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ACER
European Union Agency for the Cooperation of Energy Regulators

Flexibility solutions to support a decarbonised and secure EU electricity system

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Contents

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Executive Summary

This decade will see significant decarbonisation of the EU electricity supply. Brave changes are happening, driven by the expected rapid roll-out of wind and solar power generation in all Member States in response to the Russian war of aggression against Ukraine and Europe's commitment to become a 'net-zero' emissions continent by 2050 (expressed in the 'Fit-for-55' and the forthcoming EU climate target for 2040) ([1]).

Member States' latest 10-year national energy and climate plans, being submitted to the European Commission (EC) at the time of writing this paper, suggest a remarkable, often triple-digit, planned growth in use of these two renewable energy sources in some countries. Renewable electricity generation must double by 2030. To manage weather-dependent output, the energy system must provide adequate flexibility resources at scale from both the demand and supply side.

Flexibility is the EU power system's ability to adjust to the fluctuating generation and consumption of energy.

Delivering the energy transition effectively will require systemic, efficient and fair improvement across the whole energy system. This analysis by the European Environment Agency (EEA) and the EU Agency for the Cooperation of Energy Regulators (ACER) sketches out key elements of the flexibility challenge (a doubling of flexibility is needed by 2030) in an increasingly decarbonised EU power system. It identifies key flexibility levers. It calls for Member States to assess and unlock the potential of flexibility resources such as demand response. It sees scope for an important new role for the NECPs, alongside biennial national greenhouse gas emission projections with more complete energy parameters, as useful tools for regional cooperation to better forecast and meet Member States' flexibility needs. It points to the important role of interconnectors in enabling flexibility solutions across borders. It suggests that policy-makers coordinate their approaches assessing and utilising all flexibility levers across borders, where appropriate. Its main findings are summarised in the box below.

([1]) To be proposed by the European Commission (EC) in 2024.

Summary and recommendations

1. Enhancing Europe's energy security and tackling climate change are compatible objectives but delivering them requires urgent changes to adapt the energy system. The involvement of EU and national policy-makers, regulators, energy grid operators and users will be key.

2. Accelerating the rollout of renewables is needed yet it also brings challenges. The energy system must adapt at scale to provide adequate flexibility resources (from both the demand and supply side) to adjust to fluctuating renewable electricity supply. Today, much of the flexibility that backs up renewables is sourced from fossil fuels.

3. The flexibility challenge is significant- double today's flexibility is needed by 2030- requiring a broad mix of (clean) flexible resource and supportive policies. The ramp up in flexibility needs to match the ramp up in renewables.

What is the solution?

   a. Renewables bring the dual benefit of mitigating climate change and simultaneously enhancing Europe's energy independence.

   b. Very promising and climate-friendly flexibility resources exist (e.g. demand response or energy storage) and must be further unlocked.

   c. Europe's interconnected power system is also part of the solution, enabling flexibility — and renewables — to be procured across borders.

   d. A more coordinated 'all-hands-on-deck' approach to have complementary national assessments of flexibility needs and common policies across borders can bring extended benefits.

   e. Europe's energy system has to change in at least two major ways:

- **Use coordinated planning and operation of the energy system to manage decarbonisation and security of supply at the same time:**
    - Regularly assess the flexibility needs of the power system at the EU level and deepen the coordination on the national approaches via Member States' National Energy and Climate Plans (NECPs) and the national greenhouse gas projections in biennial progress reporting. There is scope for NECPs and projections to develop on regional cooperation to help Member States better meet their flexibilty needs.
    - Share electricity more broadly by expanding cross-border transmission capacities and improving the operation of interconnected systems and markets.
    - Optimise electrification across all sectors of the economy such as buildings and transport, and enhance opportunities for energy storage. Direct electrification with renewables is one of the most efficient ways to decarbonise demand.
- **Create incentives for consumers to actively adapt their consumption when needed and for storage to be operated dynamically. Further:**
    - Maximise the potential offered by market signals and cost reflective network charges to enable consumers from all sectors to financially benefit from changing their consumption patterns.
    - Dismantle barriers to entry and create supportive investment frameworks to enable small, climate-compatible flexibility resources to participate in all electricity markets on an equal footing with traditional centralised sources of flexibility.
    - Improve the provision of information to households and small businesses to help them overcome increasingly complex energy offers, including on energy efficiency, and take suitable and informed decisions.

1 Enhancing Europe's energy security and tackling climate change are compatible objectives, but delivering them requires urgent change to adapt the energy system

The EU and its Member States are moving towards a climate-neutral future. Until recently, the focus has primarily been on the approaching 2030 milestone to reduce the EU's greenhouse gas emissions by 55% compared with 1990 levels. However, Europe is responding to Russia's invasion of Ukraine with a faster and more profound energy transition: decarbonising all sectors, saving energy and accelerating the shift towards home-grown renewable energy sources. At the same time, EU energy market integration — exemplified by increased interconnection and enhanced cross-border capacities — has played a crucial role in mitigating price spikes and security-of-supply issues at national level (ACER, 2023a).

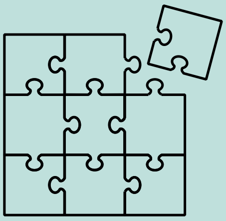
Using renewable energy makes energy bills more affordable, cuts reliance on energy imports and mitigates climate change and other health and environmental impacts linked to fossil fuels (EEA, 2023d). The EU has committed to increasing its use of renewable energy to a minimum of 42.5% (and possibly up to 45%) by 2030 (Council of the European Union, 2023).

Ramping up renewables offers a dual benefit: meeting the EU's climate targets and simultaneously enhancing energy independence.

EU policies and research emphasise the ability of electrification from renewables to decrease carbon emissions in key energy end-uses, such as heating and transport (EC, 2021a; Clarke et al., 2023; EEA, 2023a). This will require renewable electricity generation to grow rapidly, from 37% in 2021 to 69% or more by 2030 (EC, 2022a) ([2]). Europe is well endowed with domestic renewable electricity potential. Ramping up the integration of renewables into the energy system de facto offers a dual benefit: meeting the EU's climate targets and simultaneously enhancing energy independence and strategic autonomy. However, the fact that a quick integration of renewables into the system is beneficial for society does not mean it comes without challenges including having sufficient flexibility resources to make up for high/low renewable supply (see Box 1).

([2]) By 2030, the EU target objective is to increase renewable supply to 69% of all electricity generation in accordance with REPowerEU (i.e. by four percentage points more than initially foreseen in the European Green Deal).

Box 1



The flexibility challenge

Increasingly, climate-compatible resources like demand response, batteries and other solutions will be needed to meet growing flexibility needs. The task ahead is to facilitate the switch to these low-carbon flexibility solutions at a pace that keeps up with the acceleration in renewable generation build-out.

Against this background, there is considerable value in assessing future flexibility needs across Member States and in leveraging solutions to meet such needs also from a cross-border perspective, building on the EU's vast internal energy market.

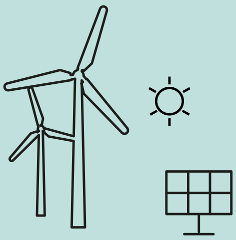
Alongside the NECPs, biennial greenhouse gas emission projections with more complete energy parameters can help to forecast flexibility needs and available resources.

1.1 NECPs must indicate Europe's decarbonisation trajectory

The EU's ambitious climate and energy goals are translated by Member States into commitments at the national level through their national energy and climate plans (NECPs). Based on the trajectories provided by governments in their NECPs and the greenhouse gas projections and energy parameters reported in their biennial national progress reports, the EC periodically monitors the progress made towards achieving these goals under the EU governance regulation, an exercise involving the EEA in the collection, compilation and quality assurance of key progress-reporting data (European Parliament and Council, 2018a). By June 2023, Member States had to submit to the EC draft NECPs, adapting their commitments to meet higher common targets for 2030 and aiming to diversify climate-compatible energy sources while tackling energy security and affordability issues. The Russian war of aggression against Ukraine and the recent energy crisis renders Member States' updating of the NECPs both relevant and timely.

Some of the submitted draft NECPs indicate that major changes are under way in the national electricity mixes (see Box 2). They confirm solar and wind energy — two variable renewable electricity (VRE) sources governed by weather conditions — as the decade's fastest-growing electricity sources. With this clean energy transition in progress, boosting the flexibility of the EU power system to ensure a secure and sufficient energy supply and minimise the risk of power outages (or costly curtailment) becomes essential.

Box 2



Planned decarbonisation paths in the 2023 draft NECPs

NECPs should inform the ways to tackle the flexibility challenge.

Many submitted draft NECPs show high ambitions to further scale up renewable energy deployment. For example, the planned shares of renewable energy sources in final energy consumption increase approximately twofold in Estonia (rise of 117%), Italy (99%) and Spain (128%).

The share of renewable energy technologies changes too, with some Member States envisioning rapid solar energy expansion narrowing the difference with wind power installations. For example, by 2030, solar power output will surpass wind generation in Italy (proportion of 3:2) and reach parity with wind generation in Spain.

Alongside the NECPs, biennial greenhouse gas emission projections with more complete energy parameters can help to forecast flexibility needs and available resources.

Today, the electricity system meets flexibility needs mainly through fossil-based dispatchable electricity generation.

1.2 Flexibility needs to double at pace with accelerated renewable rollout

This EEA/ACER assessment finds that flexibility needs will double by 2030. Both demand and supply must react to changing conditions to keep the system constantly in balance, particularly when fluctuating solar and wind generation is too low (or too high) compared with demand.

Today, the electricity system meets flexibility needs mainly through fossil-based dispatchable electricity generation. However, the operation of such units results in significant greenhouse gas and air pollutant emissions (EEA, 2022a, 2023b, 2023c), meaning they are increasingly incompatible with the EU's greenhouse gas target for 2030 and climate neutrality objective for 2050. At the same time, a rising share of EU gas supplies sourced from abroad in the form of liquified natural gas poses a risk of becoming subject to enhanced volatility per global market dynamics (ACER, 2023d).

By 2030, flexibility needs will double compared to today.

1.3 Considerable legislative effort is ongoing to tackle the flexibility challenge

Europe's 2019 clean energy package (CEP) granted consumers the right to access all electricity markets and be remunerated for their flexibility, but Member States are still to implement such provisions in national legislation, as also shown elsewhere. On the basis of ACER's preparatory work, system operators are currently drafting a regulatory proposal on demand-side flexibility. The new rules aim at facilitating the market participation of demand response, storage and distributed generation. After ACER's revision, the draft will be submitted to the EC towards the end of 2024.

The EC's legislative proposal on the electricity market design, tabled in March 2023, considers changes both in the market design and in the supportive framework (EC, 2023). For example, it introduces flexibility support schemes, improves the liquidity of forward markets and strengthens short-term markets, where resources can adjust in as close to real time as possible.

More flexible resources are needed from both the demand and supply side.

While acknowledging the role of Europe's integrated electricity markets for renewables and flexibility resources to flow across borders and meet EU consumers' needs, this paper does not delve into the details of EU electricity market design. Nor are other enabling efforts — ranging from further EU-wide carbon pricing instruments to decarbonise heating and transport ([3]) to efforts to empower citizens to participate in local energy communities and source raw materials sustainably — considered in detail (see e.g. Box 3). These topics require dedicated investigation.

Box 3

Beyond the flexibility challenge

The rapid renewable electrification also relates to concerns regarding:

- system operation (e.g. decreasing inertia);
- raw material availability;
- recyclability of technologies;
- impacts on ecosystems (e.g. land use).

These considerations merit a dedicated debate and are outside the scope of this paper.

1.4 NECPs and national projections can become powerful tools to help Member States to exploit synergies with regional coordination on flexibility

The NECPs and greenhouse gas emission projections in the biennial national progress reports, as governance mechanisms, have the potential to become even more functional (as underscored by several responses in the recent consultation on the functioning of the climate and energy governance framework). NECPs can turn into a powerful tool helping Member States consider developments in their region and make informed policy choices that exploit synergies and reinforce regional cooperation. Alongside the NECPs, more comprehensive and complete national greenhouse gas emission projections, particularly in relation to energy parameters, can bolster coherent future climate and energy planning and cross-border cooperation.

This paper argues that the EU can do more to prepare the energy system for today's decarbonisation challenge by taking advantage of the internal energy market via enhanced interconnectors and by ramping-up demand response. This can be achieved by leveraging the existing coordination mechanisms under the governance regulation, such as the NECPs and the biennial national greenhouse gas emission projections in the progress reports, and by proactively scanning the future through flexibility needs assessments, thus informing Member States' choices and approaches.

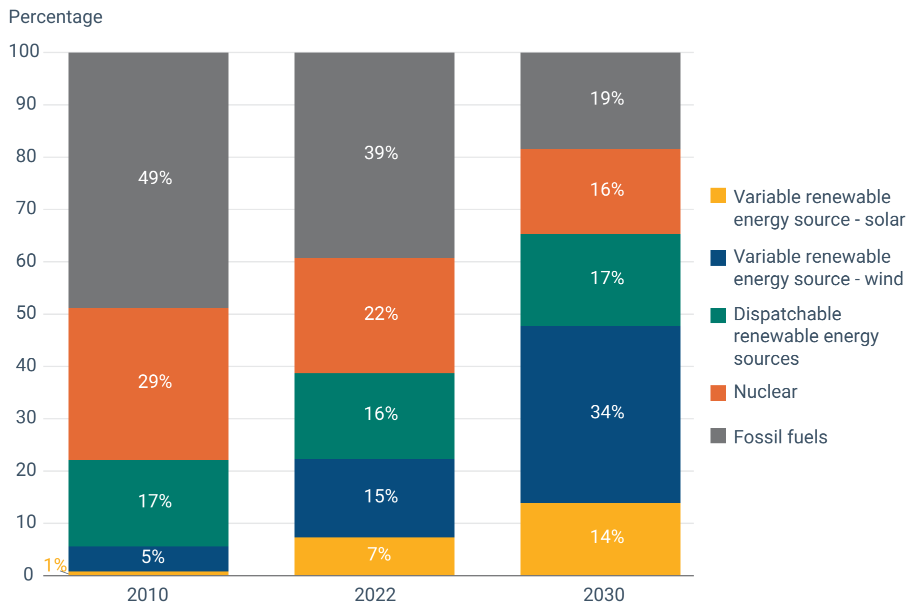
([3]) Under the new EU emissions trading scheme from 2027 onwards.

2 Smooth integration of wind and solar resources is a key challenge for this decade as we transition to a climate-compatible energy system

2.1 Variable renewables are the fastest growing electricity sources

Over the past decade, solar and wind energy, two VRE sources, have become cost-competitive across several European markets, even without subsidies ([4]) (EEA, 2022b). At the EU level, from 2010 to 2022, the share of solar and wind power in all renewable electricity generation increased from 24% to 60%, while the corresponding capacity increased more than three-fold. The use of nuclear and dispatchable fossil generation decreased by around one quarter over this period. At the same time, and despite the remarkable change in the generation mix, demand remained largely inflexible (see Section 3.2).

Figure 1 **Electricity generation in the EU-27 by source**



Notes: Dispatchable renewable energy sources includes hydropower, bioenergy, and other renewables.

Source: Ramboll, based on generation and demand data combined with historical hourly profiles from the ENTSO-E transparency platform (ENTSO-E, 2022); and 2030 annual values from the policy scenarios for delivering the European Green Deal (EC, 2021b).

([4]) From 2010 to 2021, global levelised costs of electricity generation fell by 85% for solar photovoltaic, 56% for onshore wind and 45% for offshore wind power (IRENA, 2022).

In 2022, VRE sources contributed around 22% of all EU electricity supply and represented 35% of all installed capacity. The expansion of VRE generation was partly influenced by the widespread deployment of distributed energy resources ([5]). These are units connected to lower voltage levels, such as rooftop solar panels or behind-the-meter electricity storage, which are typically easier to develop than traditional centralised resources.

Some of the most recent decarbonisation scenarios estimate VRE generation to supply almost 50% of gross electricity production by 2030 (EC, 2021b; see Figure 1). In practice, this would require VRE generation to increase by 111 TWh every year, on average — almost three times as much as the average annual VRE growth recorded between 2010 and 2022 (+38 TWh per year). Despite several challenges, recent experience indicates that such an increase is achievable. Solar and wind generation across the EU has increased by an estimated 230 TWh between 2021 and 2023, much of which is thanks to measures that EU countries have implemented since Russia's invasion of Ukraine (IEA, 2023a).

Based on the background study supporting this analysis ([6]), the rest of this chapter explains the consequences of oversupply- and undersupply of VRE, compared with demand, and discusses the flexibility needs stemming from it.

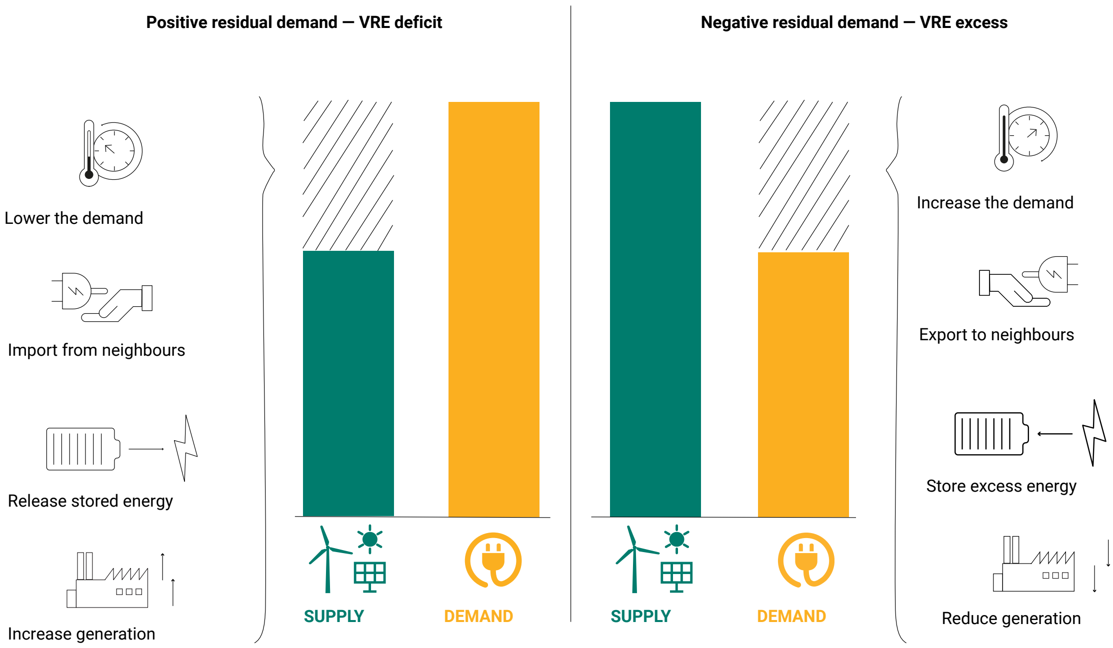
2.2 Understanding the dynamics between demand and variable renewable energy sources is key for the future of the power systems

As the share of VRE generation more than doubles this decade (see Figure 1), its effect on the supply-demand dynamic becomes crucial. Therefore, analysing the difference between electricity demand and VRE supply, known as the 'residual demand', provides useful insights. Governed by weather, VRE supply today is often not able to meet demand on its own, giving rise to a VRE deficit, also known as a 'positive residual demand'. Although less frequent, at times, VRE excess will surpass demand, leading to a 'negative residual demand' situation. These two situations are illustrated in Figure 2.

([5]) Distributed energy resources are directly connected to the distribution grid. These include small generation plant (e.g. roof-top solar), energy storage (small scale batteries) and controllable loads such as electric vehicles (EVs), heat pumps or households (demand) response. An aggregator can bundle their load (demand) together so jointly they provide flexibility to the system.

([6]) Unless indicated otherwise, findings are based on Ramboll's study Flexibility solutions to support a decarbonised and secure EU electricity system, which was commissioned by the EEA and to which the EEA Topic Centre on Climate Change Mitigation and Energy and ACER provided input and expert advice.

Figure 2 **Residual demand scenarios**



Notes: In a decarbonised electricity system, positive and negative residual demand should be met with non-carbon resources such as demand response, storage, dispatchable renewables and cross-border resource-sharing. This analysis can be further refined by subtracting non-dispatchable conventional must-run generation (e.g. combined heat and power plants) from the demand. Must-run generation can fill VRE deficit gaps, thus reducing flexibility needs in those hours, but it can also potentially run in hours of VRE excess, hence increasing flexibility needs.

Source: EEA/ACER.

During VRE deficits, demand is met by increasing controllable (today mostly gas-fired) generation, reducing demand, importing lower-cost generation from other market zones or discharging stored energy to the grid. Conversely, during VRE excess situations, excess is managed by exporting VRE generation to other market zones, increasing demand (e.g. power-to-X solutions), charging storages from the grid, decreasing controllable generation or, as a last resort, curtailing VRE generation.

Price signals in the coupled European short-term markets can effectively and continuously inform producers and consumers of the amount of VRE in the interconnected system. If, in a given period, VRE generation grows, prices decline, as higher-cost marginal resources are squeezed out by low-cost generation from renewable sources. During VRE excess, prices can even turn negative, as demand cannot soak up surplus supply, while some of the inflexible thermal generators cannot ramp down quickly enough. In the longer term, the fluctuating price levels inform about VRE excess and deficit situations and will trigger investment and innovation in flexibility resources.

Between 2021 and 2030, due to the rapid growth in VRE generation, VRE excess could increase from 0.2 TWh/year to 118 TWh/year — the latter being equivalent to the annual generation of 19 baseload thermal power plants ([7]) or nearly double the total electricity consumption of Austria in 2022. In situations of high wind and solar radiation, the surplus renewable energy can be utilised to charge electric vehicles and batteries, supply efficient and clean heat to buildings, produce renewable hydrogen or share electricity with neighbouring countries via interconnectors. VRE excess would be even higher (+133 TWh/year) if interconnectors did not spread it across borders, thus helping to avoid the likely curtailment of variable renewable production (i.e. equalling the annual generation from 21 baseload power plants, or equivalent to the total electricity consumption of Sweden in 2022). In the situation of VRE deficit, demand

([7]) An 800 MW power plant block running in 90% of the hours of the year was taken as the indicative reference.

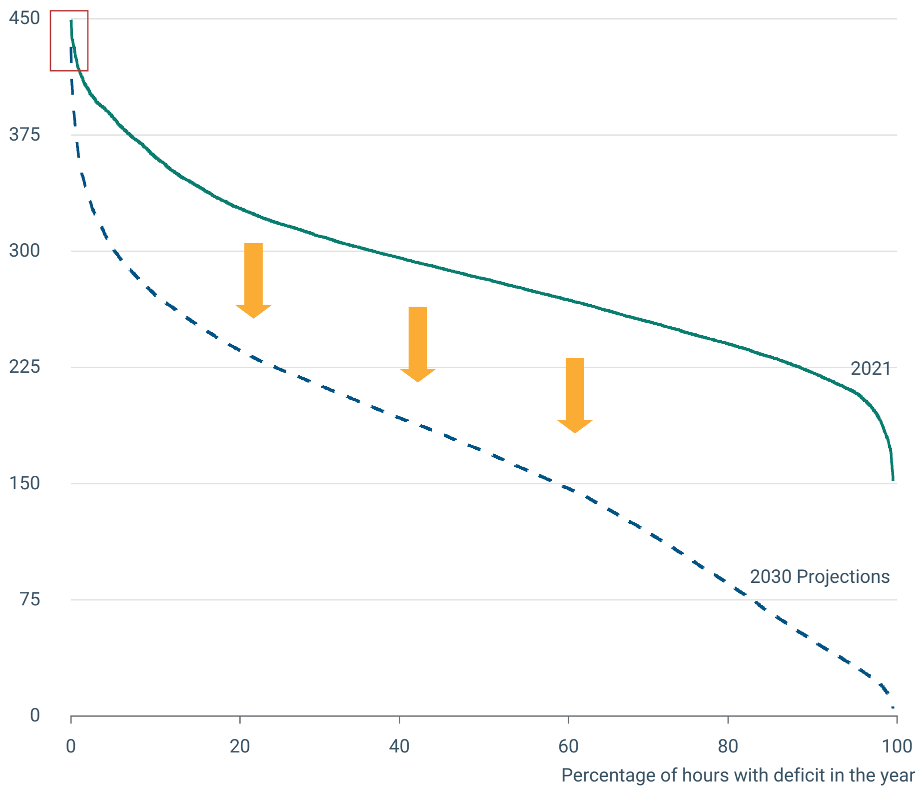
reduction becomes particularly effective. A reduction similar to the energy saving measures ([8]) introduced in the winter of 2022/2023 would mitigate the VRE deficit by 231 TWh/year, which is equal to the annual output of 37 baseload thermal power plants or the total electricity consumption of Spain in 2022 (ENTSO-E, 2022).

In the future, VRE deficit situations will become central to resource planning, as, if not managed properly, they represent a risk to the security of supply. Fortunately, due to the rapid growth of VRE, the European annual VRE deficit is shrinking considerably (see the green arrows in Figure 3). This means that, from 2021 to 2030, the need for non-VRE generation is expected to shrink considerably in most hours, in total by almost half (46%), equivalent to the annual generation of 182 baseload thermal power plants.

However, despite the considerable decrease in the need for non-VRE generation on average, high VRE deficit situations are here to stay (see the red box in Figure 3). These situations correspond to a limited number of hours in a year when VRE generation, relative to demand, is very low.

All in all, there is a very small number of hours in a year when a significant amount of flexibility resources will still be needed to fill in for the missing VRE generation. Flexibility needs will thus transform from a 'high capacity - high volume' situation (fit for gas generators) to a 'high capacity - low volume' situation, which can also increasingly be handled by new carbon-free approaches.

Figure 3 Average European duration curve of VRE deficit hours in 2021 and 2030



Note: The analysis was performed for interconnected ENTSO-E member countries.

Source: Ramboll, based on hourly generation and demand data combined with historical hourly profiles from the ENTSO-E transparency platform (ENTSO-E, 2022); and 2030 annual values from the policy scenarios for delivering the European Green Deal (European Commission, 2021b).

([8]) The analysis considered 10% of demand savings in non-peak hours without VRE excess and 5% in peak hours shiftable to hours of VRE excess before the following peak-hour period. This assumption was inspired by the targets set in Council Regulation (EU) 2022/1854 of 6 October 2022 on an emergency intervention to address high energy prices (OJ L 261, 7.10.2022, p. 1).

Demand response (peak shaving, demand shifting) and other flexibility resources such as storage will need to cover these peak events. However, without taking an integrated approach and adapting market conditions to unlock these flexibility resources, the current operating model could pose challenges to their profitability and deployment (for more information, see Chapter 3). Moreover, existing national policies and measures may not fully harness or recognise the benefits of demand response and savings, potentially leading to the underutilisation of these tools. According to the policy scenarios for delivering the European Green Deal, from 2022 to 2030, EU electricity consumption should increase by 13% in all scenarios (EC, 2021b) ([9]). Yet, according to EEA calculations based on the first national progress report submissions under the governance regulation, nationally adopted policy measures will increase EU generation by 19% by 2030 (EEA, 2023d, forthcoming) ([10]).

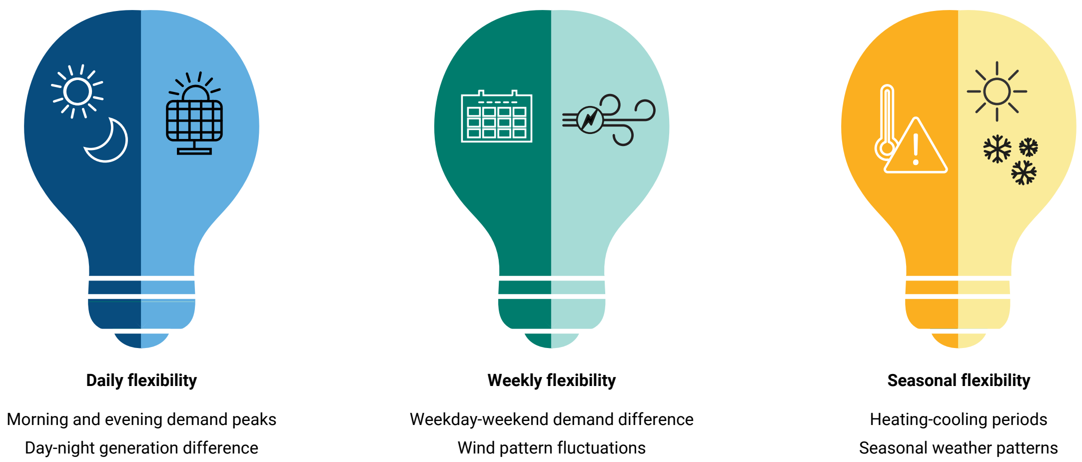
This section has provided an overall static view: hours with VRE excess and deficit. Section 2.3 will add the time element to the picture. Fluctuations in VRE generation put stress on the system. Therefore, flexibility resources will need to follow these swings to keep the system in balance.

2.3 By 2030, flexibility needs will double in a European electricity system dominated by renewables

Residual demand varies over time, alternating between moments of VRE excess and deficit. This variability of VRE generation relative to demand has to be cushioned with flexibility resources (see Box 4).

This section focuses on three flexibility ([11]) time frames to capture the fluctuations, or cycles of demand and VRE generation: daily, weekly and seasonal flexibility, as summarised in Figure 4.

Figure 4 **Graphical representation of demand and supply patterns affecting daily, weekly and seasonal flexibility needs**



Source: EEA/ACER.

([9]) Solar and wind power increase significantly, driven by direct electrification of end-uses, while overall the EU will reduce its levels of primary and final energy consumption in absolute terms through energy efficiency improvements (EC, 2021b).

([10]) Based on the national greenhouse gas projections with existing policies and measures submitted by the countries in 2023, electricity generation will increase to roughly 3 330 TWh by 2030 at the EU level, representing a 19% increase over 2021. More extensive reporting of energy parameters as part of these projections would greatly facilitate predicting the increase in VRE supply with implemented and additional national policies and measures. In turn, this would inform decisions on actions to meet policy targets (Goodwin et al., 2018).

([11]) Residual demand variability is the metric used to quantify flexibility needs. The variability is calculated as the difference between residual demand and its average over time, following the methodology from EC, Directorate-General for Energy (2019).

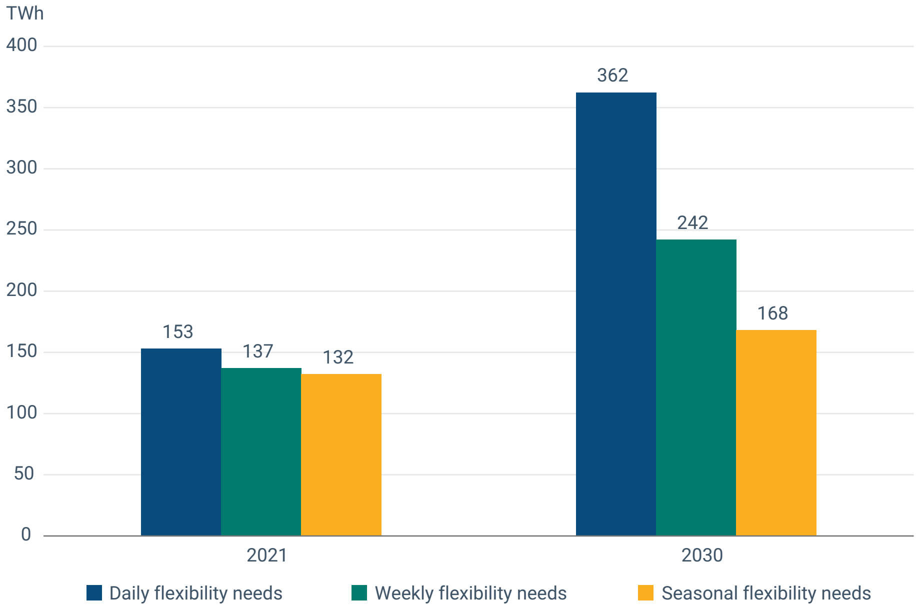
Box 4

Flexibility

'Flexibility' means the interconnected EU power system's ability to manage, with all its connected resources, the variability and uncertainty of electricity generation and consumption patterns across relevant time frames.

By 2030, the electricity system in Europe will need more than twice the current amount of flexibility resources to keep up with changing needs. The demand for flexibility will increase sharply on daily (2.4-fold), weekly (1.8-fold) and annual (1.3-fold) bases, compared with 2021 (see Figure 5) ([12]).

Figure 5 **Daily, weekly and seasonal flexibility needs in 2021 and 2030 in Europe**



Notes: The 2030 results correspond to the average simulation results under the scenarios considering existing and planned interconnectors and no demand-saving and demand-shifting measures. More VRE deficit hours than VRE excess hours are expected by 2030, so the subtraction of must-run generation would probably reduce the flexibility needs estimated in this paper.

The analysis was performed for interconnected ENTSO-E member countries.

Source: Ramboll, based on hourly generation and demand data combined with historical hourly profiles from the ENTSO-E transparency platform (ENTSO-E, 2022); and 2030 annual data from the policy scenarios for delivering the European Green Deal (EC, 2021b).

([12]) Recent assessments consistently point to a substantial growth in flexibility needs by 2030 and beyond. Estimations may, however, differ due to differences in modelling choices, including the approach to residual demand calculation, scenario assumptions and modelling the impact of demand response.

The higher short-term flexibility needs suggested by this analysis reflect the observation that VRE intermittence is greater at a higher temporal granularity, especially for solar power, affected by the ever-fluctuating motion of clouds and weather systems. Using a longer time frame, however, residual demand is smoothened thanks to, for example, the seasonal complementarity of wind and solar supply, or the higher wind production aligning with the higher electricity demand in winter (for more information, see Section 3.1). Moreover, different VRE technologies call for varying levels of flexibility. A significant deployment of solar generation (see Box 2) is bound to result in more substantial flexibility needs (most notably, daily flexibility) than an equivalent growth in wind generation (JRC, 2023). Yet meaningfully combining both technologies as part of integrated generation profiles has important flexibility benefits, as shown in Section 3.1.

In absolute terms, flexibility needs are expected to triple between 2030 and 2050; still, in relative terms - compared with the demand - growth is expected to slow down (JRC, 2023). This indicates that today the primary driver is the changing energy mix, whereas, in the next decade, electrification will become the main force behind the growing need for flexibility resources.

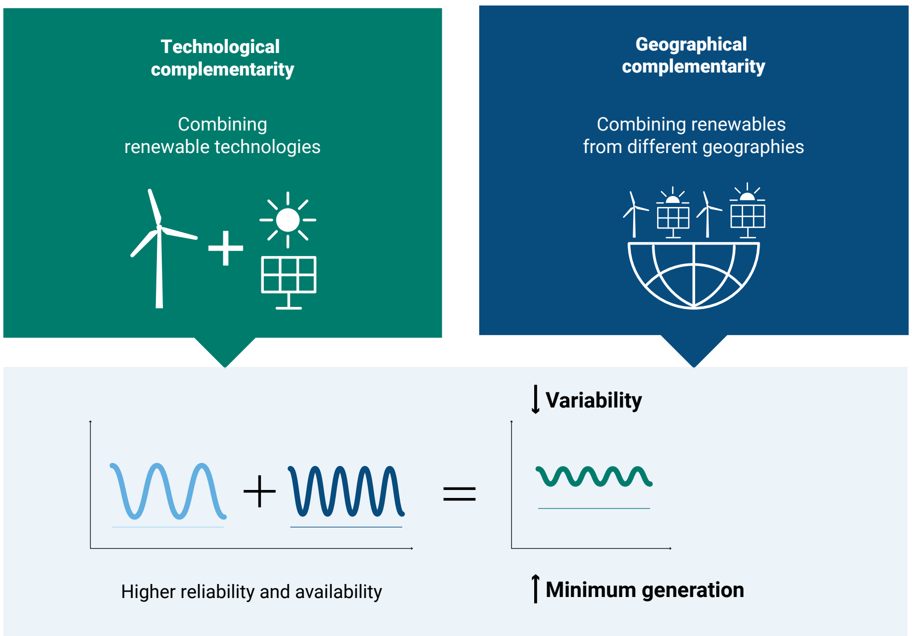
Thus, to meet the challenge of today and scale up appropriately in the next decade, the EU electricity system must be equipped with a well-designed and properly incentivised mix of flexibility solutions, starting now.

Chapter 3 outlines the supply, demand and infrastructure flexibility solutions needed to cope with fluctuations in VRE supply over different time frames. It also highlights that the system requires a combination of decentralised elements, such as demand response or distributed generation, and centralised elements, not least more ample offshore projects and interconnectors linking Member States and regional renewable hubs to make the most of the renewable resources on the continent.

3 Promising climate-compatible flexibility solutions exist. Key ones for this decade include demand response, energy storage and enhanced interconnection

As discussed in Section 2.3, solar and wind resources have varying generation profiles over different time frames. These profiles tend to complement each other on daily and seasonal bases. Wind generation is likely to peak during the night-time and in winter, while sun is likely to peak during the daytime and in summer. Moreover, differences in climatic (wind and solar irradiation) patterns across the EU become more pronounced with increasing distances between regions. Therefore, combining VRE technologies and sharing their outputs across geographies will smoothen the overall supply (Figure 6).

Figure 6 **Illustrative representation of the technological and geographical complementarity effects**



Technological complementarity refers to combining, including on a project and local level, solar and wind generation profiles with different peak and valley times. The outcome is a smoother, less variable generation than that of individual technology profiles. This lowers the needs for flexibility resources to cover the gap between generation from variable renewables and demand. Combining wind and solar electricity supply can reduce short-term generation variability by up to around 30% ([13]).

([13]) Measured as the standard deviation of hourly time series for aggregated VREs compared with the standard deviation of individual technologies.

When considering seasons, the diverging patterns of solar and wind generation in Europe affirm their complementary nature ([14]). As an example, in the continental climate with warm summers, the combined monthly generation from wind and photovoltaic never falls below 85% of their peak (IEA, 2023b). Ultimately, electrical systems combining both wind and solar technologies enable up to 20% higher renewable energy deployment than the separate deployment of these technologies (Solomon. A. et al., 2020; Couto and Estanqueiro, 2020).

Box 5

Dunkelflaute

Dunkelflaute or 'dark doldrum' ([a]) indicates a meteorological condition when little or no energy can be generated using wind and solar power for a whole day or longer. Such events are difficult to predict but put large stress on a decarbonised energy system. Fortunately, they are mostly localised in specific regions and hardly ever occur on larger geographic scales. While *Dunkelflaute* periods can persist in individual countries, they have not happened at the European level in the analysed 2015-2021 period.

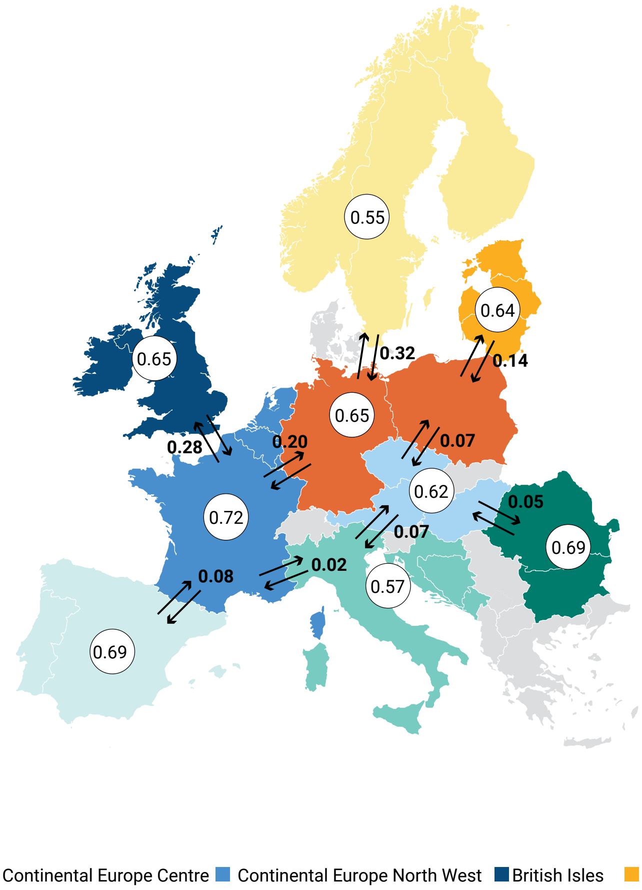
Notes: ([a]) Defined as periods when wind and solar generation present a capacity factor (electricity generation / theoretical maximum as per rated power) below 20% for at least 24 successive hours.

Geographical complementarity relies on two critical elements: the varying wind patterns across Europe and the divergent wind and solar generation potential in different countries. The benefits associated with complementarity can best be harnessed by fostering interconnectivity in the European electricity market and addressing internal congestions, both by the development of new projects and by enhancing the use of existing lines (ACER, 2023b).

As a simplified example, one could group countries based on wind energy potential in a way that sharing across clusters offers the most benefit. Recognising the opportunities to maximise geographical complementarity between regions may help, for example, to prioritise the development of optimal trans-European energy corridors (see Figure 7).

([14]) The average decorrelation between solar and wind generation is as strong as -0.85.

Figure 7 **Illustrative wind energy clusters identified in Europe — high correlation within the clusters and low correlation across them**



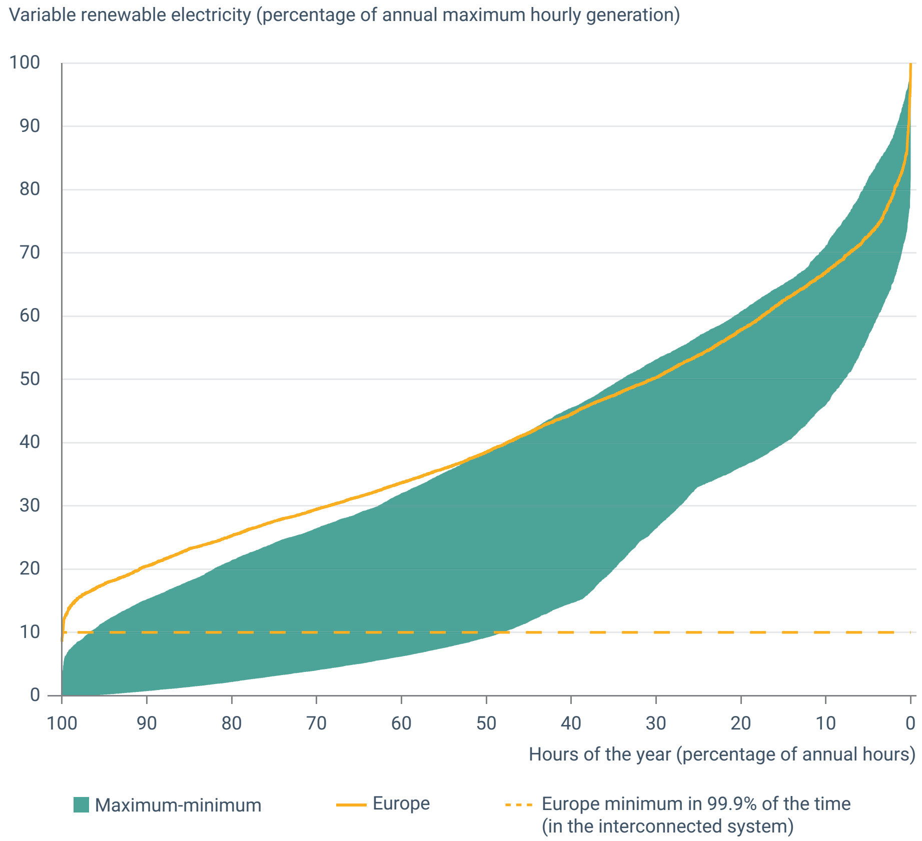
Notes: Based on historical wind generation profiles at the Member State level (not directly on wind patterns). Grey-coloured countries are those for which a cluster has not been identified or adding them to existing clusters significantly reduced the cluster's average correlation. The map is merely illustrative; multiple factors, including renewable developments (e.g. offshore wind deployment), could alter the picture.

The analysis was performed for interconnected ENTSO-E member countries.

Source: Ramboll, based on hourly generation data from the ENTSO-E transparency platform (ENTSO-E, 2022).

A recent analysis undertaken for regional forums suggests similar insights, arguing that sharing renewable resources among well-interconnected Member States enhances the certainty of availability (see Box 6) (Penta, 2023). By looking beyond national borders, Europe can always count on a minimum VRE output, as roughly 10% of the total VRE capacity will be producing at all times (see the dashed yellow line in Figure 8). The European aggregate output is also more stable, producing between 30% and 60% of the maximum generation around half of the time (see the solid yellow line in Figure 8), than the varying output in individual countries (depicted by the green area in Figure 8). Moreover, at the EU level, there will be fewer VRE production spikes that could lead to curtailment of renewable generation.

Figure 8 **Duration curves of VRE generation in Europe in 2021**



Notes: The solid yellow line depicts the aggregated European VRE generation duration curve (hourly generation arranged from the lowest to the highest). The shaded area represents the minimum-maximum range of all individual countries.

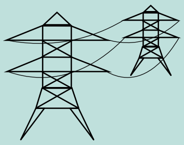
The analysis was performed for interconnected ENTSO-E member countries.

Source: Ramboll, based on hourly generation data from the ENTSO-E transparency platform (ENTSO-E, 2022).

These complementarity results are based on actual observed historical figures. Other studies using hypothetical scenarios suggest that there is an optimal combination of solar and wind generation that maximises complementarity and minimises the need for additional flexibility resources (Weitemeyer et al., 2014). This optimal resource mix may be different at the national level than at the regional or EU level if accounting for sharing resources across borders. For example, a study by a transmission system operator found that two-thirds wind and one-third solar generation would be optimal in northern Europe to avoid a structural, season-long mismatch between electricity supply and demand (Elia Group, 2021). The solar-to-wind ratios are also key to determining the adequate mix of flexibility resources, given that certain technologies are more suitable to balancing solar fluctuations than balancing wind and vice versa (Gils et al., 2017).

The implications of the envisaged solar and wind capacity developments also point to the crucial role of coherent and consistent, integrated climate and energy planning, which Member States are encouraged to undertake by the EU governance regulation framework. This should entail formulating strategies with both national and regional perspectives under the NECP mechanism and exploring relevant synergies and possibilities of cooperation, including in the context of the high-level energy infrastructure groups. Moreover, the biennially updated greenhouse gas emission projections and energy parameters reported by countries through progress reports under the governance regulation can also help to make informed strategic decisions, especially where such tools are grounded in more robust and complete energy data.

Box 6



Recent analysis from the Pentalateral Energy Forum shows the contribution of interconnectors for flexibility and the benefit of assessing flexibility needs regionally, not just nationally

The study, conducted on behalf of a group of Member States, suggests that regional cooperation is a key enabler of the cost-efficient integration of renewable energy by maximising the potential of local flexibility resources, such as hydropower in the Alps region. Therefore, system operators should maximise the availability of interconnectors across all market time frames, while significant additional investments into cross-border infrastructure will still be needed.

To date, EU policies encourage countries to cooperate on renewable energy across borders. Since 2009, countries have been able to engage in joint renewable energy project development ([15]) and operation, open national support schemes for mutual co-funding ([16]) (to accelerate renewable energy production in their territories) and buy and sell renewable energy from each other using a system of statistical transfers. To help renewable energy cooperation take off, the EC has also issued guidance on the sharing of costs and benefits (EC, 2022b). However, despite such initiatives and the recognised benefits of cross-border cooperation on renewable energy, few practical examples of actual implementation exist today (EEA, 2020). At the same time, some high-level strategic initiatives are already taking shape. The emerging idea of regional renewable energy hubs is gaining traction in the North Sea and Baltic Sea basins (Esbjerg, Ostend and Marienborg Declarations) and in the Mediterranean (MED9 format).

Beyond sharing renewable energy, interconnectors also allow for the efficient sharing of flexibility resources. The EC's Joint Research Centre (JRC) estimates that interconnectors' relative contribution at the EU level can cover 15% of the daily and 33% of the monthly flexibility needs by 2030. Interconnectors should be thought of when assessing the resource mix. For example, the same study estimates that almost 2 GW of local storage is needed to replace 1 GW of interconnectors (JRC, 2023). Maximising transmission capacities, both, physically and operationally can make decarbonisation of national systems less costly (Zachman et al, 2023).

Deepening cooperation requires considerable efforts from all Member States, particularly in making the increasing structural interdependence both acceptable and achievable.

Coordination of policy decisions regarding the national resource mixes, joint planning of investment in cross-border infrastructure and coordinated operation is key to maximise complementarity effects. To that end, new approaches may be explored and existing ones strengthened, including:

- facilitating coordinated actions at the EU level in the context of the integrated NECPs under the governance regulation (European Parliament and Council, 2018a) and by cooperating in the frame of the renewable energy directive (European Parliament and Council, 2018b);

([15]) For example, planned joint development of offshore wind and green ammonia cross-border infrastructure.
([16]) For example, a 400 MW solar photovoltaic tender in Finland with funding provided by Luxembourg.

- regularly assessing the flexibility needs of decarbonising the EU power supply while cost-effectively maintaining the security of supply, taking into account all flexibility resources, including the cross-border flexibility potential;
- jointly planning cross-border infrastructure based on cost-benefit analysis that considers both enhancing the efficiency of the existing assets and developing new lines ([17]) (ACER, 2021a);
- enhancing cooperation among transmission system operators through regional coordination centres to support integrated system and market operations, including coordinated capacity calculation and security analyses, focusing on maximising cross-border capacities with the aim of freeing up at least 70% of capacity for trade between Member States (ACER, 2023c).

Reducing flexibility needs

Uncongested interconnection capacities reduce the need for additional, sometimes less effective, local flexibility resources.

Harnessing the complementarity of wind and solar resources in an integrated European grid reduces the system's flexibility needs. Interconnectors also play a key role in efficiently spreading electrical energy from other resources, including storage and demand response. The subsequent sections introduce these key flexibility resources.

3.2 Demand response must become a key actor in a future energy system dominated by variable renewable energy sources

While EU electricity (and energy) demand has been inflexible for the most part, 2022 demonstrated the relevance of demand flexibility and savings. Businesses and, to some extent, residential consumers reduced their overall gas consumption by about 20% from average levels in previous years in response to price increases of around 400%, national information campaigns and other measures (EG3, 2022) ([18]). This helped avert higher electricity prices from marginal gas supply and potentially an acute energy supply shortage.

In the first half of 2023, some European wholesale markets recorded twice as many events of negative electricity prices as in the same period in 2022 (IEA, 2023c). These prices happen during VRE excess situations, for example when a surge of summer winds coincides with peak solar generation and with low demand (see Section 2.2) ([19]). Sub-zero energy prices indicate that electricity consumers often have limited financial incentives and information on which to respond to such price swings, which affects their ability to provide a service to the electricity system.

([17]) A number of regional groups provide strategic steering and policy guidance and monitor the progress of projects of common interest in priority regions.
([18]) Also see ACER (2023), *Wholesale Electricity Market Monitoring 2022 — High-level analysis of energy emergency measures*, Ljubljana.
([19]) Negative prices could also be a symptom of ill-designed renewable support schemes (ACER, 2022b).

Box 7

Demand response

'Demand response' refers to residential, commercial or industrial customers changing their electricity load from normal or planned consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final customer's bid to sell demand reduction or increase at a price in an organised market, whether alone or through aggregation (EU, 2019). In general, price-sensitive demand should increase in times of lower prices (VRE excess) and decrease in times of higher prices (VRE deficit), thus balancing the system.

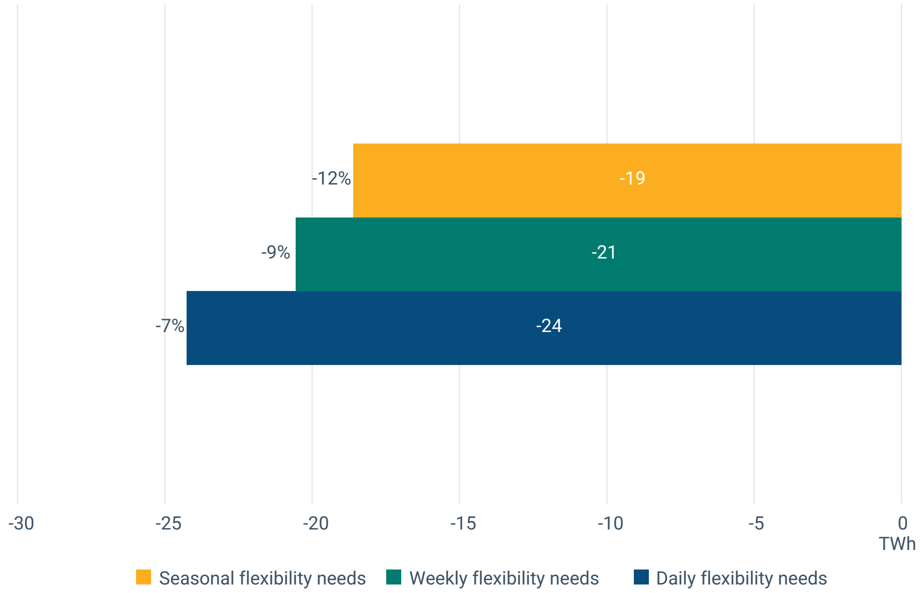
Energy efficiency and demand response (see Box 7) are therefore essential tools to help rebalance markets, reduce high prices and soak up low or negative prices. In general, it is more economical and less polluting to reduce or delay energy use than to activate additional supply or other flexibility resources.

At present, households consume around 700 TWh annually and contribute to around half of the winter electricity peak, while the private and public sectors consume a further 747 TWh annually (EG3, 2022; Eurostat, 2023). Both figures will increase in future, following a more general move from gas to electricity, the roll-out of electric vehicles and heat pumps, and the growth of digital technologies and data centres. This demand will see two main price developments linked to the high renewable energy supply projected this decade. First, consumers will probably benefit from the lower average electricity prices offered by increasing low-running-cost renewable generation. Second, significant VRE deployment could increase the need for system-balancing services, at a certain cost ([20]). Consumers will need to be able to adjust their consumption behaviour based on incentives and signals in response to the system's needs. This ability to respond can limit the costs of these balancing services, which will be incurred by consumers who either do not or cannot respond. Enabling vulnerable households to respond to such stimuli will ensure that even these consumers can reap all the benefits of VRE.

The quantitative assessment underpinning this analysis tested an electricity-demand-saving and electricity-demand-shifting scenario inspired by the EU's emergency intervention in the winter of 2022/2023 ([21]). Demand savings were implemented as peak electricity demand shifting of 5% ([22]) and electricity demand reductions of 10% during non-peak-demand hours. In total, it resulted in an annual demand saving of 7% (231 TWh) across Europe in 2030, which translates into overall reductions in all daily, weekly and annual flexibility needs of 7%, 9% and 12%, respectively, by 2030 (see Figure 9).

([20]) Market participants, including the ones with VREs in their portfolios, are responsible for the imbalances they cause. Balancing rules incorporating a well-designed incentive structure tend to minimise the overall cost to the system.
([21]) Regulation 2022/1854 of 6 October 2022 on an emergency intervention to address high energy prices (OJ L 261, 7.10.2022, p. 1).
([22]) Shiftable to hours of VRE excess before the following peak hour.

Figure 9 **Contribution of the demand-saving and demand-shifting scenario measures to the total flexibility needs in Europe in 2030**



Notes: The bars represent changes in daily, weekly, and seasonall flexibility needs for demand savings and shifting compared with the average results with the reference demand. Values correspond to the averages of all simulations performed per demand scenario.

The analysis was performed for interconnected ENTSO-E member countries.

Source: Ramboll, based on hourly generation and demand data from the ENTSO-E transparency platform (ENTSO-E, 2022); 2030 annual data from the policy scenarios for delivering the European Green Deal (EC, 2021b); and historical hourly profiles from ENTSO-E (2022).

These benefits highlight the disproportionately impactful effect of demand response measures. Although an increasing number of countries have started piloting such projects (see case study 1), there are still numerous legal, technical, economic and informational barriers to activating demand response at larger scale. The following are most prominent.

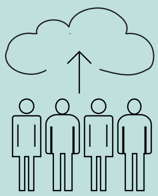
- Robust implementation of the existing supporting regulatory framework ([23]) should be ensured, for example, recognising the needs of active consumers. In addition, the timely adoption of the ongoing work on the dedicated regulation integrating demand response into the energy markets will be a key milestone.

- Barriers, such as prohibitive prequalification criteria, need to be removed to help consumers — even small, decentralised ones — to enter the market and provide demand response services via aggregation (ACER, 2021b, ACER and CEER, 2021)

- There is a need for the rapid deployment of smart meters, and submeters, with the right capabilities (e.g. two-way communication at high time-resolution) to provide the technological prerequisite for active participation.

- Getting the right range of supply choices together with the right information to consumers is necessary. This should include fixed and time-of-use types of contracts alongside, for instance, public advisory tools and one-stop-shop platforms allowing consumers to compare offers and understand their financial benefits and potential risks.

Case study 1



Virtual Power Plants in Italy

Small system users frequently face barriers to entering energy markets, including stringent requirements for offering balancing products. Commonly, ancillary services are primarily assigned to large conventional generators, thereby restricting the participation of smaller ones.

In Italy, the mixed enabled virtual units pilot project enabled small units, including demand response providers, to aggregate to form a virtual power plant and deliver ancillary services to the system operator. Embracing various forms of aggregation not only fosters a competitive environment that reduces costs for end users. It also creates a viable business opportunity for active consumers.

Wider policy choices should also explicitly consider their impact on system responsiveness. There are win-win situations, but more often there may be trade-offs, for example when designing support mechanisms for generation that does not adequately incentivise operation according to system needs or locking consumers in to fixed-price contracts without considering the needs of different consumer groups (ACER and CEER, 2023).

Integrating electricity demand and other distributed flexibility resources is one side of the coin. As renewable electrification reaches a wider range of sectors, demand could have an even larger impact on balancing VRE excess and deficit. Integrating the various energy consuming sectors will bring additional benefits, as shown in the Section 3.3.

([23]) To increase procurement of demand response and leverage the potential from distributed energy resources, the EC has introduced new definitions for demand response, active customers and aggregators as part of its clean energy for all Europeans policy package (EC, 2019a). The European Green Deal policy framework (EC, 2019b) offers a number of targeted and indirect (enabling) measures. The recent electricity market design proposal (EC, 2023) and the framework guidelines on demand response (ACER, 2022a) put forward measures to strengthen the development of demand response.

3.3 Energy system integration increases flexibility and supports the decarbonisation of end-use

To realise the full potential of demand response and benefit from the more rapid decarbonisation of electricity supply, policy-makers and planners need to move to a holistic development and integrated operation of the energy system. This will allow the EU to capitalise on rapid changes also under way in other sectors, such as buildings, transport and industry.

With appropriate incentives and standards in place, energy system integration (see Box 8) will facilitate harnessing flexibility from various resources, such as time-shifting and reducing the heating and cooling needs and shaving demand peaks by using domestic or industrial heat pumps and district heating (see case study 2).

Box 8

Energy system integration

'Energy system integration' refers to linking and coordinating across the entire chains of supply and demand for key energy carriers, such as electricity, heating and transport fuels, and integrating their associated markets and infrastructures to improve competitiveness and the security of supply (EC, 2020).

Integrated systems will also increase the potential for energy storage (see Box 9). Similar to demand response, storage solutions re-allocate energy resources in time, becoming important flexibility providers in the future (IEA, 2023b). Electricity storage provides flexibility by taking up low-priced electricity (VRE excess) and feeding it back to the system in high-price (VRE deficit) hours. Storage solutions with associated smart technologies can bring about even higher gains. This is particularly evident in the case of electric vehicles that can offer controllable capacity by adjusting battery charging and discharging patterns in direct communication with the grid. Alongside this, electricity can be stored as heat in buildings and electrolysers can increase the production of renewable (green) hydrogen during times of VRE excess.

Box 9

Energy storage

'Energy storage' is an umbrella term for several technologies that convert electricity to other forms of energy and store it, for example:

- mechanically, most commonly as pumped hydropower (water pumped upstream, then released later) but also as compressed air in a reservoir or spinning velocity in a flywheel;
- electrochemically, as chemical energy in batteries;
- thermally, converted into heat that is stored in diverse media, from hot water tanks to structural building materials;
- as hydrogen or other fuels (power-to-x), for instance by splitting water into hydrogen and oxygen using electricity.

However, as discussed in Section 2.2, even if the asymmetry reduces by 2030, more than 11 times more energy will still be needed during VRE deficits than will be produced annually during excess situations. Therefore, the ability of storage to serve as a cushion will be limited. If only incentivised by price differences at the times of VRE excess and deficit, storage units would not be able to accumulate enough surplus energy to compensate for the VRE deficit. This also means that green hydrogen production will be relatively scarce in the EU by 2030, with policy-makers needing to carefully prioritise its most valuable applications.

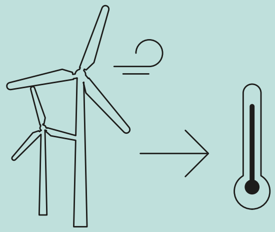
The flexibility resources, including industrial demand, electricity storage, electric vehicles, and industrial and residential heating, should react to surpluses and scarcities as conveyed by efficient price signals from all markets ([24]). For example, the revenue stream of storage technologies tends to rely on multiple market segments, including ancillary services (JRC, 2023). Therefore, it is crucial to dismantle undue market-entry barriers that may restrict solution providers and to allow the smooth integration of these flexibility sources into all electricity markets. In contrast, with the constrained participation of new and small entrants, relying on public subsidies and other out-of-market schemes is likely to become increasingly necessary.

In the EU's pursuit of a decarbonised, resilient power system, a holistic approach that takes advantage of the continental scale of the internal energy market must cohabit with the tendency for greater decentralisation of energy resources. With the ability to supply electricity closer to the end consumers, well-integrated distributed energy resources might limit the growing pressure on the distribution and transmission networks, resulting in minimised grid congestion and losses. Moving the supply closer to demand not only holds the promise of slowing down the need for extensive grid reinforcement and reducing the losses, but also opens up new business opportunities for system users to either put their capacities on the market or explore self-consumption and energy-sharing options. Deploying distributed energy resources at the residential or community level can thereby help European households and businesses mitigate their exposure to high energy prices, while simultaneously contributing to the security of electricity supply (EEA, 2022c, 2022d). Research to overcome the challenges related to the durability, stability, scalability and recyclability of new photovoltaic technologies can further increase the importance of distributed energy resources, enabling solar photovoltaic modules to become standard building material components or to be integrated into various surfaces.

Supplying energy near end consumers is also a feature of hybrid energy projects. Typically located at a single site, these projects combine various technologies to use renewable power efficiently. Such systems can effectively respond to VRE excesses and deficits through appropriate charging and discharging patterns, conversion between different energy carriers such as heat or green hydrogen, or engagement in electricity trading on the market (see examples case studies 2 and 3).

([24]) A recent study shows that the electric heating systems can unlock large virtual storage capacities, even in energy-inefficient buildings (Thomaßen et al., 2021).

Case study 2

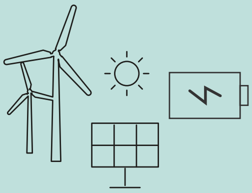


Heat Smart Orkney

In past years, Orkney in Scotland saw a transition from generating fossil-based energy to harnessing abundant wind resources. The rapid growth of wind energy led to moments of excess production, initially forcing the operator to curtail wind farm output. As a response, a community-led renewable energy project investigated the possibility of the smart electrification of the heating sector. Electricity was stored as heat energy in times of excess instead of curtailing production.

The project serves as an example of how communities can take action to address local congestion problems in the electricity grid and better utilise VRE sources. On top of that, Orkney is an illustration of a small-scale strive towards energy independence, as it reduces its reliance on fossil fuel deliveries by better using local resources.

Case study 3



Haringvliet Hybrid Energy Park

Hybrid energy parks typically integrate multiple renewable energy technologies to form an economic unit. For instance, the Dutch Haringvliet project incorporates solar and wind generation alongside battery storage.

By leveraging the synergies between technologies, hybrid parks ensure a reliable energy output that effectively balances potential excesses and deficits on-site.

The integration of the flexibility resources across sectors requires an effective European framework that can efficiently integrate the local resources into the interconnected energy market. In particular, policy-makers should work towards removing barriers hindering the market entry of new and small market participants (ACER and CEER, 2021), fostering the development of hybrid energy projects and finding ways to capitalise on opportunities offered by prosumption and distributed energy production (EEA, 2022c, 2022d).

Last, advances in information and communications technologies, artificial intelligence and digitalisation will become key drivers for the ongoing system transformation. The results of this progress are already applicable in optimising the integrated development of energy system components. The adoption of digital tools will become crucial to reduce the need for additional physical infrastructures, mitigate disturbances and facilitate greater VRE integration.

4 All-hands-on-deck and leverage complementarity across borders — a broad mix of resources and supportive policies is needed to handle the flexibility challenge

This paper points out a steep increase in flexibility needs by 2030. A number of climate-compatible technologies are available to satisfy these needs and mostly replace fossil-based flexibility resources by the end of the decade.

4.1 Flexibility is needed across all timeframes

Covering the peaks and valleys within a day requires substantial growth of flexibility resources, as their input should reach more than two times the current levels. Solutions to this include employing demand response, smart sector integration and storage technologies more amply. Weekly flexibility needs will almost double. Storage solutions such as pumped hydropower are well suited to provide the required capacity as day-night storage, but they can also cover the weekly cycle. Annual flexibility needs are expected to grow by around one-third of current needs by 2030. These swings could be covered by, for example, reservoir hydropower, electrolysers, hydrogen-based power plants and thermal storage solutions, along with the generalised energy-efficiency and savings efforts demanded by the recently updated EU energy efficiency policy framework.

Increasing electrification provides opportunities (on the demand side) for us all to play our part but also challenges. Already there are signs of not having sufficient demand-side flexibility as evidenced by more days with massively negative electricity prices across certain parts of the EU. Negative power prices are a sign of very high supply (e.g. lots of wind and solar) at the same time as low demand. It is not always easy for generators to switch off or (industrial) consumers to ramp up demand. Hence, even more flexibility (of different types) and interconnections to enable that flexibility to cross borders is key.

4.2 Flexibility needs point to the role of interconnectors as enablers of cross-border flexibility

Deploying and sharing the right mix of variable solar and wind resources within a Member State and moreover across the EU also helps to reduce the system flexibility needs through the identified technological and geographical complementarity. Interconnectors will also play a key role by enabling flexibility resources to be shared across borders on all timeframes, but particularly beyond the daily time frame, where one-third of the annual flexibility need could be provided from across borders by 2030 (JRC, 2023).

Despite the availability of these various climate-compatible flexibility options, there is no single easy answer to meet the flexibility needs at speed within the 2030 time-frame: network developments, demand response, storage technologies and system integration all need to be used in combination to guarantee that the future energy system always meets the needs of consumers. Delivering the clean energy transition will take unparalleled efforts from all stakeholders in all economic sectors, encompassing innovative solutions, coordinated planning, adaptations in network operation, changes in consumer behaviour and an array of complementary measures. Ultimately, it also includes enabling electricity to flow cross-border. As the energy crisis taught the EU, cross-border trade has a tremendous potential to dampen volatility and enhance much needed resilience (ACER, 2023a).

4.3 Strong political commitment and coordination is key

Undoubtedly, this clean energy transition will allow the EU to reduce its dependence on fossil fuels and on energy imports. Achieving a secure energy system and decarbonisation at the same time, however, necessitates strong political commitment, coordination and an in-depth understanding of the trade-offs. Most of all, the European electricity grid needs to be equipped with a well-calibrated range of flexibility resources during this decade to ensure that the system can cope with short-, medium- and long-term fluctuations in supply and demand. To enable that, this paper highlights two essential focus areas and action points.

Use coordinated planning and operation of the energy system to manage decarbonisation and security of supply at the same time.	
Assess flexibility needs thoroughly	Given the strong role of distributed resources and interconnectors, flexibility needs and potential ways to fill those needs should be carefully assessed in a forward-looking manner at the European and national levels.
Check consequences to flexible resources	When considering energy policy options (e.g. consumer protection), always check the possible unintended consequences on the availability and development of flexibility resources (e.g. demand responsiveness). Being aware of the trade-offs will help to calibrate the measures.
Tap into synergies across borders	Member States' NECPs and biennial greenhouse gas projections in progress reports can facilitate regional cooperation. Sharing information on renewables and flexibility policy choices and projections across borders fosters an integrated system view, which, in turn, helps to address domestic electricity needs. Best practices for cooperation and coordination should be identified and promoted within the NECP and the biennial national greenhouse gas projections and energy parameters alongside existing mechanisms, such as the joint development and procurement of renewable energy sources and statistical transfers.
Maximise interconnection availability	Having a well-managed national and cross-border infrastructure and the close cooperation of transmission system operators through the regional coordination centres are prerequisites for regional renewable energy hubs to reap the full benefits of sharing clean energy and flexibility resources. Freeing up at least 70% of grid capacity to make it available for cross-border trade is a key step in maximising regional benefits and meeting national and regional flexibility needs.
Create incentives for consumers to be actively adapting their consumption when needed and for storage to be operated dynamically.	
Provide price signals	Energy bills and smart meters (including carbon pricing and time-of-use tariffs) inform consumers of the actual electricity cost, which can trigger behavioural change and the adoption of new business models in response to periods of scarcity and surplus. Households' exposure to the prices should be tailored to their risk preferences. The deployment of smart meters should be sped up.
Provide trusted, targeted information	Consumers should be able to make informed choices according to their needs and circumstances, starting from their metered consumption. Competent authorities (e.g. regulators, consumer bodies and distribution system operators) should provide enhanced guidance to households to assess the suitability of flexible supply contracts and the potential financial benefits they may attain. Additional measures such as public advisory tools and guides (for instance about access to funding for vulnerable households) should complement economic incentives, to help households in particular to judge the benefits of becoming active and flexible consumers of electricity.
Take all resources on board	Small-scale active consumers, prosumers, storage units and other small system users are as essential as large consumers and generators. All resources, big and small, should be able to participate in all electricity markets on an equal footing. Dismantle barriers to entry, such as prohibitive prequalification criteria, and facilitate new actors such as aggregators to access a joint potential of distributed energy resources.
Think in broad terms about energy storage	Various energy storage technologies make it possible to choose solutions that are fit for purpose. Depending on the location, needs and available options, VRE generation surplus can be stored as electricity, heat (e.g. in energy-efficient buildings) electrofuels (e.g. green hydrogen) and in pumped hydropower water reservoirs.

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