OUTLOOK FOR RES INTEGRATION IN VISEGRAD COUNTRIES

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EXECUTIVE SUMMARY

Solar installations have been booming in Hungary and Poland in recent years and all Visegrad group countries are anticipating significant growth in variable renewable energy capacity by 2030, introducing the challenge and opportunity of surplus management. The challenge is overcoming the deeply-rooted Soviet-era energy systems designed to facilitate unidirectional flows of baseload coal and nuclear electricity, with the opportunity to seize lower energy prices, green the economy, and reduce energy dependency.

Massive grid investments in the form of cross-border projects, smart metering and smart grids, and energy storage will be required for the Visegrad countries to realize their energy transformation, but some of this classical infrastructure can be avoided or at least minimized with the development of competing and complimentary localized flexibility solutions.

Distribution level investments combined with time of use tariffs (ToU) will incentivize prosumers and battery operators to shift loads and provide grid cost-effective grid services. However, for demand response to function efficiently, transparent and dynamic price signals are needed – departure from the current regulated end-consumer price regimes.

The following recommendations are shared for each Visegrad group country and elaborate further in the final section:

- A comprehensive government-led national strategy grid operators, research institutes, manufacturers, system users and policy makers to develop a roadmap for grid development;
- Introducing the proper market design and regulatory framework for energy storage and dynamic pricing to unlock demand-response
- Evaluating potential for cost-effective local distribution-level flexibility solutions first, beginning with thermal heating and electric vehicle integration
- Provision of standardized national data for further research and analysis
- Joint regional dialogue and cooperation on flexibility measures as part of the next national strategic update

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INTRODUCTION

The V4 Energy Think Tank Platform (V4ETTP) was founded in 2018 by four representative think tanks, aiming to facilitate coordinated regional energy-related and policy-oriented research and analysis building on the expertise of each member institution in the field of energy policy studies. Within the framework of this cooperation, each organization publishes an annual policy paper which provides input and impetus for stakeholder workshops discussing the policy implications of the conclusions.

The 2023 V4ETTP work plan emphasizes regional solutions to the unprecedented energy market situation caused by Russia's war in Ukraine, which reinforces the case for accelerating the energy transition. This is the last of four working papers prepared as a joint effort between research colleagues from REKK (Hungary), SFPA (Slovakia) AMO (Czechia), and OSW (Poland).

After a period of stagnation, variable renewable energy sources (vRES) – mostly solar photovoltaic (PV) – are breaking through and poised for rapid growth in the Visegrad 4 (V4) countries. Since 2019, Hungary and Poland organized successful auctions that triggered a wave of investments in utility and rooftop solar PV respectively. Looking ahead to 2030, Hungary is expected to have among the highest solar PV growth rates and Czechia and Slovakia among the highest wind growth rates in the EU.[1]

This breakthrough is being driven by a combination of market and policy forces. Over the past decade technological advancements have significantly driven down costs for wind turbines and solar components and improved performance, meaning less direct financial support is needed in the form of feed-in tariffs from the state budget. Meanwhile, rising EU carbon emission prices will continue to erode the competitiveness of fossil-based energy production.

At the same time, the European Union (EU) has completely redefined energy policy goals under the Green Deal with respect to competitiveness, security of supply, and sustainability; all premised on a high penetration of renewables matched by a transformed energy delivery system fit for purpose. In March 20203, the EU reach a provisional agreement to raise the bloc's binding renewable energy target from 32% to 42.5% (a doubling of current capacity).

Russia's war with Ukraine has only reaffirmed this course of action for energy security purposes, attaching greater value to domestic sources of production. In May 2023, the EU agreed to the REPowerEU plan which declared the bloc's intention to free itself from Russian fossil fuels by 2027, keying in on a massive 'scaling-up and speeding-up' of renewable energy across all sectors.[2]

[1] Bartek-Lesi, Maria, et. al. (2020): National Energy and Climate Plans in the Danube Region

[2] European Commission (2022): REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition

Weather-dependent wind and solar PV will inevitably generate energy during periods of lower demand, creating a surplus that can be utilized by grid flexibility tools or curtailed. Curtailment is not only wasteful but destroys value and cost-competitiveness of variable renewable projects.[3] In order to avoid this situation, energy systems need to become more complex and decentralized, requiring not only innovative flexibility solutions but substantial levels of grid infrastructure investment.

This is all counterculture to current practices in V4 countries that have not changed markedly from Soviet times, which rely on highly centralized baseload energy systems, are in various stages of nuclear expansion, struggle to invest in aging infrastructure, and have not traditionally prioritized energy research and innovation funding. Consequently, network operators in Czechia and Poland have had to temporarily restrict renewable output in 2023. In Hungary, the bulk of winning solar PV projects from the latest auction are still facing connection delays, otherwise it would likely be in a similar situation.

The point is that energy variability has arrived in the V4, and each country is acknowledging if not embracing the upside potential for energy systems prioritizing vRES deployment, decentralization and flexibility. Most EU member states are at more advanced stages of vRES deployment and integration than the V4, but each face the same core transformational challenge: keeping infrastructure investments on pace with vRES deployments.

This paper begins by providing an overview of flexibility technologies in the EU under the broad categories of demand-response, energy storage, and interconnectivity. The next section brings the V4 into focus, comparing vRES trends and current primary energy storage shares. The next section summarizes V4 country-level flexibility plans and 2030 targets from the most recently updated strategic documents. The final section assesses V4 flexibility and energy storage needs according to the literature and in the context of the EU.

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[3] Denholm, P., Mai, T., (2017): *Timescales of Energy Storage Needed for Reducing Renewable Energy Curtailment*, National Renewable Energy Laboratory.

1 EU FLEXIBILITY SOLUTIONS FOR VRES SURPLUS

The main challenge in the transition to intermittent sources of energy is optimizing surplus produced at times of low demand - such as wind turbines running at night or high solar production in the summer - to avoid curtailment. The economic consequences of increased curtailment can be expressed externally, in terms of declining value, or internally, as an increased cost. With curtailment renewables no longer displace fossil generation, reducing economic and environmental value to the energy system and society as a whole.[4] It also increases the levelized cost of energy since fixed costs are spread across fewer energy units.[5]As much as curtailment can damage vRES project economics and suppresses investment, well planned and managed vRES integration will reduce energy prices and avoid some classic capital-intensive grid investments.

This section divides flexibility solutions into three broad categories, each of which will make significant contributions to EU flexibility requirements by 2030: demand response, interconnectivity and energy storage. These provision of capacity and services can range from highly complementary to competitive. For example, demand response can obviate the need for battery storage or add value to its operation. Energy storage is in direct competition with cross-border capacity, as it is shown to be more valuable in areas with less interconnectivity.[6] In the end, the choice comes down to cost of capital.

In fact, the diversification of flexibility technologies increases their individual contribution to covering flexibility requirements.[7] This is indicative of sector coupling, which allows for more interaction between energy vectors and sectors, for example x-to-power in times of low output (and high prices) and power-to-x in times of surplus (and low prices). The most cost-effective options are services provided by coupled electric vehicles and decentralized space heating. According to a recent European Commission study, the optimal use of these two flexibility tools could halve the need for batteries (67 GW vs 34 GW) by 2030.[8]

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[4] Mills, A., and R. Wiser (2021): *Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California*. Ernest Orlando Lawrence Berkely National Laboratory

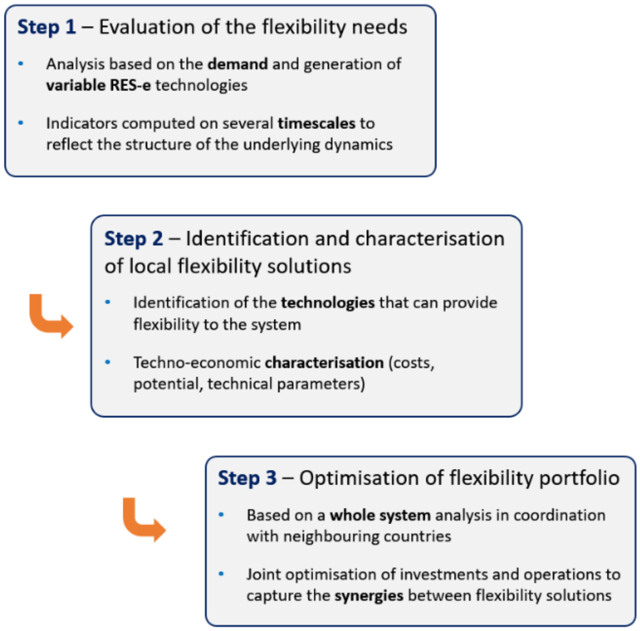
[5] Denholm, P., et. al. (2016): *Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California*, National Renewable Energy Laboratory

[6] European Association for Storage of Energy (2022): *Energy Storage Targets 2030 and 2050 Ensuring Europe's Energy Security in a Renewable Energy System*

[7] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

[8] European Commission (2020): *Study on energy storage – Contribution to the security of supply in Europe*. Final Report, DG ENER

FIGURE 1. RECOMMENDED FRAMEWORK FOR DEVELOPING FLEXIBILITY PORTFOLIOS



Source: European Commission[9]

The two most relevant pieces of EU legislation that will help set guidelines and overcome barriers to the deployment of flexibility tools are the Electricity Market Design and the network code on demand-side flexibility. In March 2023, the European Commission published its proposed reform of the Electricity Market Design. It would require by 1 January 2025, and every two years thereafter, the regulatory authority of each member state to assess the need for flexibility in the electricity system (draft Article 19c) and set indicative national targets for demand response and storage (Article 19d).[10] It also enables distribution companies to procure flexibility services from providers of distributed generation, demand response, and energy storage to promote the uptake of energy efficiency measures, especially as an alternate to network expansion (Article 32). Paragraphs 1 and 2 stipulate that member states shall provide the necessary regulatory framework to allow and incentivize distribution service operators (DSOs) to procure flexibility services including congestion management, market-based redispatching (Article 13) coverage of active customers (Article 15), and demand response aggregation (Article 17).[11]

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[9] Bardet, R., et. al. (2017): *Mainstreaming RES Flexibility Portfolios*. METIS Studies, European Commission.
[10] European Commission (2023): *Proposal for a Regulation of the European Parliament and of the Council, amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design*
[11] European Commission (2023): *Proposal for a Regulation of the European Parliament and of the Council, amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design*

1.1 DEMAND RESPONSE

Demand response, decentralization and the empowerment of prosumers are mutually reinforcing aims of the landmark 2016 EU Clean Energy package of legislative measures that have been implemented into national legislation by EU member states.

Demand response is predicated on transparent and dynamic market pricing that allows consumers to optimize distributed energy and/or storage through load management. Like energy efficiency, demand response is the most practical, cost-efficient flexibility tool that should always be considered first, before large grid investment decisions are taken. Furthermore, smart networks with controllable loads make it possible to shift demand in line with the tendencies of weather dependent production, in some cases offsetting the need for classic transmission and storage projects.[12] However such systems still require significant investments into distribution systems, including smart metering, smart grids and charging infrastructure for electric vehicles (EVs).

Smart grids enable more efficient use of existing networks and tap into the balancing and ancillary services of energy storage. Together with the time-of-use (ToU) pricing, smart meters can motivate consumers to actively participate in grid management by reducing overall consumption with information provided and shifting demand away from peak periods. Apart from shaving peak consumption, active grid management can facilitate the harmonisation of distributed generation and load profiles through local flexibility markets, which can be considered an alternative to traditional solutions like the capacity extension of balancing power plants and new transmission lines.

It is clear that network charges and dynamic tariffs are important tools for increasing the use of flexibility tools like energy storage and prosumers to reduce and shift consumption from the grid during peak hours. At the same time, energy prices are highly politically and socially sensitive, with end-user regulation a common feature throughout Europe and the V4. Therefore, the process of consumer price exposure will need to be taken cautiously and gradually.

1.2 ENERGY STORAGE

Energy storage is the pillar of energy system integration of renewable energy, electrification of the economy and the decarbonisation of other economic sectors. It can provide lower energy prices during peak times, reduce price fluctuations and empower consumers to adjust energy consumption patterns to price signals.

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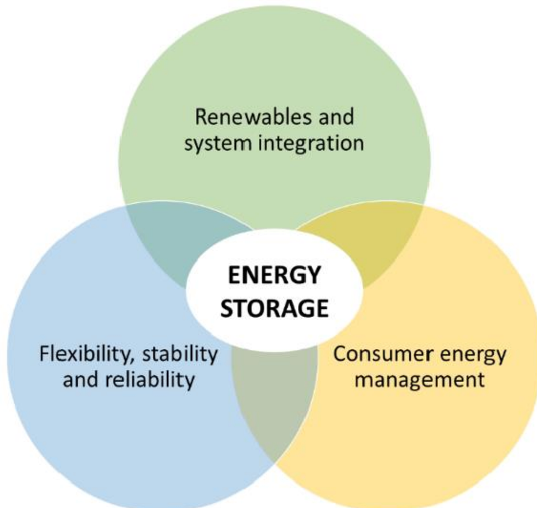
[12] Selei A., Rácz V., Törőcsik Á. (2023): *The role of energy storage within the electricity system of the future*. REKK.

FIGURE 2. ENERGY STORAGE CONNECTS VRES TO THE ENERGY SYSTEM



Source: European Commission[13]

Energy storage can be divided into four basic categories: (i) mechanical storage (pumped hydro), (ii) electrochemical storage (batteries), (iii) chemical (hydrogen) and (iv) thermal (heat). The fundamental technological differences among the storage options are expressed in terms of response time, power rating, and energy rating.

Higher amounts of solar generation typically require more daily energy shifting flexibility from electrochemical batteries whereas wind dominated systems need longer term energy shifting to account for days or weeks of low wind.[14] The European Commission model simulation shows that higher vRES capacities lead to higher ranges of profitability for energy storage.[15]

According to a recent stakeholder survey, the main barriers to energy storage in order of importance are the absence of long-term policy signals and double taxation, followed by bankability, and lastly technical limitations and incomplete data provisions. This suggests that it is not the technology holding back deployment but absence of long term policy regulation and incentives. In several EU member states storage services are not valued or rewarded ranging from short-timescale services like fast frequency response, voltage support and virtual inertia to long term services like energy security.[16]

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[13] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

[14] European Association for Storage of Energy (2022): *Energy Storage Targets 2030 and 2050 Ensuring Europe's Energy Security in a Renewable Energy System*

[15] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

[16] European Commission (2023): *Study on Energy Storage*, Energy Transition Expertise Centre, DG ENER.

Aside from properly valuing services, the business case for energy storage rests on energy arbitrage, which has to overcome two inherent side-effects of vRES on price formation; unpredictability and suppression of wholesale prices and spreads. Day-ahead and intra-day price volatility has been growing in Europe since 2020, which is a positive development for all energy storage technologies.[17]

EU storage snapshot

The European energy-storage market was strong in 2022, with a 97% year-on-year growth in grid-scale demand and 2.8 GW deployed.[18] Market deployments were led by front-of-the-meter installations, representing around 70% of the 2022 energy-storage market, followed by around 30% of residential storage, with limited growth of less than 2% planned for commercial and industrial storage.[19]

The Trans-European Networks for Energy (TEN-E) helps identify energy storage projects with cross-border impacts in the EU-wide TYNDP for selection as a Project of Common Interest (PCI), which benefit from accelerated permitting procedures and financial support from the Connecting Europe Facility (CEF). The TEN-E regulation is developing a new methodology specific to energy storage to assess the cost and benefits of candidate projects. There are currently 8 energy storage projects on the fifth PCI list (7 PHS and 1 Compressed-air energy storage (CAES)) and the draft TYNDP includes 23 storage projects totaling 41 GW.[20] The TYNDP 2022 scenario highlights the increasing relevance of flexibility options and the need to develop technologies other than cross-border transmission. The Electricity Market Directive reaffirms, this, encouraging TSOs to consider alternatives to network expansion, including energy storage.

The EU strategy for energy system integration highlights the importance of energy storage for sector coupling.[21] There are also several measures within the Fit-for-55 package promoting demand response and storage flexibility solutions, like the Energy Taxation Directive (aiming to end the double taxation of energy storage), RED III (facilitating demand response with deployment

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[17] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

[18] Darmani, A. (2022): *Europe's grid-scale energy storage capacity will expand 20-fold by 2031*. Wood Mackenzie Opinion.

[19] European Association for Storage of Energy (2022): *Energy Storage Targets 2030 and 2050 Ensuring Europe's Energy Security in a Renewable Energy System*

[20] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

[21] European Commission (2020): *Powering a climate-neutral economy: An EU Strategy for Energy System Integration*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

of electric vehicles), and Energy Efficiency Directive and the Energy Performance of Buildings Directive (installation of private smart recharging infrastructure).

The REPowerEU plan specifically highlights the importance of energy storage in ensuring flexibility and security of supply in the energy system by facilitating integration of renewables, supporting the grid and shifting energy so it is available when most needed.[22] It also acknowledges the important role of energy storage to reduce the use of gas power plants, which should be reconsidered especially by 2030.[23]

In March 2023, the European Commission published a series of recommendations on energy storage, outlining policy actions to help ensure greater deployment across the bloc.[24]

The EU legislative framework for inclusion of storage in network planning is largely set in place, but there are lags in implementation at the national level – both national transmission and local distribution network development plans. For now, energy storage assets are not sufficiently considered in the national networking planning process as an alternative to network expansion. In several member states storage is explicitly excluded from TYNDPs. TSOs tend to favor traditional capital expenditure heavy transmission infrastructure solutions over storage and less costly smart network investments. Furthermore, TYNDPs tend not to be aligned with NECPs, which could result in development scenarios that assess the role of storage providers differently, especially for smaller assets like demand side response (DSR), electromobility and residential scale batteries.[25] Currently energy storage assets (pumped hydro and/or others) are included in only 6 EU member state TYNDPs and energy storage in only five NECPs.[26]

1.2.1 THERMAL STORAGE

Sector coupling enables the storage of energy carriers other than electricity to provide services to the power system and allows for the possibility of thermal energy storage (TES). This requires a device that converts heat into electricity, for example stored heat can be used in secondary thermodynamic cycle with a steam turbine to generate electricity that can be injected into the grid in periods of peak electricity load.[27]

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[22] European Commission (2022): *REPowerEU Plan*. Communication from the Commission to the European Parliament and the European Council, the European Economic and Social Committee and the Committee of the Regions.
[23] European Association for Storage of Energy (2022): *Energy Storage Targets 2030 and 2050 Ensuring Europe's Energy Security in a Renewable Energy System*
[24] IEA (2023): *Grid-Scale storage*
[25] European Union Agency for the Cooperation of Energy (ACER) (2012): *Opinion No 05/2021 on the electricity national development plans.*
[26] European Commission (2023): *Study on Energy Storage*, Energy Transition Expertise Centre, DG ENER.
[27] Enescu et al. (2020): *Thermal Energy Storage for Grid Applications: Current Status and Emerging Trends*. Energies 13(2), 340 https://doi.org/10.3390/en13020340

Given certain conditions TES can be the most economically efficient storage technology, for example with installed heat pumps. Therefore, like energy efficiency and demand-response, TES should be considered first because it can moderate the need to increase generating capacity and lead to significant investment savings.[28]

TES responds to price differences on the electricity market (daily to seasonal) and allows an industrial process, a district heating network or a building to deliver services to the electricity market more cost-effectively than employing electricity storage. The primary revenue source for 'latent' and 'sensible' heat storage options are 'services to support behind the meter customer energy management'.[29]

1.2.2 ELECTROCHEMICAL - BATTERY STORAGE

Utility-scale battery storage protects against solar PV curtailment or cannibalization during peak hours, thereby increasing project profitability. This can further support system-wide cost-reduction by deferring the need for peaking plants and transmission capacity, limiting loads and reducing congestion.[30] At the same time, the arc of technological innovations, cost reductions and improved performance will allow utility-scale batteries to compete with conventional fossil-fuel peaking plants independent of vRES in some cases.[31]

Several factors including location, installed available power, and size of the storage units determine how economic and effective energy storage will be. The basic cost structure - high upfront capital and fixed costs - is similar to renewables. Currently ancillary services provide the primary revenue stream, followed by generation support and bulk storage services.[32]

Energy storage investments should be driven by the market rather than a regulated entity. This is why market design is critical, especially in the early stages, to ensure a price signal that is predictable and sufficient to stimulate investments. Specific supporting tools and enabling signals include: capacity contracts; floor and ceiling pricing; 24/7 clean power purchase agreements; contracts for difference; hourly energy attribute certificates; time-differentiated network tariffs or nodal pricing; energy savings performance contracts. Energy storage also shows promising profitability at higher emissions allowance prices.

However, this takes time to develop, and uncertainty surrounding planning permissions and wholesale electricity prices are formidable obstacles to large-scale battery investment. In the

[28] European Commission (2020): *Study on energy storage – Contribution to the security of supply in Europe*. Final Report, DG ENER

[29] European Commission (2023): *Study on Energy Storage.* Energy Transition Expertise Centre, DG ENER.

[30] SolarPower Europe (2022): *European Market Outlook For Residential Battery Storage*.

[31] Denholm, P., et. al. (2016): *Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California*. National Renewable Energy Laboratory

[32] European Commission (2023): *Study on Energy Storage*. Energy Transition Expertise Centre, DG ENER.

meantime the business case could be supported by a long-term capacity contract, which could be included in the regulated costs of the TSO. TSOs can help stimulate the market by organizing tenders with long-term contracts or contributing to the business case through with some ownership and auctioning capacity to the market on equal and transparent terms. Some believe that if storage has positive technical properties and a positive cost benefit analysis in specific circumstances, like intermittent congestions, then TSOs should be able to own and operate a storage facility for this purpose.[33]

TSOs can help stimulate market-based investments by setting tenders that ensure equal and transparent terms. They can also go a step further by taking ownership (regulated asset) and auctioning capacity to the market for all relevant timeframes (intraday, day-ahead, year-ahead), similar to interconnection capacity treatment. However, TSOs are not inclined to invest in utility battery storage precisely because of the risks - uncertainty over the length of planning permissions and wholesale electricity prices.

Furthermore, the provision of system and network information by network operators allows market participants to anticipate system conditions, which helps for example storage operators optimize siting and sizing decisions, and also determine whether to offer balancing or dispatching. For now, the level of information provided by network operators on the ENTSO-E Transparency Platform varies per data type and TSO/member state, focusing on cross-border capacities and scheduled commercial exchanges rather than locational data that would serve DSOs procuring storage and TSOs re-dispatching services and voltage control.[34]

Household or behind the meter energy storage includes all energy storage systems that are connected to the residential, commercial and industrial infrastructures to maximize self-use of distributed energy resources (DER). The rooftop solar + battery pairing has the potential to reduce network costs, provide more stable energy prices, and empower prosumers.[35]

The desire of electricity consumers to use self-generated solar power and appetite for backup power will be the major drivers of residential-scale batteries, expected to make up around one quarter of global storage installations by 2030.[36] This will be accelerated through the implementation of net settlement regulation, which provides that self-consumers do not pay grid tariffs for own consumption.[37]

1.2.3 MECHANICAL - PUMPED HYDRO STORAGE

[33] ENTSO-E (2016): *Energy Storage and Storage Services*. ENTSO-E Position.
[34] European Commission (2023): *Study on Energy Storage*, Energy Transition Expertise Centre, DG ENER.
[35] SolarPower Europe (2022): Unleashing the potential of solar & storage, June, 2022
[36] BloombergNEF (2021): *Global Energy Storage Market Set to Hit One Terawatt-Hour by 2030*.
[37] ENTSO-E (2023): *Opportunities for a more efficient European power system in 2030 and 2040*. System Needs Study, TYNDP 2022, Final Version.

Traditional pumped hydro storage (PHS) dominates Europe's existing energy storage landscape and project pipelines. Out of 23 total TYNDP 2022 energy storage projects, 19 are PHS.[38] As such this technology will maintain an important role in the energy system, but as a bulk storage best suited for seasonal variations, it will lose ground to battery storage, which is better suited for short duration intervals, in the transition to renewable energy systems. The further expansion of PHS also carries environmental and social concerns for new sites.

1.2.4 CHEMICAL - ELECTROLYSIS

The growing share of vRES and their often-decentralized generation sites will increasingly provide opportunities for chemical electrolysis solutions. Ultimately, electrolysers can provide enhanced long-term flexibility to power grids that reduce the social cost of curtailment and provide green hydrogen for the decarbonisation of other sectors, especially industry and transport. However, they remain among the most expensive and least efficient flexibility tools due to the additional transformation from power to hydrogen and back to power.[39]

1.3 INTERCONNECTORS

Interconnector capacity is widely used today for load following. The larger the connected area the more they can be used to lower flexibility needs and to smooth out residual demand by aggregating weather variations and differences in energy mixes. The more interconnected a country is to its neighbors, the less it needs to invest in other flexibility options like storage and demand response.

Already the European Commission encourages such cross-border transmission projects in order to strengthen the single market and open competition among energy producers, ultimately benefiting consumers. Among the selection criteria for EU projects of common interest (PCIs, elaborated in the last section) with a cross-border impact is the integration of renewables.

Similarly, the European TSO network (ENTSO-E) has identified several opportunities to improve Europe's power system through additional interconnectivity. According to one simulation, 64 GW of additional capacity would be economically efficient between 2025 and 2030, a 55% increase from 2025.[40] Another model for 2040 estimates overall EU flexibility needs to be 132 GW, of which 88 GW are cross-border capacity and 41 GW of storage.[41]

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[38] ENTSO-E (2023): TYNDP 2022 Project Sheets

[39] ENTSO-E (2022): Potential of P2H2 technologies to provide system services.

[40] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

[41] ENTSO-E (2023): *Opportunities for a more efficient European power system in 2030 and 2040*. System Needs Study, TYNDP 2022, Final Version.

This infers that there should be several economically justifiable cross-border projects especially looking across a longer time horizon. Furthermore, the European Joint Research Centre (JRC) concluded that in terms of 2030 flexibility solutions, interconnectors will play a dominant role across all time scales, particularly longer ones.[42] In response, ENTSO-E and European TSOs have committed to support and deliver increased cross border integration through multilateral cooperation within Regional Coordination Centres.[43]

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[42] European Commission (2023): *Future EU power systems: renewables' integration to require up to 7 times larger flexibility*. News Announcement.
[43] ENTSO-E (2019): *Vision on Market Design and System Operation Towards 2030*.

2 V4 RENEWABLES AND FLEXIBILITY PROFILE

V4 countries arrive at some of the lowest 2020 renewable energy targets in the EU and reached them for the most part by virtual transitioning to biomass in the heat sector. Biomass remains by far the single largest source of renewable energy supply in the V4, with shares of 80-90% compared to 41% EU-wide[44]. Outside of Poland, solar PV has been the clear vRES technology of choice (see Table 1).

TABLE 1. V4 RES COMPOSITION

	Renewable energy supply in 2022				Renewable electricity capacity in 2022			
	Hydro	Biomass	Wind	Solar PV	Hydro	Biomass	Wind	Solar PV
Czechia	4%	90%	1%	4%	23%	17%	7%	53%
Slovakia	18%	79%	0%	3%	67%	10%	0%	22%
Hungary	1%	80%	2%	11%	2%	14%	8%	76%
Poland	2%	84%	10%	3%	5%	5%	38%	53%

Source: IRENA

V4 countries have traditionally relied on biomass for household heating in rural areas and increasingly co-firing of combined heat power plants. Governments have been reluctant to embrace vRES over the past decade because of exorbitant feed-in-tariffs under long-term (15 year) contracts from the early 2010s and because it is such a departure from the classical centralized, unidirectional energy systems the countries are accustomed to operating.

The traditional Soviet era baseload power grids in the V4, anchored by nuclear (Czechia, Hungary and Slovakia) and coal power generation (Czechia and Poland), have not changed much to date. These units are capable of providing long duration demand flexibility along with pumped-hydro storage (PHS) for seasonable variability and real time balancing, while short-term fluctuations in weather dependent production are still mostly covered by gas-fired power plants.

This is especially the case for Hungary, which is the only V4 country without any tradition of PHS (or hydro power), having opted for flexible gas-fired capacity instead of hydro in the mid-1990s (see Table 2). Hungary is also a first mover among the V4 in utility scale battery deployment. Since 2020 six new electrochemical storage projects have increased capacity more than 4x to 30 MW.

[44] S&P Global (2023): EU adopts renewable energy directive targeting 42.5% share in 2030

TABLE 2. CURRENT V4 PRIMARY ENERGY STORAGE TECHNOLOGY POWER CAPACITY (MW)

	Electrochemical	Mechanical
Czechia	12.4	1175
Slovakia	~2	1017
Hungary	28.18	0
Poland	1.2	1746

Source: ENTSO-E and national updates

The V4 National Energy and Climate Plans (NECPs), submitted in 2020, envisioned a similar renewables mix for 2030, maintaining if not slightly increasing the share of biomass. They each received the same criticism from the European Commission for lack of renewables ambition and detailed measures.[45] Four years later, the situation has changed rather dramatically for Hungary, Poland and Czechia.

Solar PV growth started to rise in Hungary and Poland already in 2018 before booming over the last few years to the point that each country has far exceeded expectations. Already in 2023 Hungary almost achieved its (first) 2030 target of 6.5 GW, reaching 5.5 GW (just over 2 GW household[46]) capacity. As recently as 2021, Poland's national energy strategy anticipated that solar PV capacity would reach 5-7 GW by 2030 and currently it is about 13 GW (10 GW household) with more than 20 GW of contracted capacity to be connected to the transmission and distribution networks.[47] Poland is the only V4 country with significant shares and plans for wind energy, with at least 9-10 GW onshore windfarms and 4-6 GW offshore expected in 2030.[48]

Poland's capacity market mechanism established in 2017 led to substantial storage and demand response contracts paired with vRES in 2018 and 2019 auctions. However, the introduction of a 50% discount for connection fees in the 2021 Energy Law amendment led to a spike in household PV installations without corresponding flexibility tools until the rule was changed in April 2022. This has led to the current situation of overvoltage in pockets of high-density household areas. The national TSO (PSE) was forced to reduce the generation of solar energy generation for the first time on 23 April 2023, a day of favorable weather conditions and low demand, after declaring a threat to the security of electricity supplies. This is after PSE ordered seven wind curtailments over the previous twelve months, none of which declared a threat to the system. The overcapacity exceeded 3000 MW, and both 110 kV and medium voltage sources were reduced by

[45] European Commission (2020): Assessment of the final national energy plan of *Czechia* / *Slovakia* / *Hungary* / *Poland*. Commission Staff Working Document.
[46] MAVIR (2023): *Installed capacity of PV generators from 2010 to October 2023*
[47] Ministry of Climate and Environment (2021): *Energy Policy of Poland until 2040.*
[48] PSE (2022): *Development Plan for meeting the current and future electricity demand for 2023-2032*.

approximately 2,200 MW. If not for the risk to the system, it would have set a new record for solar energy production (8.6 GW) that was set just two days earlier (8.4 GW). A PSE spokesman took the opportunity to warn that if the development of renewable energy sources only concerns production, curtailment can be expected to occur more frequently.[49]

Czechia, meanwhile, added nearly 300 MW of solar PV capacity in 2022, which is a year-on-year increase of 366%.[50] This perhaps contributed to Czechia's first case of curtailment, in fact only a matter of days before Poland's experience, on Easter Sunday, when the national TSO (CEPS) disconnected hundreds of solar PV units from the grid (approximately 400 MW for two hours).[51] However, the CEPS spokesman was confident that this was an isolated case created by a rare combination of adverse factors – the neighboring countries were all in surplus for Easter Sunday and the sun radiation for April was an anomaly.[52] Unlike in Poland, the owners of the plants will receive compensation.

Hungary's generous KAT scheme led to an explosion of utility scale solar PV projects, but they are facing a cumbersome connectivity process, perhaps buying time to delay Hungary's first curtailment episode.

All three countries have had to reevaluate their previous solar PV strategies accordingly (see Table 3). Czechia is preparing for the possibility of 5x the level of 2022 wind (.3 GW) and solar PV capacity (2.1 GW) in 2030.[53] Hungary has nearly doubled its previous 2030 solar PV target. Poland is in a similar situation to Hungary and expected to raise targets significantly in its revised NECP. Even with a more conservative approach, Slovakia is bracing for its first period of high vRES growth, and consequently all V4 countries are now focusing their attention on the pursuit of flexibility solutions.

[49] Sawicki, B. (2023): Stan zagrożenia dostaw prądu. Za dużo energii ze słońca
[50] OEnergetice.cz (2023): ČEPS v pondělí odpojil kvůli nerovnováze v soustavě stovky fotovoltaik od sítě
[51] Zachova, A. (2023): Czechia unplugs hundreds of solar plants due to sunny weather. Euractiv Czechia.
[52] OEnergetice.cz (2023): ČEPS v pondělí odpojil kvůli nerovnováze v soustavě stovky fotovoltaik od sítě
[53] Ministerstvo Průmyslu a Obchodu (2023): Vláda schválila klimaticko-energetický plán. Nastíní cestu dekarbonizace české ekonomiky

TABLE 3. V4 2030 RENEWABLE TARGETS

	Gross final renewable energy consumption		Renewable energy sources in electricity (RES-E)	
	first NECP 2030 target	updated NECP 2030 target	first NECP 2030 target	updated NECP 2030 target
Czechia	22%	30%*	16.9%	37%*
Slovakia	19.2%	23%	27.3%	29.5%
Hungary	21%	29%	20%	31.2%
Poland	21%	N/A	12%	N/A

Source: country NECPs

**WAM3 scenario achievable share*

3 OVERVIEW OF V4 PLANS AND PRIORITIES FOR FLEXIBILITY SOLUTIONS

3.1 V4

As mentioned above, V4 governments are exceedingly aware of the complex and unique challenges and opportunities they face integrating vRES into their energy systems. They have only recently set more ambitious vRES 2030 targets with some flexibility capacity targets, which are summarized below.

Prosumer / distributed energy – Because of the diffuse nature of small household distributed energy (rooftop solar PV and batteries), there are inconsistencies in national definitions and granular data is mostly unavailable.

V2G – All V4 countries except Slovakia are very ambitious with 2030 EV targets (see Table 4).

TABLE 4. V4 ELECTRIC VEHICLES

	Current EVs (2020)	2030 EV Target
Czechia	16,000	220,000 – 500,000
Slovakia	4,000	30,000
Hungary	10,000	700,000
Poland	20,000	1,000,000

Source: FPPE[54] with some additional national updates

As noted above, V2G can significantly enhance network efficiency and provide grid services, and without it such high EV growth and capacity rates could overwhelm the local grid system. For now, only Czechia and Poland mention V2G in their NECPs, but they do not provide concrete targets.

Smart meters – All V4 countries emphasize the need for smart grids and smart metering. Hungary set a target of 1 million smart meters by 2030 and Poland aims to have 80% of households equipped by 2028. Czechia is targeting 1.2 million in the first phase of its national strategy.[55][56]

Time of use (ToU) tariffs: V4 governments responded to the energy crisis with blunt policy interventions to shield households from volatile wholesale prices. While this was needed to a

[54] Mizak, J. (2021): *Visegrad Electromobility, State perspectives and challenges*. FPPE.
[55] Janouš, V. (2022): Malá revoluce. Češi dostanou chytré elektroměry, o akci se však příliš neví. Denik.cz.
[56] Ministry of Climate and Environment (2021): *Energy Policy of Poland until 2040.*

degree, especially for lower income households and considering the historic price levels, it supressed the price signal that would encourage less consumption.[57] At the moment, Hungary is the only V4 country that has not implemented ToU tariffs.[58] For Czechia, Poland and Slovakia ToU only applies to distribution and not transmission tariffs, and only Czechia includes power-based ToUs in addition to energy-based.

Interconnectors – The newfound consensus on vRES is encouraging neighboring member states to explore joint opportunities to exploit high potential wind and solar PV areas, connecting a production site in one country to a demand outlet in another. V4 countries already have excellent interconnectivity that provides cheap flexibility. For Hungary, cross-border flows are the main load following units in the power system.[59]

Green hydrogen – This remains an expensive flexibility technology. All V4 strategic documents highlight the potential for electrolysis but only Czechia has set a 2030 target of 400 MW.

Battery storage - Only the governments of Hungary (1 GW) and Slovakia (250 MW) have set indicative 2030 battery storage capacity targets, while Czechia utility CEZ has announced its desire to build 300 MW by 2030.[60]

New member states including V4 countries are rated among the worst locations for investing into storage by prospective investors.[61] This is attributable to financing challenges for capital intensive projects, lack of market development, and lower range of vRES shares which is less profitable for energy storage. Also, V4 countries are well connected and TSOs clearly recognize the benefits and potential of greater connectivity which, as alluded to above, decreases the value of storage. Reaffirming this, it is estimated that over the next decade the top ten European markets will be responsible for 90% of new grid-scale battery deployments.[62]

Nonetheless, storage solutions are needed urgently in certain situations under the backdrop of growing V4 vRES shares, meaning it is important to provide an enabling regulatory framework that allows the technology to compete fairly and be utilized properly (see Table 4).

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[57] Sklenář, O. (2023): *V4 fiscal response to the energy crisis*. AMO, V4ETTP.
[58] ACER (2023): *Report on electricity transmission and distribution tariff methodologies in Europe*.
[59] MAVIR (2023): *Gross daily electricity load, production and import*.
[60] ČEZ (2023): *ČEZ ESCO postaví ve Vítkovicích největší akumulátor v ČR. Baterie velká jako rodinný dům pomůže stabilizovat českou energetickou soustavu*
[61] European Commission (2023): *Study on Energy Storage*, Energy Transition Expertise Centre, DG ENER.
[62] Darmani, A. (2022): *Europe's grid-scale energy storage capacity will expand 20-fold by 2031*. Wood Mackenzie Opinion.

TABLE 5. V4 ENERGY STORAGE REGULATORY FRAMEWORK

	CZ	SK	HU	PL
Licensing body	No	URSO	MEKH	NRA
Participation in DA and ID markets	only PHS	Yes	Yes	Yes
Subject to double charging	Yes	No	Yes	No
Financial support	MF RES+ program	MFF, MF, JTF, REPowerEU chapter RRF	MFF, MF, national tender for batteries + vRES	
Included in Network Development Plan (NDP)	No	Yes	No	Yes, under special conditions
Participation in capacity / ancillary service markets	Yes, only aggregators	Yes, Yes	Being prepared	No, Yes
Distribution withdrawal tariff for battery operators / prosumers	N/A, Yes	Yes, Yes	Yes, Yes	No, Yes
ToU tariffs	Yes*	Yes*	No	Yes*

Source: EnTEC study on energy storage March 2023 and some national updates

**only distribution not transmission*

Slovakia is a good example, since it seems that its first standalone battery storage commissioned in August 2022 is a success, with five companies licensed to provide ancillary services[63]. At the same time, the western distribution company (ZSE), also behind the ACON PCI cross-border smart-grid project, has received criticism over its TYNDP listed 384 MW capacity (250 GWh) grid scale battery project at a cost of EUR 250,000 million, which would become one of the largest in Europe. A group of companies and organizations sent a joint letter to the Ministry of Economy, arguing that the size does not align with need or capacity.[64] This shows that especially in less favourable markets like the V4, battery storage must be thoroughly evaluated on a case-by-case basis to ensure that there are not better alternatives available.

3.2 CZECHIA

In Czechia's updated NECP, the first headline electricity target calls for the major development of wind farms (to complement solar PV installations), followed by the development of flexibility management elements (storage and demand response). It states that the national TSO (CEPS) will

[63] SEPS (2023): Podporné služby
[64] Energieportal.sk (2023): Na Slovensku sa plánuje obrovské batériové úložisko. S vysokými nákladmi a otáznym prínosom

build an electricity data center that will anchor implementation of a new market model involving electricity sharing, storage and flexibility. It promises to provide balancing services with enhanced options compared to the current situation, relying on gas fired plants, with the aim of enabling decentralized energy. Regardless, it admits that with the pace of renewables growth and the need to strengthen the grid's resiliency and ability to adapt, natural gas will temporarily play an enhanced role.[65]

It is also worth noting that the document confirms that no parts were prepared at a regional level because joint programming was not possible due to time constraints during the preparation and with it being the first of its kind. With this in mind, it expresses a desire to initiate joint preparation of selected topics with neighboring member states when drawing up the next revision.

In 2021, the national utility (CEPS) updated the network code to allow participation of battery storage units in balancing markets. The latest (2022) TYNDP acknowledges the improving competitive position of batteries attributable to the decreasing cost and being near compulsory for rooftop solar power plants. It also highlights the importance of DSO plans for covering investments in technological system development, and the need to continuously update investment plans to keep up with applications for: electromobility and related charging infrastructure, storage development, integration of decentralized generation and renewable sources, development of flexibility and aggregation, increased data transmission and demand on IT systems and security. It expects smart charging management to be developed for electromobility, with V2G activated from 2025 to support grid stabilization.[66]

The government approved the last update of the National Smart Network Action Plan (NAP) in the fall of 2019, which deals in detail with demand side and overall flexibility measures. The law stipulates that from July 2024 companies will have to start installing smart meters at consumption points above 6 MWh/year, all of which should be replaced by the end of 2027.[67] Smart metering will also be mandatory for owners of solar PV.

Finally, while cautioning that high prices of materials and inflation are set to push investment levels for vRES integration even higher - to billions of euros over the next ten years - it notes that the figure depends on the success of legislative and technical measures which, if done correctly, can reduce total investment costs. It asserts that these costs will need to be reflected in network charges for end consumers, rising gradually.[68]

[65] Czech government (2023): *Update of the Czech National Plan of the Republics in the field of energy and climate*.
[66] ČEPS (2023): *Resource Adequacy Assessment of the Power Grid of the Czech Republic until 2040 (MAF CZ 2022)*
[67] *Vyhláška č. 359/2020 Sb.Vyhláška o měření elektřiny.*
[68] ČEPS (2023): *Resource Adequacy Assessment of the Power Grid of the Czech Republic until 2040 (MAF CZ 2022)*

3.3 SLOVAKIA

Slovakia's updated NECP points to the current electricity generation structure, anchored by a 55% share of nuclear power that is expected to grow to 70%, as the main obstacle for increasing national wind and solar PV ambitions. It also warns that 'rapid uncoordinated' connectivity of wind and solar PV will raise demand for support services which have yet to be developed. As such, it recognizes the growing need for flexibility solutions in the national energy system to provide the means for deploying domestic energy sources, demand response and energy storage, and outlines specific measures and actions to achieve this, including:[69]

- Providing a centralized data center to organize data flows from storage operators, energy communities and active customers.
- Improving grid mapping and analysis to develop local consumption management and storage (especially EV) concepts in an effort to minimize the transformation of electricity to higher voltage and then back to lower voltage at the point of consumption.
- Continuing to maintain and support existing PHS capacity and operation.

With support from the REPowerEU chapter of its national RRP, Slovakia succeeded in launching its energy data center in October 2023, operated by the short-term electricity market operator (OKTE). As dictated in the amended national energy law, it will serve as the central platform for data exchange, to improve market functioning for active consumers (including with access to the electricity market for new entrants) aggregation activities, electricity sharing and operation of storage facilities.[70]

Prior to this, Slovakia introduced a new energy law No 251 (October 2022) and Market Rules Decree (March 2023) that give energy storage the right to connect to the TSO/DSO system, participate in ancillary services and provide flexibility, also for aggregation. Under the current regulation batteries are only eligible to provide FCR services and prosumers are (over) charged with injection and withdrawal capacity fees.[71]

Both the Ministry of Economy and national TSO (SEPS) are outspoken in their conviction that intelligent battery storage will become the new standard for energy markets. In January 2022, the Ministry set a target of 68 MW energy storage by 2026.[72] Then in October 2023, it launched a call from the RRP to support new VRES installations and battery systems to increase power grid

[69] Ministry of Economy of the Slovak Republic (2023): Draft update of the Integrated National energy and climate plan for 2021-2030.
[70] SEPS (2023): *OKTE spúšťa Energetické dátové centrum, ktoré umožní prístup na energotrh poskytovateľom flexibility, energetickým spoločenstvám aj prevádzkovateľom zariadení na uskladňovanie elektriny*
[71] European Commission (2023): *Study on Energy Storage*, Energy Transition Expertise Centre, DG ENER.
[72] Jenčová, I. (2022): *Rezort hospodárstva podporí uskladňovanie obnoviteľnej energie. V hre sú vodík aj batérie*. Euractiv.

flexibility. SEPS identifies the development of smart metering systems and smart grids as a key condition to meet emerging trends of aggregation, flexibility and dynamic pricing.

3.4 HUNGARY

Hungary's original NECP already emphasized the importance of flexibility services, recognizing that the higher penetration of renewables can only be achieved in parallel with the development and 'enhanced intelligence' of transmission and distribution network operation.[73] Furthermore, it recognizes the potential and need for innovative energy storage and flexibility solutions in the electricity market and outlines regulatory and support structures to achieve this, including:

- Developing complex price regulation to encourage innovative smart solutions and market procurement of flexibility services (storage and demand response). For energy storage in particular, it will simplify the authorization process for market accreditation and develop balancing products that help to optimize technical potential.
- Focusing on the active participation of consumers on the energy market, which allows them to control their overhead expenses and potentially contribute to system balance - opportunities that can be exploited with digital and smart devices.
- Proposal to eliminate price caps on balancing markets and introduce marginal cost-based scarcity pricing to ensure price signals encourage investments.

It encourages several pilot projects for seasonal storage, e.g. converting excess electricity into heat and storing it in DH systems using electric boilers and hydrogen, also using the transmission and distribution networks in order to:

- Develop power-to-gas technology based on the already operating domestic prototype.
- Convert surplus electricity into heat and its storage in district heating systems also using electric boilers.
- Develop optimal storage and consumption of hydrogen produced with electricity.
- Test small-scale commercial application of cold energy and heat storage solutions under operating conditions.

As regards innovative system balance (flexibility energy storage and demand management), it encourages DSOs and TSOs to launch pilot projects within energy storage systems, specifically for:

- The establishment of a complex, pilot-scaled research and development centre to coordinate and complete currently fragmented research to test the systemic interconnection of various renewable sources of energy and energy storage technologies.
- Testing of complex DSR solutions on the level of individual prosumers.

[73] Ministry of Innovation and Technology (2019): *National Energy and Climate Plan.*

For the last METAR auction scheme in 2022, the Hungarian Ministry of Energy added a requirement for battery storage capacity to accompany bidding projects in the renewable energy tender, providing at least 10% of the nominal power plant capacity.[74] Then in February of 2023, Hungary's energy minister announced the need for the construction of CCGTs to provide flexibility for the boom in solar capacity.[75]

From the updated NECP, the first headline target for improving flexibility capabilities in the electricity market is the addition of 1500 MW of CCGT capacity by 2027, while the second headline target refers to electricity storage.

The document also draws attention to the Slovenian-Hungarian cross-border line completed in late 2022, which means that Hungary is now connected to all neighboring countries. Under sector coupling, it identifies the key task to be strengthening market integration in both intraday and balancing markets.[76]

In June 2023 the European Commission approved Hungary's EUR 1.1 billion support scheme for the installation of at least 800 MW/1600 MWh of new electricity storage facilities.[77] The storage projects to be supported under the scheme will be selected through a competitive bidding process, which will be organized by the energy regulator (MEKH). The aid will have two pillars: an investment grant, which will be paid during the construction phase of the supported projects; and support in the form of a two-way contract for difference ("CfD") to be paid annually during the first ten years of the operations phase of the supported projects.

Finally, Hungary is also prioritizing energy storage in the coal transition. The LIFE-IP North-HU-Trans project is responsible for the decarbonisation of the Matra Power Plant, the last remaining coal power plant in the national energy system, and in doing so sets out to develop, test and evaluate innovative flexibility tools such as energy storage and network solutions, to support the expansion of renewable energy generation.[78]

3.5 POLAND

Poland's first NECP recognizes that the growing volume of vRES connected to the distribution and transmission grid, especially distributed generation, is changing the profile of electricity consumption and the need to develop short duration energy storage technology along with it.[79]

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[74] Renewables Now (2022): *Hungary opens tender for 864 GWh of renewable power*

[75] Portfolio (2023): *Orbán Viktor bejelentése után máris indul az új gázerőművek közbeszerzése*. Kormány.hu (2023): *Ajánlati szakaszba lépnek a kelet-magyarországi erőművi blokkok közbeszerzései*.

[76] *Hungary National Energy and Climate Plan, Revised version*. 2023.

[77] European Commission (2023): *State aid: Commission approves €1.1 billion Hungarian scheme to support electricity storage facilities to foster the transition to a net-zero economy*

[78] IEA (2022): NECP - LIFE-IP North-HU-Trans project

[79] Poland did not submit its updated NECP at the time of this writing.

It also highlights the positive impact of developing technologies for energy storage and their positive impact on the scale of vRES utilization - specifically battery energy storage systems (BESS) facilitating the integration and development of distributed energy. It views energy system wide innovations seizing on technological advancement, efficiency of operation and competitiveness of business models, as key drivers of the Polish economy.

It also highlights the potential for hydrogen and electrolysis to advance energy storage solutions, with its unique ability to absorb surplus vRES for long periods with the possibility of rapid utilization, and perceives tremendous opportunity for electromobility and the use of EV batteries to store energy, stabilize grid operations, and advance battery technology. At the same time, it will prioritize the development of gas-based generation to back-up weather dependent renewable energy.

Concrete measures include:

- Increasing flexibility of the energy system in relation to renewable energy, including real time price signals and the introduction of intra-day trading (dynamic pricing will be introduced in 2024).
- Guaranteeing appropriate flexibility though expansion of networks, modern generation units with control options, and smart networks along with smart metering systems.
- Supporting V2G technology with the development of charging infrastructure.

Poland's most recent national strategic document from 2021 identifies two important and mutually reinforcing milestones for progress.[80] First is the creation of a new energy market operator (OIRE) to oversee data availability and transparency which will become an opportunity for the development of new services, products and incentives for end consumers, as well as for the efficient use of energy in public space. Wider access to information will also allow the TSO and DSOs to manage the power system in a more optimal way. Second is the smart metering of households, towards achieving the connectivity target of 80% end consumers to a distribution network by 2028 set out in the 2019 draft amendment to the Energy Law that introduced the Polish smart metering system.[81] The stated foundation for its development is information and communication technology (ICT) solutions. In addition to two-way digital communication systems, this includes smart metering systems, automation, regulation and grid protection and metering for the flow of power and energy data.

The smart grid will integrate the behaviour and actions of all users connected to it – generators, consumers and prosumers of renewable energy, while OIRE will ensure the exchange of information between system participants. With access to their metering data, consumers will be able to respond to dynamic tariffs and contribute to flattening of the daily energy demand curve.

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[80] Ministry of Climate and Environment (2021): *Energy Policy of Poland until 2040.*

[81] Executive Summary of Poland's National Energy and Climate Plan for the Years 2021-2030

This is a major step to building a new, decentralised energy system and market model based on distributed energy generation and dispersed consumption, where end consumers are active market participant through demand-side response, aggregation, and dynamic price contracts. In recognition of this, DSOs will be provided the opportunity to create separate local balancing areas to keep energy localized and reduce transmission losses. Energy communities are also singled out, with a target of 300 by 2030.

The Polish TSO (PSE) considers direct energy storage and hydrogen-based technologies the most promising energy storage options. It also notes that under the EU Clean Energy package, implemented in in 2019, all member states TSOs are obliged to make available not less than 70% of technical connection capacity for cross-border exchange as of 1 January 2020, but Poland was granted an exemption until 1 January 2026.[82]

[82] PSE (2022): *Development Plan for meeting the current and future electricity demand for 2023-2032*.

4 OUTLOOK FOR EU AND V4 FLEXIBILITY

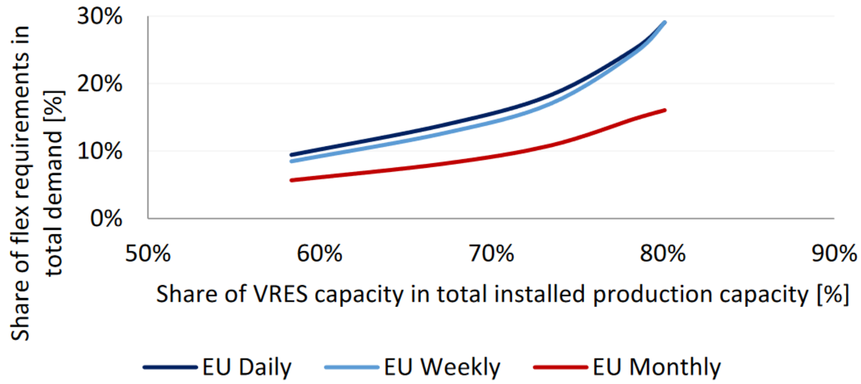
In 2022, over 40 GW of solar PV was installed in the EU, nearly 50% more than in 2021 (compared to only 19 GW of wind, less than a 10% growth from 2021), which prompted a group of EU renewable associations to author a letter to the European Commission warning of curtailment in the absence of adequate grid solutions.[83]

A natural question is whether there is a common linear relationship between renewable energy share and energy storage needed in an electricity system. This has been addressed quite extensively in the literature, with estimates for energy storage shares ranging from 20% to beyond 60% of the renewable energy share.[84] Of course there is no single and precise answer to this question. The extent to which balancing can be done largely without energy storage depends on several factors: the grid design, quality of the grid, size of the system, technologies used to generate electricity, the capacity of interconnections with other systems, how markets are operated, the level of demand side management and the international cooperation with neighbouring systems, i.e. energy storage is more pressing for an island system than a large and well connected market.

V4 countries lag behind EU averages and are nowhere near the 60% vRES threshold the bloc as a whole and several member states are preparing for (see Table 3). Past studies have landed on a 33% threshold for vRES penetration, finding that up to this level changes to grid operation - including greater regional cooperation and demand response - can lead to economic integration without the need for significant deployment of 'enabling' technologies such as energy storage or curtailment.[85]

[83] Jones, F. (2023): *EU renewable associations call for renewable curtailment solution*.
[84] European Parliament (2015): *Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?*, Study for the ITRE Committee, DG for Internal Policies, Policy Department A, Economic and Scientific Policy.
[85] Denholm, P., et. al. (2016): *Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California*, National Renewable Energy Laboratory

FIGURE 3. SHARE OF DAILY, WEEKLY AND MONTHLY FLEXIBILITY REQUIREMENTS IN TOTAL DEMAND IN RELATION TO INCREASING SHARE OF VRES CAPACITY IN TOTAL INSTALLED PRODUCTION CAPACITY IN THE EU



Source: European Commission JRC analysis[86]

Contrary to widespread belief, a few percent of solar PV capacity in the energy mix tends to decrease the needs for daily flexibility since generation coincides with periods of high-power demand and smooth out the residual demand over the day. As a result, solar power capacity does not create additional needs for flexibility as long as the PV generation is lower than 10-12% of the annual power production.[87] Hungary and Poland have just entered this range in solar PV and wind respectively.

[86] Koolen, D., et. al. (2022): *Flexibility requirements and the role of storage in future European power systems*. Joint Research Centre, European Commission

[87] European Commission (2016): *The role and need of flexibility in 2030: focus on energy storage*. Study S07, METIS Studies.

5 CONCLUSION AND RECOMMENDATIONS

This paper highlights several options for mitigating the balancing effect of vRES on the electricity system and avoiding curtailment. It starts in the earliest stages of conception, beginning with smart project planning, ideally near a demand center, and better forecasting or shorter gate closure periods, which allows for smart grid solutions.

Going forward, each country will need to evaluate current conditions with an aim to guide and incentivize the most cost-effective combination of flexibility solutions at every opportunity. This starts with the aforementioned optimization of THS and EVs while developing and improving demand response systems in an effort to minimize classic grid scale projects.

Member states need to ensure that TYNDPs reflect the revised NECPs to so that flexibility strategies are aligned with higher renewable targets. The strategies themselves should reflect the urgent need to reduce fossil fuel imports and advancements in storage technology innovation and cost assumptions. Moreover, full adoption of the aforementioned EU regulations and recommendations is essential for market transparency, competition and price signals.

Provided favourable technical and economic conditions, electricity storage combined with other sources of flexibility can help optimize the whole network development plan, including lowering cost of vRES integration and addressing public acceptability issues. Another advantage of storage is that - assuming the proper regulatory framework and incentives exist - it can be rapidly implemented, e.g. in response to curtailment. For example, a standalone battery can be deployed in less than a year and behind-the-meter in a matter of days.[88] However, there are also cases where more efficient sector coupling solutions like THS, EVs, distributed energy load shifting, or interconnector capacity would make battery storage investment redundant. Most importantly, energy storage should be considered a facilitator rather than a requisite for renewable energy growth and integration; the key issue and challenge is how to ensure the balancing of the system at all times with increasing sources of intermittency.

The following recommendations apply for all EU member states to varying degrees, some having made more progress than others, but especially V4 countries which are in the early stages of the energy transformation:

- **Comprehensive national strategy** - A government led constructive dialogue between all involved parties should start now to define the relevant technical requirements and develop a roadmap to make the new tools available to the system in time, bringing together TSOs, DSOs, research institutes, manufacturers, system users and policy makers.

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[88] European Commission (2023): *Energy Storage – Underpinning a decarbonized and secure energy system*. Commission Staff Working Document

- **Sector coupling** - Given the wide variety of options and complementarity between infrastructure (new or upgraded transmission infrastructure, electricity storage, power to gas or hybrid infrastructure) and non-infrastructure solutions (demand response flexibility and load shifting), sector coupling opportunities should be explored and exhausted before major classical infrastructure investments are made.
- **Market design** - Providing a framework for transparent and dynamic ToU energy pricing that enables and incentivizes demand response, energy storage and load shifting, alongside locational signals to ensure adequate vRES interconnectivity and reduces curtailment.
- **Network planning** –DSOs should be encouraged to prepare localized development plans and coordinate with TSOs.
- **Residential charging infrastructure** – The often overlooked but key measure to enable electromobility is found in the Energy Performance of Buildings Directive for the installation of private charging infrastructure. EVs spend the most time parked at home or work, where V2G can provide grid services.
- **Data access and aggregation** - There is an increasing need for data transparency and granularity, including on network congestion, renewable energy curtailment, market prices, renewable energy, GHG emissions content and installed energy-storage facilities; behind-the-meter storage facilities and thermal storage data is especially limited.
- **Regional dialogue and cooperation** - To ensure the cost-effective flexibility demand relevant V4 ministries and agencies should conduct regular exchanges of experience with counterparts to share experience relating to law, regulation, incentives and technological best practices in this process, especially pertaining to the next NECP update in two years.

AMO.CZ OSW REKK SFPA

ANNEX 1: V4 BATTERY STORAGE FACILITIES**

Country	City	Facility Name	Technology type	Power capacity (MW)	Energy Capacity (MWh)	Commissioning
Czechia	Dalesice	Dalesice-1	Mech./PHS	120	575	1978
Czechia	Dalesice	Dalesice-2	Mech./PHS	120	575	1978
Czechia	Dalesice	Dalesice-3	Mech./PHS	120	575	1978
Czechia	Dalesice	Dalesice-4	Mech./PHS	120	575	1978
Czechia	Jesenik	Dlouhe Strane-1	Mech./PHS	325		1996
Czechia	Jesenik	Dlouhe Strane-2	Mech./PHS	325		1996
Czechia	Mydlovary	Mydlovary	El.chem./Li-ion	1	1.75	2018
Czechia	Prakšice	Prakšice	El.chem./Li-ion	1	1.2	2017
Czechia	Královské Poříčí	N/A	El.chem./Li-ion	5		2023
Czechia	Vítkovice	N/A	El.chem./Li-ion	10	9.45	2023
Czechia*	Vraňany	N/A	El.chem./Li-ion	20	22	2024
Czechia*	Brno	N/A	El.chem./Li-ion	4	3.1	2024
Czechia	Stechovice	Stechovice-2	Mech./PHS	45		1948
Slovakia	Trenčín	Čierny Váh-1	Mech./PHS	122.5	605	1982
Slovakia	Trenčín	Čierny Váh-2	Mech./PHS	122.5	605	1982
Slovakia	Trenčín	Čierny Váh-3	Mech./PHS	122.5	605	1982
Slovakia	Trenčín	Čierny Váh-4	Mech./PHS	122.5	605	1982
Slovakia	Trenčín	Čierny Váh-5	Mech./PHS	122.5	605	1982
Slovakia	Trenčín	Čierny Váh-6	Mech./PHS	122.5	605	1982
Slovakia	Dobšiná	Dobšiná	Mech./PHS	24		1953
Slovakia	Dobšiná	Dobšiná III	Mech./PHS	0.32		2014
Slovakia	Trenčín	Liptovská Mara	Mech./PHS	198		1975
Slovakia		Ružín	Mech./PHS	60		1972
Slovakia	Ždiar, reg. Poprad	Ždiar - Bachledova dolina	El.chem./Li-ion	0.6	1.2	
Slovakia	Martin		El.chem./Li-ion	1.25	1.2	2022

Country	City	Facility Name	Technology type	Power capacity (MW)	Energy Capacity (MWh)	Commissioning
Slovakia	Senec		El.chem./Li-ion		432 (kWh)	2020
Slovakia	Humenné		El.chem./Li-ion		432 (kWh)	2020
Slovakia	Námestovo		El.chem./Li-ion		433 (kWh)	2020
Slovakia	Ilava		El.chem./Li-ion		864 (kWh)	2023
Slovakia*	Panické Dravce, reg. Lučenec		El.chem./Li-ion	6		N/A
Slovakia*	Sobrance		El.chem./Li-ion	9		N/A
Slovakia*	Piešťany		El.chem./Li-ion	35		2025
Slovakia*	Čierny Váh		El.chem./Li-ion	70	105	2031
Hungary	Tiszaújváros		El.chem./Li-ion	0.5	1	2013
Hungary	Kazincbarcika		El.chem./Li-ion	5.7	5.2	2021
Hungary	Békéscsaba		El.chem./Li-ion	1.19	2.4	2021
Hungary	Százhalombatta		El.chem./Li-ion	3.84	7.68	2021
Hungary	Aszófő		El.chem./Li-ion	2	2.3	2022
Hungary	Törökszentmiklós		El.chem./Li-ion	4.95	12.15	2022
Hungary	Budapest	Wärtsilä	El.chem./Li-ion	10	6.1	2018
Poland	Dychów	Dychow H1	Mech./PHS	28	83	1936
Poland	Dychów	Dychow H2	Mech./PHS	29	84	1936
Poland	Dychów	Dychow H3	Mech./PHS	28	83	1936
Poland	Miedzybrodzie Zywieckie	Porabka Zar H1	Mech./PHS	135	500	1979
Poland	Miedzybrodzie Zywieckie	Porabka Zar H2	Mech./PHS	135	500	1979
Poland	Miedzybrodzie Zywieckie	Porabka Zar H3	Mech./PHS	135	500	1979
Poland	Miedzybrodzie Zywieckie	Porabka Zar H4	Mech./PHS	135	500	1979
Poland	Zabrodzie	Solina Hydrozespol H1	Mech./PHS	68	686	1968
Poland	Zabrodzie	Solina Hydrozespol H2	Mech./PHS	68	686	1968
Poland	Zabrodzie	Solina Hydrozespol H3	Mech./PHS	31	313	1968
Poland	Zabrodzie	Solina Hydrozespol H4	Mech./PHS	31	313	1968
Poland	Tresna	Tresna	Mech./PHS	21		1966

Country	City	Facility Name	Technology type	Power capacity (MW)	Energy Capacity (MWh)	Commissioning
Poland	Zarnowiec	Zarnowiec H1	Mech./PHS	179	900	1983
Poland	Zarnowiec	Zarnowiec H2	Mech./PHS	179	900	1983
Poland	Zarnowiec	Zarnowiec H3	Mech./PHS	179	900	1983
Poland	Zarnowiec	Zarnowiec H4	Mech./PHS	179	900	1983
Poland	Zydowo	Zydowo H1	Mech./PHS	62	223	1971
Poland	Zydowo	Zydowo H2	Mech./PHS	61.6	223	1971
Poland	Zydowo	Zydowo H3	Mech./PHS	62.6	224	1971
Poland	N/A	N/A	El.chem./Li-ion	1.26	2.52	2018

Source: ENTSO-E 2020 report with national updates

**announced projects*

***Poland has not been updated after 2020*