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Integration of renewable energy in the Latvian grid

Executive summary

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Executive summary

Context and objectives of the study

Variable Renewable Energy Sources (vRES, solar PV and wind)[1] capacity in Latvia has grown from 100 MW in 2022 to over 420 MW in 2024 (Figure 1). The huge interest from vRES developers during last years and growth in vRES capacities in Latvia is expected to continue as well as their technical impact on the existing grid. Indeed, projects requesting connections to the transmission network is over 6 GW. The project queue is significantly larger than the existing generation capacity in Latvia (3.3 GW) and more than 5 times the current and short term forecasted demand capacity. Similar trends are observed in the other Baltic countries.

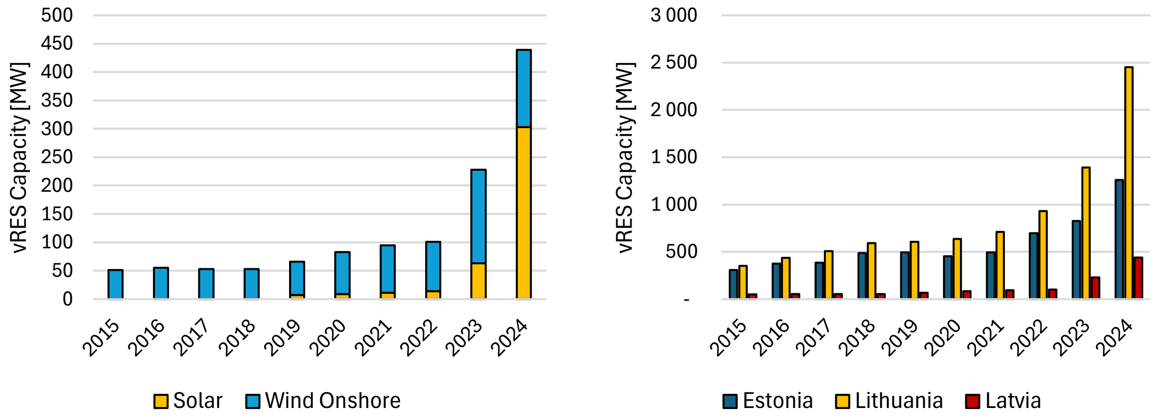

Figure 1: Solar and Wind installed capacity in Latvia (left) and in the Baltic countries (right). Source: ENTSO-E

The integration of large amounts of renewable comes with the need to increase in transmission capacity. Traditional grid infrastructure reinforcements (e.g. new lines) are costly and take around 10 years to be built. **Innovative Grid Technologies** (IGTs, also known as grid-enhancing technologies "GETs") **can be a complement to traditional infrastructure reinforcements**, allowing to reduce investments needs and increasing grid capacity. These technologies can often be deployed faster than traditional reinforcements, accelerating the integration of renewable energy waiting for transmission buildup. IGTs encompass a wide variety of technologies, including advanced equipment that enhances the capacity of existing infrastructure, such as Flexible Alternating Current Transmission Systems (FACTS) devices or Phase-Shifting Transformers (PST) that allow to control flows on the power grid, and software solutions that improve the operation of the grid such as real-time or curative redispatch and topology optimization.

Within this context, this study was prepared on behalf of Latvian electricity Transmission System Operator AS "Augstsprieguma tikls" (hereinafter – AST) with the following **two main objectives**:

[1] We make the distinction between vRES (PV, wind) and RES, which includes controllable generation such as hydro and geothermal.

1- Assess the hosting capacity of variable renewable energy sources in the Latvian transmission network, and
2- Evaluate the benefits of innovative grid measures in the integration of variable renewable energy sources

Methodology

The study is structured it two steps. First, an overview of IGTs was carried out, providing a knowledge base on the and the technical and regulatory requirements for the implementation of IGTs. Second, the hosting capacity of the Latvian grid and the benefits of IGTs were assessed through grid simulations. From the quantitative results, recommendations are formulated.

To perform the quantitative assessment, detailed grid simulations of the Latvian transmission system for representative operating points of demand and renewable generation integration were carried out using **PowSyBl Metrix**[2]. PowSyBl Metrix simulations are performed in two steps. First, a generation-demand balance is carried out without accounting for network constraints. Second, a **Security Constrained Direct Current approximation Optimal Power Flow** (SC DC OPF) ensures that the generation dispatch is compatible with the secure operation of the network. For this, the SC DC OPF computes optimal preventive and curative remedial actions (e.g., redispatch actions or adapting setpoints of IGTs) to respect all network constraints in all N and N-k conditions.

A base case without innovative measures and four innovative measures were implemented within this framework:

- Base case scenario, considering only preventive redispatch (before contingency)
- Curative redispatch (after contingency)
- Dynamic Line Rating (DLR)
- Equipment for increased power flow control (FACTS/PST)
- Battery energy storage systems (BESS)

Based on simulations performed for various levels of vRES installed capacities, we evaluated the **hosting capacity** of the Latvian grid for each of the innovative measures in study. The hosting capacity was determined by identifying the vRES installed capacity in Latvia for which the **marginal curtailment level[3] reached 5% of annual vRES energy generation**. The 5% threshold on curtailed energy is in line with existing flexible connexion contracts in France and Belgium[4].

[2] https://www.artelys.com/news/artelys-perform-smart-grid-cost-benefit-analysis-with-open-source-powsybl-metrix/
[3] The marginal curtailment is the curtailment of the additional integrated MW. While the average curtailment across all vRES installations might be low, the additional capacities might face higher levels of curtailment.
[4] Council of European Energy Regulators (CEER), 2023, *CEER paper on Alternative Connection Agreements*

Assessed scenarios

The vRES hosting capacity generally depends on demand and interconnection capacity. Therefore, the study was performed for the years 2025, 2030 and 2040, considering the latest projections on demand growth in Latvia. No grid infrastructure developments are considered by 2025 or 2030. 2040 scenarios consider the LasGo interconnector (Latvia-Sweden) and reinforcements in the western part of the grid including a subsea cable from Latvia to Estonia.

To account for the development of green hydrogen products based on vRES generation, two scenarios of electrolyzer development in Latvia were considered for the years 2030 and 2040 (Min H2, Max H2). For each year, the maximum vRES capacity assessed was limited to a reasonable level of around two times the maximum demand, as further vRES levels do not impact the hosting capacity. Key indicators for the studied scenarios are shown in Table 1.

Table 1: Peak demand (without electrolysis), electrolyzer capacity and assessed range of vRES capacities for the studied scenarios

Scenario		Peak demand [MW]	Electrolyzer capacity [MW]	vRES range [MW]
Year	Electrolyzers			
2025	-	1 196	0	0 – 2 500
2030	**Min H2**	1 599	260	0 – 5 000
	Max H2		750	
2040	**Min H2**	2 550	870	0 – 10 000
	Max H2		2 500	

Main results

The integration of vRES appears necessary to accompany the increase in demand in Latvia

The demand in Latvia is expected to increase in the coming years due to electrification and the development of hydrogen-derivatives products. Therefore, additional generation capacities or increasing imports will be necessary. The integration of vRES into the Latvian system allows to reduce fossil-fueled generation and import needs from neighboring countries, as shown by the results from the generation-demand balance phase of the simulations. By 2030, up to 2500 MW (Min H2) to 5000 MW (Max H2) of vRES can be added into before the Latvian system becomes a net exporter[5]. By 2040, 4000 MW (Min H2 scenario) can be added before Latvia becoming a net exporter, as shown in Figure 2.

[5] Even if Latvia is a net importer at the annual level, there can be hours of the year when Latvia exports excess generation.

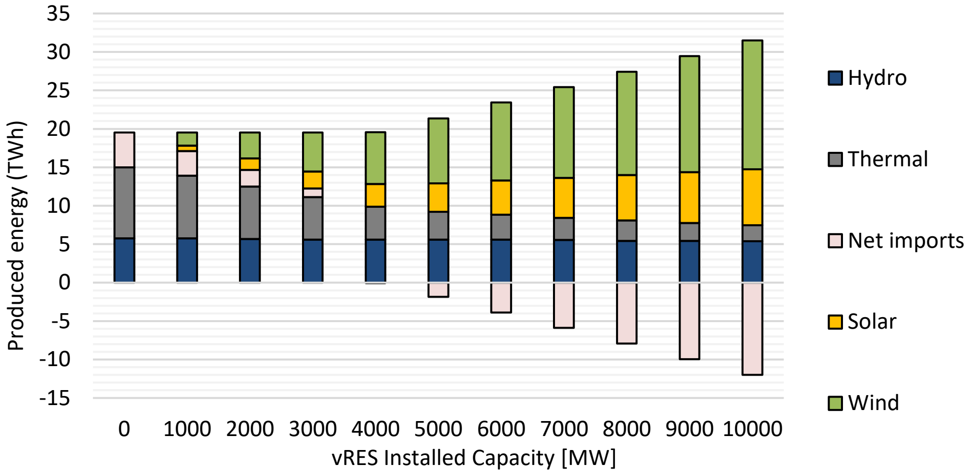

Figure 2 : Generation-demand balance in Latvia, 2040 – Min H2 scenario. Balance before any redispatch measure is taken. Negative net imports are exports.

The hosting capacity of the Latvian grid is between 3000 MW by 2030 and 5000 MW by 2040.

The SC DC OPF phase of the PowSyBl Metrix simulations identified vRES **curtailment due to grid constraints**. Curtailing vRES production is necessary to maintain the secure operation of the network (i.e., avoiding overloading of lines) in the N (pre-contingency) and N-k (post-contingency) situations. The hosting capacity of the Latvian grid was identified based on the marginal curtailment, which is the curtailment incurred by the additional vRES capacities.

In the base case, only **preventive curtailment**[6] was considered. By 2025, no significant curtailment is observed up to 2500 MW of vRES capacities. In the 2030 scenarios, curtailment starts appearing around 2000 MW of installed vRES, and growing quickly beyond 3000 MW, as shown in Figure 3, left. In the 2040 scenarios, due to the increase in demand (including electrolyzers), significant congestions are observed in the Latvian grid leading to curtailment even at low levels of installed vRES. Curtailment then grows quickly beyond 5000 MW of installed vRES as shown in Figure 3, right.

[6] Preventive curtailment is performed in is performed in advance of real-time (e.g., in day-ahead or intraday timeframes).

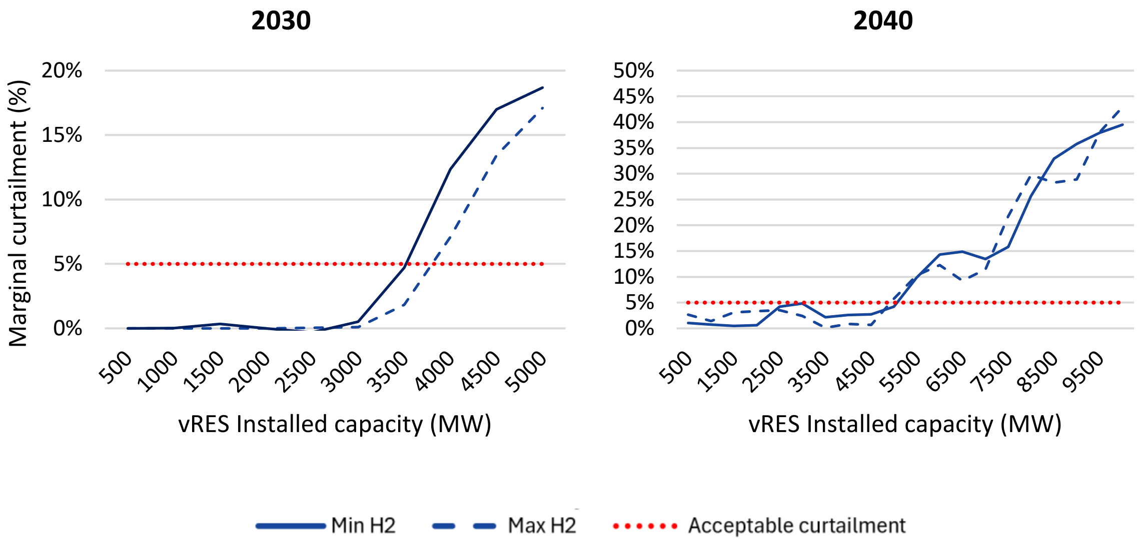

Figure 3 : Marginal curtailment for vRES in Latvia in 2030 (left) and 2040 (right), for both electrolyzers scenarios

The hosting capacity of the Latvian grid was computed by identifying the vRES capacity where the marginal curtailment reaches 5%. However, not all system operators have tools or legal basis (i.e., regulatory framework) to curtail vRES generation. Results show that **implementing preventive curtailment allows a significant increase of the hosting capacity of the grid,** as evidenced by comparing the cases with no curtailment allowed and allowing up to 5% of marginal curtailment (see Table 2 below)**.** This increase in hosting capacity will bring significant benefits to the system operation, allowing to reduce thermal generation and imports to Latvia as previously shown, at the cost of small levels of lost vRES generation.

Table 2 Hosting capacity of the Latvian grid with and without preventive curtailment

Year	No curtailment	5% Curtailment
2025	2000	>2500
2030	1500-2000	3500-3800
2040	<1000	5000

Results also show that the **electrolyzer deployment level has little to no impact in the hosting capacity of the Latvian grid.** An increase of around 300 MW in the hosting capacity is observed in 2030, and no difference is observed in 2040. This is due to two factors: first, the electrolyzers are relatively large and concentrated loads, not necessarily located close to vRES which are much more distributed all over the country. This limits the impact of electrolyzers in reducing grid congestion, as they are not co-located with vRES. Second, grid capacity is a limiting factor in the integration of renewable energy, and the overall increase in demand will put increasing pressure in the grid which cannot be relieved by electrolyzer deployment, as shown in the 2040 scenarios. Grid reinforcements would be needed to increase the hosting capacity of the grid.

Innovative grid measures can increase the hosting capacity of the Latvian grid.

The implementation of IGTs can increase the hosting capacity of the grid. IGTs reduce vRES curtailment by increasing the transmission capacity of the transmission lines (DLR), allowing to control flows on the grid (PSTs) and implementing new operational processes that improve the utilization of existing assets (curative redispatch).

The **hosting capacity of the Latvian grid can increase by up to 40%** with the implementation of IGTs. Hosting capacity can reach up to 4800 MW in the 2030 scenarios (+1200 MW), and by up to 7000 MW in 2040 scenarios (+2000 MW), as shown in Figure 4. The highest gains are observed for curative redispatch, followed by DLR. Battery energy storage systems (BESS) show little impact on the hosting capacity. Flow control equipment (PSTs/FACTS) gains can be important at the local level, but do not show significantly at the national level and are not shown in the figure. Higher gains can be expected if two or more IGTs are deployed jointly (e.g., curative curtailment and DLR).

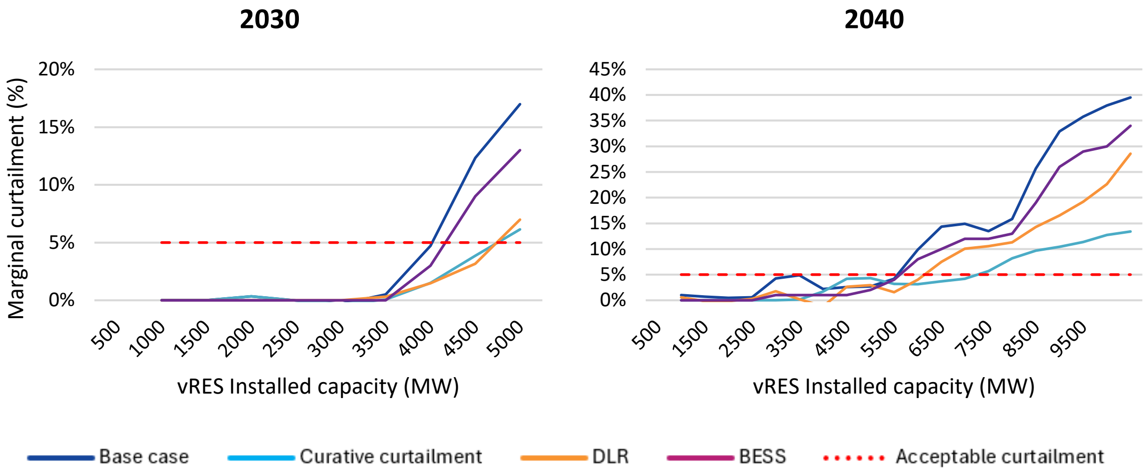

Figure 4 : Marginal preventive curtailment for 2030 (left) and 2040 (right) Min H2 scenarios, for the base case and three innovative grid measures

Innovative measures can provide significant economic benefits

An economic evaluation was performed based on the results of the simulations, that is the key factor for TSO, as regulated business. The benefit of each technology was calculated based on the **avoided curtailment**[7] allowed by the technology at the improved hosting capacity level. The avoided curtailment was then valued at 50 €/MWh to obtain a total value. Costs estimates were identified during the overview of IGTs phase. The benefit-to-cost ratio can be quite high for some IGTs in favorable conditions.

[7] Avoided curtailment by a given technology is the difference between the curtailment observed without the implementation of the technology and the curtailment observed with the implementation of it. This indicator is used by ENTSO-E (Indicator B3, RES Integration) for Cost-benefit analysis within the TYNDP context. See ENTSO-E, 2023, 4th ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects [link]

Table 3 : Range of benefits for the transmission system, costs and benefit-to-cost ratio (annualized) for the studied IGTs

IGT	Benefit range	Annual costs	Benefit-to-Costs ratio
Curative redispatch	7 – 26 M€	<5 M€	1.5 – 5.1
DLR	109 – 208 k€/DLR	23 – 128 k€/DLR	1.0 – 5.7
PST/FACTS	15 – 25 k€/MVA	5 – 22 k€/MVA	0.8 – 4.2
BESS (4-h)	5 – 26 k€/MW	170 k€/MW	<0.2

Curative redispatch provides the highest increase in hosting capacity and benefit-to-costs ratio of the studied IGTs

With curative redispatch transmission lines can be operated at higher levels, knowing that in case of a contingency actions will be taken quickly to restore the operational security of the network. Results show that curative redispatch has the highest benefits of the studied IGTs. It can **reduce curtailment by around two thirds** with respect to the case with only preventive redispatch, and this reduction is consistently observed even at higher levels of vRES penetration (see Figure 4). As such, the benefits of curative redispatch are more important in case of high vRES penetration (2040 scenarios).

Dynamic Line Rating can provide targeted increase of transmission capacity in wind-rich areas

DLR shows the second-best increase in hosting capacity among studied IGTs and presents high benefit-to-cost ratios (albeit a high uncertainty on due to a wide range of costs reported in the literature). DLR allows an increase in transmission capacity, and therefore allows to "delay" the occurrence of curtailment events to higher vRES penetration rates. However, contrary to curative redispatch, at once saturation is reached no further gains from DLR can be expected, requiring the buildup of traditional grid infrastructure.

Due to the increase of line transmission capacity to wind speed**, DLR is particularly well suited to be implemented in wind-rich areas**, helping the integration of wind generation. Results show that DLR can help reduce over 50% of wind curtailment, even in high vRES-penetration scenarios. The impact on solar generation is significantly lower (reduction of around 20% of solar curtailment in high vRES scenarios).

Advanced power flow control equipment can provide high value in congested corridors, allowing significant vRES integration in its vicinity

Technologies that allow to control the flow on power lines such as FACTS and PSTs can have significant impact on the integration of renewable energy in the area around its installation. They can be well suited in corridors with high levels of congestion and alternative routes to where flows can be redirected (e.g., meshed grids or parallel lines with uneven loading). FACTS (and in to a lesser extent, PSTs) can also have fast response times, allowing to adapt their setpoints in the curative phase (after a contingency), thus helping to use load lines at a higher level.

Results show that vRES curtailment in the area near the installation of flow control equipment can be drastically reduced, and the cost-to-benefit ratio based on the reduction of curtailment alone can be quite high in areas where there are recurring congestion issues and associated curtailment.

BESS used for the sole purpose of increasing vRES integration (e.g., avoiding curtailment) are not economically viable. Complementary value streams are needed for BESS installation.

Results show that BESS used only for increased renewable integration are not economically viable, being able to recover less than 15% of the annual costs from avoided curtailment. Additional value streams would be needed by battery operators to obtain profits from BESS installation, such as actively participating in the energy markets (energy arbitrage at the day-ahead and intraday timeframes) or balancing markets. Storage as transmission asset (SATA) approaches could still be possible is specific cases, specially **coupled with curative redispatch solutions** (e.g., SATA can override the N-1 criterion). The compatibility of stacking SATA with other value streams need to be assessed.

Recommendations

Recommendation #1 Unlock barriers to allow efficient curtailment in the operation of the power system

Preventive curtailment is the first step to integrate large amounts of renewable energy into the power system. Allowing preventive curtailment is a requirement for more advanced technologies or operational processes (e.g., curative redispatch). For this reason, the implementation of efficient preventive curtailment should be a priority for system operators and regulators. We identify three main aspects that should be addressed:

1- **Regulation:** Regulation of electricity markets and grid operation should allow the curtailment of renewable when deemed necessary (e.g., to ensure grid security). However, curtailment creates risks to vRES investors, and should be limited as much as possible. For this, regulation should ensure that curtailment is transparent (e.g., clearly defined rules or methodologies for curtailment) and compensated if needed.
   Regulation can also leave room for different mechanisms for curtailment, such as flexible connection agreements, which can allow vRES to have faster or cheaper connections to the transmission system in exchange of being able to be curtailed in critical situations (see ACER report[8]).
2- **Tools and processes for efficient redispatch:** TSOs should equip themselves with appropriate tools and processes to manage redispatch (including curtailment) in an optimal fashion, such as SC-OPF-based tools. In the first implementation, the redispatch process can take place in D-2 or D-1 timeframe. However, as renewable forecasts improve closer to delivery time, vRES curtailment processes should aim to be implemented as close to real-time as possible.

[8] CEER, 2023, *CEER paper on Alternative Connection Agreements*

3- **TSO-DSO coordination:** A significant amount of vRES will be connected to distribution systems, especially solar PV. Therefore, congestion in the transmission level can occur due to vRES generation at the distribution level, which can reduce the amount of vRES connection to the transmission system. In other words, to achieve the hosting capacities shown in this report, it is very likely that DSOs will face other challenges that were not investigated in this report as they are not under the TSO responsibility. In addition, TSOs and DSOs should establish coordinated procedures to implement curtailment on their respective systems, especially when curtailment is needed on DSO side to address a congestion on TSO side. This can include harmonizing communications and control requirements for the connection of vRES (e.g., ensuring that wind farms connected at the transmission and distribution level have the same control capabilities), and establishing communication and control procedures between the TSOs and DSOs.

Recommendation #2 Improve transmission planning processes for vRES integration and IGTs

IGTs should be integrated into planning processes as one of the business-as-usual options to increase grid capacity, being a **complement to traditional grid reinforcement options**. TSOs should therefore establish a knowledge base on the technologies, adopt appropriate tools and methodologies for their evaluation.

We note the following points, some of which go beyond what was performed in this study:

- Improve vRES models to assess hosting capacity. This includes: performing detailed market simulations to demand-supply balance and export capacities, and grid simulations to assess congestion and redispatch; improve timeseries modelling of vRES to account for spatial differences in Latvian regions;
- Use adapted modelling tools and methodologies to evaluate IGTs, such as SC OPF and multi-criteria analysis. A multi-criteria analysis approach should be considered to identify all the costs and benefits that IGTs can provide. IGTs can allow, among others, improved market integration among countries (e.g., by increasing cross-zonal transfer capacities), reduce generation and redispatch costs, and increased vRES integration (See for example the indicators used by ENTSO-E in their Cost-Benefit analysis, for which only one was assessed in this study).
- Have an efficient exchange of information between stakeholders to improve transmission planning and vRES sitting, including transparent information of development plans and timeline from vRES developers, and information about the available connection capacity of the transmission network from TSOs.

We propose a timeline for the implementation of IGTs in the Latvian transmission network:

- **In the short term**, identify candidate lines for the implementation of DLR. As DLR can have short deployment times and can be implemented line-by-line, it can be **deployed progressively** into the grid. DLR integration will also need to establish new processes or adapt existing ones (e.g., perform forecasting of line capacity, integrate DLR forecasts into cross-zonal capacity calculation, adapt operational procedures or protection setpoints).

- **In the short-to-medium term (2030),** assess the opportunities for advanced flow control equipment in the grid (FACTS/PSTs). Our analysis showed their economic viability in highly constrained corridors under high vRES penetration. Nevertheless, a complete assessment of the benefits of these technologies might make them viable under less restrictive conditions. It should be noted that detailed studies would be needed to identify the better-suited technology to be deployed, and correctly size the equipment.
- **In the medium-to-long term (2030 to 2040),** implement curative redispatch solutions in the Latvian transmission network.

It should be noted that the proposed timeframes depend on the speed of vRES deployment into the Latvian grid. A rapid uptake of vRES in Latvia can require the deployment of IGTs sooner and at larger scales.

Recommendation #3 Start work on advanced grid management, preparing the ground for solutions such as with curative redispatch

Implementation of advanced grid management solutions (e.g., curative redispatch) may be needed in the mid to long-term timeframe (beyond 2030). However, the implementation of these technologies complex involving several stakeholders (TSOs, vRES operators, BESS operators), and various entities inside them (planning division, operation division).

TSOs and other stakeholders should start working on setting the ground for these technologies now. We identify three main action points:

- **Technical requirements for advanced control of vRES:** Connection requirements for vRES plants should be defined to be compatible with future advanced control strategies. These requirements should include communication protocols/requirements, control modes (e.g., **emergency mode** to quickly shut down the vRES plant, and **limiting mode** where a maximum injection point is defined), and response times.
  These requirements should also be aligned for other technologies that may play a role in grid management such as BESS.
- **Flexibilities management:** TSOs should start working on the use of flexibility for the operation of the power grid. Implementing processes to make use of flexibility at the local level from both transmission-level assets and distribution-level assets (e.g., demand response) should be a first step. While BESS might not be economically viable as a pure transmission asset, they can still provide services to the transmission system through other mechanisms (e.g., redispatch, local flexibility markets, etc.).
- **Skills building:** Operational and planning process will be impacted by these technologies, requiring agents to have the preparation to manage grids in real-time.