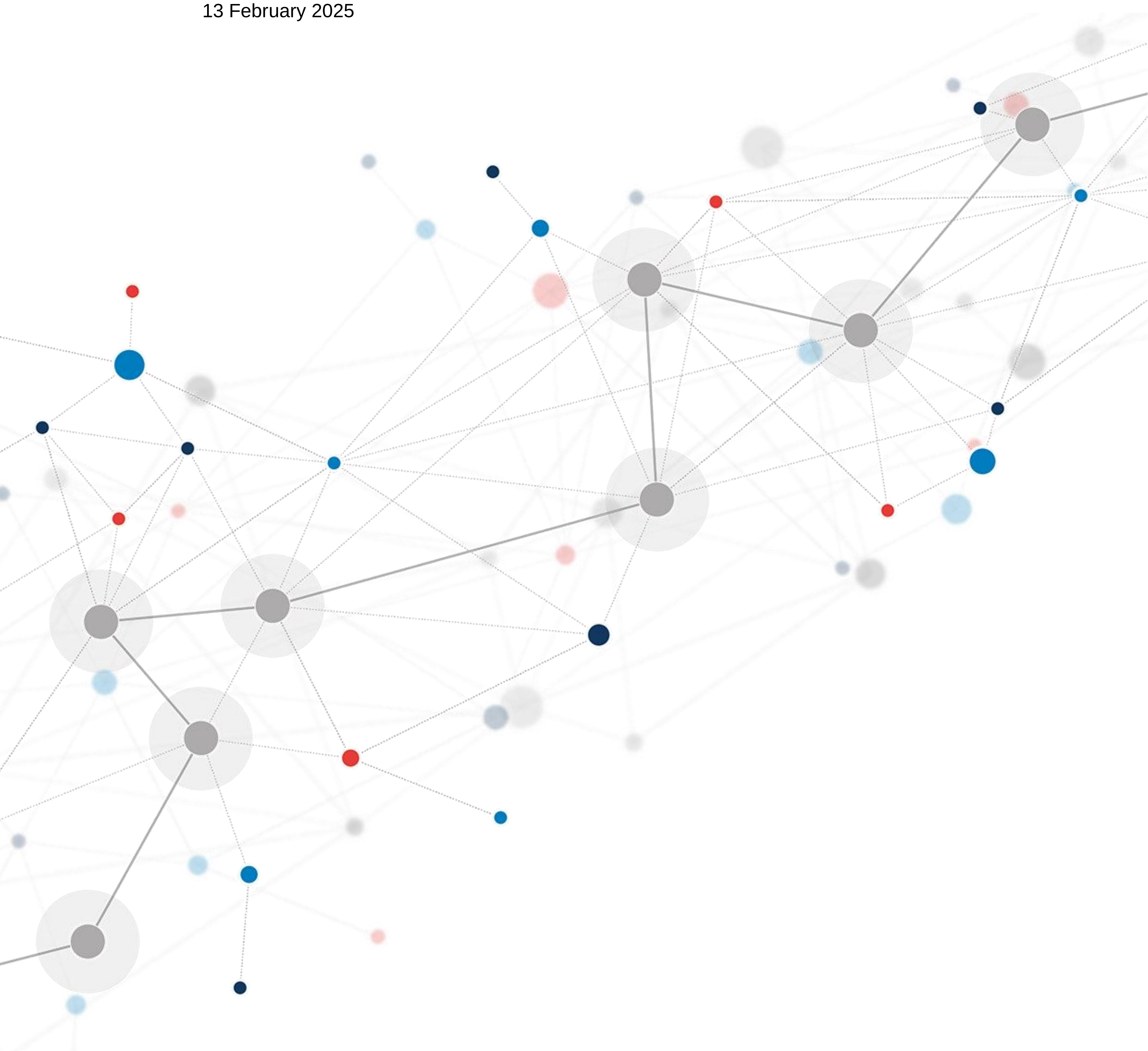
Redefining Energy Security

In the age of electricity

Eurelectric flagship study

Compass Lexecon

13 February 2025



Contents

1 Introduction: objectives, methodology and structure of the study

Key objectives of the study

1 The key objectives of this study are to:

- **Define the forces shaping the new definition of energy security and security of power supply** (what we call 'Security of Supply 2.0') **in Europe** and develop **methodological principles** to assess it**;**
- **Interpret what security of supply (SoS) means for the modern European power system**.
- **Evaluate system needs to maintain SoS** (adequacy and flexibility) in Europe as a whole and in specific regions/countries, while assessing the **profitability** of asset types;
- **Assess the current investment framework** to ensure SoS and **develop policy recommendations** to fill the gaps and guarantee Security of Supply in a net-zero world.

2 This study includes a quantitative assessment based on power system modelling. It **focuses on one specific dimension lacking focus up to date** – the challenges for the electricity system within this expanded SoS concept related to growing shares of variable renewable energy sources (RES), which have primarily to do with ensuring adequate investment and availability of flexible capacity. Our quantitative assessment also considers firm capacity, and we look at the missing money of both firm and flexible capacity.

Methodology of the study

3 The enhanced concept of SoS across the value chain indicates the need to expand the current regulatory and market framework to cover different pillars. To achieve that, we need an expanded system needs assessment and investment support framework, and, in the operational timeframe, improved market signals, as well as supplementary monitoring and governance enhancements.

4 We have reviewed the exogenous factors that drive changes to the energy system drawing upon recent reports and existing Eurelectric analysis. We particularly focused on three main elements: (i) hybrid threats (physical and cyberattacks), (ii) impact of climate change on power demand and supply and infrastructure, and (iii) procurement, which includes access to raw materials and control over key supply chains.

5 In addition, we conducted an in-depth modelling analysis and a regulatory review to assess potential gaps in firm[1] and flexible[2] capacity within a renewable energy-dominated power system, allowing us to develop key policy recommendations to ensure SoS.

6 The study includes a case study of energy security during a real war-time scenario – the current war on Ukraine. Collaboration and special interviews with DTEK have been conducted as part of this exercise.

Structure of the report

7 This study is structured as follows:

- In section 3, the need to develop a new approach towards energy security with an increasing role for electrification is explained, and the exogenous and endogenous drivers of change for the power sector are reviewed;
- In section 4, what a decarbonised and electricity-based energy system can deliver is outlined;
- In section 5, an enhanced approach towards Security of Supply 2.0 is framed;
- In section 6, the three pillars to enhance security of supply in the electricity sector are summarised;
- In section 6.1, the gaps and key policy recommendations regarding the framework required to assess power system needs are presented;
- In section 6.2, the gaps and key policy recommendations to enhance the investment framework to ensure security of supply are presented; and
- In section 6.3, the gaps and key policy recommendations to refine the markets and operations framework are presented.
- In Annex A, a real-life case study of energy security in times of hybrid attacks, the current situation in Ukraine is given. This sections also provides key learnings from the past 2 years, relevant for both Ukraine and Europe.

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1 The dispatchable generation, demand-side flexibility, or storage to ensure adequacy between available generation and residual load during stress events (e.g. at peak hours, after subtraction of variable generation).

2 The extent to which capacities in a power system can modify their electricity production or consumption in response to variability of the system state, expected or otherwise.

2 Executive summary of the study's key conclusions

Why should we develop a new approach towards security of energy supply?

8 Today, a new European Energy Security Strategy is needed, building upon an integrated definition of energy security and with an increasing focus on homegrown electrification as the predominant energy vector. This is driven both by a combination of exogenous and endogenous factors. The former include e.g. geopolitical risks and resilience (a lesson learnt from the 2022-23 energy crisis) and the impact of climate change while the latter includes the high penetration of variable RES, predominantly solar and wind. The balancing of supply and demand at all times requires special focus on the deployment of flexibility in the system, as well as the strategic expansion and digitalisation of the power grids.

9 Indeed, during the recent energy crisis, the lights stayed on, and generation adequacy was maintained. However, the crisis revealed more than just the need to keep electricity flowing, it underscored the importance of avoiding demand loss and ensuring security of supply. It showed how security of supply is tied to affordability and external challenges, such as reliance on critical materials, the growing complexity of the electricity system, vulnerability to cyberattacks, and the impact of geopolitical tensions on costs.

10 Hence, a new and integrated approach to SoS "Security of Supply 2.0" is required, encompassing a broader set of energy policy objectives, in particular ensuring clean and affordable energy supply, adequate network infrastructure and firm and flexible capacities.

11 Electrification is a key strategic component to European energy independence and smart strategic autonomy[3]. Clean electrification is instrumental to achieving both decarbonisation and security of energy supply objectives, while also contributing to the affordability aspect, a critical issue for all consumers, including EU industries whose competitiveness is at stake in the transition.

How? The new approach towards security of supply needs to be integrated and encompass a wide range of dimensions

12 So far, the European framework for security of supply has been fragmented. On the one hand we have fossil fuel import dependency issues, and on the other, an electricity system mainly focused on generation adequacy and network resilience.

13 The rising electrification of the energy system brings security of electricity supply in the centre of the broader energy security issue, and requires an integrated approach across the value chain including end-uses that electrify.

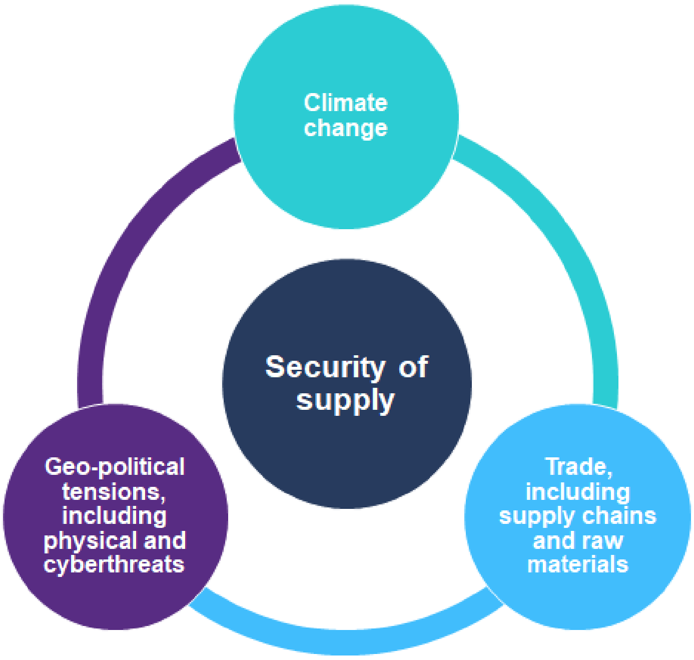
14 At the same time, new solutions enhancing SoS are emerging. The decentralisation of the electricity system, driven by the nature of variable RES, brings new challenges (need for flexibility and

[3] A focus on measures that balance our inability to be 100% self-reliant while also addressing the need to ensure our critical systems are shock resistant and can continue to run our society in the case of a crisis

cybersecurity) but also reduces dependence on fossil fuel imports while improving resilience[4] e.g. to physical attacks.

15 To ensure SoS in an increasingly electrified energy system, we therefore need to reframe and broaden the concept of SoS to include further aspects: firm capacity and services, flexible capacity and services, transmission and distribution grids, and also raw material supply and supply chain resilience to climate change, physical and cyberattacks, geopolitical risks, etc.

Figure 1: The different macro dimensions of the broader concept of security of supply



Source: Compass Lexecon

<u>What?</u> Key policy recommendations to enhance security of supply

16 The main policy recommendations in this study aim to enhance the efficiency, security, and resilience of the electricity system and can be summed up as follows:

- **<u>Preparedness and assessment of system needs</u>**: A more integrated approach should streamline, consolidate and ensure consistency across the different planning tools already included in EU and national laws. It should consider the entire value chain and possibly all energy vectors (electricity, gases, heat, transport, etc.)—upstream, downstream, and end-use sectors—to better identify system needs and options for decarbonisation and electrification. This includes developing new methodologies for improved forecasting and system analysis. The institutional and governance arrangements that support infrastructure planning and end-use sectors will also need to evolve to support efficient market functioning.
- **<u>An improved investment framework</u>**: A more consistent market-compatible investment framework addressing all system needs should be implemented. This includes, where deemed necessary, contracting mechanisms for firm and flexible technologies to secure and coordinate timely investments across the value chain (production, networks, end-uses, etc.) and ensure

[4] Power system resilience is the ability to limit the extent, severity, and duration of system degradation following an extreme event.

electricity supply, in particular through capacity mechanisms. Incentives and coordination in network infrastructure investment should be enhanced to ensure that the necessary investments can be made on time. Such mechanisms would serve as an insurance for the power system and the European economy as a whole: securing electricity supplies may cost money, but this would ultimately be to the benefit of European consumersby preventing the significantly higher risks and costs of inaction.

- **Markets and operations framework**: Market signals could be improved to better reflect physical system needs, whilst enhanced forward markets should offer better hedging opportunities for firm and flexible assets. Greater consumer participation to provide demand-side response (DSR) should also be encouraged. To do so, the focus should now be on proper and swift implementation of the recent reforms of the Electricity Market Design (EMD, notably 2019 and 2024).[5] The aim should be that market players and consumers get access to the expected benefits of these revisions as soon as possible. Their implementation reviews are expected by December 2025 (Directive) and June 2026 (Regulation). These reviews will be an opportunity to assess the status of implementation across Member States, to confirm whether provisions agreed upon are properly implemented across Member States and, in particular, to examine whether flexibility develops at all levels (transmission and distribution).

5 Regulation (EU) 2019/943. Accessible here. Regulation (EU) 2024/1747. Accessible here. Directive (EU) 2019/944. Accessible here. Directive (EU) 2024/1711. Accessible here.

3 Why should we develop a new approach towards energy security?

17 In this section, we explain that a new approach towards emergy security is needed in light of recent geopolitical events and the desired acceleration of the decarbonisation of the energy system. We review successively:

- The exogenous factors driving change (i.e. the external factors affecting the sector); and
- The endogenous factors driving change (i.e. the drivers of change within the electricity sector affecting security of supply).

Exogenous factors driving change

18 In recent years, particularly following the Russian invasion of Ukraine, the policy debate on energy and decarbonisation has evolved towards a greater focus on energy security, increasing strategic autonomy and resilience against external shocks with the REPowerEU strategy.

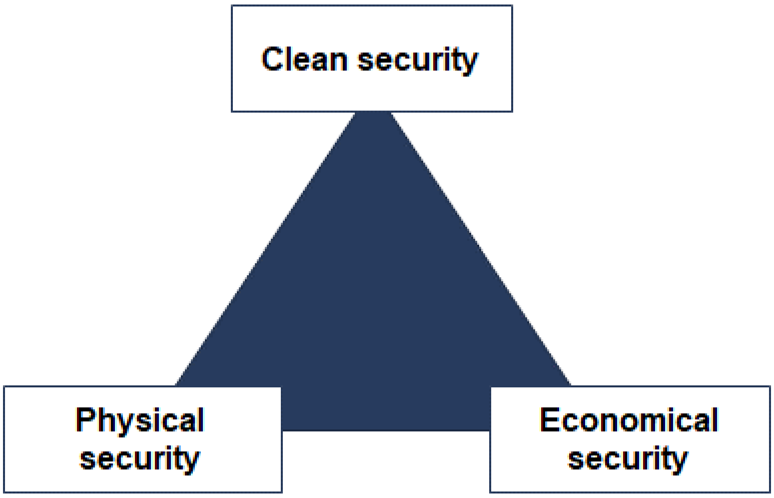
19 The risks of gas supply shortage for Europe led to the 2022 energy crisis. During that crisis, generation adequacy was upheld and the overdependence on Russian gas was overcome, but several challenges to other dimensions of SoS took centre stage, with affordability, diversification in trade and trade partners, especially for critical materials, secured supply chains, and the resilience of the electricity system (to handle shocks and extreme events, including physical and cyberattacks) being the most important ones.

20 From a macroeconomic standpoint, the increasingly important role of electricity in the energy system and in the wider economy, marked by an expected acceleration in electrification, underlines the need to ensure competitive and reliable access to electricity. Affordability of the electricity supply and the adequate distribution of system costs to consumers is crucial to protect against industrial demand destruction and ensure European economic competitiveness at large. Reducing exposure to fossil fuels through clean electrification also limits risks associated with the volatility of fossil fuel prices and their costs for the system and consumers.

21 Therefore, SoS in the current policy context cannot be seen independently of the other pillars of the EU energy policy. The broadened concept of security is interlinked with the other dimensions of the energy trilemma, and needs to encompass them: “clean” security, “physical” security, and “economical” security:

- “Clean” security: clean electricity supply to ensure a decarbonised system and reduce dependency on fossil fuels;
- “Physical” security: ability of the electricity system to guarantee electricity supply to consumers with a clearly established level of performance; and
- “Economical” security: affordability of electricity supply available to consumers to protect against demand destruction.

Figure 2: The broadened concept of security of supply



Source: Compass Lexecon.

22 In the REPowerEU strategy – the EU's response to the Russia invasion of Ukraine – EU leaders agreed that the best shield against future energy supply shocks is increasing reliance on domestic, renewable, and clean electricity. Electrification can indeed contribute to greater EU energy independence and strategic autonomy, compared to an energy system relying on fossil fuels, in which the EU is not naturally endowed. A critical outcome of the energy transition will be the dominance of electricity as the energy carrier of the future: whereas today, only 23% of final energy demand is served by electricity in Europe, the European Commission's ambition is to increase its share to 60% by 2050.

23 The International Energy Agency (IEA), the International Renewables Energy Agency (IRENA), Eurelectric, as well as other organisations and stakeholders[6] have shown the potential of electrification through various studies and reports to address several societal issues such as competitiveness, societal wellbeing and, of course, climate change.

24 In the Decarbonisation Speedways scenario from Eurelectric,[7] electrification of new usages such as electric vehicles (EVs), heat pumps, industrial processes and electrolysis[8] leads to an increase of demand from around 4,700 TWh of annual demand in 2030, to close to 5,900 TWh in 2040 and 6,900 TWh in 2050 for the EU, Switzerland, Norway and Great Britain, as shown in Figure 3 below. In addition, peak electricity demand for the area also increases, from 732 GW in 2030 to 924 GW in 2050, an increase of 26%.

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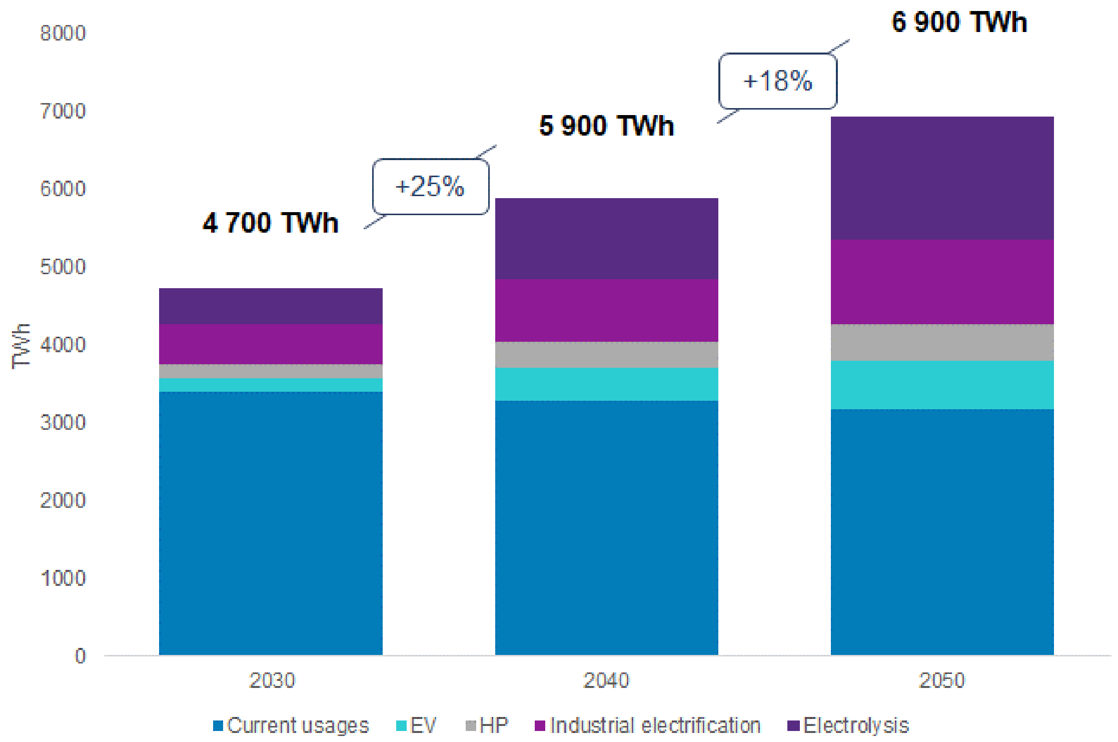
6 IEA, Electrification. Accessible here. IRENA (2019) Electrification with renewables. Accessible here. McKinsey (2020) Plugging in: What electrification can do for industry. Accessible here.

7 Eurelectric (2023) Decarbonisation Speedways. Accessible here.

8 Since the release of the Decarbonisation Speedways study, the projections for electrolysis demand in the coming years and even early 2030s have been revised downwardly due to higher-than-expected costs and lack of H2 infrastructure. While Decarbonisation Speedways RePowerEU scenario projects c.460 TWh of electrolysis by 2030, according to IEA's Global Hydrogen Review 2024, electrolysis demand for Europe is still expected to be below 400TWh if all announced projects are realized.
However, it does not change the general conclusion of this study as there would still be a strong overall electrification trend.

Figure 3: Projected annual electricity demand by usage in the EU, Switzerland, Norway, and GB in 2030, 2040 and 2050 (TWh)



Source: Compass Lexecon analysis based on data from Decarbonisation Speedways.

25 This fundamental shift towards widespread electrification in Europe undoubtedly affects the way we define SoS. To ensure reliable and secure energy supply, we must adopt an integrated approach that considers both the upstream (raw materials, components, labour, cyber and physical security, etc.) and downstream value chain challenges (integration of end-uses, critical role of all flexibility solutions including on the demand side, etc.). The REPowerEU initiative also calls for installing millions of geothermal and ambient heat pumps and modernising district heating systems to replace fossil fuels, which will need to be considered hand in hand with electrification.[9]

26 This new integrated approach to SoS is tied to the need for greater resilience in the face of disruptions and unforeseen events. As electricity becomes increasingly central to the energy system of the future, any disruption can have significant and expanding macroeconomic impacts.

27 Moreover, the growing interactions across sectors and with global markets highlight the importance of resilience and security in each of these areas, as well as the need for coordination amongst them. Recent developments, including rising geopolitical tensions, cyberattacks, and extreme weather events, have underscored the urgency of addressing concerns about physical security and the stability of international supply chains, as well raw materials.

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9 Eurelectric, What is geothermal power. Accessible here.

Endogenous factors driving change - i.e. the drivers within the electricity sector with relevance for security of supply

28 In recent years, the power sector itself has undergone a rapid transformation. In the EU, 74% of electricity is already decarbonised as of today.[10] The EU foresees a strong increase of the RES share in electricity generation by 2030 (69% according to REPowerEU), which, coupled with other decarbonised sources, will further decarbonise the European electricity mix.

29 The rapid uptake of variable renewable electricity, which is expected to represent 81% of electricity supply by 2050, creates new challenges regarding SoS. By 2040, we already expect renewables installed capacity to reach 2000 GW – over a three-fold increase from where we are today.

30 This transformation, led initially by policy and technological advancement of renewables, is affecting electricity flows in the power system, requiring upgraded system operations.

31 **Technology** is also a key driver of change, transforming the landscape, particularly with the rise of variable RES, primarily wind and solar. These technologies, while essential for sustainability, bring new challenges, such as less predictable generation outputs and greater short-term variability, which must be managed to ensure a stable and reliable energy supply.

32 In addition, the traditional linear value chain, where electricity flows from generation through transmission to distribution, is transforming into a more complex, more interconnected system. Drivers such as increased decentralisation, self-generation, and the rise of distributed energy resources (DERs) are creating multiple, dynamic feedback loops. Moving forward, we need to manage bidirectional energy and data flows owning to increased consumer activity, as opposed to the old one-directional model.

33 **The growing number of stakeholders** increasingly involved at the planning stage —ranging from Member States, regulators, grid operators to energy producers, professionals of adjacent sectors etc.— is driving changes in coordination needs. In particular, cross-sector relationships surrounding the electricity sector require coordination with stakeholders in e.g. gas, hydrogen (H2), heat and transport sectors. Equally, decentralisation is driving a greater need for coordination with distribution system operators (DSOs). This includes long-term planning and investment decisions, as well as real-time operational choices, which in turn require changes in **governance structures and institutional approaches**.

34 These internal drivers of change in the power sector come with both new challenges and opportunities. Harnessing these opportunities will be key to support SoS in its expanded concept, including digitalisation, the rise of flexibility and diversity of supply sources both in terms of technologies and localisation.

- **Digitalisation** – information and communication technologies (ICT) in general – plays a crucial role in improving real-time coordination. As the power system grows more complex, the importance of digital solutions grows exponentially. These technologies enable more efficient management of energy flows, grid stability, and the integration of variable RES. At the same time, digitalisation brings new challenges as electricity stands as one of society's most critical sectors. As highlighted in the last Eurelectric reports looking at digitalisation and cybersecurity,[11] the higher degree of power system digitalisation may make it more vulnerable to cyberattacks, which doubled between 2020 and 2022 in the energy sector. This brings cybersecurity and data

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10 Eurelectric, Electricity generation by fuel. Accessible here.

11 Eurelectric (2023) Wired for Tomorrow. Accessible here. Eurelectric (2024) A snapshot of Cybersecurity in the EU. Accessible here.

protection to the heart of the SoS 2.0 definition. In parallel, the digitalisation of our economies also stimulates electricity consumption, notably from data centres. According to the IEA, data centre electricity consumption in the EU already represented almost 4% of electricity demand (100 TWh) in 2022, and is forecasted to grow by 50% between 2022 and 2026.[12] To ensure their smooth integration to the power system, generation capacities should be further deployed, grids should be reinforced concomitantly with data centres, and attention should be paid to adequate distribution of costs.

- **Flexibility,** i.e. the ability of the power system to adapt to fluctuations of supply, demand, or grid availability, is becoming a cornerstone of SoS in this evolving landscape. With the power system becoming increasingly dominated by variable renewable energy sources (such as wind and solar), the need for flexibility increases to ensure that power systems can quickly respond to changes in supply and demand. This much-needed flexibility can be provided by both the supply and demand sides. The former includes technologies such as batteries, peaker gas plants, pumped-hydro and cross-country interconnections, while the latter refers to both load shifting and shaving on the consumer side (also with additional flexible demand such as electrolysers). This strengthens the role of traditional decarbonised sources of flexibility such as hydropower, hydro reservoirs, and pumped-hydro storages but also, a large part of the European nuclear power plants (e.g. most nuclear plants in France can vary their output by 80% within 30 minutes).

  In the future, the decarbonised supply side will be reinforced by H2 combined cycle gas turbines (CCGT) and, possibly, gas CCGT with carbon capture and storage (CCS). The ongoing electrification of energy uses, particularly in transport, buildings and industry, brings **new opportunities for DSR**. While large industrial consumers are currently the most active participants in DSR programs, smaller consumers can engage further (e.g. via aggregators). By 2030, the potential for DSR is expected to significantly increase as more sectors electrify.

- **Diversity of supply sources**, both in terms of technology (such as various clean energy technologies) and geographical location (with centralised and decentralised systems coexisting), has a direct impact on energy security. Low-carbon fuels (e.g. H2), produced with decarbonised electricity generated in Europe for instance, are emerging as solutions for cost-effective decarbonisation of the EU while reducing reliance on imported fossil fuels. Physical threats call for lessons from countries where warfare provides experience for evaluating how to increase the resilience of future EU electricity which will mix centralised and decentralised sources.

- **Energy efficiency** was highlighted in the 2023 Energy Efficiency Directive (EED) as a one of the key aspects to be considered by Member States when making planning and investment decisions. It is becoming increasingly important not only to decarbonise generation, but to also make our energy use more efficient to optimise consumption.

12 IEA, Electricity 2024, Analysis and forecast to 2026. Page 32. Accessible here.

4 What a decarbonised and electricity-based energy system can deliver

35 In this section, we set out a vision as to how a fully decarbonised system with substantial direct and indirect electrification of end-uses can address the different challenges associated with maintaining SoS.

36 Indeed, electrification of the energy system is a key way for Europe to reduce its import dependence on fossil fuels and enhance SoS. But electrification of the economy also makes security of electricity supply central to the broader energy security issue, and requires an integrated approach across the value chain including end-uses that electrify.

37 Electrification also comes with new challenges related to the growth of variable renewables, but also with new solutions to enhance SoS, such as increased electricity system decentralisation, which can contribute to enhancing resilience e.g. to physical attacks.

38 In what follows, we outline how moving away from a fossil-based system to an electricity-based system allows us:

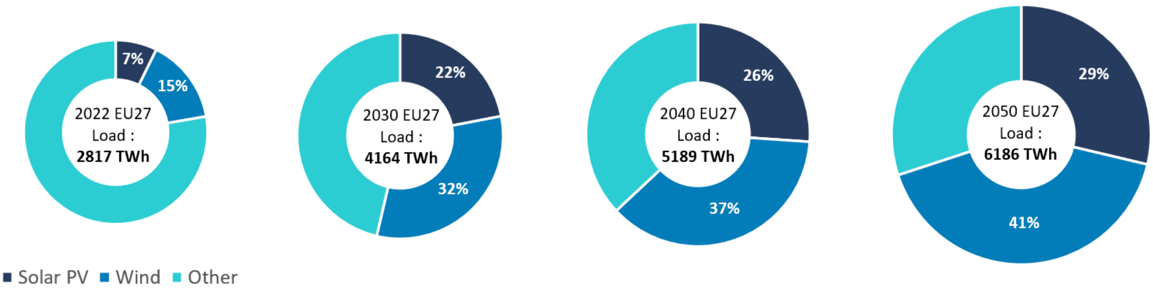
- to leverage the potential of “home-grown” renewable sources available in Europe;
- to reduce dependence on imported fossil fuels, although supply chains and raw materials will create new forms of dependence which have to be de-risked;
- to invest in the European productive capital and improve its commercial balance;
- to make the energy systems more resilient through diversification and a mix of centralised and decentralised generation; and
- to enhance competitiveness of energy supplies and ultimately to fully benefit from the strength of the EU’s internal market.

Leverage Europe’s renewable energy potential

39 Being a vast continent with diverse landscapes and climates, Europe possesses a varied and strong renewable energy potential, widespread across Europe. In particular, the south of Europe exhibits ideal conditions for solar production and the north is particularly attractive for wind (onshore and offshore). Moreover, Europe has mountainous areas with a strong potential for hydropower (e.g. Alpine countries and the Nordics).

40 Using natural resources means ensuring Europe's SoS is less dependent on outside players for combustibles (except for construction materials necessary to build certain assets). As shown in Figure 4 below, increasing the share of renewable energy in Europe's electricity mix over the period 2022-2050 (by 3% per year) will make the most of the continent's many natural resources and ensure greater energy independence.

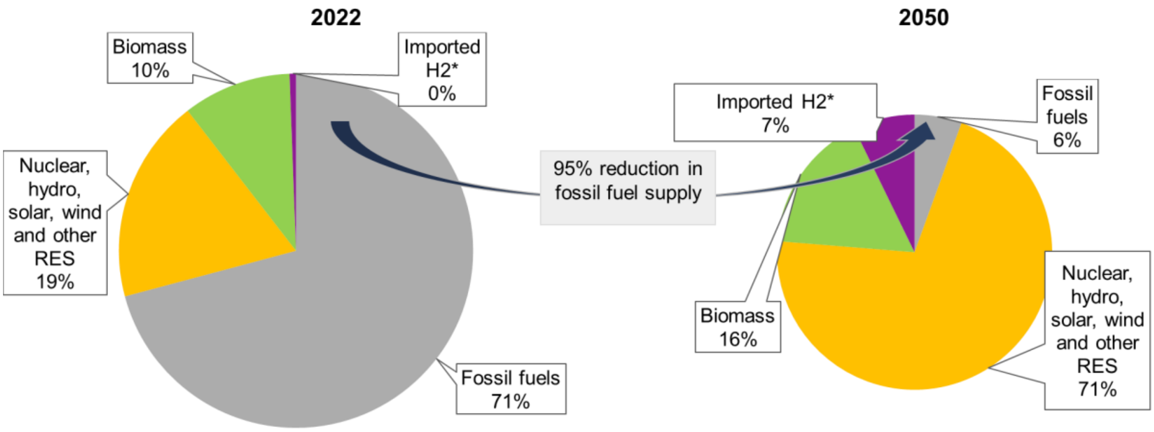
Figure 4: Load and participation of renewable energy in load serving in EU27 – 2022 - 2050



Source: Compass Lexecon analysis and data from Eurostat for year 2022.

41 To leverage this potential, electrification will be essential. As shown in Figure 5 below, renewable energy and low-carbon generation will gradually replace fossil fuels used not only in power generation, but also in transport, industry, heating, etc., to make the most out of Europe's renewable energy potential.

Figure 5: EU27 Primary energy supply mix (%) in 2022 and in 2050 in TYNDP 2024 Distributed Energy scenario

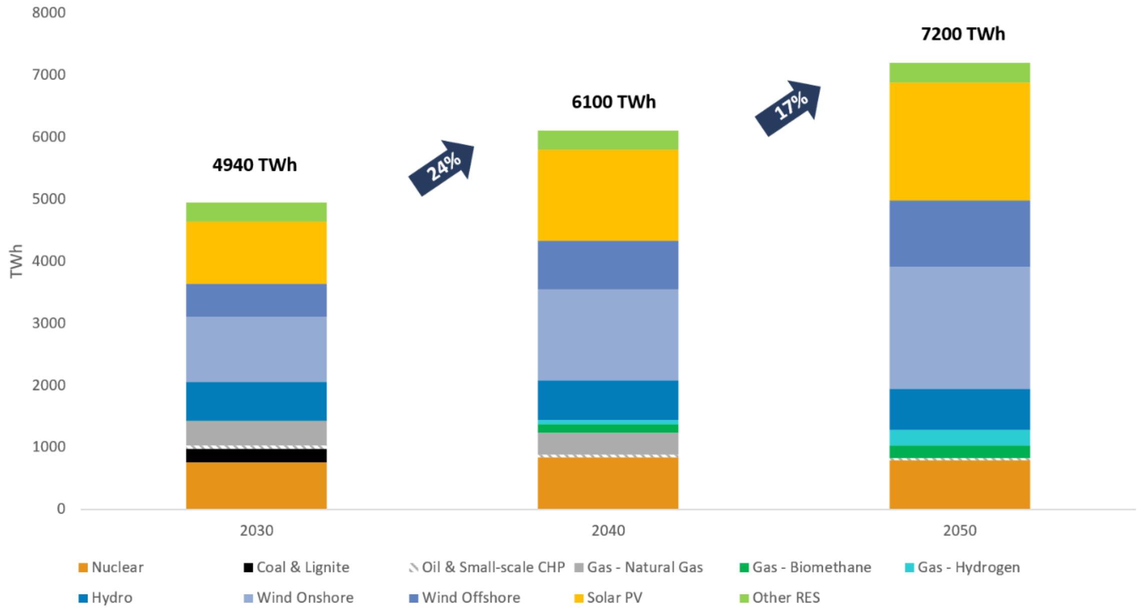


Source: Compass Lexecon analysis based on data from ENTSO-E TYNDP 2024 Distributed energy scenario.
Note: 2022: 16,203 TWh of primary energy supply / 71% from fossil fuels / 60% imported. 2050 (TYNDP 2024 DE): 9,566 TWh of primary energy supply / 6% from fossil fuels / 13% imported. Other RES includes tide, wave, ocean, geothermal energy.

42 In power generation, as visible on Figure 5 above, the share of RES (solar PV, wind onshore, wind offshore, hydro and other renewables such as biomass) in the EU, Switzerland, Norway and Great Britain's domestic generation is expected to increase from 71% in 2030 to 82% in 2050, while electricity generation and demand increases by almost 50% in the meantime (See Figure 6).[13]

[13] Compass Lexecon analysis based on Decarbonisation Speedways RePower EU scenario.

Figure 6: Projected annual electricity generation in the EU and Switzerland, Norway, and Great Britain in 2030, 2040 and 2050 (TWh)



Source: Compass Lexecon analysis based on data from Decarbonisation Speedways, RePower EU scenario

43 Moreover, these sources are complementary, which enhances security of supply as they provide different services to the system. Each technology type presents specific characteristics (e.g. different generation patterns, dispatchability, energy-limits, ramping rate) that allows it to answer to different system needs. For instance, nuclear can offer bulk decarbonised electricity without being reliant upon resource availability. Solar PV production is higher in summer and can be correlated with peak demand due to air conditioning in the southern regions of Europe. Conversely, wind tends to blow more in winter, when demand is higher, especially in Northern Europe. Hydropower, including reservoirs and pumped storage, and green gas plants are a key source of short-term and seasonal flexibility, as well as firm capacity.

Moving from a fossil-fuel-intensive to a raw-material-intensive economy

44 The development of decarbonised generation and clean electrification (heating, transport, and large swathes of industrial consumption) will reduce our dependence on fossil fuels. Energy importation in the EU is expected to decrease from ~60% of its energy supply in 2022, to ~13% in 2050, largely driven by electrification of transport (through EVs) and heating (through heat pumps).[14] It represents approximately 5.4 billion less barrels of oil in 2050 than in 2022.[15]

45 Concerning the primary use of gas, as shown on Figure 7 below, our analysis of Eurelectric's Decarbonisation Speedways scenario highlights that, for the EU, Switzerland, Norway and Great Britain combined, despite increasing electricity consumption, electricity generated from natural gas is reduced from around 400 TWh in 2030, to around 350 TWh[16] in 2040, while electricity demand is expected to rise by 1,160 TWh. In 2050, no more natural gas is used in electricity generation,

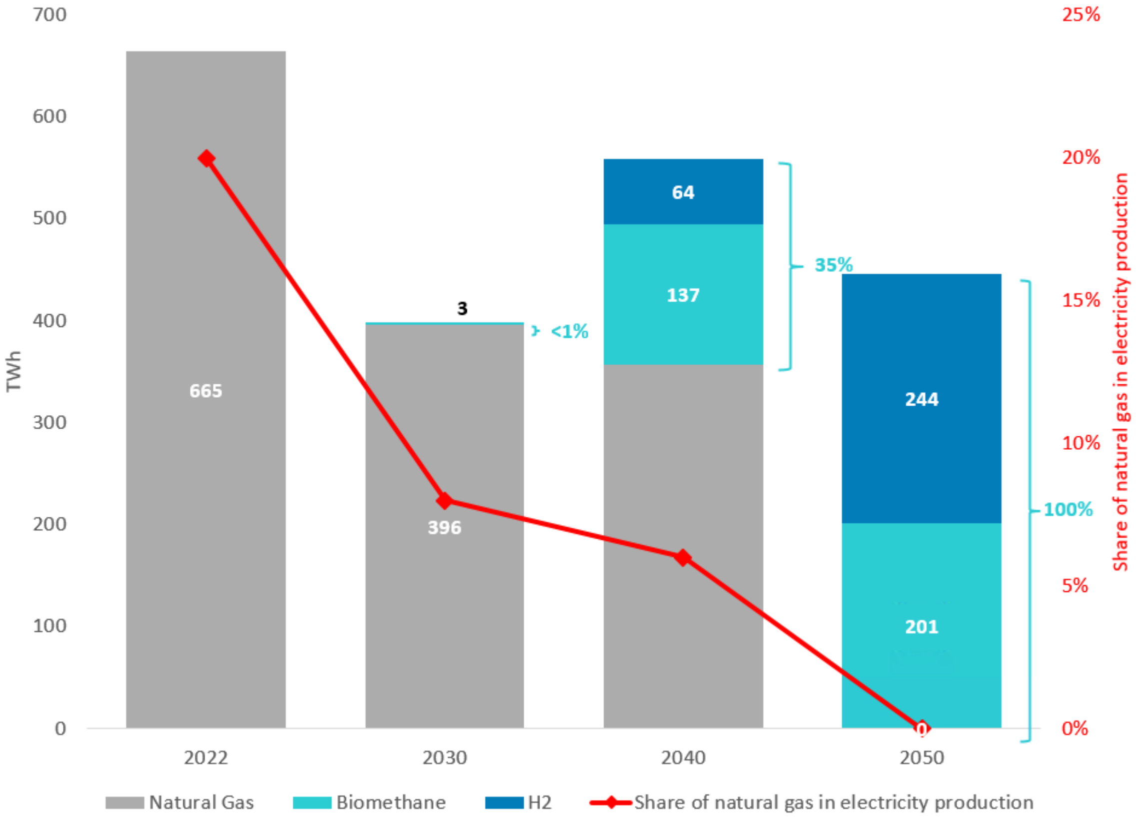
14 TYNDP 2024 Distributed energy scenario. Accessible here. Fossil fuels = menthanes, liquids and solids.

15 1 barrel of oil gives up approximately 1.7 MWh.

16 The decrease in the generation from natural gas between 2040 and 2030 is also progressive because it depends on the growth of H2 and biomethane used for electricity production, which is limited at first, but expected to ramp up strongly after 2040 in these scenarios.

while electricity generated from biomethane triples between 2040 and 2050 and electricity generated from H2 increases by almost 50% over that decade. Electricity generated from green gas represents less than 1% of electricity generated from gas in 2030, increasing to 35% in 2040 and 100% in 2050. This reduced reliance on natural gas is due to the development of renewables and the availability of green gas (biomethane & H2).

Figure 7: Electricity generated from gas – EU and Switzerland, Norway, and GB (TWh)



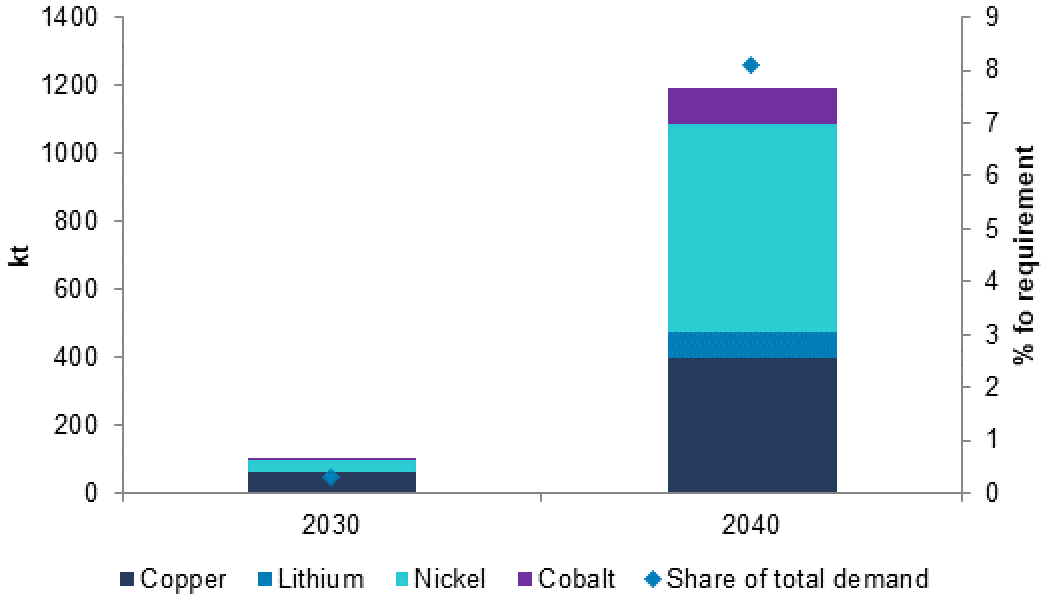
Source: Compass Lexecon analysis based on Decarbonisation Speedways. For 2022 data, Compass Lexecon analysis, based on Eurostat, and official statistical offices of Switzerland and the United Kingdom.

46 To transition from a fossil-fuel-intensive to an electricity-based and decarbonised economy, Europe will need to invest in renewable and clean energy assets, network infrastructure, energy storage, EVs, etc. Access to critical raw materials – essential for some of these assets – will be key to the energy transition.

47 As production and processing are currently concentrated in a few – non-EU – countries (such as China for rare earth, Chile for copper, The Democratic Republic of Congo [DRC] for cobalt), this may result in a new form of dependence. This new dependence is, however, fundamentally different

by nature and can be mitigated. The required quantities are much smaller[17] and are used to build lasting assets, not combusted. Additionally, although processing is currently concentrated today, supply chains are evolving, giving the opportunity for more independence, and developing strategic trade relationships.[18] Finally, these materials can be reused and recycled, further reducing end-use and thus dependence, as illustrated on Figure 8 below. Emerging waste streams from clean energy technologies (e.g. batteries, wind turbines) could significantly reduce primary supply requirements in the future.

Figure 8: Contributions of recycling and reuse of batteries towards reducing primary supply requirement for selected minerals, 2030-2040 (kt)



Source: IEA (2021) The Role of Critical Minerals in Clean Energy Transitions. Note: IEA Sustainable Development Scenario.

48 Finally, it is important to consider supply chain challenges, particularly for production of PV panels, EVs, batteries and wind turbines. On top of the raw materials that are required to build these assets, several challenges can and have already emerged, such as the difficulty to scale up manufacturing capacity, which leads to production bottlenecks. Extensive investments are needed to grow production capacities in line with demand, which requires visibility on demand. Moreover, building up logistics and installation capacities, recruiting qualified engineers and engineering, procurement and construction (EPC) contractors can also be challenging. Offshore wind development is also confronted by the shortage of vessels used for installations. Finally, project developers have to navigate sometimes complex legal and regulatory environments surrounding asset production.

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17 In the last three years, the EU imports of energy products – petroleum oils (petroleum oils from natural gas condensates and petroleum oils obtained from bituminous minerals, crude), natural gas (liquefied and in gaseous state) and solid fuels (coal, lignite, peat and coke) – were between 700-800 million tonnes per year (Eurostat, EU imports of energy products. Accessible here). As a comparison, if the deployment of clean technologies is driven by the cost-competitiveness of technologies – what BNEF calls its Economic Transition Scenario – the world could require 3 billion metric tons of metals across 2024 to 2050. That doubles in a pathway where net-zero emissions are reached by mid-century, to 6 billion tons. BloombergNEF (2024) Mining Industry Needs $2.1 Trillion Dollars in New Investment by 2050 to Meet Net-Zero Demand for Raw Materials, Finds BloombergNEF in New Report. Accessible here.

18 For instance, a major wave of investment in manufacturing clean technologies is underway, with many new factories being built across the world. Global investment in clean technology manufacturing rose by 50% in 2023, reaching USD 235 billion. See IEA (2024) Energy Technology Perspectives 2024. Accessible here.

These supply chain challenges also come with high volatility of component prices, directly impacting financial viability and the participation in auctions for renewable energy projects. However, solutions have already been identified to mitigate these challenges, such as vertical integration, partnerships with suppliers, and improved risk management strategies.[19]

Investing in Europe rather than spending on imports exposed to high volatility

49 The power sector transformation towards low-carbon technologies and flexible assets represents a fundamental change in cost structures. Indeed, we move from technologies with substantial operating expediture (OpEx) associated with, for instance, gas/gas imports towards technologies with substantial capital expenditure (CapEx) and associated multiplier effects such as on jobs and tax revenues to national budgets. In such a context, and with a strong and competitive European power industry, funding electrification and low-carbon energy projects drives new investments that contribute to the development of EU industries, in particular if accompanied with an EU industrial policy to foster domestic production of equipment. These investments also strengthen the region's energy independence, unleashing productive capital in Europe rather than importing expendable fuel.

50 REPowerEU alone requires €300 billion in investments by 2030, in addition to the Fit for 55 investments. Moreover, the European Commission estimates that a total investment of €583.8 billion investment in the electricity grid will be necessary by 2030, [20] while Eurelectric estimates that annual investments of €67 billion are needed by 2050 to deliver a distribution grid that will enable the energy transition.

51 Overall, total energy system costs are expected to fall between 2030 and 2050 according to the European Commission, driven by the decrease in overall energy purchases alongside continuous rise in clean electrification.[21] The Commission consider that, subject to price trajectories, "*the fossil fuel import bill will be 50% to 63% lower than in 2020 depending on scenarios*" by 2040.[22] This number would reach 80% by 2050, representing more than €250 billion saved annually on fossil fuel imports compared to 2020. This is in part due to a large decrease in natural gas imports planned in the EU, dropping from 243 Mtoe natural gas in 2021[23] down to 70-90 Mtoe in 2040, depending on the European Commission scenario.[24]

52 Moreover, as illustrated to the extreme during the energy crisis, commodity prices can be highly volatile. The power sector transformation will reduce the exposure of the EU economy to this volatility and the risks it poses for EU stakeholders.

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19 McKinsey (2023) Renewable-energy development in a net-zero world: Disrupted supply chains. Accessible here. Danx Carousel (2024) Powering up in the industry. Accessible here.

20 European Commission (2022) Implementing the repower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets. Accessible here.

21 European Commission (2024) Primes modelling. Accessible here.

22 European Commission (2024) Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. Impact Assessment report part 3. Page 231. Accessible here.

23 European Council (2024) Where does the EU's gas come from? Accessible here. Imports of natural gas amounted to 290 bcm in 2021 across the different EU trading partners, equivalent to 243 Mtoe.

24 European Commission (2024) Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. Impact Assessment report part 3. Page 29. Accessible here.

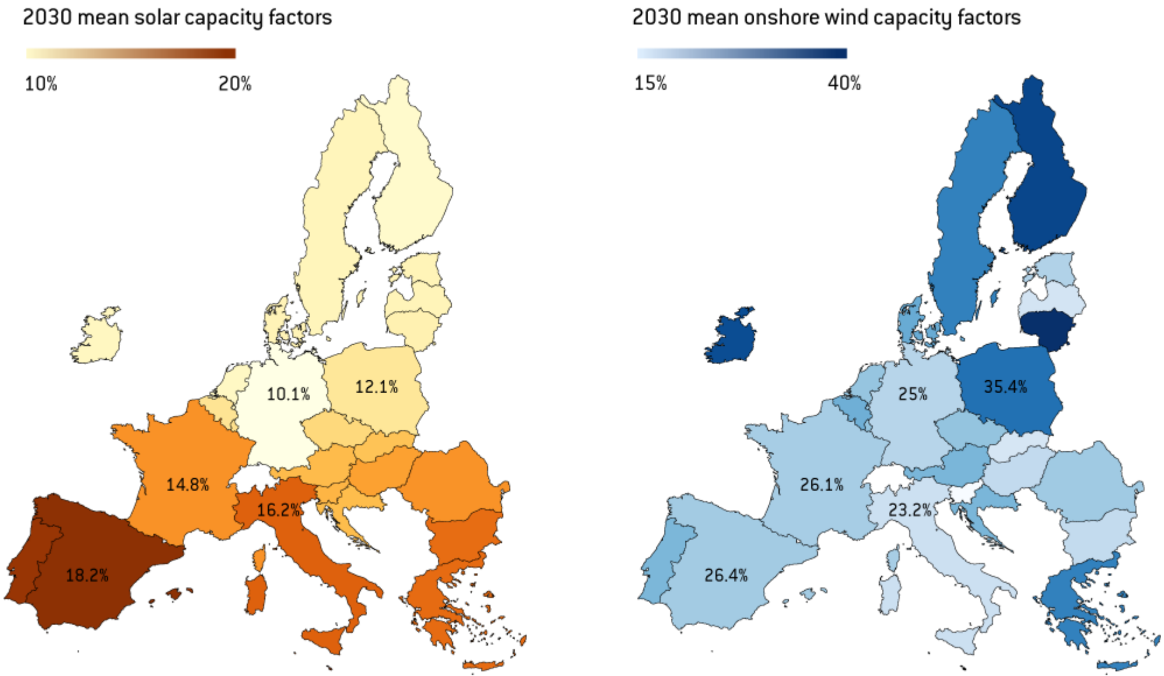
53 These significant and volatile cashflows, currently regularly leaving the EU, can thus be redirected inside the Union in the new electrified system, for more clean energy projects, innovative storage and flexibility solutions and modernising grid infrastructure.

54 The benefits of these investments in the power sector are complemented by their positive multiplier effects. The IEA estimates that in the European Union, clean energy accounted for nearly one-third of GDP growth in 2023.[25] Investments in renewable energy also have positive effects on the labour market.

Diversification and decentralisation

55 Clean electricity can be produced by diverse, centralised, and decentralised assets. Hence, a diversified portfolio, combining centralised and decentralised generation can improve power system resilience to various shocks. As stated above, and as illustrated in Figure 9 below, there is a large diversity of resources in Europe for wind and solar, which are widely distributed, with particularly strong resources in some of the countries at the periphery or Europe.

Figure 9: Solar and wind potential in EU27 in 2030

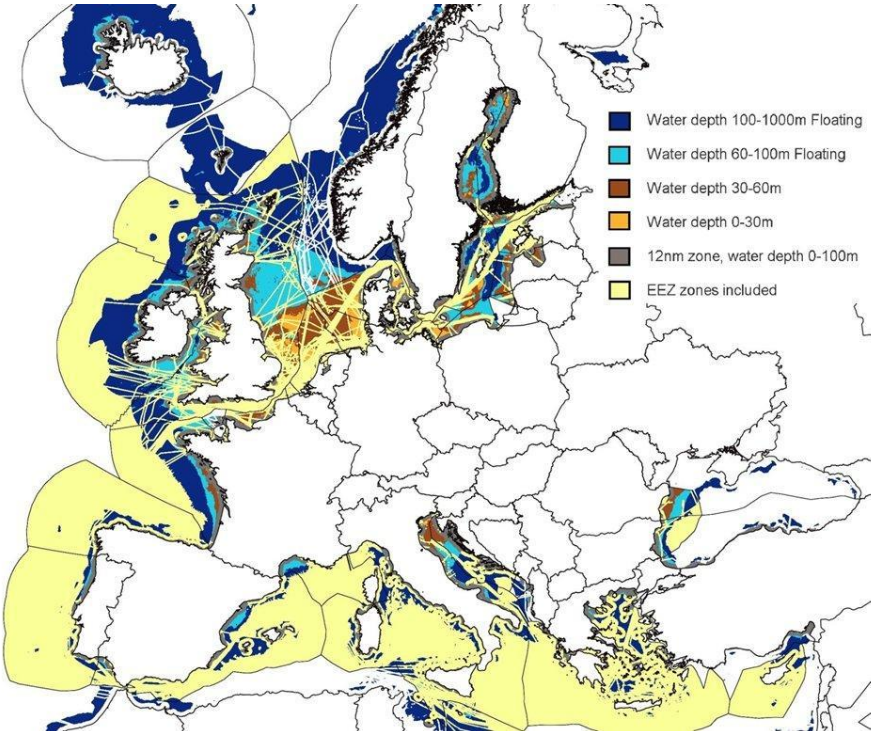


Source: Bruegel based on ENTSO-E's European Resource Adequacy Assessment.
Note: 'Capacity factor' refers to electricity produced at realistic wind or solar conditions, relative to the amount produced if the plants would in each hour have operated at their peak capacity. The figures are based on the assumptions for installed renewable capacities in 2030 reported to ENTSO-E.

56 The European Commission also highlighted the important offshore wind technical potential accessible to EU27 countries. The results shown below in Figure 10 highlight that the North and Baltic seas, seabed topology has allowed and will allow dynamic development of offshore windfarms and front runner hybrid interconnector projects.

[25] IEA (2024) Clean energy is boosting economic growth. Accessible here.

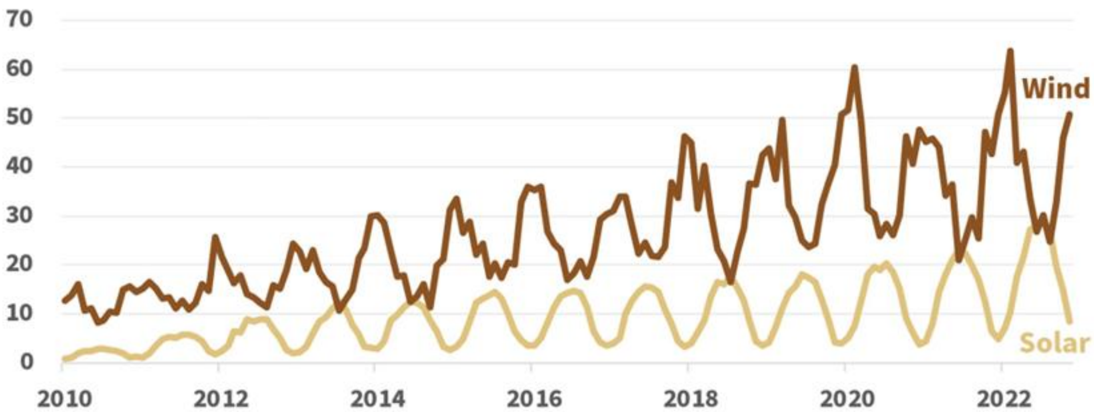
Figure 10: Offshore wind technical potential accessible to EU27 countries



Source: European Commission.

57 Furthermore, wind and solar exhibit temporal complementarity, as illustrated in the Figure 11 below. Wind and solar may be complementary at the seasonal level, with summer having lower wind speeds but large levels of irradiance, and winter exhibiting the opposite.

Figure 11: Wind and solar generation in the EU – 2010-2022 (TWh per month)



Source: IEA, Monthly Electricity Statistics, Data to November 2022.

58 An integrated and reinforced grid is a central element of a SoS strategy here, both to harness the diversity of renewable resources across Europe, and to ensure system resilience by leveraging the diversity of the different sources of clean power production connected to the European network. As highlighted in the Grids for Speed study, "*electricity grid reliability and resilience are critical in an*

increasingly electrified society, where electricity will make up 60% of all energy demand, compared with just 20% today."[26]

59 Centralised and decentralised generation can indeed both contribute to enhance SoS:

- Centralised low-carbon generation contributes to SoS by providing predictable firm supply, as well as in some cases flexible supplies, reducing the need for flexible power and in some cases reducing the need for network extension.
- Decentralised generation, especially variable generation, comes with variability challenges that can be addressed through the deployment of flexible resources and the adaptation of network infrastructure. Greater resilience can be achieved by harnessing the large geographic diversification of renewable resources across Europe, for instance by tapping into the large potential of offshore wind in the north, and of solar in the south of Europe. In addition, decentralised renewable production can also help enhance the diversity and resilience of the power system at a local level, for instance in the case of *Dunkelflaute*.[27]

60 In conclusion, an electricity-based system combining centralised and increasingly decentralised resources enables Member States to build the energy system that makes the most sense for them, while enhanced cross border interconnection capacity and market integration can leverage the benefits of both geographic and technological diversity to enhance security of supplies at the European level.

Enhance competitiveness of energy supplies to secure industrial demand through the power of the internal energy market

61 As pointed out in many studies, such as in the Future of European competitiveness report, energy and climate costs are currently a disadvantage in many European countries for several energy-intensive industries when compared to circumstances for their international competition, leading to a critical impact on competitiveness.[28]

62 Ensuring reliable access to cost-competitive renewable and low-carbon sources of electricity to bring down energy prices while decarbonising the economy is therefore crucial for the competitiveness of energy-intensive industries. A framework fit for scaled investment in cost-efficient renewable and low-carbon supplies and infrastructure is key to support industrials and other sectors of the economy in their transition towards electrification and decarbonisation.[29]

63 A more electrified and efficient system with a high share of renewables can indeed bring important affordability gains for consumers, alongside its environmental and SoS benefits. Certain clean energy technologies are already amongst the most affordable ones (e.g. PV, wind), with the virtuous circle of innovation, accelerated deployment, economies of scale and policy support reducing

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26 Eurelectric (2024) Grids for Speed. Accessible here

27 This refers to situations in which there is a combination of low or no sunlight and low or no wind, leading to reduced energy production from solar PV and wind turbines for consecutive days or even weeks.

28 Compass Lexecon (2024) Energy and climate transition: How to strengthen the EU's competitiveness. Accessible here. The results of the study are valid at an aggregated/average level, compared to other parts of the world, but Europe is not uniform and local specificities, regulatory choices or progress in energy transition may lead to differences across European countries.

29 European Commission (2024) The future of European competitiveness. Accessible here. Compass Lexecon (2024) Energy and climate transition: How to strengthen the EU's competitiveness. Accessible here.

financing costs. Worldwide, in 2023, more than 95% of new utility-scale solar PV installations and new onshore wind capacity had lower generation costs than new coal and natural gas plants.[30]

64 In turn, decarbonising industries with clean electrification contributes to this expanded SoS concept in two ways; as predictable and flexible demand, allowing savings and improving energy efficiency, and as an additional source of reducing fossil fuel consumption.[31]

65 Hence, reducing dependence to fossil fuels by supporting direct and indirect electrification of end-uses limits Europe's exposure to imported fossil fuel supply disruptions and to fossil fuel price volatility (gas prices have surged as much as 15-fold during the energy crisis compared to early 2021[32]), which in turn improves affordability and competitiveness for European citizens and businesses. By improving the resilience of the power system to external shocks, such as gas supply shortages as observed during the energy crisis, we limit the risks for industrial, commercial, and residential consumers.

The strength of the internal market in a context of increased electrification

66 Indeed, the energy crisis in 2022 highlighted the strenght of the European internal market, with electricity exchange between countries, allowing to ensure SoS, and high prices sending key signals to consumers.

67 As such, a more integrated market and regulatory framework at the EU level, combined with the development of cross border transmission capacity, could bring significant benefits in a context of increased electrification and decarbonisation of end-uses. [33]

68 Significant techno-economic benefits can be secured by optimising the design and operation of several national electricity systems jointly, rather than individually. These include decreased reliance on fossil fuels and decreased price volatility, better exploitation of regional resources, sharing of backup capacities reducing the total back-up investment needs and enhanced system resilience. The European Agency for the Cooperation of Energy Regulators (ACER) quantified the benefits of the internal market in times of crisis/supply shocks, showing that price volatility in the EU would have been around seven times as high in 2021 in isolated electricity markets compared to a situation with integrated markets.[34]

69 In particular, Bruegel estimates that an integrated market, with countries cooperating, could reduce the need for dispatchable back-up capacity by 19% in Central Western Europe in 2030 compared to a scenario with countries operating alone. Regional cooperation between countries in northern and central Europe can reduce the need for flexibility investments by up to 20%.[35]

70 There are also several managerial-governance related benefits, including: competition fostering innovation and consumer surplus, trust in institutions, and lower cost of capital.

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30 IEA, Strategies for affordable and fair clean energy transitions. Accessible here.

31 Compass Lexecon (2024) Energy and climate transition: How to strengthen the EU's competitiveness. Accessible here.

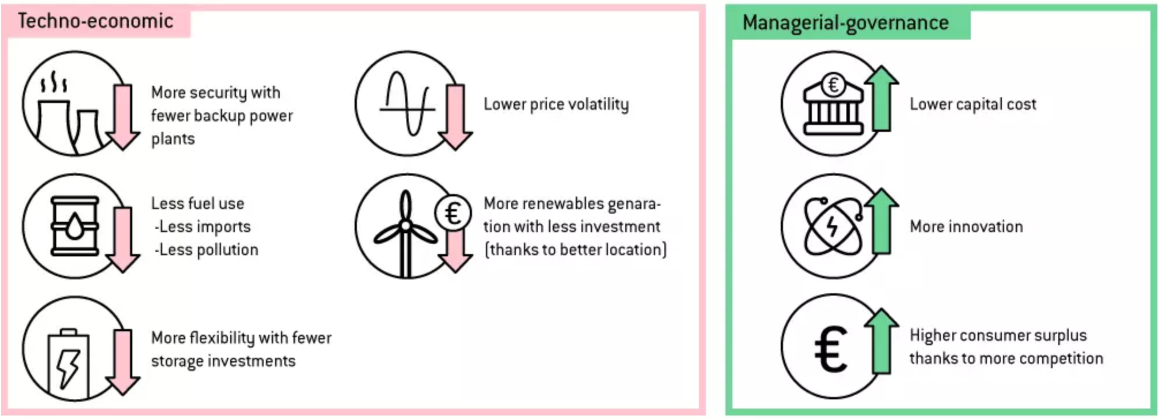
32 IMF (2022) Beating the European energy crisis. Accessible here.

33 Georg Zachmann, Carlos Batlle, Francois Beaude, Christoph Maurer, Monika Morawiecka, Fabien Roques (2024) Unity in power, power in unity: why the EU needs more integrated electricity markets. Accessible here.

34 ACER (2022) ACER's final assessment of the EU wholesale electricity market design. Accessible here.

35 *Ibid*.

Figure 12: Benefits of market integration



Source: Georg Zachmann, Carlos Batlle, Francois Beaude, Christoph Maurer, Monika Morawiecka, Fabien Roques (2024) Unity in power, power in unity: why the EU needs more integrated electricity markets. Accessible here.

5 How? A new approach towards energy security and SoS is needed

71 In this section, we set out the key principles of the new enhanced approaches for energy security and security of supply. We successively:

- Recall the key gaps in the traditional approach to energy security in the EU;
- Outline a new expanded SoS 2.0 typology with its different dimensions;
- Present the key drivers of a secure energy system extrinsic to the power system; and
- Explain our focus, in the rest of this report, on electricity security of supply specifically – that is the drivers that are intrinsic to the power system.

We conclude by laying out the key pillars of an enhanced market design and regulatory framework to ensure clean, affordable, and secure electricity supply.

Traditional approach to energy security

72 So far, the EU framework for energy security has focused essentially on solidarity mechanisms, risk preparedness, and adequacy issues. These principles were enshrined in the EU Energy Security Strategy[36] in 2014, as well as the communication from the European Commission on a Framework Strategy for a Resilient Energy Union in 2015[37] for instance, which covered a range of security dimensions such as:

- Emergency/solidarity mechanisms, coordination of risk assessments
- Strategic infrastructure protection
- Increasing EU energy production and reducing demand
- Diversifying external supplies and related infrastructure
- Climate change policy to establish acceptable supply interruption risk levels

73 Historically, the Ten-Year Network Development Plan (TYNDP) for electricity and gas networks and the power adequacy assessment (through the European Resource Adequacy Assessment [ERAA]) have been the most important inputs of Europe's long-term SoS strategy in the electricity sector. However, the evolution of the energy and electricity systems though calls for a broader approach.

36 European Commission (2014) Communication from the Commission to the European Parliament and the Council European Energy Security Strategy. Accessible here.

37 European Commission (2015) A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. Accessible here.

Security of energy supply 2.0 – the different macro dimensions

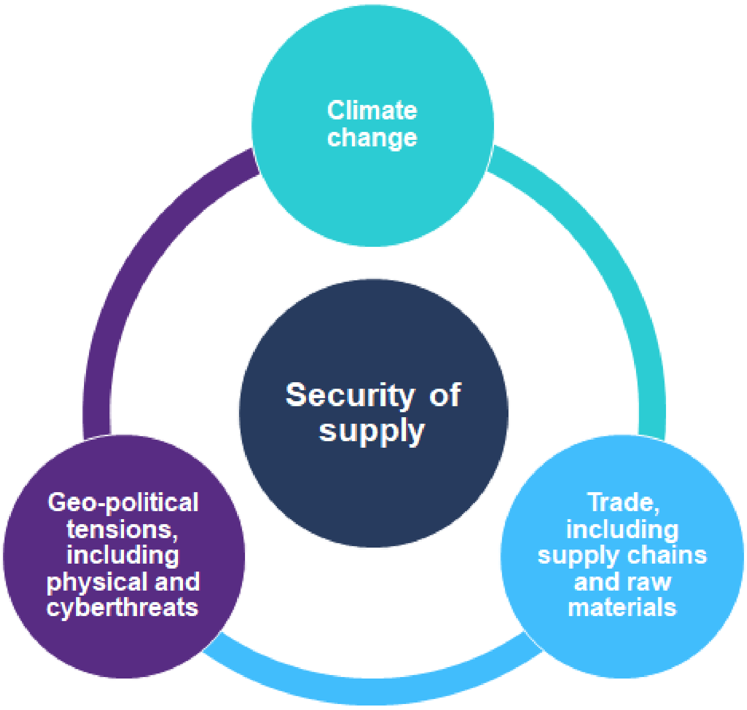
74 The ongoing transformation of the energy system across Europe calls for a holistic approach to security of supply. This holistic approach needs to start with upstream segments of the sector covering supply chain security, and go all the way to downstream end-uses. Additional to the traditional approach, techno-economic considerations need to be complemented by security analyses, prevention, and mitigation measures where necessary.

75 There is an imperative need to take a broad perspective in building a more resilient and secure energy system for the future. This broader perspective has two layers: the “macro” layer which has to do with ‘energy security’ and is described in this section and the “micro” one which is more focused on the power sector and how the sector is doing its part in securing the energy system. We present the “micro” layer in detail in sections 6 and 6.1 to 6.3 of this report.

76 Several macro factors affect SoS in its broad sense. These factors are exogenous to the power sector, as it lacks the ability to control them:

- **Geopolitical tensions**, affecting both physical and cybersecurity – also referred to as hybrid threats;
- **Climate change** amplifies extreme weather event frequency and severity, affecting power infrastructure resilience;
- **Tense trade relationships** with effects on the power sector’s supply chains of equipment and raw materials.

Figure 13: The different macro dimensions of the broader concept of SoS



Source: Compass Lexecon

77 **Geopolitical tensions** are posing direct physical or cyber threats – so-called hybrid threats – to the energy system and include conventional warfare, sabotage and cyberattacks. The incidence rate of conventional warfare seems to be increasing, as best exemplified in Europe by Russia’s war

in Ukraine and their attacks on energy infrastructure or developments in the Middle East. Sabotage, such as the Nord Stream pipeline, the Houthis' attacks on shipping in the Red Sea, and cyberattacks directed at energy infrastructure threaten energy system security and increase the risk of price volatility. From 2015 to 2022, EnergiCERT (the energy sector cybersecurity centre) counted 48 publicly known successful attacks against European energy and supply companies, 31 ransomware attacks, and 15 attacks affecting the operational technology of networks (20 of these took place in 2022 alone).[38]

78 **Climate change** is already happening and also poses threats to the energy system. Extreme heat, fires, flooding, drought and severe storms – summarised as extreme weather events – occur with increased frequency and severity, with consequences for physical infrastructure. With the Paris Agreement target of 1.5℃ becoming less and less attainable, considerations for a secure energy system will need to account for these risks.

79 **Global trade relationships and procurement** are also increasingly under strain. This concerns both access to raw materials – which are lacking in Europe – and the increasingly long and complex supply chains for net-zero technologies and the risk of bottlenecks. Protectionist trade measures and economic sanctions can impact procurement necessary to safeguard energy security, which is also linked to geopolitical tensions.

80 As the world accelerates its transition away from fossil fuels, the demand for raw and processed materials, like lithium, copper, aluminium, wafers, and permanent magnets to make the energy transition a reality is exponentially increasing. The European Commission estimates that the EU demand for rare earth metals is expected to increase six-fold by 2030 and seven-fold by 2050. For lithium, EU demand is expected to increase 12-fold by 2030 and 21-fold by 2050.

81 At the same time, Europe is lagging behind regarding its access to critical raw materials because domestic extraction and production of minerals and materials is limited, due to its geological structure, a lack of recent geological research and local opposition. Consequently, European industries are presently highly reliant on international markets to access a wide range of raw and processed materials.

82 Apart from being dependent on international markets, the EU also faces a problem of overdependence on some suppliers. The European Commission's assessment shows that China provides 100% of the EU's supply in heavy rare earth elements (REE), Turkey provides 99% of its supply in boron, and South Africa provides 71% of its supply in platinum, and an even higher share of the platinum group metals iridium, rhodium and ruthenium.

Security of energy supply 2.0 – key policy recommendations on macro dimensions

83 Eurelectric has published several reports over the past years covering policy recommendations related to these different macro factors affecting the expanded concept of SoS in detail. The study The Coming Storm[39] focuses on the impact of climate change, while Wired for Tomorrow and Grids

38 Eurelectric (2024) A snapshot of Cybersecurity in the EU. Accessible here.

39 Eurelectric (2022) The Coming Storm. Accessible here.

for Speed[40] highlight geopolitical and cybersecurity challenges for grid assets. Eurelectric has also developed publications on the topic of procurement, and in particular on raw materials.[41]

Hybrid threats

Cyberattacks

84 First, an extensive amount of legislation and regulation has been introduced in the past years to enhance cybersecurity in the EU, such as NIS2[42] (the EU directive setting up an EU-wide legislation on cybersecurity) or the Network Code on Cybersecurity (NCCS).[43] The full implementation of this new regulatory framework will require time and money for the electricity sector,[44] but its implementation will enable enhanced coordination, mitigation of risks, and quick responses to incidents.[45]

85 To ensure resilience and SoS against **geopolitical threats**, modernising electricity grids, both physically and digitally, especially at the distribution level, is essential to mitigate the effectiveness of hybrid attacks and cultivate a strong ex-ante and ex-post cooperation with the relevant national and EU institutions. Joint assessments of the threat situations must be carried out. Preventive measures need to be put in place to increase the resilience of the system by making attacks more difficult or by managing the impacts through e.g. redundancies. Reactive protocols that are aimed at containing the effects of an attack and returning the assets to a normal state through practiced processes and structures must also be enacted by organisations.

86 Furthermore, recruiting and training a skilled workforce and facilitating essential investments is required to respond to increasingly sophisticated cyber threats. The increased costs arising from cybersecurity measures should be acknowledged in regulatory remuneration frameworks.

87 While companies in the power sector cannot fully prevent the occurrence of attacks on their infrastructure, prevention needs to be enhanced in cooperation with the relevant authorities (internal affairs ministries, security agencies, etc.), so that companies can minimise risks, and react more effectively in case of attacks. A mapping of the different EU enforcement mechanisms and agencies should be conducted to identify the most efficient cooperation framework.

Physical attacks

88 As observed since the beginning of the Ukraine war, energy assets are particularly targeted by physical attacks in war times. Russia has attacked grid infrastructure, conventional generation assets, and renewable generation assets since the war's onset. Energy assets can be attacked outside of Ukraine as well, for instance with the severing of Baltic Sea cables identified as likely

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40 Eurelectric (2023) Wired for Tomorrow. Accessible here. Eurelectric (2024) Grids for Speed. Accessible here.

41 Eurelectric (2023) Escaping dependencies: Europe moves to find balance in the global energy picture. Accessible here.

42 Directive (EU) 2022/2555 of the European Parliament and of the Council of 14 December 2022 on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016/1148 (NIS 2 Directive). Accessible here.

43 Commission Delegated Regulation (EU) 2024/1366 of 11 March 2024 supplementing Regulation (EU) 2019/943 of the European Parliament and of the Council by establishing a network code on sector-specific rules for cybersecurity aspects of cross-border electricity flows. Accessible here.

44 Eurelectric (2024) A snapshot of Cybersecurity in the EU. Accessible here.

45 Eurelectric (2023) Wired for Tomorrow. Accessible here. Eurelectric (2024) Grids for Speed. Accessible here.

sabotage by the German Ministry of Defence. Sweden and Finland also pointed out having been on high alert in relation to attempted sabotage attacks.[46]

89 Lessons from the DTEK example in Ukaine (see Annex A) include the following ideas to ensure resilience of energy assets against physical attacks:

- Increased interconnection and synchronisation with neighbouring countries;
- Increased decentralisation of assets to limit the impact of attacks;
- Close cooperation between the energy sector and other sectors, such as defence, telecommunication and technology; and
- Implementation of the Critical Entities Resilience Directive (CER)

These ideas still need to be further investigated for the rest of Europe.

Climate change

90 On **climate change**, an essential starting point is to take a holistic system approach to the energy system to ensure stronger coordination and continuous communication between all power system stakeholders. In particular, coordination of services between network operators is of utmost importance. Furthermore, the European Commission should involve all energy sector stakeholders in climate adaptation, including EU DSO Entity and the European Network of Transmission System Operators for Electricity (ENTSO-E). [47]

91 System operators and generators should implement key actions to increase their resilience, such as: [48]

- Establishing emergency management teams
- Adopting a multimedia approach to provide information to the public
- Considering redundancy in the design, operation, and maintenance of the power system
- Relying on cost-benefit analysis and impact assessments

92 More specifically, thorough regulation for system operators, taxonomy screening criteria for private investments and resilience funding should be strengthened to encourage power system climate adaptation.[49] Regulators and policymakers should promote a Resilience Incentive Mechanism to encourage utilities to pursue adaptation measures, such as physical system hardening, improvements in system operation, recovery planning, capacity building, and smart grid technologies like smart meters, remote control, and advanced automation. Moreover, integrating national climate adaptation plans and company investment plans will further enhance resilience.

93 Moreover, adaptation should be considered in partnership with mitigation, as a failure to sufficiently mitigate climate change could lead to unbearable adaptation costs that would threaten the European economy.

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46 Financial Times (2024) Severing of Baltic Sea cables likely to be sabotage, Germany says. Accessible here.
47 Eurelectric (2022) The Coming Storm. Accessible here.
48 Eurelectric (2022) The Coming Storm. Accessible here.
49 Eurelectric (2022) The Coming Storm. Accessible here.

Raw materials and critical supply chains

94 Finally, turning to **global trade, procurement and the resilience of supply chains**, there is a need to support smart strategic autonomy in Europe and strike the right balance with robust trade policy to secure the critical supply chains needed for energy security. Smart strategic autonomy can be defined as a focus on measures that balance our inability to be 100% self-reliant while also de-risking our trade relations to ensure our critical systems are shock resistant and can continue to run our society in the case of a crisis To that aim, non-price criteria, e.g. looking at local content, or sustainably-sources content, could be integrated in the procurement process.

95 Moreover, the surest way to reduce dependencies and supply chain risks, beyond diversification, is to reduce the very need for lithium, cobalt, and nickel, for which innovation and recycling are paramount.[50]

[50] Eurelectric (2023) Raw materials: future-proofing supply chains for Europe's energy transition. Accessible here.

6 Security of supply in the electricity sector

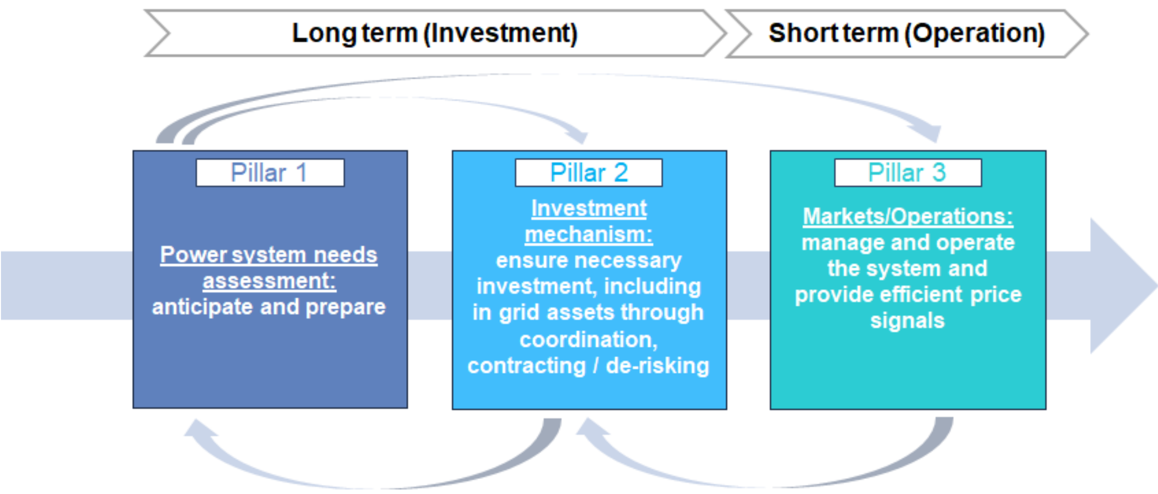
96 To complement this existing work, we **focus, in this report, on electricity security of supply specifically, that is, the drivers that are intrinsic to the power system**. In this section, we therefore set out the key principles for SoS in the electricity sector given a new approach to energy security. We successively:

- Explain our focus in the rest of this report on electricity SoS specifically – that is the drivers that are intrinsic to the power system; and
- Conclude by laying out the key pillars of an enhanced market design and regulatory framework to ensure clean, affordable and secure electricity supply.

The three key pillars

97 To deliver a decarbonised, affordable, and secure electricity system, we identified several key principles to enhance the current market and regulatory framework and policy gaps across different pillars. We refer to these in the rest of the report as the three key pillars of policy recommendations.

Figure 14: The three key pillars to ensure security of supply in the electricity sector



Source: Compass Lexecon

98 **A power system needs assessment** is required to identify the needs across different time horizons and eventually the resources needed to ensure security of electricity supply. The assessment of the different types of system needs should be carried out well in advance. This essential prospective assessment is necessary to inform policies, regulatory design, and investment decisions.

99 **An investment mechanism** is necessary to ensure that the required investments will materialize in a timely way to ensure SoS for EU consumers. These investments are driven by price signals spurred by market mechanisms as well as complementary investment mechanisms. While investment signals are necessary to meet system needs, coordination across the value chain and energy-vectors is necessary to ensure that the required infrastructure and capacities are delivered on time. Simple contracting mechanisms may be needed in some circumstances to complement the market framework to de-risk investments and/or ensure that the different system needs are adequately addressed.

100 **A sound markets and operations framework** is needed to ensure the efficient operations of the system, given the capacities and infrastructure already installed at a given time, to meet SoS requirements. This entails ensuring that the market arrangements and regulatory framework ensure effective operational signals in real time and allows consumers to contribute to SoS by adjusting their energy usage in response to market conditions. These signals in turn feed back into investment incentives, provided they can be reflected in longer-term markets.

101 In the following three sections, we focus on each pillar of this expanded SoS concept to identify gaps in the current market design and regulatory framework and develop policy recommendations.

102 In compliance with the European framework, our recommendations preserve "Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply, without prejudice to Article 192(2)(c)."[51]

103 Our recommendations can be summarised as follows in three key pillars which are further detailed in the next sections of this report:

System needs assessment Anticipate & prepare	▪ A more integrated approach should **streamline, consolidate and ensure consistency across the different planning tools already included in EU and national laws**. It should **consider the entire value chain and possibly all energy vectors** (electricity, gases, heat, transport...) —upstream, downstream, and end-use sectors—to better identify system needs and options for decarbonisation and electrification. ▪ This includes developing **new methodologies** for improved forecasting and system analysis. ▪ The **institutional and governance arrangements** that support infrastructure planning and end use sectors will also need to evolve to support an efficient market functioning.
Investment mechanism Ensure investment	▪ A **more consistent market-compatible investment framework addressing all system needs** should be implemented. This includes, where deemed necessary, **contracting mechanism for firm and flexible technologies** to secure and coordinate timely investments across the value chain (production, networks, end-uses etc.) and ensure electricity supply, in particular through **capacity mechanisms**. ▪ **Network and other related infrastructure challenges** associated with the electrification and the development of renewables should be properly recognised and **appropriate solutions should be implemented for these challenges to be met**, and in particular to ensure a **coordinated and timely deployment of different infrastructure along the value chain**.
Markets/ operations Manage and operate the system with efficient price signals	▪ **Market signals** could be improved to better reflect physical system needs, whilst **enhanced forward markets** should offer better hedging opportunities for firm and flexible assets. ▪ **Greater consumer participation to provide demand-side response** should be encouraged. To do so, the focus should be on the proper implementation of the recent reforms of the Electricity Market Design.

Source: Compass Lexecon

[51] Article 194.2 of the Treaty on the Functioning of the European Union. Accessible here.

6.1. Pillar 1: Improving the framework to assess power system needs

104 A long-term assessment of the different system needs in line with the EU policy targets to decarbonise and deploy renewables is important to anticipate possible needs and provide relevant information to market participants and other relevant stakeholders, including system operators.

105 However, the current framework at the European and national levels to assess system needs is too narrow and solely focused on adequacy and network development. For instance, the integration of flexibility needs in the planning exercise still lacks harmonised methodologies, and the time horizon of these exercises if often too short-term and disconnected from the 2040 and 2050 policy targets, keeping in mind the large uncertainties of these horizons that require a simple approach.

106 The first pillar of gaps identified and policy recommendations in this section therefore focuses on the need for a more integrated assessment framework of the system needs that considers the entire value chain and possibly all energy vectors (electricity, gases, heat, etc.) — upstream, downstream, and end-use sectors — to better identify system needs and options for decarbonisation and electrification. This new approach includes developing new methodologies for improved forecasting and system analysis.

107 To do so, the institutional and governance arrangements that support infrastructure planning and end-use sectors will also need to evolve to support efficient market function. Indeed, the system needs assessment process currently lacks the appropriate governance arrangement fit for the task, as ensuring a broader, cross-sector planning exercise requires enhanced, coordinated governance.

108 Finally, following the new Commission's objective of simplification, any reform should review existing tools partially covering this approach (TYNDP, Commission Impact Assessments, National long-term (LT) strategies, etc.). In addition, they should aim to gain in efficiency by complementing and streamlining the system needs assessment process and suppress unnecessary tools.

109 We therefore successively outline:

- The key gaps of the current system needs assessment framework; and
- Policy recommendations for the system needs assessment framework.

Key gaps of the current system needs assessment framework

The scope of the current system needs assessment framework is too narrow and short-term, and the methodologies used do not adequately cover resilience issues

110 The current EU framework for long-term studies[52] is already well developed, but its scope and implementation maturity are insufficient to effectively inform policy makers, investors, and other stakeholders and to coordinate the large-scale investments required to reach European Green Deal and REPowerEU objectives, the transition to a climate-neutral economy by 2050 and increase Europe's energy independence from unreliable suppliers and volatile fossil fuels. While the current

[52] Such as the Ten-Year Network Development Plan (TYNDP) of ENTSOE and ENTSOG and the European Resource Adequacy Assessment (ERAA) of ENTSOE.

framework has started to evolve to address these new challenges, gaps remain in the system needs framework.

111 The first step for implementing a new framework is to assess the existing framework to identify the gaps, with policy evaluation exercises and tools. More specifically, each piece of the existing framework should be assessed to evaluate if it contributes to the objectives set in the current EU context, e.g. as part of REPowerEU, or of Ursula von der Leyen's political guidelines for the European Commission. Based on this evaluation, the new system needs assessment framework can be developed, complemented and implemented.

112 Currently, the key EU long-term studies focus primarily on electricity and gas network expansion (TYNDP) and power adequacy (ERAA). The TYNDP has started to develop a 'system need' perspective, with flexibility assets (storage and CO2-free peaking units) as an additional investment option for the 2040 horizon to address network-related issues.[53]

113 The focus of these exercises remains narrow, covering only partially different system needs, such as flexibility (long-term and short-term), or technologies that can provide these services, and they lack coordination with each other, and other sectors. Beyond traditional frequency and voltage ancillary services, inertia for example is also key to ensure the dynamic stability of the system for secure system operation, and thereby, SoS. Anticipating and ensuring the dynamic stability of a power system implies assessing and securing inertia needs, especially in a European power system with a declining number of generation facilities providing rotational inertia. In addition, the time horizon of ten years for some of the exercises mentioned is too short for the path to net-zero.

114 As identified by ACER,[54] the current metrics are designed to quantify the need for firm capacity, but not for flexible capacity. Some countries have already developed assessment methodologies while others are starting to acknowledge the increasing importance for assessment. Still, there is a lack of maturity and harmonisation for these studies. However, the regulatory framework which will bring harmonisation within Europe is moving forward, with the recent publication of ENTSO-E and EU DSO Entity public consultation on flexibility needs assessment methodology, implementing Article 19e of the Electricity Market Design Regulation (EMDR [Regulation 2024/1747]).[55] The methodology proposed by the two actors aims at:

- Considering appropriate reference conditions to account for planned investments in grid/flexibility, cost-efficient contributions of existing and planned flexibility resources, and different assumptions in respect to electricity market prices, generation, and demand;
- Providing flexibility needs through capability types, i.e. actionable metrics; and
- Providing guiding criteria to best interpret flexibility needs and orient policy makers.

115 Furthermore, long-term flexibility requires a large focus to ensure sufficient capacity is brought online. Harmonising the planning framework is necessary, while allowing each country to leverage its own resources, with Europe as a whole benefiting from cross-border complementarity.

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53 ENTSOE (2023) TYNDP 2022 - Opportunities for a more efficient European power system in 2030 and 2040. Accessible here.

54 ACER (2024) Flexibility needs assessment methodology. ESC workshop.

55 ENTSO-E (2024) Public consultation on flexibility needs assessment methodology. Accessible here. ENTSOE (2024) Explanatory document for the public consultation. Accessible here.
Article 19e of the EMDR requires the development of a methodology for the analysis by transmission system operators and distribution system operators of the flexibility needs.

116 In addition, new provisions have been developed in recent months, such as the EU Hydrogen and Gas Decarbonisation Package[56] or the EED.[57] The implementation of these new regulations and framework should be done in a consolidated and coordinated fashion.

117 The ongoing transformation of the energy systems across Europe calls for a holistic system needs assessment framework. The current scope does not sufficiently capture the relevant dimensions to ensure SoS. Several dimensions are lacking in the system needs assessment framework, such as:

- The sustainable access to raw materials to deliver the required energy sector transformations;
- The capability of the supply chains;
- The inclusion of disruptive events linked to climate change, cyberattacks, etc. in the assessment as business-as-usual rather than extreme scenarios;
- The need for flexibility alongside adequacy, which is provided in the electricity market design reform, but needs to be fully integrated in a holistic system needs assessment and account for all technologies capable of delivering flexibility; and/or
- The coordination between sectors and the need to better bring together the different exercises to better account for their interactions.

118 Today's mineral supply and investment plans fall short of what is needed to transform the energy sector, raising the risk of a delayed or more expensive energy transition. Securing sustainable access to raw materials is therefore a relevant dimension of security of energy supply, which should be incorporated in the system needs assessment framework.

119 Beyond raw materials, SoS also relies on the capability of supply chains to scale to the extent required by the energy transition, which is currently a rising concern in the EU. For instance, concerns have been raised by the European Commission regarding the resilience of the EU wind manufacturing industry's supply chains in the European Wind Power Action Plan.[58] Moreover, Member States may heavily rely on foreign countries for key goods. This is the case for solar panels for example, with China and Asia Pacific countries holding close to the totality of the manufacturing capacity for wafers, cells, and modules.[59]

120 The system needs assessment should also account for disruptive events, for instance caused by climate change or cyberattacks. As global average temperatures increase[60], the frequency and duration of extreme weather events are increasing, further stressing the electricity system.[61] This is not expected to stop. What was previously considered as an acute phenomenon with low possibility of occurring is becoming a chronic one that is fundamentally affecting supply and demand patterns. The current assessment frameworks consider these events as extremes/stress cases and not as business-as-usual. As a result, the frameworks do not assess the necessary climate adaptation and resilience investments in addition to climate change mitigation.

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56 European Commission (2024) EU Hydrogen and Gas Decarbonisation Package. Accessible here.
57 European Commission (2023) Energy Efficiency Directive. Accessible here.
58 European Commission (2023) European Wind Power Action Plan. Accessible here.
59 IEA (2023) Energy Technology Perspectives 2023. Accessible here.
60 Following the Paris Agreement, the goal is to limit the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels.
61 Eurelectric (2022) The Coming Storm. Accessible here.

121 Regarding cybersecurity, electricity grids are also increasingly exposed to cyberattacks, threatening SoS.[62] While the European Commission published the NCCS in March 2024,[63] it still needs to be implemented. Moreover, cybersecurity risks, such as a major cybersecurity breach, are not considered in the system needs assessment framework.

The current governance and coordination arrangements are not adapted for coherent multi-dimensional system needs assessment

122 In addition to widening the scope of the system needs assessment, the current framework also faces governance and coordination issues. First, energy system needs are currently estimated through a number of separate studies, lacking harmonisation. As mentioned above, several distinct studies perform adequacy assessments, such as the ERAA, the TYNDP, and the national risk preparedness plans. Despite progress in terms of aligning gas and electricity TYNDPs, these studies lack in consistency, for instance by using different sets of underlying assumptions and diverging between European and national levels.

123 Furthermore, while the assessment of flexibility needs forms part of the 2024 electricity market design reform, a harmonised framework for assessing flexibility needs has not yet been developed. The provisions included in the electricity market reform stipulate that:[64]

- ENTSO-E and EU DSO Entity shall develop a methodology for the analysis by transmission system operators (TSOs) and DSOs of the flexibility needs, including guiding criteria on how to assess the capability of the different sources of flexibility to cover the needs;
- National regulatory authorities (NRAs) shall estimate flexibility needs for a period of at least 5 to 10 years at national level, every two years;
- ACER shall issue a report analysing the national flexibility needs estimations and provide recommendations on issues of cross-border relevance; and
- Member States shall establish a single indicative target at national level for non-fossil flexibility allowing for different types or resources, with a focus on the contributions by demand response and energy storage.

124 Currently, studies on SoS still focus on adequacy and expansion of the electricity network, with no or little focus on flexible capacity contributions to SoS. Existing studies of flexibility needs at a European level are also limited, as they only consider flexibility needs narrowly at an hourly, weekly, or seasonal granularity. While the provisions in the latest market reform are a step in the right direction to develop a prospective assessment of flexibility needs, it does not provide for an EU-wide flexibility needs' assessment integrated in other system needs' assessments. Moreover, the precise parameters to assess flexibility needs across Member States in a harmonised way is yet to emerge.

125 Finally, the studies often lack a comprehensive vision from a full energy system perspective, especially the end-uses. Given the cross-sector interdependencies, with electrification and gas network transformation, coordination is key beyond electricity and gas TSOs – to include H2, end-uses and DSOs. This dimension has already been identified to some extent, with ENTSO-E and

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62 Energi CERT (2022) Cyberattacks against European energy & utility companies. Accessible here.

63 European Commission (2024) Commission Delegated Regulation (EU) 2024/1366. Accessible here.

64 European Union (2024) Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943 as regards improving the Union's electricity market design. Accessible here.

ENTSO-G (-gas) recently launching a joint initiative for multi-sectoral Planning Support, but this is limited to the gas and electricity sectors, and with a planned implementation only in 2028.[65] This framework needs to develop earlier, given the urgency of efforts required to meet policy targets, and be accompanied by a robust governance framework. For TSO-DSO cooperation, the Distribution Network Development Plans (DNDPs), which are strategic documents mandated by the EU Directive 2019/944, will need to be further integrated into the overall system needs assessment framework.

Policy recommendations for the system needs assessment framework

126 The current market design needs a reframed and broadened concept of SoS to include a number of new dimensions intrinsic to the sector such as firm capacity and services, flexible capacity and services, transmission and distribution grids but also new exogenous factors such as raw material, supply chain resilience, impact of climate change on supply and demand patterns and also broader hybrid threats.

127 To do so, a holistic and integrated system needs assessment framework is required, which takes a broader, longer-term, and cross-sectoral perspective and aims towards a resilient, shockproof energy system. Its governance should ensure enhanced coordination across Member States and interested parties, through a clear coordinator mandate given to the Commission and ACER, and a working coordination group amongst Member States, involving key EU stakeholders.

Policy recommendations

128 **Recommendation 1: Broaden and consolidate system needs assessments to analyse the new challenges the system is facing (flexibility, inertia, resilience, cross-sector interactions etc.) with a longer timeframe and to ensure consistency across studies and sectors thanks to an improved governance framework.**

129 **Scope**: Building upon the EU and regional system needs assessment framework, all system needs should be covered in a consistent way, in particular focusing on adequacy, the different types of flexibility and grids. It should be cross-sectoral (e.g. taking into account natural gas, electricity, hydrogen and heating systems) and should consider the need for resilience by looking at extreme events (e.g. climate, physical and cyberattacks, etc.). It should also account for access conditions to raw materials and supply chains and their potential disturbances.

130 **Timeframe**: System needs should be assessed over the long-term in line with decarbonisation policy targets, with common timeframes going beyond 10 years, such as 2040 or 2050.

131 **Geographical scope**: The EU power system is strongly interconnected with other non-EU countries, including within the same synchronous areas.[66] The system needs assessment should account for this physical reality and therefore cover, as much as possible, non-EU countries such as the UK, Norway, Switzerland and Western Balkan countries.

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65 ENTSOE (2020) ENTSOE Roadmap for a multi-sectorial Planning Support. Accessible here.

66 For instance, due to the central geographical position in Europe, Switzerland's role as an electricity hub for the synchronous grid of continental Europe, but also in view of the crucial role for trans-European gas and (future) hydrogen flows, EU-Swiss energy security cooperation is crucial for ensuring European security of supply. Integration of the Balkan region is also key for wider security of supply in Europe, as illustrated by the recent voltage collapse and total black out in the south-eastern part of the continental Europe power system on 21 june 2024. See ENTSOE (2024) Grid incident in south-eastern part of the Continental Europe power system – Update. Available here.

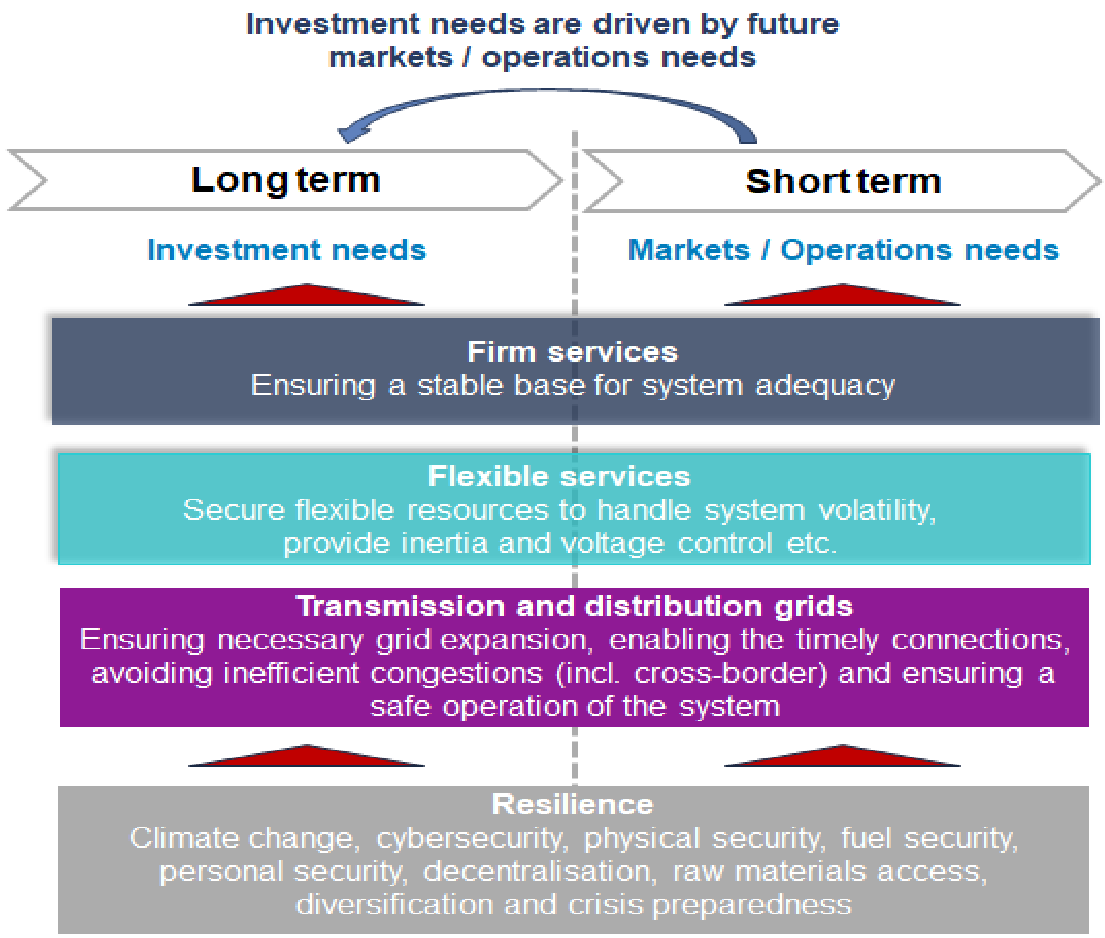
132 **Governance**: Stronger cross-sector coordination should be implemented to ensure consistency across these sectors and along the value chain. The European commission and/or ACER should make sure sufficient coordination is in place when reviewing system needs assessment studies. A joint and enhanced electricity and gas coordination group with a clear mandate and responsibilities that includes stakeholders' representatives, would support efficient coordination between these plans and policies with adequate stakeholder engagement.

On the scope:

133 The system needs assessment framework requires a widened scope, both cross-sector and across timeframes, but also approach, considering resilience, flexibility needs, coordination between TSOs and DSOs, other critical infrastructures, generation, and flexible resources – both across the long-term and short-term timeframes.

134 The broadened scope of the system needs assessment should be integrated with the existing studies, to ensure a coherent assessment framework. Currently, the key EU long-term system needs assessment studies are spread across electricity and gas network expansion (TYNDP) studies, and power adequacy (ERAA). At the national level, EU Member States also develop national energy and climate plans (NECPs) to outline how they intend to meet the EU energy and climate targets, and develop national resource adequacy assessments (NRAAs) and national network development plans (NDPs). As highlighted in paragraph 111, new system needs should be articulated coherently with these existing studies, to ensure full consistency across those exercises, with the assessment of interactions, etc.

Figure 15: The framework to assess system needs



Source: Compass Lexecon

135 The energy system is affected by multiple inter-related factors: raw materials, climate change, cybersecurity, physical security, geopolitical risks, decentralisation, not to forget the essential need of procuring skilled workforces, necessary for the transition, etc. While planning for the different steps of the supply chain is outside of the power sector's responsibility, the power sector system needs assessment should be consistent with supply chain capacities, and should integrate potential disruptions in supply chains to increase robustness (with e.g. the consideration of requirements on local content in case of severe risk of disruptions).

136 The cross-cutting assessment framework should consider expected exogenous and endogenous evolutions discussed in section 3, including for instance the considerations to the changes in weather impacting future production from renewables, hydro and thermal plants.

137 To secure system operation, and as a result of the evolution of the energy mix in the Member States, some (up to now rather forgotten) dimensions of system resilience should also be addressed in the system needs assessment. As an example, inertia, historically provided by rotating machines, also contributes to the dynamic stability of the European system, beyond the traditional frequency and voltage ancillary services. Considering the declining number of generation facilities providing rotational inertia in the European power system, inertia must also be assessed, valued, and secured to ensure the dynamic stability of the system for secure system operation and SoS.

138 Furthermore, the system needs assessment should also consider synergies with district heating. System flexibility can also be achieved via heat, and district heating plays a crucial role in the energy transition, particularly in countries with colder climates. Incorporating technologies such as heat pumps, electrode boilers, fourth generation (low temperature) heating networks, and integration with power systems (e.g., thermal energy storage) enables greater efficiency.

139 Last, major investments in infrastructures and networks should be delivered in a timely manner. To do so, improved coordination between system needs assessments across generation, electrification, flexibility and networks and an adequate framework to support anticipatory investments are necessary. System needs assessments should account for interdependences, e.g. including impact of a lack of transmission capacity on adequacy and flexibility needs.

On the governance:

140 The coordination between NECPs, ERAA, NRAAs, TYNDP and NDPs and the upcoming flexibility need assessments (methodology under development by ENTSO-E and DSO Entity), and the collaboration between all relevant parties should be ensured via a governance framework for cross-sector system needs assessment and improved stakeholder engagement. This should include the coordination between and with the relevant authorities at the Member State level and at the EU level, as well as tight links with regional organisations such as DSOs.

141 This strengthened coordination should hence ensure consistency across the different plans, including for distribution networks and district heating. For instance, flexibility needs can arise both on transmission and distribution networks to relieve congestions, but can in some cases be resolved by the same distributed flexibility assets. The same assets may also respond to other adequacy or flexibility needs. Coordination is therefore of utmost importance to avoid double-counting or overprocurement. Similarly, while decisions concerning contracting mechanisms remain a Member State prerogative, the coordination of the needs assessment would enable coherently articulated assumptions, scenarios and ultimately system needs across Europe.

142 Cooperation between relevant authorities and the electricity industry on physical, cyber and supply chain risks could also be strengthened.

143 As already said and summarised in paragraph 132, when reviewing system needs assessment studies, the European Commission and/or ACER should make sure that the broader, cross-sector approach described above is implemented consistently. In particular, a joint and enhanced electricity and gas coordination group, with clear mandate and responsibilities that includes stakeholders' representatives would support efficient coordination between these plans and policies with adequate stakeholder engagement. This would build incrementally from the current arrangements, helping to avoid the multiplication of separate studies, for which assumptions are not systematically harmonised.

144 **Recommendation 2: Define, operationalise and coordinate the methodologies for the assessment of flexibility needs to ensure a consistent view across Europe.**

145 While the 2024 energy market reform provides a framework for flexibility needs assessment, it needs to be defined and operationalised. The first step should be to build a methodology for flexibility need assessment to implement at the European and national levels the electricity market reform provisions, including all existing and planned investments. The flexibility needs assessments should also cover the long-term to match net-zero scenarios.

146 Within the flexibility assessment methodology, quantitative metrics for flexibility should be defined at EU level, forming the basis of a harmonised assessment. This could build on existing methodologies developed by ACER and at national levels. Harmonised methodologies should cover the different timeframes and types of flexibility needs based on techno-economic metrics rather than aiming at political objectives detached from actual needs.

147 Beyond flexibility needs, quantifying the 'demand' for flexibility, the assessment framework should also assess the expected development of the 'supply' of flexibility resources, to check whether gaps are expected to appear.

148 **Recommendation 3: Develop and properly implement methodological guidelines at EU level to incorporate resilience to extreme events and capture interdependencies within the system needs assessment framework.**

149 The system needs assessment methodologies need to grant a greater focus on the resilience of the system to extreme events. This includes for example supply shortages, climate change impacts, cyberattacks, physical attacks, etc. System needs should be assessed with respect to resilience to these events, with stress tests and risk-preparedness plans to be prepared at national, regional and EU levels.

150 In practice, this could entail the use of forecasted climate years, that already take into account the consequences of climate change, as well as the inclusion of extreme scenarios of disturbances in the modelling underlying the system needs assessment, stress-testing energy system disruptions. To do so, a cross-sector framework should be developed at EU level to identify and quantify the risk of climate and cyber-related extreme events and physical attacks. For instance, for physical attacks, stress tests can look at the impact of the loss of critical infrastructures and mitigation measures. The resulting system needs assessments should combine adaptation and mitigation measures against these extreme events to improve the resilience of the system, and thus safeguard SoS.

151 Moreover, in line with previous recommendations, methodological guidelines at EU level should account for the upgrade in scope and timeframe, cover cross-sector interactions and include flexibility assessment methodologies and metrics, also building up on the ongoing work conducted

by ENTSO-E and DSO entity.[67] Indeed, adequacy and flexibility needs should be assessed jointly as same capacities may be able to contribute to those needs.

152 In addition, the viability of the different types of resources needed in the system should also be assessed as part of the framework. This could be based on an enhanced ERAA Economic Viability Assessment (EVA) methodology. Ideally, the EVA shall need to ensure the viability of resources to meet wider system needs beyond adequacy. To do so, all sources of revenues, including specific support mechanisms, should be taken into account with an improved modelling and considering stacking-up limitations, as providing system services also provides other sources of income to energy resources.

67 See ongoing public consultation on flexibility needs assessment methodology organised by ENTSO-E and DSO entity. Accessible here.

6.2. Pillar 2: Enhancing the investment framework to ensure system needs are met

153 The second pillar of policy recommendations focuses on market design and regulatory framework that need to support the deployment of the investments necessary for new capacities or to maintain existing assets (clean, firm and flexible resources, as well as networks) for a secure energy transition. Most clean, firm and flexible resources require large CapEx investment, which suggests that a specific focus on the investment framework for capital-intensive technologies is needed, through e.g. contractual mechanisms that can reduce risks for and /or ensure that there is a timely deployment of the required resources. Such mechanisms would serve as an insurance for the power system and the European economy as a whole: securing electricity supplies may cost money, but this would be to the benefit of European consumers ultimately.

154 There is also a need to properly recognise network and other related infrastructure challenges associated with the electrification and the development of renewables, and in particular to ensure a coordinated and timely deployment of different infrastructure along the value chain.

155 In this section, we focus on the key gaps in the current market and regulatory framework, and argue that there is a need to enhance the current set of contracting arrangements that form a market-compatible investment framework for clean and flexible technologies to secure the necessary investments and provide a secure electricity supply. Furthermore, enhancing incentives and coordination in network infrastructure investment is key to ensure that the necessary investments can be made on time.

156 We therefore successively outline:

- The key gaps in the current investment framework; and
- Policy recommendations for the investment framework.

Key gaps of the current investment framework

The current EU investment framework can be further improved

157 The investment framework can be improved in the current market design to support capital-intensive large-scale investment in clean technologies. To reach REPowerEU targets, substantial investment is necessary in renewables, firm and flexible capacities, and grids. The European Commission analysis indicates that REPowerEU alone needs €300 billion of investments by 2030, in addition to the Fit for 55 investments needed.

- The latest Commission Staff Working Document shows that 510 GW of wind and 592 GW of solar PV will be needed to reach REPowerEU targets by 2030.[68] By comparison, in 2020, installed wind capacity amounted to 175GW, and 100 GW for solar PV.[69]

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68 European Commission (2022), Implementing the repower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets. Accessible here.

69 Eurostat, EU 27.

- Investments of about €350-450 billion will be needed in the coming decades to maintain the same nuclear capacity in the EU.[70]
- Regarding flexible assets, the IEA highlighted in 2024 that at the global level, investments in battery projects would need to grow by 25% every year in order to triple installed renewables capacity by 2030, as agreed by parties at the COP28.[71]

Deep dive: flexibility needs are increasing substantially to maintain security of supply

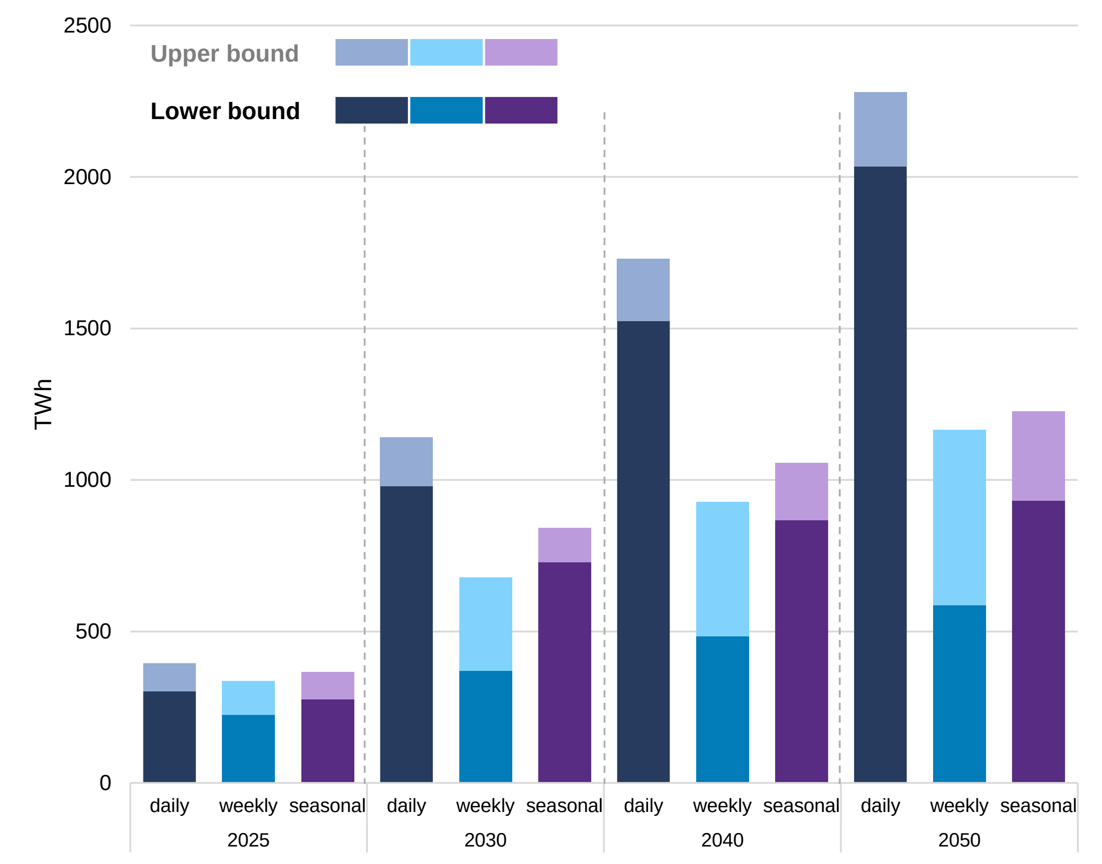
Our analysis of the evolution of flexibility needs at the EU level shows that the **EU's flexibility needs increase materially across all timeframes**, especially at the daily level due to the development of solar PV (as shown on Figure 16 below). The analysis also shows the important contribution of European integration and interconnectors that smoothen flexibility needs and support flexible capacities' sharing. This is consistent with the findings of a number of studies conducted recently at the European or country level to assess the evolution of flexibility needs. In particular, in a study published in 2023, ACER identified a large increase of daily flexibility needs which are expected to more than double between 2021 and 2030.[72]

70 European Commission (2022) Opening speech by Commissioner Simson at the 15th European Nuclear Energy Forum in November 2022. Accessible here.

71 IEA (2024) World Energy Investment 2024. Accessible here.

72 ACER (2023) Flexibility solutions to support a decarbonised and secure EU electricity system. Accessible here.

Figure 16: Evolution of flexibility needs across different timeframes in Europe, 2025-2050 (TWh)

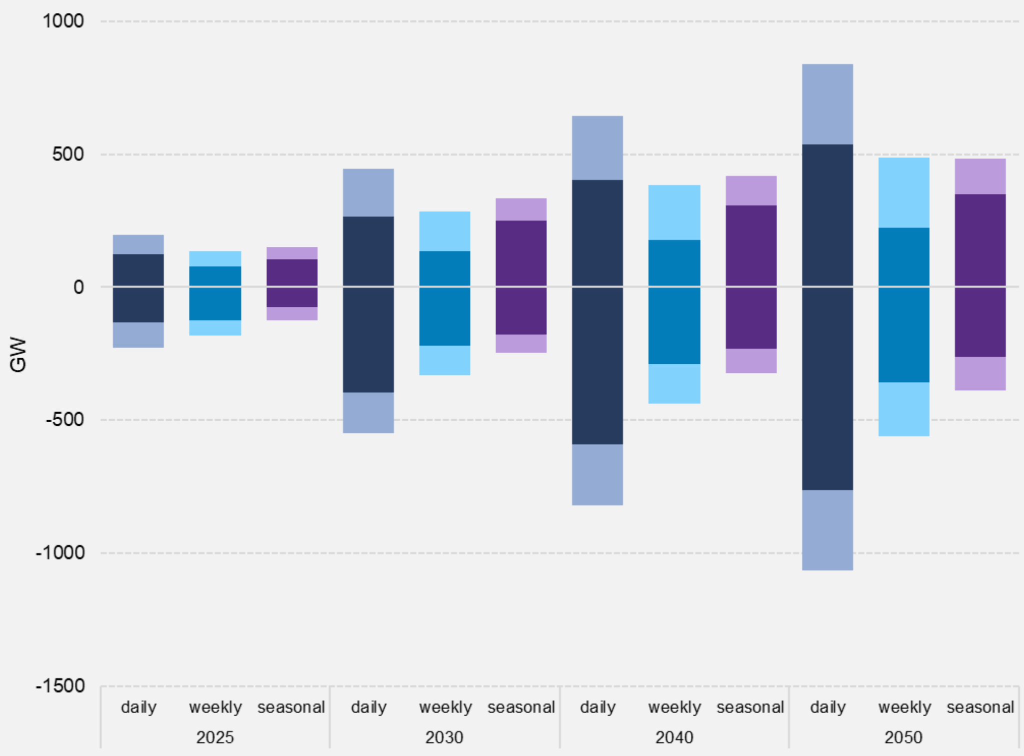


Source: Compass Lexecon analysis.

Notes: EU flexibility needs methodology: Upper bound: Assuming no cross-border netting, each country's individual needs are summed up across the EU. Lower bound: Assuming that the EU is a 'copper plate' with infinite interconnection capacity between the countries.

Annual flexibility energy needs (in TWh) refer to the sum of absolute needs in both direction (upwards and downwards). Flexibility capacity needs (in GW) refer to the maximum flexibility need in upward and downward directions. Calculations are based on generation and demand profiles of 2009 as a climatic year. Electrolysis demand is not included in the calculations as it is considered as a flexibility provider.

Figure 17: Upward and downward capacity flexibility needs in Europe, 2025-2050 (GW)



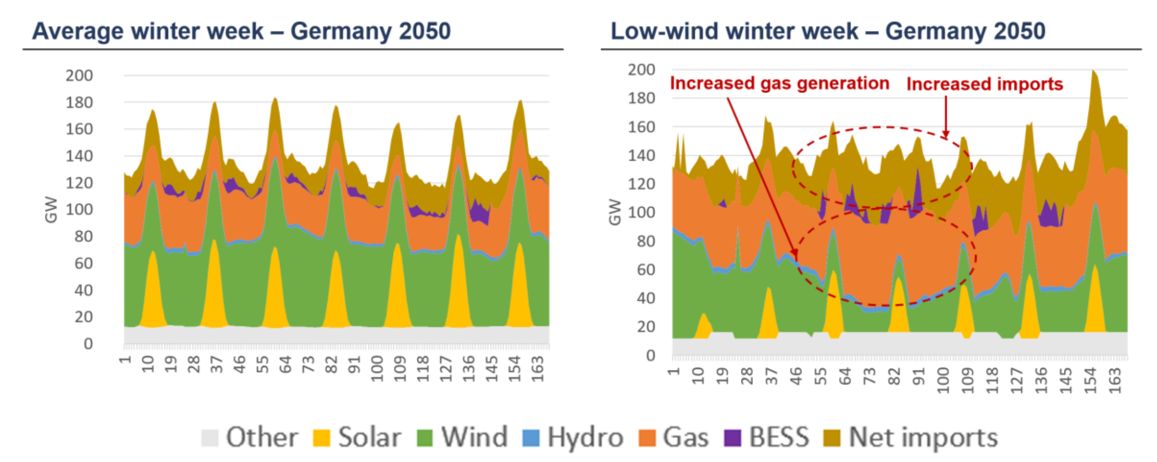
Source: Compass Lexecon analysis.
Notes: EU flexibility needs methodology: Upper bound: Assuming no cross-border netting, each country's individual needs are summed up across the EU. Lower bound: Assuming that the EU is a 'copper plate' with infinite interconnection capacity between the countries.
Annual flexibility energy needs (in TWh) refer to the sum of absolute needs in both direction (upwards and downwards). Flexibility capacity needs (in GW) refer to the maximum flexibility need in upward and downward directions. Calculations are based on generation and demand profiles of 2009 as a climatic year.
Electrolysis demand is not included in the calculations as it is considered as a flexibility provider.

Our results highlight that both energy and capacity flexibility needs in Europe increase significantly over time on daily, weekly and seasonal scales. Across the three studied time horizons, the daily energy and capacity flexibility needs are expected to grow the fastest, by over 100% from 2025 to 2030 (upper bound) and by around 100% from 2030 to 2050 (upper bound).

This strongly evolving need leads to challenges to ensure that sufficient capacities can provide flexible services. Indeed, while flexibility solutions are more mature to answer short-term needs, and short-term flexibility is already remunerated across different markets provided there are no restrictions on prices, alternative technologies (e.g. power to gas) must further mature to compensate for the closure of thermal plants and complement nuclear and hydropower to satisfy seasonal flexibility and/or adequacy needs.

Moreover, a range of **system stress events could further increase flexibility needs**. For example, the climate crisis, with extreme weather conditions, can lead to an extra burden on the power system, which in turn increases flexibility needs. Stress tests conducted with our model, as shown in the figure below, highlight that in periods of low-wind generation, flexibility providers such as gas plants, interconnectors and battery energy storage system need to increase generation/imports.

Figure 18: Comparison of an average winter week with a low-wind week - Germany, 2050 (GW)



Source: Compass Lexecon analysis based on data from Decarbonisation Speedways.

164 Given the significant investments needed and the importance of maintaining required existing assets, it is necessary to build an enhanced and more consistent investment framework, in which long-term contracts, including private contracts such as power purchase agreements (PPAs) and public de-risking arrangements, will play a growing role. Long-term contracts are the anchor of an investment framework, as they support efficient risk allocation. This de-risking acts to reduce the cost of financing, and ultimately the costs of secure energy supply for consumers.

165 The investment framework can be improved in the current market design, as three main challenges arise which may hinder the development of the required investments to ensure SoS in the future:

- Firm and flexible capacities may face missing money issues with market remuneration;
- Investment in capital-intensive and long-lifetime assets is risky to achieve security of supply; and
- Investments across the energy sector are not adequately coordinated.

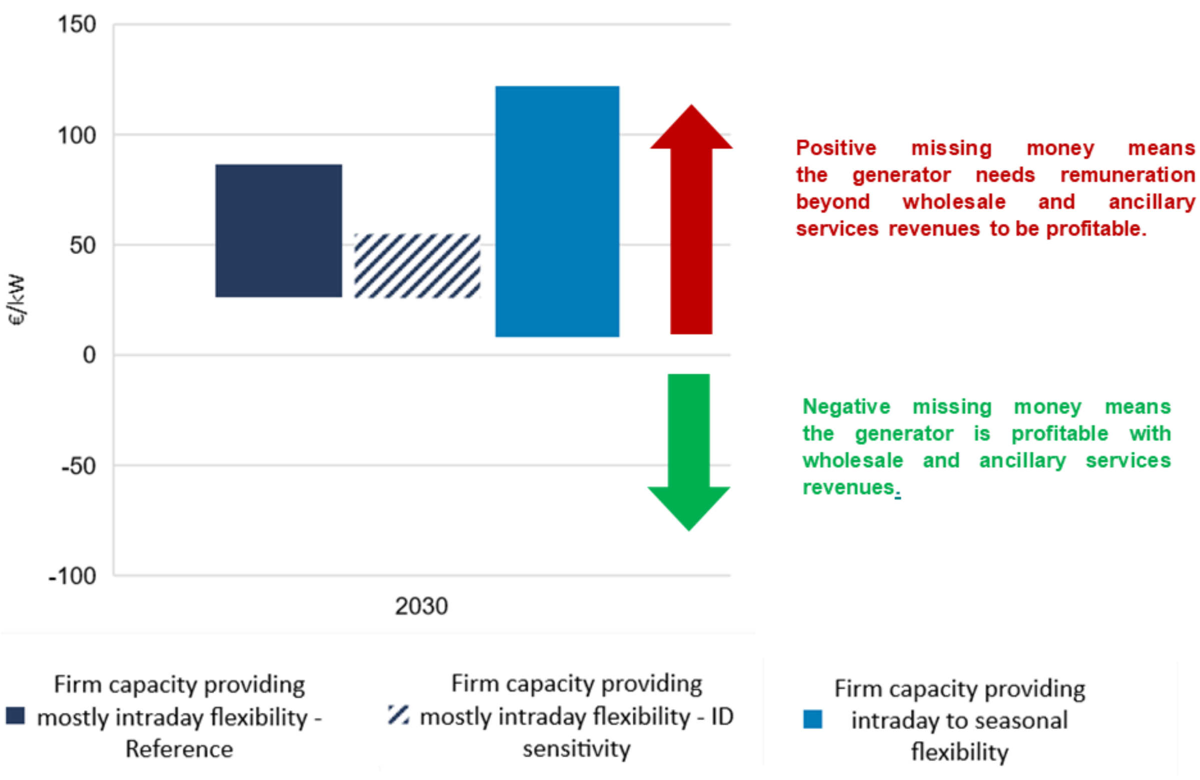
Firm and flexible capacities may face missing money issues in absence of capacity remuneration

166 Even with well-functioning electricity markets, many new and existing firm and flexible technologies in Europe may still need complementary remuneration in addition to wholesale and ancillary services revenues in the energy transition.

167 Figure 19 below presents the average ‘missing money’ of new firm and flexible capacity providers – i.e. the missing money equals the missing revenues beyond the wholesale and ancillary services revenues to cover investment and operational costs in such capacities, without including potential revenues from existing or upcoming capacity remuneration mechanisms or flexibility support schemes – as modelled in the Eurelectric REPowerEU Decarbonisation Speedways scenario. With market remuneration only (including wholesale and balancing markets’ revenues), we find that most

firm and flexible capacity providers face a missing money problem on average.[73] Without an adequate mechanism, the missing money issues could prevent necessary investments to ensure SoS.

Figure 19: EU + GB average missing money range for firm and flexible capacities commissioned in 2030 across their entire economic lifetime (in € 2023/kW derated)



Source: CL analyses based on REPowerEU Decarbonisation Speedways scenarios, ENTSO-E, EC impact assessment. The average missing money considers different types of flexible technologies. 'Firm capacity providing mostly intraday flexibility' considers capacities mainly contributing to intraday flexibility, such as battery energy storage systems (BESS) and demand-side response. 'Firm capacity providing intraday to seasonal flexibility' considers capacities contributing to intraday, weekly & seasonal flexibility, such as nuclear, CCGT, OCGT and pumped storage hydropower. In the ID sensitivity, BESS collect additional revenues from the intraday market, equal to 40% of their net revenues on the day-ahead and ancillary services markets, while in the Reference scenario, no Intraday revenues are considered and BESS only capture day-ahead and ancillary services markets revenues.

168 As such, despite revenue stacking opportunities across different markets, the level of revenues that can be captured in electricity and ancillary services markets may be insufficient for asset owners to cover their fixed costs. This could be caused by market failures in the current market design that might limit revenue opportunities for flexible assets,[74] leading to a misalignment between the value that new capacities can bring to the system and the remuneration received. In particular:

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73 In our analysis of the Eurelectric REPowerEU Decarbonisation Speedways scenario, amongst firm and flexible capacity providers, conversion of existing hydro reservoirs to pumped storage may not present missing money on average, but its development potential is limited, and the investment costs may differ strongly from one project to another given the specificities of the sites.

74 Most frequent market failures in EU power system include participants' risk aversions, imperfect competition, existence of price caps and inability for prices to reflect the value of loss load. See for instance, France Stratégie (2014), The Crisis of the European Electricity System, box 2. Accessible here.

- Revenue stacking opportunities for flexible assets are potentially limited, as some technologies are still not allowed to participate in all market segments and overly strict technical rules may unnecessarily hamper the participation of certain capacities in various schemes[75]; and
- Short-term price signals might not adequately reflect system needs and reward assets. In particular, policy interventions[76] or price caps in spot markets tend to induce distortions and reduce revenues.

169 As a result, in addition to correcting, to the extent possible, the market failures identified, complementing market signals with additional incentives might be necessary in some cases, to compensate the missing money, maintain necessary firm and flexible capacities and unlock investments. This is highly relevant from a SoS perspective, since failure to deliver the investments or to avoid the premature retirement of existing assets would lead to unfulfilled needs endangering SoS.

Investment in capital-intensive and long-lifetime assets comes with high uncertainties impacting cost of capital

170 Taking investment or existing assets' life extension decisions, investors and lenders seek to balance out the certainty of revenues with the asset risks and costs, in order to evaluate whether the rate of return for the project is acceptable with regard to the risks involved.[77]

171 However, revenue uncertainties can emerge from different sources for investors in firm or flexible capacities. This includes for instance high volatility in market prices, lack of predictability over future revenue streams or competitive landscape,[78] market design or policy uncertainties.

172 As a result, investors may fear that future revenues would not cover their fixed costs and ensure a sufficient return on investments. This is particularly the case for capacities with long asset lifetime, long development lead times and high share of capital expenditure. This may increase costs for consumers, or reduce investments altogether, which eventually can negatively impact SoS.

173 In this context, private and public long-term contracts as part of an investment framework can play a critical role to support these investments in capital-intensive capacities and technologies. Long-term contracts facilitate financing and reduce the cost of capital, thereby reducing the total cost of investments and benefitting consumers.

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75 For instance, as noted by ACER, for wholesale and balancing markets "[…] some national legal frameworks may limit market access to distributed energy resources, individually or aggregated". This view is shared by many EU stakeholders, as shown by the European Commission consultation on demand response participation in electricity markets: "[…] currently, many stakeholders from different EU Member States identify the lack of access to electricity markets as a barrier that hinders the development of DR." See ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back? Accessible here. See also European Commission (2024) Barriers for demand response in electricity markets and State aid support. Accessible here.

76 For instance, during the recent energy crisis, policy interventions in the wholesale markets were introduced across Europe such as inframarginal price caps.

77 Riverswan energy advisory (2021) Filling the flexibility gap Realising the benefits of long duration electricity storage. Accessible here.

78 European Commission (2023) State Aid SA. 104106 (2023/N) – Italy - Support for the development of a centralised electricity storage system in Italy. Accessible here.

Investments across the value chain need to be better coordinated

174 Appropriate mechanisms to deliver the coordinated investments identified as part of the system needs assessment exercise are missing across the energy sector. This is particularly true in a context of fast evolution of the energy system with forced closure of fossil fuel capacities, electrification and development of renewables.

175 Indeed, timely development of network infrastructure, both at the national level and for interconnectors, sources of flexibility as well as firm power is needed alongside the growth of renewables. At the same time, new flexibility resources will also emerge both on the supply side with new technologies (e.g. storage) and on the demand side with new flexible loads from the electrification of the transport, industry and buildings sectors.

176 As a result, there is a need to coordinate investments (and decommissioning) across industry segments, demand-side and sectors as they develop. In this regard, a public long-term contracting mechanism is a powerful instrument for policymakers to ensure that investments in clean and flexible assets are made in a timely manner in line with the system needs identified. Contracting for certain system needs over the long-term allows to send investment signals ahead of market signals, and ensure that the SoS is upheld as the energy transition unfolds.

177 An improved coordination of investments can bring system costs down, especially given increasing congestions in the system. As such, locational signals across the investment timeframe could help provide adequate incentives to locate new investments in a way that contributes to alleviating these congestions and limits infrastructure costs, or at least that avoids creating additional constraints. To do so, it is important to provide these signals across the investment timeframe so that they can be efficiently factored into investment decisions.

The current contracting mechanisms in place are heterogeneous in Europe, and face design issues

178 To ensure adequacy, a patchwork of capacity remuneration mechanisms have been implemented across Europe, showing the lack of ex-ante harmonisation principles leading to their convergence. Capacity remuneration mechanisms have been introduced across Europe with marked differences, such as decentralised capacity markets (France), centralised capacity markets (Belgium or Poland, with a zonal design in Italy, or accounting for local congestions in Ireland) strategic reserves (Germany), etc.

179 While capacity mechanisms open to all new and existing capable technologies are now an integral part of the European electricity market, as confirmed by the Commission in the last market design revision, there is not yet a common vision at the EU level on their design. Several design shortcomings remain in the capacity mechanisms implemented so far in Europe to ensure security of supply, such as:[79]

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[79] See for instance ACER (2023) Security of EU electricity supply. Accessible here. ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back? Accessible here.

- Potential barriers and an uneven playing field for the full participation of all types of capacities remain in capacity mechanisms in Europe;[80]
- Cross-border participation in most capacity mechanisms is not yet functioning as intended;[81] and
- Most current capacity mechanism designs do not send the right signals to consumers as costs are generally passed on to consumers through a ‘flat’ fee over the delivery year, and do not reflect periods of peak demand/scarcity (which correspond to the periods for which assets have been contracted as part of the capacity mechanism).

180 Moreover, the current generic capacity mechanism design targets capacities providing adequacy services, and does not *per se* value their contribution to flexibility needs. As flexibility needs develop significantly, and if they risk not being covered, contracting mechanisms may need to value capacities’ contribution to these flexibility needs to ensure that they are met.

181 Furthermore, despite batteries securing capacity contracts in some European capacity mechanisms, these may be insufficient. To support flexible capacity, a diversity of dedicated support mechanisms is being implemented across Europe. However, these support schemes often target specific technologies, mostly battery storage, rather than underlying flexibility needs, which introduces distortions across technologies. These are implemented in an uncoordinated way and also lack harmonisation. While EU regulation now allows flexibility support mechanisms as part of the market design, there are no clear guidelines for the implementation of such schemes.

182 The introduction of targeted (i.e. technology-specific and limited to new capacities) flexibility contracting may also crowd out other capacities, leading to the risk of a ‘slippery slope’ effect. Indeed, flexibility contracting, especially if targeted, would incentivise the development of additional flexible capacities in the market. These new capacities could affect prices in the wholesale and balancing markets and may crowd-out other un-supported capacities from the dispatch. Thede capacities would earn lower revenues for their contribution, risking that they no longer remain profitable and exit the market. Such exits could eventually create additional SoS issues. As a result, targeted support mechanisms risk dis-optimizing capacity development in the system.

Policy recommendations for the investment framework

183 Massive investments are needed to meet decarbonisation objectives while maintaining high standards of SoS, ensuring affordability, reducing dependence on imported fossil fuels, and addressing identified system needs. The investment challenge requires building a stronger framework to support these investments, fostering their timely delivery and facilitating financing.

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80 For example, ill-designed parameters to reflect the contribution of energy-limited assets to adequacy in capacity mechanisms could disincentivise the update of such assets. For instance, in Great Britain, the ESO reviewed its methodology for BESS derating, to include considerations of the storage fleet contribution to adequacy, rather than its previous assessment relying on ‘equivalent firm capacity’ to evaluate the contribution of storage assets with different durations, as well as the ‘technical availability’ of assets. See ESO (2024) Storage de-rating factors methodology review. Accessible here. ModoEnergy (2024) Capacity Market 2024/25: Increased derating factors for BESS confirmed. Accessible here.

81 European integration has led to the development of cross-border specifications in capacity mechanisms. However, without the right level of harmonisation, and without sufficient capacity products adapted to cross-border contracts and ensuring comparable rights and obligations, these mechanisms have not been successful in most EU countries.

184 To complement Eurelectric's existing work on investment frameworks and long-term contracts, and in particular on contracts-for-difference (CfDs),[82] our contribution focuses here on contracting mechanisms adapted to firm and flexible capacities.

Policy recommendations to improve the investment framework

185 **Recommendation 4: Ensure that identified system needs are met by providing an investment framework for firm and flexible technologies through (i) efficient short-term markets and, where necessary, (ii) contracting mechanisms.**

186 Markets are an essential cornerstone for providing signals, but they can be imperfect, requiring a framework to ensure they deliver effective planning. Complementary contracting mechanisms valuing firmness and/or flexibility (such as capacity mechanisms) may be needed in some cases. As confirmed by the European Commission in the regulation on the internal market for electricity,[83] Member States should be able to implement capacity remuneration mechanisms as a structural part of the market design, if they consider that energy-only markets will not suffice to attract the necessary investments. The decision to develop contracting mechanisms should remain the prerogative of Member States at national level.

187 The introduction of a contracting mechanism for firm and flexible technologies can help address three different, complementary, objectives to achieve SoS:

- **Missing money coverage**: Covering any missing-money issues arising from insufficient market revenues to cover costs for new capacities or to maintain necessary assets and deliver the required system needs;
- **Investment de-risking**: With high-risk environments, contracting mechanisms could be considered to lower risks, and so lower cost-of-capital and unlock investments;
- **Investment coordination**: Given the need to coordinate investments across industry segments, demand-side and sectors, the contracting mechanism can ensure timely investments in line with the planning framework in a market-driven way.

188 **If energy markets do not provide sufficient investment signals for SoS**, different contracting mechanisms can be implemented depending on whether system needs include firm capacity, flexible capacity or both:

- When only a flexibility need arises, and not adequacy, **a flexibility contracting scheme** should be implemented alongside energy markets. These schemes are dedicated contracting mechanism to incentivise maintaining operations or investing in flexible capacity in response to specific flexibility needs.
- When only an adequacy needs arise, but not flexibility, a **capacity remuneration mechanism** should be implemented. These are mechanisms to incentivise maintaining existing capacities operations or investing in new capacity and reach adequacy standards. They should be open to participation of all resources that are capable of providing the required technical performance, including energy storage and demand side management.

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82 Eurelectric and Compass Lexecon (2024) Unlocking the power of two-way CfDs to accelerate the energy transition. Accessible here. Eurelectric and Compass Lexecon (2022) Electricity Market Design Fit for Net Zero. Accessible here.

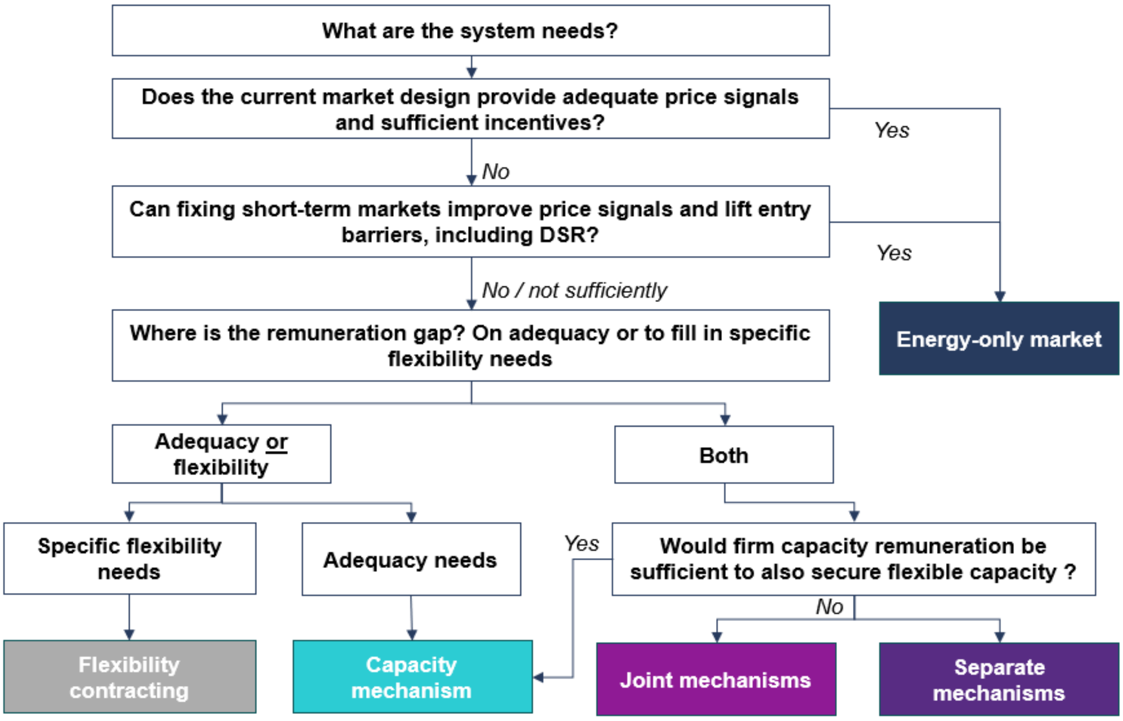
83 Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (2024). Accessible here.

189 If the need for a contracting mechanism for both firm and flexible capacity materialises, and should a capacity mechanism not be sufficient or adapted to address such need and a complementary mechanism be necessary, the relevant implementation option would depend on the overlap between the group of resources which can provide firm capacity, and the group of resources which can provide flexible capacity. Two main contracting mechanisms would be possible:

- **Joint optimised contracting mechanism**: mechanism to incentivise investiment to meet both adequacy and flexibility needs together, through a single mechanism co-optimising the contracting of both needs.
- **Separate capacity and flexibility mechanisms:** mechanism to incentivise investiment to meet adequacy and flexibility needs separately, through a contracting mechanism covering both needs separately.

190 In Figure 20 below, we summarise the process to determine whether contracting mechanisms are required, and if so which type depending on the underlying system needs.

Figure 20 - Market design archetype determination process



Source: Compass Lexecon

191 In practice, the resources delivering firmness and flexibility overlap: assets provide some level of firm capacity and some flexibility, the relative contribution to the two aspects depend on the technology. This stresses the importance of articulating the flexibility contracting schemes with other mechanisms, particularly capacity mechanisms. This could be addressed through appropriate rules for the cumulation of support e.g. under State aid rules. Moving to multiple-products capacity mechanisms should be considered to address both adequacy and flexibility issues, where necessary.

192 Wherever flexibility is jointly contracted with another service, through joint procurement schemes, there are two main implementation options:

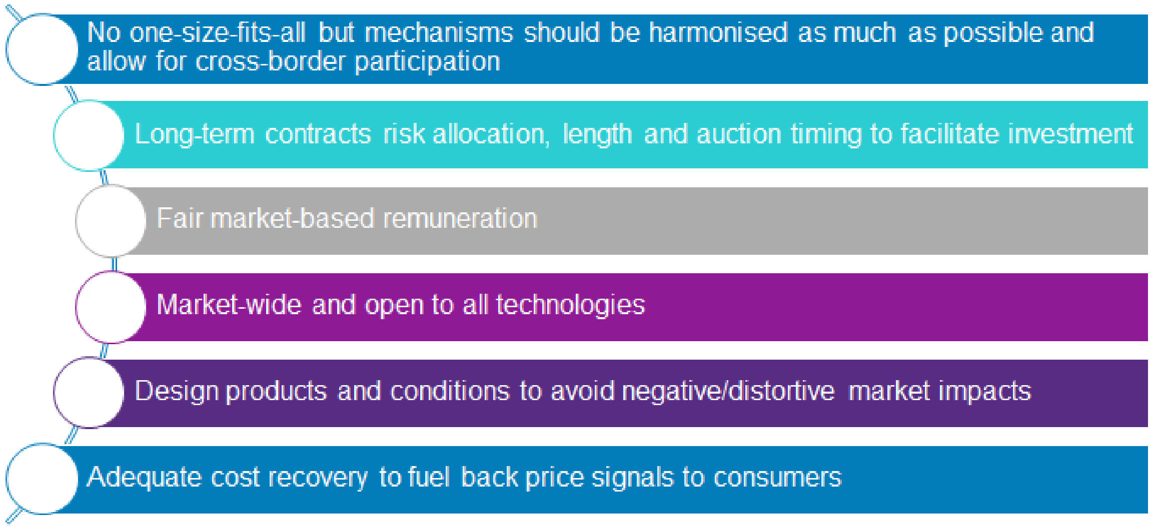
- **A single product** could be defined based on the contribution of each technology to reach the SoS target, taking into account both adequacy and flexibility system requirements. This product would be procured through a single auction/clearing price. This product could be for instance a capacity contributing to adequacy while also exhibiting characteristics to ensure flexibility, such as a pre-determined ramping speed.
- **Two products**, for firm and flexible capacity, could also be defined separately in a single mechanism. Distinct derating factors would be associated to each technology class depending on their firm and flexible capabilities. The demand for each product would be calculated separately, and products could be procured through separate or joint auctions, taking into account the substitutability and complementarity between the two products.

193 It is worth noting that firm and flexible capacity can also be combined by norms, to ensure emission characteristics or ability to provide short-term services.[84]

194 **Recommendation 5: Develop guidelines to design contracting mechanisms for firm and flexible capacities respecting key principles (market-based, market-wide, undistortive mechanisms supportive of long-term contracting and open to all technologies) and fostering harmonisation and cross-border integration at European level.**

195 An efficient investment framework should be based on the following key principles, that are detailed in the next paragraphs:

Figure 21: Key principles of the investment framework



Source: Compass Lexecon

196 Even if there is **no one-size-fits-all framework** for investment given local specificities across Europe, mechanisms valuing firmness and flexibility **should be harmonised as much as possible** to promote and facilitate stronger interoperability/compatibility and ultimately potential convergence across Europe, to better reflect cross-border contribution and facilitate cross-border participation to the greatest possible extent to achieve a level-playing field, while taking into account local and regional specificities when required. Moreover, given their central position in the European system

84 Capability requirement to provide balancing services – which should then be remunerated in short-term markets.

or the increasing interconnection levels, cross-border cooperation, and more broadly the investment framework, could be extended to the UK, Switzerland and other non-EU countries.

197 To facilitate investment in new capacities or repowering/major overhaul for existing capacities, public **long-term contracts** (e.g. capacity remuneration contracts, two-way CfDs) should be granted on the basis of the **capital intensity and risk exposure**. **Auction timings should be adapted** not to discriminate against any technologies with longer or shorter lead times, including through anticipated procurement of long-lead-time technologies based on planning needs and low regret approaches. Conversely, shorter-term procurement could be used for system needs closer to delivery and to facilitate participation of short-lead-time capacities.

198 Next, **market-based remuneration** as a key principle of public contracting mechanisms should ensure fair remuneration to all capacities, existing and new, that contribute to system needs. Contracting mechanisms may also encompass specific features to avoid ex-post intervention in case of alleged 'windfall profits', to strengthen investor confidence. When market-based remuneration is based on auctions organised by Members States, these could take the form of 'two-way CfDs' or 'reliability options' for instance, to avoid the perception of structural over-remuneration or structural deficits in the allocation of risks between investors and consumers, which could trigger policy interventions. In such cases, impacts on (forward) market liquidity and ability to set adequate price parameters should be duly considered.

199 Furthermore, **market-wide, technology-neutral mechanisms** should form the basis of the investment framework to ensure fair competition, including for capacity mechanisms. This entails the open participation of all capacities able to answer to adequacy needs, including DSR. The product design should result from the system needs assessment and the characteristics and features needed, rather than targeting specific technologies. As a result, market-wide technology neutral capacity mechanisms should be implemented by Member States in priority.

200 Additionally, the public investment framework should strike a balance between robust revenue stabilisation and effective incentives to participate in the forward, spot, and balancing markets. Indeed, the framework should be designed using products and conditions which **avoid negative or distortive impacts on the market**. For example, availability-based commitments should be used instead of market-distortive delivery obligations.

201 Last, for the chosen public contracting mechanisms, **adequate cost recovery should enable fuelling back price signals to consumers** to ensure that they can respond and implicitly contribute to lowering adequacy and flexibility needs.

202 European guidelines could provide more specific measures to ensure that the generic principles outlined above are met. These guidelines can also foster further harmonisation in the design of contracting mechanisms to facilitate cross-border participation in Europe, as it could enable a stronger integration of capacity mechanisms across Member States and higher efficiency.

203 **Recommendation 6: Where flexibility contracting schemes are required to safeguard SoS, implement contracting mechanisms addressing flexibility needs in a technology-neutral and cost-efficient way.**

204 Technology neutrality is a key design issue for the implementation of investment schemes for flexibility. Contracting mechanisms for flexible assets can in theory either target specific technologies, or be designed as technology-neutral – all technologies capable of answering system needs being eligible. Suitable eligibility rules depend on the nature of system needs and on the level of maturity of the different flexible technologies.

205 For the implementation of flexibility mechanisms, technology-neutral mechanisms should be preferred by default, based on system needs, as competition between technologies would improve the efficiency of the mechanism and reduce costs for consumers. The introduction of targeted support schemes should be avoided, or otherwise subject to robust justifications, in particular due to the discriminatory aspects and the risk of 'slippery slope' effect described on paragraph 182. The choice of targeted or technology-neutral mechanisms to support flexible assets should also at least consider:

- Benefits from inter-technology competition, especially in terms of cost-efficiency;
- Interactions with other mechanisms (e.g. capacity markets);
- Complexity of design; and
- Contribution to complementing flexibility already available to address actual needs.

206 **Recommendation 7: Provide better locational signals at the investment timeframe, e.g. within the contracting mechanisms or local flexibility market arrangements.**

207 Locational signals across the investment timeframe could improve investment coordination and help bring down system costs, while preserving liquidity and stability of energy markets. Such locational signals could be provided by, e.g.:

- locational components integrated in the investment framework, both in mechanisms to support the development of clean energy and in contracting mechanisms for firm and flexible capacities;
- local flexibility market arrangements between DSOs, TSOs and flexibility providers.

Policy recommendations to foster investment in electricity networks

208 **Recommendation 8: Enhance network operators' incentives to deliver the necessary infrastructure investments, both at the national level and in interconnectors.**

209 In addition, the regulatory framework should provide network operators enhanced incentives to invest in their infrastructures, both at the national level and in interconnectors. Providing system operators with adequate returns – i.e. in line with capital markets expectations – on their investments is key to achieving this. A resilient infrastructure, that strengthens EU integration, is the backbone of SoS, but the investment challenge in power grids is substantial. To achieve the REPowerEU scenario across the EU27+Norway, around €67 billion annual investment is required on average between 2025 and 2050 for distribution grids alone.[85] This sum can be reduced substantially to €55 billion annually if certain regulatory incentives are set inter alia allowing for anticipatory investments and grid-friendly flexibility usage by DSO.

210 Distribution grids will play a key role in Europe's energy transition with 70% of new RES to be connected on distribution level.

211 First, regulatory frameworks should increase in agility to face evolving investment needs and underlying costs. Allowed revenues within the price control frameworks should incorporate provisions for network companies to adapt investment plans within price control periods in order to quickly respond to identified needs.[86] This would allow to avoid delays in CapEx recognition in tariffs, and hence, enhance incentives for network operators to invest at the right time. In addition,

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85 Eurelectric (2024) Grids for Speed. Accessible here.
86 See for instance Eurelectric (2024) Grids for Speed. Accessible here.

investment costs could also be updated more regularly within cost recovery frameworks, accounting for evolutions in the cost of debt or underlying inputs more dynamically.

212 Second, if financing challenges are faced by network companies, or the affordability can not be ensured otherwise, in delivering the necessary infrastructure for SoS, greater use of non-tariffs funding as well as third party financing models could also be investigated.

213 Third, the connection processes and arrangements can also be improved to optimise infrastructure uses and development. For instance, the use of flexible connection agreements must be implemented nationally as a readily available option in order to fast-track connections despite local constraints. From a network user perspective, the general framework should incentivise network users to only request connections when needed, to limit long connection queues. Last, Member States should be allowed, where needed, to set connection prioritisation linked to societal benefits through appropriate coordination with regulators and network companies.

214 **Recommendation 9: Coordinate and, when necessary, anticipate investments to ensure that the required infrastructure is delivered on time to ensure SoS.**

215 The regulatory framework should ensure that the necessary investments are delivered on time and provide adequate incentives to unlock the large amount of investment required for electricity grids. To do so, NRAs need to include specific provisions to allow and incentivise anticipatory investments in the investment framework for networks, to ensure that electricity infrastructure development does not act as a bottleneck to the development of the required capacity for a clean and secure energy system.

216 Barriers to investments should also be lifted to enable the development of the required infrastructure. This includes competitive returns expected by financial markets to allow access to private capital, speeding up and streamlining the permitting or authorisation procedures for grid projects ahead of the confirmed need and encouraging efficient prioritisation of grid projects. For instance, permitting for grid development could take a ‘bundled’ approach, such as for renewable energy projects linking permits to grid extension permits.

217 **Recommendation 10: Enhance incentives for network companies to leverage flexibility for grid-related purposes.**

218 The regulatory framework for power networks should facilitate the development of innovative solutions. This includes making the best use of grid-friendly flexible solutions (mostly OpEx), such as by providing allowed expenditure and, on top, output targets and/or financial incentives for the use of flexibility or other innovative technologies within the remuneration framework. Such incentives may be based, for instance, on the sharing of the benefits of flexible solutions between DSOs and tariffs. Together with necessary grid reinforcement, these solutions can speed up connection and limit grid constraints through greater system optimisation, and ensure SoS at lower costs for consumers.

6.3. Pillar 3: Ensure efficient markets and operations in real time

219 The third pillar of policy recommendations focuses on the operational timeframe issues regarding SoS, namely that efficient price signals are essential to ensure efficient system operations and maintain SoS. These signals are required across the market timeline, from forward markets up to real time balancing signals. The integration and development of EU short-term wholesale markets has successfully brought consumer benefits over the past 20 years. While most necessary reforms have been or are being implemented, there are areas where implementation choices need to be taken adequately and a higher consumer engagement would be desirable.

220 To manage and operate the system efficiently, market signals need to reflect the system situations, and enhanced forward markets should offer better hedging opportunities for firm and flexible assets. As demand is more and more flexible and controllable, encouraging greater consumer participation to provide DSR, both implicitly and explicitly, further enhances SoS in real-time. The proper implementation at national level of the principles already set out in the European legal and regulatory framework is key.

221 In this section, we successively outline:

- The key gaps of the current markets and operations framework; and
- Policy recommendations for the markets and operations framework.

Key gaps of the current markets and operations framework

There are still gaps hindering efficient short-term price formation

222 The short-term wholesale market is essential for the efficient functioning of the power system and has ensured efficient dispatch of generation and flexibility assets, efficient cross-border trading and therefore reduced volatility, despite the exceptional circumstances of the energy crisis.

223 Efficient price development in energy markets can translate SoS issues into clear signals to market participants, driving their decisions in operational, but also long-term timeframes – even though, as illustrated before, these short-term price signals might not be sufficient to drive all necessary investments.

224 By reflecting the actual short-term costs of different actions and technologies, efficient price signals also incentivise flexibility resources to modify the level of production or consumption in response to the system needs. As we look back at the past 20 years and the current status of EU wholesale markets, it is important to emphasise the success of the integration of EU wholesale energy markets, which brings benefits to consumers. Short-term and forward markets can nonetheless be enhanced to provide the right price signals to ensure SoS, in particular through the proper implementation of the EU framework.

225 Furthermore, hedging on forward markets is often hindered by low demand for long-term hedging, liquidity issues, collateral requirements and difficulties to hedge across borders. As a result, there are only rare options in Europe to trade over more than three years in forward markets – and no options beyond ten years – and the liquidity of these products is low. Moreover, long-term transmission rights (LTTRs) do not have maturities higher than a year, which hinders the ability to trade across borders in forward markets. This prevents effective hedging of market participants

(producers, suppliers, aggregators) via the forward market, which can impede their viability and, eventually, SoS.

226 Finally, the evolution of the power system also gives rise to increasing real-time issues and requires resilience, efficient system operations and adequate ancillary services (inertia, voltage control, transient phenomena etc.).[87] In particular, with an increasing share of RES and a declining number of generation facilities providing rotational inertia, the power system would loose inertia, resulting in higher risks on dynamic stability. This should be taken into account to improve short-term operations and ensure proper framework and incentives for all technologies to contribute to addressing these real-time issues based on their technical capabilities.

227 As such, alongside wholesale markets, balancing services, ancillary services and local flexibility markets to resolve congestion are also key to provide fair remuneration to capacities providing adequacy and flexibility services to the system. However, in the current market design, heterogeneity remains in balancing markets across Europe which creates distortions and hinders efforts for greater European integration closer to real time. Barriers to participation may still remain in some countries, for instance for certain flexibility resources such as DSR. In addition, mandatory reserve provisions still remain in some countries for which flexibility services provided by the obligated capacities are not remunerated.

The European framework needs to be properly implemented to incentivise consumer engagement in short-term markets

228 Consumer engagement through demand-side infrastructure investment and flexibility is essential to guarantee a safe and affordable system. Indeed, DSR can bring substantial benefits in the electricity system, in terms of decarbonisation, SoS, and affordability.

229 However, a large share of energy consumers are not engaged in the market. This can be due to e.g., the lack of information or awareness regarding risks and opportunities, the lack of retail pricing structure providing time-differentiated signals,[88] barriers to the development of explicit DSR or policy interventions distorting consumer price signals.[89] For example, while smart meters are often a prerequisite to consumer engagement in operational timeframes, only 54% of European households had a smart meter as of late 2021[90] with significant divergences between Member States in terms of roll-out.

230 The Clean Energy Package set the focus on consumer engagement with a series of measures to empower consumers and facilitate demand-side flexibility.[91] Consumers could therefore be more reactive to market prices, which could contribute to alleviate future crises. These measures are not yet fully implemented in all of the Member States or need to be further clarified before

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87 RTE (2023) Reliability report. Energinet, Outlook for ancillary services 2023-2040. Accessible here.

88 While the Electricity Directive sets requirements for consumers equipped with a smart meter to be able to access time-differentiated tariffs, several Member States do not transcribe this requirement in their regulatory framework. See ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back? Accessible here. Page 46.

89 See for example ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back? Accessible here. and Smarten (2024) 2023 Market Monitor for Demand Side Flexibility. Accessible here.

90 ACER-CEER (2022) Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2021. Accessible here.

91 European Commission (2019) Clean energy for all Europeans package. Accessible here.

implementation. For example, the participation of explicit aggregation of demand-side flexibility is not allowed in all European energy markets and capacity remuneration mechanisms.

Policy recommendations for the markets and operations framework

231 Well-functioning wholesale and balancing markets are the cornerstone of the market design, to signal the most efficient resources to maintain secure system operations at least cost. To fully unlock the benefits of the market and consumer engagement, the existing EU framework for wholesale and balancing markets needs to be fully implemented, unnecessary policy interventions distorting markets should be avoided and consumer engagement should be fostered through undistorted retail markets and an adequate demand-side response framework.

Policy recommendations

232 **Recommendation 11: Focus on the implementation of the existing regulatory framework to ensure efficient short-term markets and operational arrangements and to send efficient signals reflecting system needs and avoid short-term market interventions.**

233 More specifically, this requires for each Member State to:

- Further develop market integration and continue to improve price signals through the full and proper implementation of the regulatory framework and further optimisation of interconnection capacity;
- Open balancing markets to all technologies and providers; and
- Harmonise further balancing market design across Member States.

234 Market integration is still in progress and can be further developed. The complete and effective implementation of recent market design reviews, short-term market integration (intraday and balancing), additional interconnection, full implementation of all services to be provided by regional coordination centres and further improvements in cross-zonal capacity calculation will positively contribute to achieving SoS objectives in Europe. For instance, this includes the optimisation of interconnection capacity to allow sufficient allocation for short-term markets, including the adequate application of the rule that at least 70% of the existing transmission capacity is offered for cross-zonal trade.[92]

235 In addition, the efficient functioning of wholesale and balancing markets and efficient price signals should be ensured by an adequate and timely implementation of EU regulations.

236 Balancing markets should also be open to all technologies, provide a fair remuneration for provided services and should be further improved, better integrated and harmonised at European level. For instance, the balancing platforms still need to be used across all Member States and their functioning can be further improved. Imbalance pricing can also be further aligned. This will ensure that flexibility services are adequately remunerated for market participants and facilitate cross-border exchanges of balancing energy and capacity.

237 The regulatory framework should be predictable, especially to reduce the moral hazard created by *ad hoc* market interventions in case of a price crisis. In particular, regulatory interventions on the wholesale and retail markets during the crisis, but also as a structural part of market design in some

92 While respecting security limits.

Member States, may prevent efficient price signals from being sent to consumers to enable their contribution to SoS.

238 **Recommendation 12: Improve current forward markets by removing existing barriers and foster the development of other long-term hedging tools (e.g. PPAs).**

239 Removing barriers to forward market hedging for both firm and flexible assets improves the economic viability, and ultimately the contribution to SoS of these capacities.

240 The current forward markets should be improved, in particular to increase liquidity in the market and for products beyond three years of maturity, such as by:

- easing collateral regulations; and
- introducing more frequent LTTR auctions with maturities higher than a year.

241 Going further, if the efforts to remove barriers to forward market hedging and facilitate cross-border hedging, including with cross-border PPAs, are not sufficient and there are still hurdles to hedging in the long-term, more direct actions may need to be undertaken to improve the liquidity on forward markets on an ad hoc basis. This could include the investigation of voluntary mechanisms for market makers in forward markets to stimulate liquidity up to seven to ten years for instance.

242 **Recommendation 13: Unlock the flexibility potential of consumers by developing explicit and implicit DSR through the proper implementation of the EU framework.**

243 Consumer engagement, both through explicit and implicit DSR,[93] can provide key benefits and consumers should be allowed to provide either, based on their preferences. Implicit and explicit DSR should thus be facilitated at local, national, and European levels. Efficient market price signals are key for implicit DSR, and an adequate regulatory framework needs to be implemented everywhere, in application of EU regulation, for explicit DSR. Both approaches bring significant benefits to the system and are complementary, and it is key to allow consumers to access both mechanisms.

244 To ensure SoS in the context of rapid electrification, the current market design framework for DSR needs to be thoroughly implemented, so that DSR can be remunerated based on its competitive value on (all) electricity markets. This requires:

- The timely implementation of the Electricity Directive, Electricity market reform, and upcoming Network Code on Demand Response,
- To lift the technical blockers for the participation of DSR in all electricity markets, including capacity mechanisms.

245 First, progress in implementing provisions of EU legislative framework is uneven across Member States, with a need to put efforts on the national implementation of these provisions. The Clean Energy Package already included a series of measures to empower consumers and facilitate demand-side flexibility. These measures are not yet fully implemented everywhere in Europe or

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93 Explicit DSR is committed, dispatchable flexibility that can be traded (similar to generation flexibility) on the different energy markets. Implicit DSR is the consumer's reaction to price signals. Where consumers have the possibility to choose hourly or shorter-term market pricing, reflecting variability on the market and the network, they can adapt their behaviour (through automation or personal choices) to save on energy expenses. Smarten (2016) Explicit and Implicit Demand-Side Flexibility. Accessible here.

need to be further clarified before implementation, but their implementation should be the priority. With respect to DSR, Member States should:

- Define at least one aggregation model applicable to all types of DERs for each market and system operation service in national rules; and
- Implement a proper transfer of energy model between independent aggregators and suppliers to allow participation in all market segments and fair competition.

246 Beyond the regulatory framework, technical blockers for the participation of DSR in the electricity markets should be lifted. To ensure that the key enablers are in place for demand-side participation, the penetration of smart meters in the Member States should be accelerated to reach the 80% target of smart meter roll-out as early as possible. Further, data access and interoperability of data, in a non-discriminatory and secure manner should also be ensured. Last, adequate DSR volume estimation methodologies (baseline) should be implemented, as proposed in the draft network code on DSR.

247 Both implicit and explicit DSR can bring significant benefits to the system, and they are complementary. As a result, it is key to allow consumers to access both mechanisms. Doing so, the interface between explicit and implicit DSR should be taken into account in the framework. This is particularly the case to measure and control for the actual response provided by consumers, in order to correctly identify DSR volumes activated for both implicit and explicit DSR, avoid double-counting and ensure fair remuneration for the different actors based on their contribution to system needs.

248 Regarding implicit DSR, all consumers should have access to time-differentiated contracts and should be able to choose according to their preferences. Time-differentiated retail prices should reflect the reality of the system. Network tariffs could also include static time-variant charges,[94] provided that the right balance is found between cost-reflectivity and complexity.[95] Time-differentiation can also be adapted to the local situations (e.g. periods of lower network tariffs could differ). On the retail market, Member States should avoid regulatory interventions on price levels in order to preserve market prices sending signals to consumers to adapt their energy consumption to system needs. Moreover, taxes and levies' application should be assessed to avoid them dampening or distorting efficient signals.

249 Improving consumers' awareness and access to information could also drive engagement in the short-term, as well as hedging. Didactic information and increasing "energy literacy" could drive aggregated PPAs across small users for instance.

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94 Static time-of-Use (ToU) network tariffs apply different prices for predefined time intervals, i.e. higher 'on-peak' prices and lower 'off-peak' prices.

95 See for instance Eurelectric (2024) Grids for Speed. Accessible here.

A Case study - The fight for light: energy security in a time of war

A.1 DTEK, Ukraine's largest private utility, has been facing the real cost of SoS threats come to bear for over 1,000 days. The timescale of days is more appropriate than years, as every day is a struggle to keep the lights on for Ukrainians – a metaphor of Ukraine's very struggle for existence. Nonetheless, DTEK remains the largest private investor in the wartime economy of Ukraine.

A.2 In a series of discussions with key figures within DTEK, Eurelectric has prepared this case study with their permission to tell the cautionary tale of SoS in the 21st century. Due to the ongoing state of war, information that is a matter of national security has been omitted while still offering a wholistic perspective of the situation on the ground and the actions taken to address the challenges faced. These revolve namely around hybrid attacks – both physical and cyber – and they may not be relevant for every utility's circumstances.

A.3 DTEK's fight for light has led to them drawing three key conclusions on SoS:

a. **Interconnection is indispensable**: diverse energy mixes that are connected to one another provide valuable flexibility when national generation cannot match demand. Synchronisation with the European grid proved crucial to SoS when Russia began targeting Ukraine's energy infrastructure.

b. **Decentralisation dilutes destruction**: consequences of destruction are greater for generation assets and collection nodes handling larger portions of capacity. Decentralising increases the cost of targeting these assets while reducing the equipment requirements for restoration in the case of damage.

c. **Defence and energy go hand in hand**: the energy system is the lifeline of a society and disruption not only has consequences for human life, but also signals reality on the ground. The war in Ukraine demonstrates the susceptibility of the system to kinetic attack and signalling advances, justifying collaboration among the energy sector and defence apparatuses.

A.4 These conclusions are especially relevant for Ukraine's energy system in a time of war. The following is a case study that reflects that reality. It goes without saying that there is no silver bullet and varying national circumstances may prove these conclusions more or less applicable, depending on SoS circumstances of that country.

Hybrid threats to energy security: physical and cyber attacks

A.5 Russia's war operations in Ukraine have included a campaign of targeted hybrid assaults on the country's energy infrastructure, both in terms of physical and cyberattacks. For DTEK, these attacks already began in 2014 with Russia's annexation of Crimea and operations in Donbas. Looking at the conflict spanning these ten years, we can break it into four distinct waves, with foresight on a fifth, and outline the specific impacts these phases had and may have on the future of Ukrainian SoS.

Wave 0: Pre-full scale war annexation and cyberattacks

A.6 The annexation of Crimea and operations in Donbas since 2014 meant that many assets in these regions fell into the hands of Russia, effectively rendering them useless. This immediately reduced the available capacity to power Ukraine and is a lasting feature of the conflict as territory is conquered or liberated. This is the most fundamental threat to a country's SoS in a time of war.

A.7 Looking back, DTEK's experience also showed them that a looming physical attack is generally preceded by cyberattacks. Cyber-related malicious activity has a baseline level, but leading up to the full-scale invasion on 24 February 2022, the scale and scope of cyberattacks increased significantly with millions of attempted infiltrations, signalling a grander strategy in motion supported by a foreign State adversary. Such cyberattacks lay the groundwork for invasion by taking critical energy infrastructure offline and sowing confusion and increasingly need to be considered in modern day SoS.

Wave 1: Physical attacks on grid infrastructure

A.8 In the days leading up to Russia's official invasion, energy infrastructure already came under attack. Infrastructure in Luhansk thermal power plant was shelled for 48 hours leading up to the invasion, leading to grids being disconnected. Then, in the early hours of 24 February, Russian forces crossed the border and began a march on Kyiv. Advances were preceded by grid disconnections which signalled to DTEK that those physical locations losing connection were seeing foreign forces move into the area. Shortly after the full scale war began, 500 MW of wind capacity in DTEK's portfolio was also occupied.

A.9 Following the foiled march on Kyiv and the settling in of a longer war, Russia, in autumn of the same year, began targeted shelling of transmission system substations to disconnect the country and plunge it into darkness. At one point Ukraine was an energy island meaning that it was disconnected entirely from external power sources, but since then, internal cooperation and interconnection with the European grid has reconnected the country and taught DTEK how to avoid large-scale blackouts which have not been returned to since.

Wave 2: Physical attacks on thermal and hydro generation

A.10 Ukraine's effectiveness reconnecting the country after the first wave pushed Russia into its second wave of the campaign to kill Ukraine's light. This time, they started to destroy thermal and hydropower generation assets, as well as substations of nuclear stations. These centralised assets were valuable targets as they represented large shares of Ukrainian power capacity.

A.11 This wave was quite effective, taking 90% of capacity offline. Despite this, DTEK has been able to restore around 70% of this capacity. Nonetheless, this was a wakeup call for Ukraine's allies. At the end of October 2024, anticipating further Russian attacks on energy infrastructure, ENTSO-E agreed to increase cross-border capacity with Ukraine from 1.7 GW to 2.2 GW and up to 2.5 GW in emergency situations.

Wave 3: Physical attacks on renewable generation

A.12 A new angle adopted by the Russians came in June 2024 when they began targeting the substations connecting RES to the grid – taking some 200 MW offline. However, such tactics seem more costly to Russia than to Ukraine. While the cost of a single missile can be exorbitant, a single renewable asset generally has a relatively low capacity and can be brought back online within days of a strike. DTEK has also been able to build 114 MW of wind power during the conflict, and they have committed to focusing efforts on drastically expanding renewable capacity in the country as a SoS priority.

Wave N: Post-war cyberattacks

A.13 When the kinetic war comes to an end, DTEK does not expect the hybrid threats to evaporate. They are anticipating a post-war period that becomes dominated once again by coordinated cyberattacks to knock out the country's energy system. Even beyond hot war, hybrid threats pose challenges to a country's SoS.

DTEK's response and key conclusions

A.14 Throughout these waves and in anticipation of the next, DTEK has been responding to the SoS challenges and drawing vital conclusions for its preparedness. These conclusions are summarised at the beginning of the case study but are further developed below.

Interconnection is indispensable

A.15 DTEK highlights that one of the key reasons the fight for light is still ongoing is thanks to the synchronisation of the EU and Ukrainian grid. This interconnection with the Bloc's abundant and diverse energy system provides indispensable flexibility to the Ukrainian system when generation is taken offline. The decision to increase available cross-border capacity ahead of winter 2024-25 is another step that shores up SoS for the Ukrainian system. As Ukraine rebuilds the energy system after the war, they foresee expanding interconnection capacity with Europe even more.

A.16 Beyond direct electricity connections, an interconnected energy system can also apply to the equipment needed to keep the system operational. DTEK is a vertically integrated company giving them access to stocks of equipment that has proven useful in repairing damaged and destroyed assets elsewhere. It also enables them to cannibalise some assets closer to the front that are not able to switch on and use the equipment for restoring assets further west, away from the front.

A.17 On a larger scale, the Ukrainian energy ministry pioneered the 'Mobile Brigade' which sends rapid response teams to locations across Europe where power plants are being decommissioned to collect equipment that is in shortage and bring it back to Ukraine. As a result, companies like DTEK have been able to procure the equipment they need rapidly without going through the regular procurement process which can take up to nine months in some cases.

Decentralisation dilutes destruction

A.18 The three waves of the kinetic war clearly showed DTEK that their most resilient assets were their decentralised renewable assets. A single missile that can take out a plant nearing a gigawatt of capacity can only destroy a single wind turbine or a small section of solar panels with a capacity of tens of megawatts. The dilution of destructive potential is clear, and it puts an opportunity cost on the enemy when deciding to launch an expensive missile at a low-yield target.

A.19 What is more, DTEK has found that these assets can be quickly repaired and brought back online, while their larger thermal plant can take months to bring back online. As Ukraine rebuilds its energy system, DTEK commits to putting renewables ironically at the centre of that new system. Already, all new assets being built are renewables – with a wind park being completed amid the current hostilities – and in the future, such assets as well as small modular reactors (SMRs) with the same decentralisation potential will be the forefront of their renewed energy mix.

A.20 Crucially for Ukraine today though, decentralisation is also helping make old Soviet energy maps in Russia's possession obsolete. The more Ukraine decentralises their system today, the less effective this intelligence is for the enemy, once again diluting the destructive potential of each Russian attack.

Energy and defence go hand in hand

A.21 The war has nonetheless proven that energy infrastructure is critical infrastructure, and it must be defended as such. Ensuring households have electricity is a social issue that, when not met, erodes morale, and connection to the internet not only helps manage the energy system but also depends on that system to power it. Given this criticality and the amount of effort expended by the Russians on destroying this infrastructure, DTEK has attributed a vital role to coordination with defence structures.

A.22 The most influential component of this relates to air defence. Unless air defence can be guaranteed for a DTEK asset, it does not run, meaning close collaboration with the country's military is necessary. This has been complex, as Russia's targeting abilities have improved from being able to strike within tens of meters to being able to strike within a meter. Meanwhile, the defence systems shooting incoming missiles down need the ammunition to do so. Coordination is the only way to ensure energy infrastructure is not at risk and that the defence structure is prepared to do the necessary to protect it.

A.23 But beyond that, in anticipation of future cyberattacks, the defence community would do good to collaborate with companies like DTEK to foil attempts to take out critical infrastructure and improve cyber-resilience across the board. Increasing decentralisation also means increased data flows that are susceptible to and provide information for attacks.

Five lessons for European energy security from DTEK case study

A.24 While not all of DTEKs conclusions apply entirely to each European utility, there are some common lessons we can learn from them to improve our SoS standing in regard to hybrid threats. These include:

a. The value of increasing decentralisation where possible

b. The value of secure supply chains for critical equipment

c. The value of an interconnected internal energy market

d. The value of cyber-resilience and preparedness for cyber threats

e. The value of coordinated approaches to energy security with the defence community

A.25 Safeguarding and/or developing in these areas, we can make a more secure European energy system suited to the current disruption in the world.

A.26 The EU should add other examples in addition to the DTEK one before concluding.

Who is DTEK?

A.27 DTEK is the largest private utility in Ukraine, the largest renewables developer and also has an international branch that invests in clean energy projects in Poland, Croatia, Romania and Italy. They are supportive of Europe's Green Deal and intend to use their international experience to bring lessons back to Ukraine.

A.28 As a vertically integrated company, DTEK in Ukraine provides traditional thermal generation such as coal and gas, as well as renewables and nuclear, providing about one quarter of the country's generation. They also produce about 1.6 bcm of gas in the country and they distribute about 40% of the power in Ukraine.

A.29 We thank DTEK for the discussions in preparing this case study and commend its fight for light in Ukraine.

Locations

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