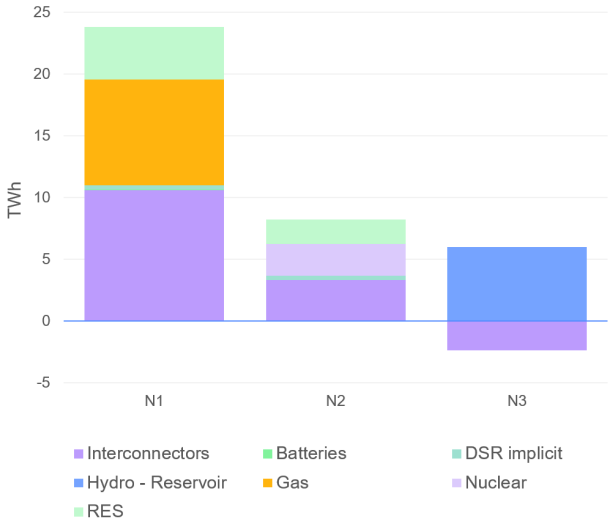
The results show that large forecast errors can create situations with high uncovered short-term needs at a given time. However, the total impact in terms of uncovered energy can be relatively small as errors might cancel each other over time. For example, forecasts might underestimate RES generation in a given hour, which can lead to additional curtailment in real-time. Forecast can also overestimate RES generation at the day-ahead, which might create only limited or no curtailment in real-time.

The EU-flex model also allows to measure how each technology contributes to meeting the short-term needs between the two market timeframes. In other words, it identifies which technology adapts their dispatch to solve the forecast errors.

Figure *16* shows the contributions to meeting the short-term needs for the three nodes. Interconnectors contribute to solve a significant share of the short-term needs in the system and have an overall positive impact. In particular, they meet about a third of the short-term needs in N1 and N2.

Interconnectors contribution comes from two main ways. First, it allows to compensate an error in one zone by an error in the opposite direction in another zone, hence contributing positively to both areas. Second, they also allow flexible assets in one zone can contribute to solving forecast errors from other bidding zones. This is the case of N3, hydro provides the flexibility to manage their local forecast errors and even go beyond their own needs and export flexibility to their neighbours through interconnectors. In this case, the contribution of interconnectors to N3 needs is negative, as it allows to export flexibility beyond the local need.

Figure 16: Contributions to short-term needs, with N3 exporting through its interconnectors (negative values) the flexibility of its hydro reservoirs



Source: ACER calculations

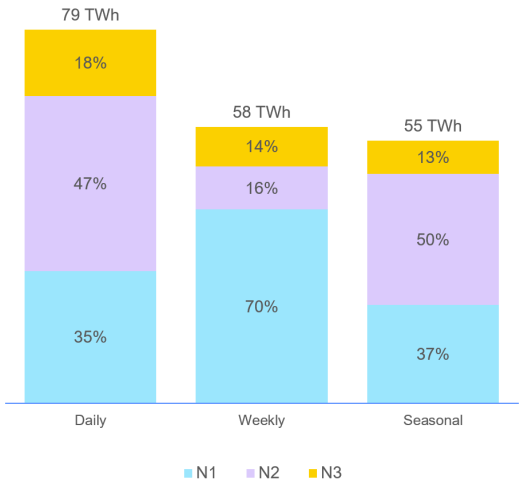
4.3. Flexibility is better handled together

The EU-Flex model allows to assess other aspects of flexibility, beyond the main FNA indicators. The daily, weekly and seasonal flexibility needs are computed[30] based on the residual load[31]. These indicators represent the variability of residual load that must be met with flexibility resources[32] at different timescales. A flat residual load requires no flexibility, whereas a residual load that has big swings will have high flexibility needs. For example, a typical *duck curve* in an area with a lot of solar photovoltaic will have high daily flexibility needs, and a residual load with large summer-to-winter difference will have high seasonal flexibility needs.

[30] Please refer to the FNA methodology for details on how the daily, weekly and seasonal flexibility needs are computed.
[31] The residual load is computed using the potential renewable generation, i.e., before any renewable curtailment taking place.
[32] Flexibility solutions can include generation, storage and demand response assets being operated in a flexible manner. This can include curtailment of renewable energy in response to price or network signals.

Figure *17* shows the residual load flexibility needs for the daily, weekly and seasonal timescales. Daily flexibility needs, which are mostly driven by solar generation and daily demand patterns, are highest in node N2, which has the largest solar capacity. Weekly needs, which are mostly driven by wind generation and weekly demand variations (e.g., weekday vs weekend demand levels), are highest in node N1, which has the highest wind generation capacity. N3, which has the lowest variable renewable generation sees the lowest flexibility needs overall.

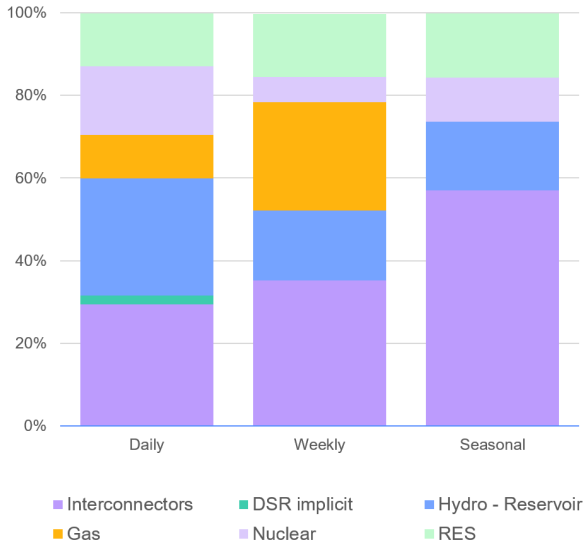
Figure 17: Residual load flexibility needs



Source: ACER calculations

The EU-Flex model also allows to compute the contributions of different technologies to meet the residual load flexibility needs, shown in Figure *18*. The contributions reflect which technologies adapt their dispatch to the residual load needs, increasing generation or decreasing demand during periods of high residual demand, and conversely decreasing generation or increasing demand during periods of lower residual demand.

Figure 18: Aggregated contributions to flexibility needs



Source: ACER calculations

In line with results from the FNA indicators, the results show the significant role of interconnectors in meeting the flexibility needs at all timeframes, contributing between 30% to 40% of the aggregated needs. Interconnectors allow to take advantage of complementarities in terms of generation mix

between nodes. On one side, they allow to share flexible resources with neighbouring zones, such as the abundant and highly flexible hydro in N3. On the other side, interconnectors can also smoothen the residual load, as the variability of demand and renewable generation is spread across larger areas.

The role of interconnectors is lower in the daily timeframe, as the zones can have coincidental daily flexibility needs. This is because periods of excess RES generation (e.g., solar at midday) or peak demand (evening) can coincide across the different nodes.

Conventional technologies (gas, nuclear [33] and hydro) contribute largely to the flexibility needs of their own zones, and to neighbouring ones through interconnectors. RES can also contribute to the flexibility needs through market-based curtailment, which can be a cost-efficient solution to meeting flexibility needs.

DSR and batteries have a relatively small share of contributions, due to relatively small capacities in the system. DSR and batteries contributions are most important at the daily timeframe, as they can shift load and generation mostly within one day.

4.4. Short-term markets modelling reveals the economic value of flexibility

The large-scale integration of variable renewables has increased the importance of short-term markets. During these timeframes, market participants adjust their positions to manage uncertainty, coming from forecast errors or forced outages.

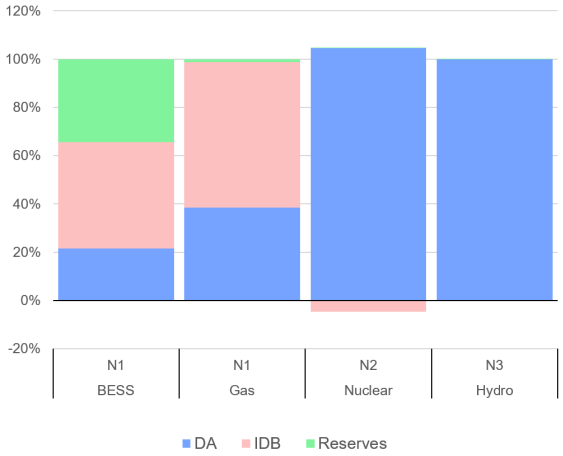
Large renewable capacities can create a high need for intraday and balancing adjustments to for example manage errors in forecasted renewable generation. By explicitly modelling two market timeframes, the EU-Flex model can provide a better assessment of how the power system operates under high-renewable conditions, and the revenues that flexible assets can earn.

Three main revenue streams are captured by the EU-Flex model: day-ahead energy[34] and reserve profits, computed based on the results of the day-ahead timeframe, and intraday-balancing profit, computed based on the adjustments made between the day-ahead and intraday-balancing timeframe.

Figure *19* shows the breakdown of revenue streams of four technologies in our test case[35]. To allow for comparability, the results are shown in relative terms. Results show the value of modelling a full revenue stack to better assess the economic profitability of technologies. This is particularly true for batteries, which earn revenues from all the three revenue streams, as well as for gas, for which adjustments made in the intraday-balancing timeframe represent an important revenue stream. On the other hand, nuclear loses money in the intraday-balancing timeframe, as it can suffer heavy economic losses in case of forced outages during high-price periods[36] and has more limited capabilities to adjust the dispatch closer to real time.

[33] The modelled nuclear technology can ramp and down within its technical limits and can be started up and shut down at the day-ahead timeframe.
[34] Energy profit is computed as the total revenues from selling energy at the hourly energy price of the bidding zone, minus variable costs (fuel and CO2 costs) and startup and shutdown costs. Fixed operational and maintenance costs and capital costs are not included in this indicator.
[35] Note that the results are illustrative and valid for the simulated system conditions. A different system configuration, or the entry/ exit of new capacities may change the revenues of technologies.
[36] If a technology suffers a forced outage and cannot cover its day-ahead scheduled dispatch, it needs to “buy back” the energy at potentially higher costs.

Figure 19: Share of profits for four technologies in the test case



Source: ACER calculations

4.5. The EVA shows that market profitability drives adjustments in resource capacities.

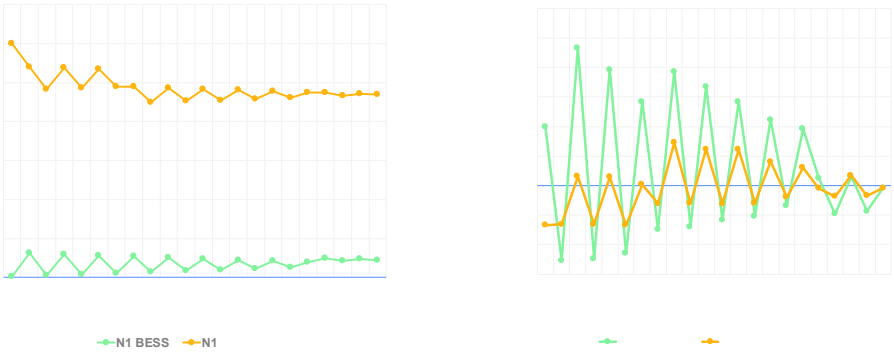
Based on the simulation of the market model, costs and revenues are computed to assess the profitability of the different technologies or assets considered in the simulation. Through the iterative process of the EVA, technologies that are profitable are expanded, and those that are not decommissioned. Iterations continue until the NPVs are within a tolerance range, meaning that investors would have neither a significant incentive to invest more nor to decommission.

For illustration purposes, gas is considered a candidate for decommissioning, and batteries a candidate for capacity expansion, meaning that their capacities can decrease or increase respectively, according to the market results.

below shows the iterative process for both technologies. The existing gas generation capacity is unprofitable, and part of its capacity can be decommissioned from the system, while on the other hand, the battery technology is profitable and can be expanded. The EU-Flex model progressively adjusts the capacities of these two technologies until the system reaches an equilibrium, where the NPV of both technologies is within the tolerance range of +-20k€/MW[37].

[37] We considered a threshold of 20k€/MW for the case study, as it falls within a small range of uncertainty of the total NPV over the lifetime of the candidate assets. It represents less than 10 % of the discounted fixed operational and maintenance cost of the gas technology assessed for decommissioning, and less than 3 % of the CAPEX of the battery technology, assessed for expansion.

Figure 20: Iterative adjustments of the capacity of gas generation and battery storage in the EVA (left), based on their NPV (right)



Source: ACER calculations

5. Conclusions

The transition towards a more electrified and renewable-based power system will inevitably increase the relevance of and need for flexible power systems. Flexibility will play a fundamental role in ensuring that electricity supply and demand can be matched efficiently, ensuring security of supply, supporting the integration of RES sources and facilitating the operation of our power networks in a cost-effective way.

Meeting these needs will require a combination of possible options: from conventional to non-fossil flexible assets, to improved cross-border coordination and market integration. A better understanding of how these options can interact and of their potential contribution in meeting future flexibility needs will be important to support sound policy and investment decisions.

The EU-Flex model under development will be able to identify common challenges and synergies across Member States and the European Union by providing a broader EU-wide perspective, thereby offering additional insights to policy makers, complementing the information gathered through the national FNAs. Moreover, the EU-Flex model includes features that will enhance the understanding of the economic value and contribution of flexible assets in a power system with high renewable energy penetration.

With this work, ACER also aims at contributing to greater transparency in energy modelling, fostering dialogue and collaboration among stakeholders and, thereby, supporting robust, evidence-based policy making. Making the model and its approach public will allow stakeholders to better understand the assumptions underlying ACER's EU-wide FNA, and to provide feedback and contribute to its further development.

The analysis presented in this document represents an initial application of the model and an opportunity to illustrate its potential contribution to the assessment of European flexibility needs. For example, the test case described in this paper illustrates the value of interconnectivity in sharing flexibility across borders and of short-term markets in driving investments in flexible resources. Further work will build on this initial experience and on stakeholder feedback to strengthen the model and its usefulness for future assessments.

Annex

This annex presents the installed capacities of each node included in the test case. It also presents the values for uncovered RES integration and short-term needs as calculated by the EU-Flex model using the test case presented in this paper. Ramping needs are not included as the test case does not assume ramping constraints.

Table 1: Installed capacities in the test case, in MW

Technology	N1	N2	N3
Gas	30 000	0	0
Nuclear	0	15 000	0
Hydro	0	0	20 000
Wind	30 000	5 000	5 000
Solar	10 000	35 000	10 000
Batteries (2h)	100	0	0
DSR	1 500	1 500	1 500
Peak demand	22 355	24 913	23 776

Table 2: Uncovered RES integration need, in TWh

Node	Curtailment	RES integration target (5% of RES potential)	Uncovered RES integration need [TWh]
N1	6.8	4.6	2.2
N2	4.7	2.5	2.2
N3	0	1.3	0

Table 3: Uncovered short-term needs

Node	Max uncovered upwards short-term need [MW]	Max uncovered downwards short-term need [MW]	Total uncovered upwards short-term need [GWh]	Total uncovered downwards short-term need [GWh]
N1	0	14 241	0	1 788
N2	981	6 088	1.6	-1 026
N3	0	0	0	0

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