Power System Flexibility in the Penta region – Current State and Challenges for a Future Decarbonised Energy System

Final report

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CONTENTS

List of acronyms

[a/m]FRR	[automatic/manual] Frequency restoration reserve
ACER	European Union Agency for the Cooperation of Energy Regulators
ALPACA	Allocation of Cross-zonal Capacity and Procurement of aFRR Cooperation Agreement
BRP	Balance-responsible party
BSP	Balancing service provider
BSUoS	Balancing Services Use of System
CAPEX	Capital expenditure
CBA	Cost-benefit analysis
CCGT	Closed cycle gas turbine
CCR	Capacity calculation region
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CEER	Council of European Energy Regulators
CEP	Clean energy package
CESA	Continental Europe Synchronous Area
CREG	Belgian Federal Commission for Electricity and Gas Regulation
CRM	Capacity remuneration mechanism
CSP	Congestion management service provider
CWE	Central and Western Europe
DA	Day-ahead
DA/RE	Data exchange/Redispatch
DR	Demand response
DSO	Distribution system operator
EB	Electricity Balancing Regulation
ENTSO-E	European Network of Transmission System Operators for Electricity
ERCOT	Electricity Reliability Council of Texas
ETM	Electricity target model
EV	Electric vehicle
FCR	Frequency containment reserve
GCT	Gate closure time
GOPACS	Grid Operator Platform for Congestion Solutions
GW	Gigawatts
HV	High voltage
iCAROS	Integrated Coordination of Assets for Redispatching and Operational Security
ICT	Information and communications technology
ID	Intraday
IGCC	International Grid Control Cooperation
ISP	Imbalance settlement period
JRC	Joint Research Centre
LDES	Long duration energy storage
LV	Low voltage
MARI	Manually Activated Reserves Initiative
MFF	Market Facilitation Forum
MV	Medium voltage
NDP	Network development plan
NRA	National regulatory authority
NTC	Net transfer capacity

OCGT	Open cycle gas turbine
OTC	Over-the-counter
P2G2P	Power-to-gas-to-power
P2X	Power-to-X
PHES	Pumped hydro energy storage
PICASSO	Platform for International Coordination of Automated Frequency Restoration and Stable System Operation
PLEF	Pentalateral energy forum
PV	Photo-voltaic panel
RES	Renewable energy source
RR	Replacement reserves
RTE	Réseau de Transport d'Électricité
SCADA	Supervisory control and data acquisition
SDAC	Single day ahead coupling
SDIC	Single intraday coupling
SLP	Synthetic load profile
TERRE	Trans-European Replacement Reserves Exchange
ToE	Transfer of Energy
TSO	Transmission system operator
TYNDP	Ten-year network development plan
USEF	Universal Smart Energy Framework
V2G	Vehicle-to-grid

Executive Summary

Flexibility needs and potentials in 2030, 2040 and 2050

Flexibility is needed to balance electricity demand and supply at any moment and to ensure a stable and reliable power system. It is becoming increasingly important in view of the ongoing and planned expansion of variable renewable energies, in particular solar PV and wind energy, and the cost-efficient integration of new electricity uses. Flexibility is required at different timeframes: sub-hourly, daily (within the hours of a day), weekly (within the days of a week) and seasonal. Flexibility can be valorised explicitly, through the procurement of flexibility products such as balancing services, or implicitly through price differentials in the wholesale electricity markets.

Flexibility needs are expected to increase significantly in the Penta region, at all timeframes. At the sub-hourly timeframe, the large-scale integration of renewables will increase the need of flexibility to maintain grid stability against unforeseen events, such as forced outages due to the reduced inertia of the power system, and to maintain system balance against uncertainties in forecasts, due to renewable generation forecast errors. These flexibility needs are largely satisfied explicitly through balancing reserves. New products, such as faster reserves or inertia, or increasing volumes of reserves could be required in the future.

Flexibility needs at the daily, weekly and seasonal timeframes were assessed quantitatively based on the results of the Ember study for a decarbonised European electricity system by 2035[1]. They represent the variability of the **residual demand** (the total system demand less the non-dispatchable generation, such as variable renewables) that has to be met with flexible solutions at various timescales. **Flexibility needs at the daily and weekly timeframes**, driven by the integration of solar PV and wind energy generation respectively, **will be most impacted, increasing by up to 2 times by 2030 and up to 6 times by 2050 compared to today**, as shown in Figure 0-1. Seasonal flexibility needs are expected to increase at a lower rate, by a factor of 3 by 2050 compared to today, due to complementarities in different drivers of flexibility needs.

The flexibility needs will be met by existing and additionally required resources. The composition of flexibility portfolios will drastically change, shifting from dispatchable conventional thermal power plants (which are subject to phase-out strategies in several countries) to a major role of cross-border exchanges, storage and demand side flexibility as shown in Figure 0-2. Significant investments will be needed in low-carbon flexibility assets, including flexible electrolysers, demand-side response (industrial demand, smart charging and V2G-capable electric vehicles), storage assets and hydrogen-based power generation (coupled with hydrogen storage).

[1] Ember (2022) New Generation: Building a clean European electricity system by 2035

Figure 0-1: Cumulated flexibility needs of Penta countries for the three different scenarios of the Ember study, 2020 to 2050 (without regional cooperation)

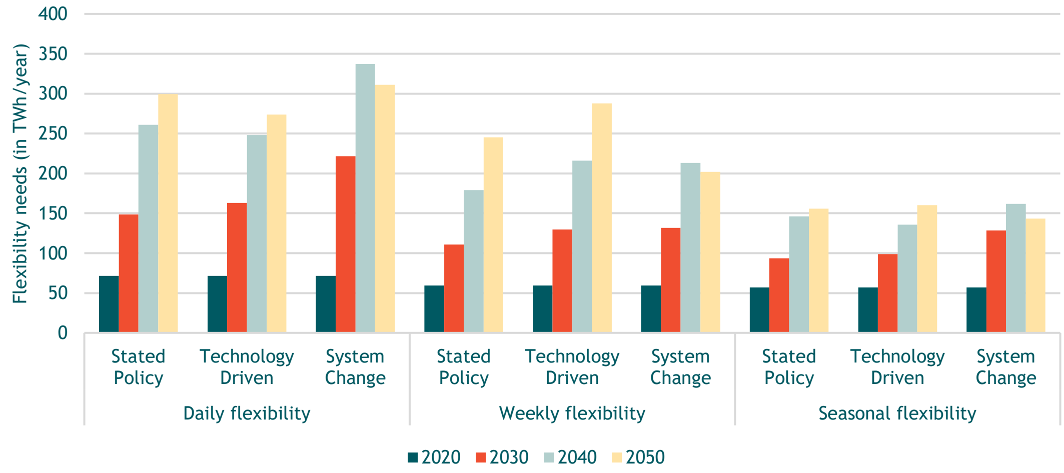
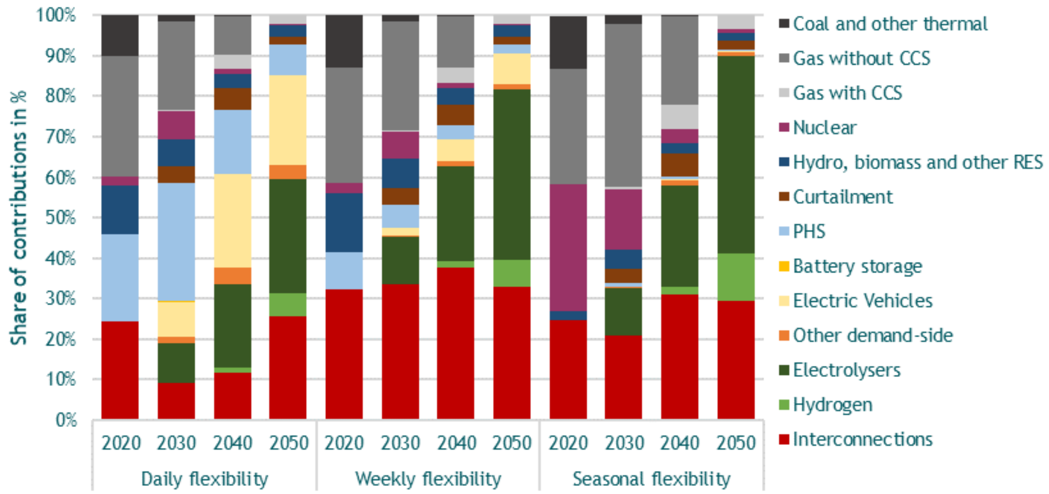


Figure 0-2: Share of technologies providing system flexibility in the Penta countries for daily, weekly and seasonal timeframes, Technology Driven scenario.



Regional cooperation is a key enabler for a cost-efficient integration of renewable energy, with interconnections enabling to reduce flexibility needs across states and market coupling facilitating liquidity and efficiency of markets, allowing to fully use the potential of local assets such as hydropower in the Alps region. Consequently, significant investments will be needed, with total cross-border interconnection capacities in the Penta region almost tripling by 2050 compared to 2020 in the scenarios of the Ember study.

To identify potential policy measures to facilitate the development and efficient utilisation of flexibility resources in the region, the present study identifies and compares existing as well as planned regulations enabling or hindering the deployment of flexibility solutions in the electricity sector in the Penta countries. The following topics are analysed in detail in chapter 4:

- ✓ Day-ahead and intraday markets;
- ✓ Electricity balancing;
- ✓ Congestion management;
- ✓ Network tariffs and contracts;

- ✓ Independent aggregators;
- ✓ Network planning;
- ✓ Value stacking;
- ✓ Collective self-consumption.

The Pentalateral Energy Forum can play an important role in facilitating and stimulating cross-border coordination and cooperation, including by exchanging information on good practices on how to activate and integrate flexibility, in particular from small electricity generators, demand side response and storage. Improving market design and rules, facilitating investments in flexibility assets and empowering prosumers/consumers will be required to cost-efficiently meet the increasing flexibility needs.

Based on our analysis, we have identified potential domains for enhanced cooperation at the Penta level and formulated concrete recommendations to steer the transformation of the concerned countries' energy systems. The recommendations are presented in chapter 5 per main topic: governance of the energy system, electricity market design, and network aspects. They cover various regulatory and non-regulatory measures to identify and address flexibility needs, foster the integration of regional electricity markets and exchange best practices across Penta countries, remove barriers for participation of and provide adequate signals to flexibility resources, and ensure electricity networks facilitate the integration of flexibility resources with network operators procuring flexibility whenever necessary in a non-discriminatory manner.

1 Introduction

This report aims to provide the members of the Pentalateral Energy Forum with a better understanding of flexibility and its integration into the electricity system (including demand-side response and energy storage), with a focus on improving market design, investments and consumer empowerment.

The specific objectives of this study are to:

- Achieve a common understanding of flexibility, including aspects related to its applications, its sources and the differentiations.
- Provide qualitative estimations of future flexibility needs and potentials in the Penta Region for 2030, 2040 and 2050, address the current barriers to flexibility in electricity markets and study potential market developments to facilitate the deployment of flexibility, including by cross-border exchanges.

This study focuses on the electricity systems and markets in the countries of the Pentalateral Energy Forum, i.e. Austria, Belgium, France, Germany, Luxembourg, Switzerland and the Netherlands, and in particular on the flexibility solutions in their national electricity systems and markets, but with special regard to cross-border cooperation to cover flexibility needs at least cost via efficiently used interconnections, coupled spot markets and cross-border procurement and exchange of balancing capacity and energy by TSOs.

Next to the relevant EU and national policies and regulations regarding flexibility, as well as the barriers and relevant market places, the flexibility needs and potentials in 2030, 2040 and 2050 are identified and assessed.

2 Definition and common understanding of flexibility

2.1 Common understanding of flexibility

This section establishes a common understanding of flexibility. This common understanding is crucial when analysing the flexibility needs and their underlying drivers, and the role of different flexibility solutions, both technical and non-technical.

2.1.1 Definition of flexibility

Power system flexibility can be defined as ***the ability of a power system to manage with all its resources the variability and uncertainty of the electricity demand, supply (including renewable generation) and grid availability across all relevant timeframes***[2]**.** The timeframes of flexibility needs go from seconds or minutes (sub-hourly needs) to days (daily or weekly needs) or years (seasonal or inter-annual needs).

The main purpose of flexibility is:
✓ Ensuring system stability, and
✓ Facilitating deployment of intermittent renewable energy sources (RES), while
✓ Minimising system costs

Flexibility is therefore not a specific product or good that can be sold individually, but rather the capability of different actors of the power system to react to (market price) signals, indicating a variation in electricity demand, supply and grid availability.

The concept of flexibility should not be confused with adequacy. Adequacy is the *ability of the electricity system to supply the aggregate electrical demand within an area at all times under normal operating conditions*[3]. In particular, it refers to the ability of generation assets to cover the peak load, i.e., ensuring there is enough generation capacity available to avoid loss of load.

2.1.2 Drivers for flexibility needs

In order to ensure the operation of the power system, the electricity supply and demand must be balanced at all times. Therefore, the flexibility of the power system is driven by the uncertainty and variability of both power generation and consumption. Flexibility needs are expected to increase in the coming years in the Penta countries, driven by various factors.

Electricity demand: Numerous factors including temperature, behavioural patterns, daylight and exceptional events affect the temporal dynamics of the electricity demand. Electrification of end-use sectors such as buildings, industry and transport will increase the total demand for electricity, modifying demand patterns and potentially increasing peak demand.

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[2] Based on IEA (2018) Status of Power System Transformation and ENTSO-E (2022) Vision: A Power System for a Carbon Neutral Europe
[3] IEA (2021) Analytical Frameworks for Electricity Security

Penetration of variable RES: Generation from solar and wind power is intrinsically variable and uncertain (generation cannot be forecasted perfectly), requiring flexibility sources such as dispatchable generation, storage or demand side flexibility to maintain the supply and demand balance. RES penetration will increase in the Penta countries to achieve the EU decarbonization objectives[4], driving up the flexibility needs of the power system.

Potential disruptions to the energy system: Extreme weather events will become more frequent due to climate change, such as droughts or storms, which can affect the generation or grid availability. International conflicts can also disrupt supply chains and impact commodity prices.

Decommissioning of dispatchable generation: Coal-fuelled power generation capacities are set to phase-out in all Penta countries, with the latest plants to be decommissioned by 2030 in Germany.[5] Nuclear phase-out is also part of the energy strategy of some Penta countries, including Germany, Belgium and Switzerland. In the long term, unabated fossil gas generation should also be phased out in order to fulfil the decarbonization objectives. While not increasing flexibility needs, the reduction of dispatchable generation will reduce the available solutions to cope with increasing flexibility, putting the system at stress.

The growth of variable RES-based electricity generation and electricity demand will have **impacts on flexibility needs at different timeframes**:

- **Sub-hourly:** Sub-hourly flexibility is needed to maintain supply and demand balance in real-time, with two complementary requirements: maintaining grid stability against unforeseen events, such as forced outages, and maintaining system balance against forecast errors. At this timeframe, flexibility needs are mostly driven by the stability needs to withstand unplanned outages of generators, and by the necessity to face the imbalances caused by variable RES forecasting errors.
- **Daily:** at this timeframe, the flexibility needs are mostly driven by three main factors. First, the integration of solar PV, which presents a daily cycle of generation. Second, the daily demand patterns caused by the higher demand during the day due to human activity. And third, the new usages that can increase the peak demand if their consumption is not managed appropriately, such as for electric vehicles and heat pumps.
- **Weekly:** at this timeframe the flexibility needs are driven by the weekly pattern of demand (weekdays vs. weekends) and wind power regimes which usually last for several days.
- **Seasonal:** at this timeframe, there are several drivers of flexibility needs. On the supply side they include the variation of solar power generation which is higher during summertime, the variation in wind power generation which is higher during wintertime in the Penta region, and the hydropower availability which is subject to the differences between dry and wet (or glacial) seasons. On the demand side, the seasonality of the electricity demand drives seasonal flexibility needs, which in Penta countries is higher during wintertime due to heating needs and which could be exacerbated by electrification.

[4] European Commission 2050 long-term strategy following the European Green Deal objectives.
[5] According to the latest political decisions in Germany

- **Inter-annual:** Inter-annual flexibility needs are driven by the variability of weather patterns between years, which affects RES generation (wind and solar availability), hydro generation (variable rainfall) and demand (colder winters lead to an increase in electricity demand). Climate change can modify weather patterns, exacerbating inter-annual variability such as in droughts or other extreme weather events.[6]

A summary of the underlying drivers of the flexibility needs in different timeframes mentioned above is presented in Table 2-1.

Table 2-1: Summary of underlying drivers of the flexibility needs in different timeframes.

	Solar PV production	Wind power production	Hydro production	Power demand	Other power generators
Sub-hourly	✓ Forecast errors & variability (ramps)	✓ Forecast errors & variability (ramps)		✓ Forecast errors & variability (ramps)	✓ Unplanned outages
Daily	✓ Daily solar cycle (day vs night)			✓ Daily demand patterns	
Weekly		✓ Wind power regimes		✓ Working days vs weekends	
Seasonal	✓ Seasonal solar cycle (summer > winter)	✓ Seasonal wind cycle (summer < winter)	✓ Seasonal rainfall patterns	✓ Thermo-sensitivity (space heating)	
Inter-annual	✓ Inter-annual solar irradiance variability	✓ Inter-annual wind regimes variability	✓ Inter-annual rainfall variability	✓ Inter-annual temperature variability	

2.2 Technical and non-technical flexibility solutions

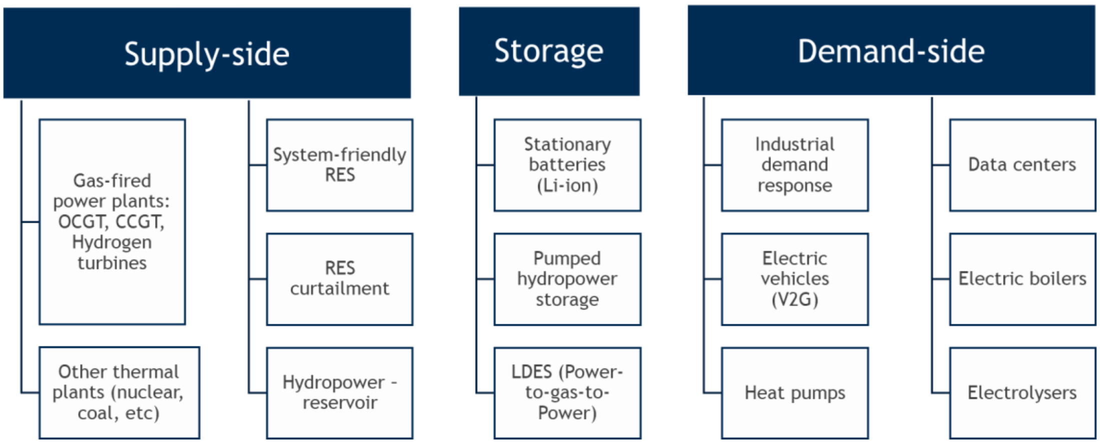
Flexibility solutions are essential to provide flexibility to the system across the different timeframes. There are multiple flexibility solutions available, which can be distinguished based on their technical or non-technical nature, the timeframe in which they meet the flexibility needs, their costs and other characteristics.

2.2.1 Technical flexibility solutions

Technical flexibility solutions that can provide flexibility services on the timeframes mentioned above are presented in Figure 2-1. They are divided into three categories corresponding to their location in the electricity value chain which are: supply-side, storage and demand-side. It must be noted that other solutions not included in this selection already provide flexibility to the system or might become relevant providers of flexibility in the future[7].

[6] This timeframe will not be covered in detail in this report.
[7] Technical characteristics for generation, storage and electrolyser technology can be found in Annex 6.16.1.3.

Figure 2-1: Selected technical flexibility solutions to be focused on (non-exhaustive). OCGT: Open-cycle gas turbine, CCGT: Closed-cycle gas turbine, LDES: Long-duration energy storage, V2G: Vehicle-to-grid



- **Supply-side solutions:**
    - **Dispatchable generation assets**, which include fossil fuel power plants (gas, coal), nuclear and hydropower plants, can provide flexibility by adjusting their output to demand. Their technical characteristics, such as ramp rates, start-up times, minimum load levels or storage capacity of hydro reservoirs, constrain the amount and type of flexibility they can provide.
        - Fast generation assets such as gas turbines and hydropower plants can provide flexibility at the sub-hourly to seasonal timeframes, whereas more slow-responsive assets, such as nuclear or coal plants, are more suitable to provide weekly or seasonal flexibility.
    - **Variable RES** are also able to provide flexibility even though they are one of the drivers of the flexibility needs.
        - **System-friendly RES** assets are designed in a way that facilitates power system integration. This can correspond to advanced wind turbine designs to better exploit low wind speeds or solar PV technologies with single/dual axis tracker or east-west orientation. Such technologies provide a smoother or complementary generation profile, thereby reducing flexibility needs. RES equipped with advanced power electronics (grid forming) can also help maintain grid stability by providing ancillary services such as synthetic inertia, frequency regulation and voltage support.[8]
        - **RES curtailment**, which is the deliberate reduction of RES production, can play a significant role by, for example, maintaining the flows through power lines within the operational limits in case of grid congestion.
- **Storage solutions:** A number of storage solutions exists, with different storage - capacity ratios. The main storage technologies are the following:
    - **Batteries** store energy based on electrochemical charge/discharge reactions. They can provide short-term flexibility to the system, in the sub-hourly and daily timeframes. They include both stationary batteries and mobile batteries integrated in

[8] IEA and RTE (2020), Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050.

EVs, which can provide energy back to the grid through vehicle-to-grid technology (V2G).

- ○ **Pumped-hydro energy storage (PHES)** store energy by pumping water from a lower to an upper reservoir. They have discharge times between 1 hour up to 1 month for large pumped-hydro plants. They can provide daily and weekly flexibility as well as sub-hourly flexibility if equipped with capable technology.
- ○ **Long-duration energy storage (power-to-gas-to-power)** corresponds mainly to large-scale gas or hydrogen storage, which can be stored underground in salt caverns or in pressurized tanks. This storage can also provide flexibility at daily and weekly timeframes (in combination with thermal power plants and/or the flexible operation of electrolysers).

- **Demand-side solutions:** Correspond to the share of electricity demand, including the one coming from the electrification of other energy sectors, that can be voluntarily reduced, increased or shifted in a specific period of time. Demand-side flexibility will be increasingly important with the large-scale integration of electrolysers, electric vehicles, heat pumps, data centres and electric boilers[9]. However, the deployment of demand-side flexibility is relatively recent, especially via aggregators, and has not yet reached its full potential, as shown in Figure 2-2. Demand-side flexibility can mostly provide flexibility at the sub-hourly and daily scales.

Figure 2-2: Demand-side flexibility applications classified by flexibility time scale and technological maturity[10]

Application	Time scale	Flexibility resource	Maturity
Balancing unpredictable fast changes	Seconds	Industrial DR providing reserves	● ● ●
		Aggregators providing DSF	● ◐ ○
		Smart charging EVs	● ○ ○
		Electrolysers providing reserves	◐ ○ ○
Balancing forecast errors (load and generation)	Minutes	Aggregators providing DSF	● ◐ ○
		Smart charging EVs	● ○ ○
Balancing variability in net load	Hours/Days	Electric water heaters	● ● ●
		District heating	● ● ◐
		Aggregators providing DSF	● ◐ ○
		Smart charging EVs	● ○ ○
Balancing seasonal energy availability	Months	District heating	● ● ◐
		Hydrogen for seasonal DSF	◐ ○ ○

Demand-side flexibility will be key in sector-coupling, in particular with hydrogen and transport sectors. Electrolysers can be operated in a flexible manner by adapting their power consumption to power prices and RES surplus in the short run (daily/weekly timeframe), and represent a long-term storage option in combination with large-scale hydrogen storage and hydrogen-based power generation (power-to-gas-to-power).[11]

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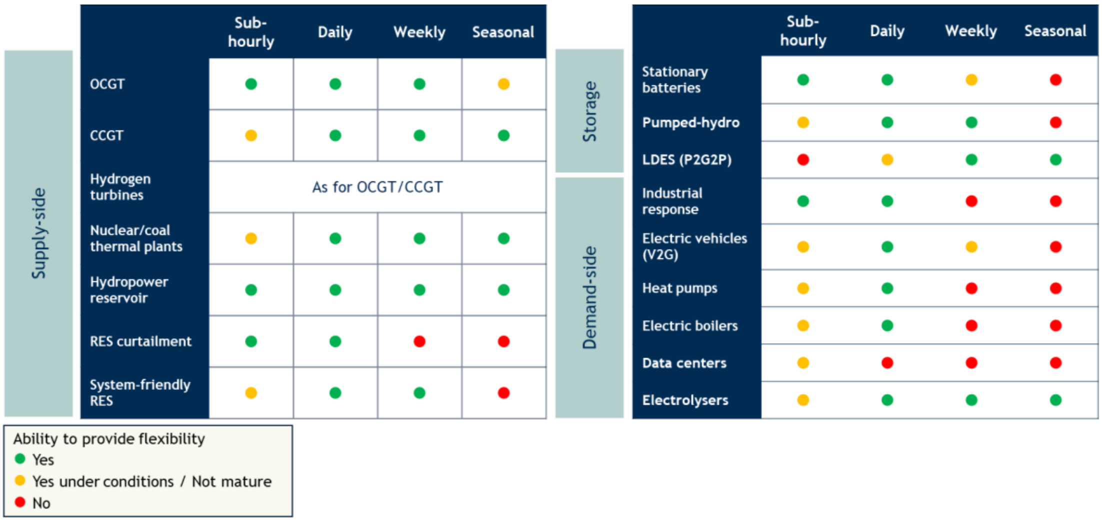
[9] A detailed identification of demand-side flexibility solutions can be found in: Guidehouse, r2b energy, and Compass Lexecon (2023) Work Package 2, Guidelines and recommendations to determine demand-side response (DSR) potential as input for resource adequacy assessment. Methodological improvements of Resource Adequacy Assessments

[10] D'Ettorre et al. (2022) Exploiting demand-side flexibility: State-of-the-art, open issues and social Perspective, adapted from IRENA (2019) Demand-side flexibility for power sector transformation

[11] The ability of electrolysers to provide flexibility depends on the technical characteristics of the technology. Also, the economic viability of electrolysers requires a certain minimum number of full-load hours and thus constraints the flexible operation to a certain extent. A comparison of technologies can be found in Annex 6.1.3.

A traffic light assessment of the ability of the different technical flexibility solutions to provide flexibility at different timeframes is presented in Figure 2-3, where green denotes the ability of a solution to provide flexibility in a specific timeframe, red the inability or limited role, and yellow that the solution can provide that flexibility but under certain conditions or where the technology is not mature yet.

Figure 2-3: Assessment of technical flexibility solutions ability to participate in the provision of flexibility at different timeframes



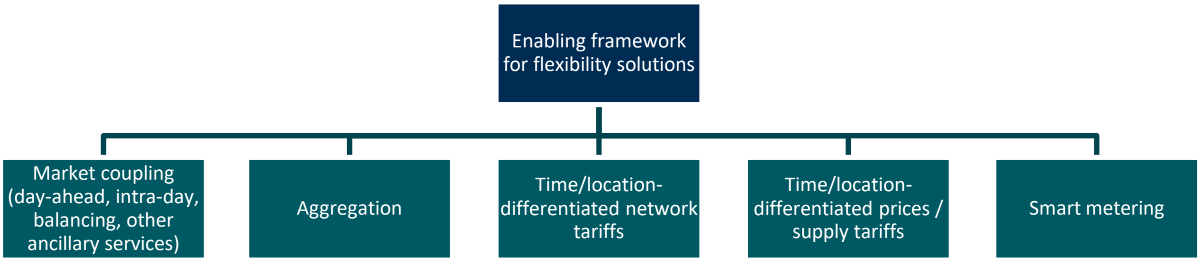
The role of OCGTs for seasonal flexibility is limited due to cost efficiency, with CCGTs being more adapted for that case. CCGTs, coal and nuclear power plants can provide sub-hourly flexibility, but they need to be already connected (no fast-start) and ramp rates are limited. For PHES, only recent technology allows plants to provide sub-hourly frequency regulation services but it is not yet a standard of today's operation modes.

Concerning the demand-side flexibility solutions, the aggregation and control processes to provide sub-hourly flexibility is not yet mature. However, significant research is been carried out in Europe with commercial options already available, in particular for industrial flexibility (most mature technology) and for EVs. The same is applied for the data centres that could provide sub-hourly flexibility services but would require management solutions which are not yet mature.

2.2.2 Enabling framework for flexibility solutions

Under enabling framework for flexibility, we group those enabling policies and (regulatory) measures which incentivise the availability and deployment of technical flexibility sources introduced above, both at the transmission and distribution level. These are presented on Figure 2-4. Examples are often related to the development and further improvement of electricity markets, which ultimately facilitate the procurement as well as the remuneration of flexibility services. Further elements for an enabling framework arise from regulatory provisions and requirements for TSOs and DSOs, or market-based incentives that enable consumers to modify their usage following price signals. The wider roll-out and use of smart metering can also play an important role.

Figure 2-4: Enabling framework for flexibility solutions



- **Market coupling:** Electricity markets are the vehicles that facilitate entry and participation of different flexibility sources. Market coupling in all possible timeframes and product types, combined with cross-border trading impacts electricity prices and has a positive effect on welfare, while enabling flexibility. Coupled markets can mitigate any potential price impacts of intermittent RES production and reduce the frequency of demand disturbances, ultimately delivering substantial economic benefits. If there are adequate rules and regulations in place for the participation of small operators, market coupling can thus deliver significant flexibility potential and societal welfare.

- **Aggregation:** As also demonstrated on Figure 2-5, aggregation of different electricity supply profiles (especially variable RES, CHP and storage) brings social benefits, as the variability of a total mixed supply portfolio is lower than the variability of a single generation unit. Moreover, aggregators can provide high value to the electricity system by combining the demand flexibility potential from multiple end-users, either independently from their concerned electricity suppliers or in the framework of their supply contracts with flexibility clauses. Aggregators can thus facilitate the provision of flexibility services in different timeframes, and act as intermediaries between flexibility providers and wholesale and balancing markets.

- **Time-and location-based network tariffs:** Network tariffs and network contracts have an effect on the costs incurred, and revenues collected after the deployment of various flexibility sources, in case of both transmission and distribution grids. In case time-differentiation applied to transmission and distribution tariffs (making them 'dynamic'), these can easily act as signals for market players to change their offtake or injection volumes from the network. The harmonisation of the structure and cost of network tariffs across regions and countries would have a positive impact on the deployment of flexibility.

- **Time-and location-based (consumer) prices:** Market price signals, if set right, are a key motivator for changes in supply and demand for customers, and thus for fostering flexibility. Based on the time of use (e.g. peak usage) and location (e.g. congested areas), a price increase might eventually result in changing demand patterns, reducing the peak load and shifting the power demand curve to a more balance state. The more flexible consumers and suppliers can react, the greater the social benefit.

- **Smart metering:** The use of smart metering is the best way to measure, and ultimately manage electricity consumption and uncover flexibility potential. Smart meters enable more efficient demand-side management, thus often there are specific metering requirements in place for small operators to be able to participate in flexibility markets.

2.3 Exchange of flexibility

2.3.1 Interconnections

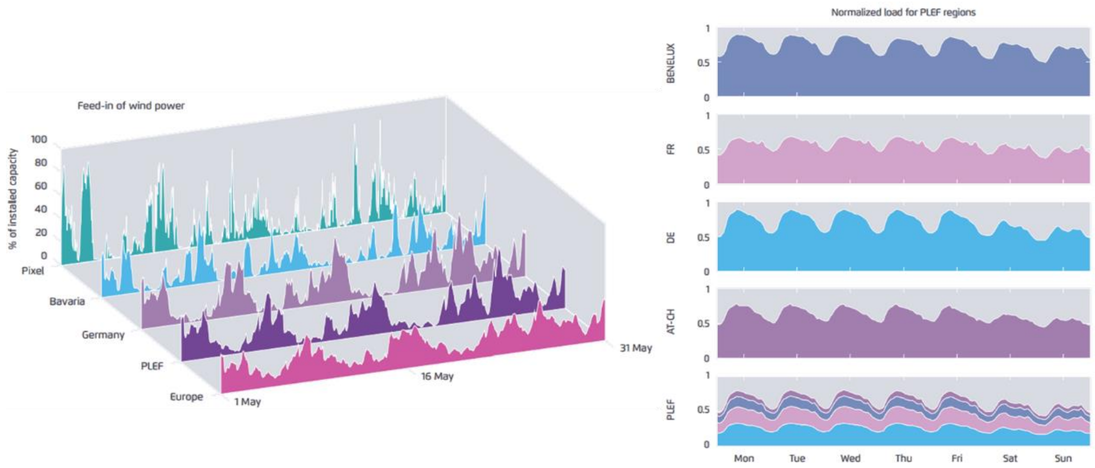
The flexibility solutions presented above allow to shift energy generation/demand across time, however, the power systems of the Penta countries are strongly interconnected, allowing to shift demand/generation across space. This way, interconnections are an **enabler** for sharing flexibility across countries. Grid interconnections can also reduce the flexibility needs as there is a smoothing effect of demand and variable generation profiles when aggregated across large areas.

For demand, behavioural differences and slightly varying hours of daylight for different interconnected areas which affect the electricity demand pattern, reduce the variability of the aggregated load profile, thus reducing the flexibility needs.

Aggregating variable RES generation profiles also provides benefits, as the variability of the total RES generation profile across increasingly larger interconnected areas is lower than the variability of a single unit. Therefore, interconnections play a key role in the integration of variable RES.

The smoothing effect of aggregation is shown in Figure 2-5, for wind power generation (left) and demand profiles (right), aggregated over different areas. However, this effect is dependent in the capacity of the power grid to transport electricity across large distances. Grid constraints, arising in the internal grid or in the interconnections, reduce the smoothing effect.

Figure 2-5: Left: Time series of onshore wind power generation in a simulation for May 2030 at different levels of aggregation. Right: Load profiles as observed in the PLEF region for a week in July, normalized to peak load[12]



Interconnections also allow the exchange of flexibility between countries, as a larger pool of flexibility resources are available. This can help to reduce the costs of the power system operation, as a flexibility need can be supplied by a resource situated in another country, if economically more efficient. Thus, the flexibility activation and the required capacity of flexibility assets in the region can be minimized.

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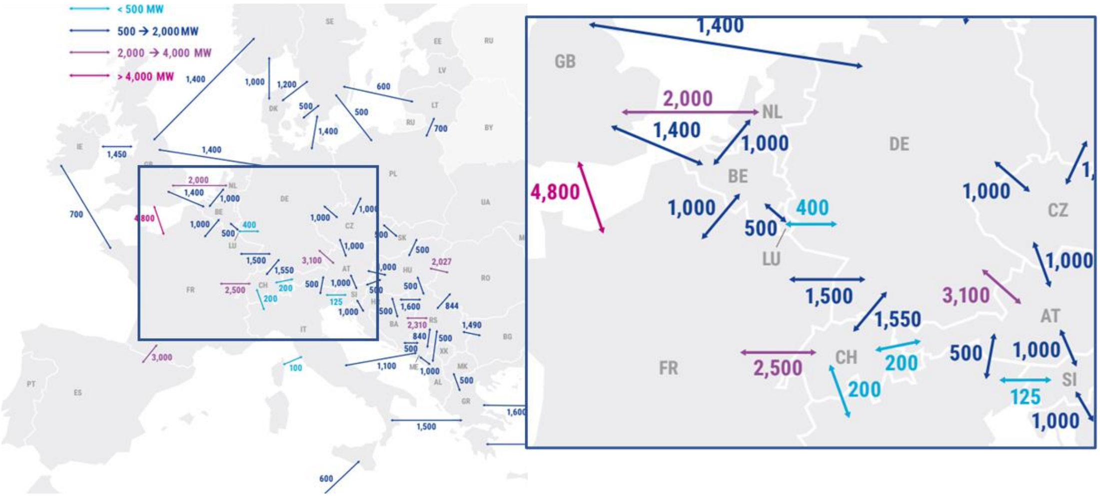
[12] Agora Energiewende and Fraunhofer IWES (2015) The European Power System in 2030: Flexibility Challenges and Integration Benefits

To integrate large shares of variable RES, reinforcements of the national grids and additional interconnection capacities will be needed. The required reinforcements are for instance identified by ENTSO-E in the TYNDP process, shown in Figure 2-6Figure 2-6 for the 2030 horizon with a focus on the Penta region.

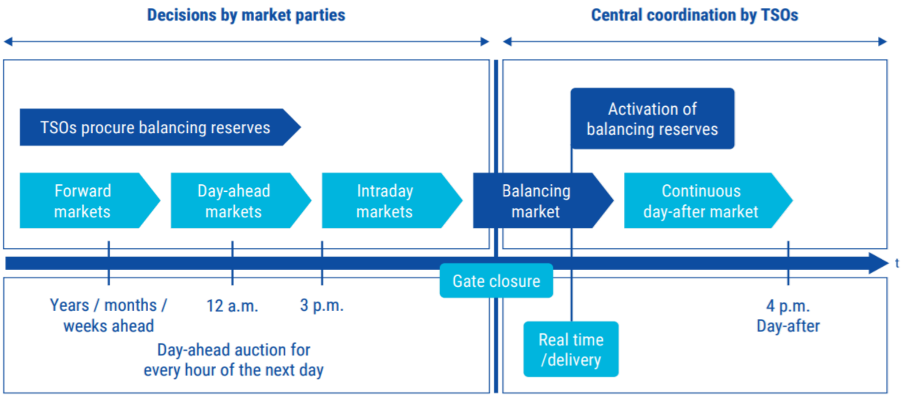
Figure 2-6: Needs for capacity increases identified in the 2030 horizon, additional to the 2025 network with a focus on the Penta region[13]



2.3.2 *Flexibility services and market places*

The electricity markets are established to ensure supply and demand balance at different timescales. The electricity markets are structured in sequential stages, which start at the long-term and move steadily closer to the time of delivery. This sequence of markets allows actors to continuously adjust their positions as they obtain better information and forecasts on their assets. The four main stages of electricity markets are shown in Figure 2-7.

Figure 2-7: Overview of different timeframes of the wholesale and balancing markets[14]

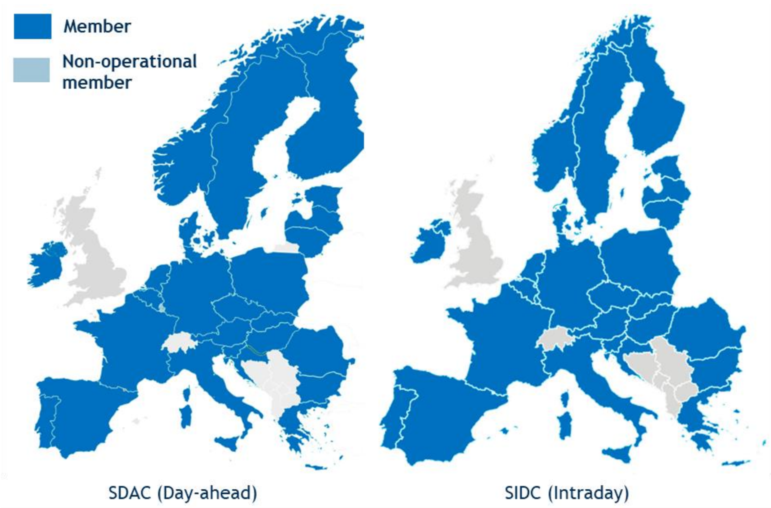


1. **Forward energy market**, where market participants establish bilateral contracts[15] for electricity supply/demand at a price agreed upon today, for a delivery months/years after.

[13] ENTSO-E (2023) System needs study. Opportunities for a more efficient European power system in 2030 and 2040
[14] ENTSO-E (2022) Market report 2022
[15] Three main types of transactions exist:

2. **Day-ahead market,** where participants can sell and/or buy electricity one day before the actual delivery. Participants that have contracts from the forward market can readjust their positions closer to delivery time. The day-ahead market is a common, harmonized market for the majority of Europe, called Single Day-ahead Coupling (SDAC)[16]. The SDAC is a multilateral trading platform exchange. Switzerland has a day-ahead market but is not part of the SDAC, limiting the integration of its power system into the region.
3. **Intraday market**, where market participants can trade energy continuously during the day of delivery. Intraday trading allows participants to balance their portfolios taking into account the latest forecasts (for example of RES generation). As for the day-ahead market, the intraday market is harmonized for the majority of Europe with the exception of Switzerland which is not a member yet (Single Intraday Coupling, SIDC)**.** The SIDC is a multilateral OTC platform exchange.
4. **Balancing markets**, in which TSOs procure flexibility to maintain the stability and balance of the system. There are platforms dedicated to support a cross-border balancing energy and capacity market in Europe while securing a reliable electricity supply for the participating countries. These platforms will be analysed in Working Package C. Some platforms are still in the implementation phase and are not yet fully operational in some Penta countries. Where there is no balancing platform operational, the TSO procures the balancing services at the national level only.

Figure 2-8: Day-ahead and intraday markets map[17]



Flexibility can be valorised through several stages of the electricity markets. Flexibility can be valorised implicitly through price differentials in the wholesale electricity markets (forward, day-ahead, intraday). This is the case of flexibility at the daily, weekly and seasonal timeframes, and part of the

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1. Bilateral trading, or Over-The-Counter (OTC) mechanisms, where an agreement is achieved between two parties (in volume and price traded).
2. Multilateral trading platform exchanges where participants submit generation and demand bids in an auction mechanism. The market is cleared once per predefined time period according to the market and a single market price is determined.
3. Multilateral OTC platform exchanges, where participants submit generation and demand bids with transactions cleared continuously as soon as compatible offers exist. No single market price is determined.

[16] Luxembourg is part of the SDAC included in the German bidding zone.

[17] ENTSO-E (2022) Single Day-ahead Coupling and Single Intraday Coupling

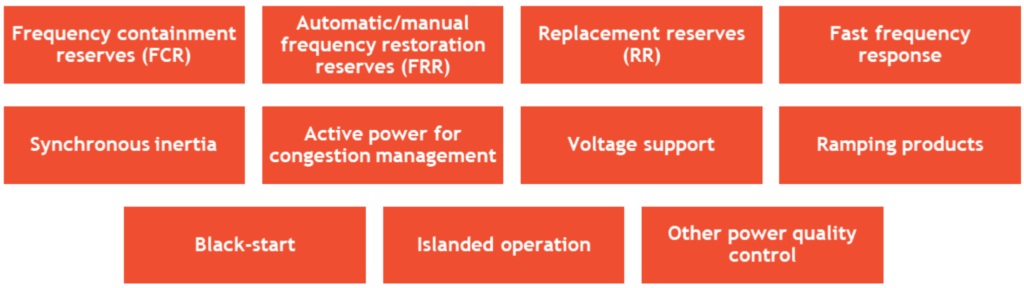
sub-hourly flexibility[18]. For example, price differentials between peak and low demand-hours can trigger the flexible operation of battery storage.

However, the part of the flexibility needs that are not covered by the wholesale markets results in residual imbalances that need to be covered by the system. Imbalances can be reduced by providing incentives for self-balancing of actors (through imbalance pricing), and the residual imbalances are covered by balancing services. In this case flexibility is procured (and valorised) explicitly by the TSO through the definition of various **flexibility services**, in this case called balancing services. Four types of balancing products are defined in Europe:

- **Frequency Containment Reserve (FCR)** which quickly stabilizes the frequency after a disturbance, with a maximum activation delay of 30 seconds.
- **Frequency Restoration Reserves (FRR)** which brings back the frequency towards the nominal value, with an activation delay of 5 to 15 minutes. The activation can be automatic (aFRR) or manual (mFRR).
- **Replacement Reserves (RR)** which reconstitutes the used frequency restoration reserves. The activation time is around 30 minutes.

Besides balancing reserves, additional flexibility services can be defined by TSOs to ensure the safe and secure operation of power system, together called ancillary services. A non-exhaustive list of ancillary services is shown in Figure 2-9. It should be noted that not all of these services are currently procured by TSOs in Europe, such as synchronous inertia. Not all of these services are covered in this report.

Figure 2-9: Ancillary flexibility services



[18] Imbalance settlement periods (thus, market prices) are being aligned to 15 minutes.

3 Flexibility needs and potentials for 2030, 2040 and 2050

The strive for decarbonisation requires the power systems in the Penta countries to evolve rapidly. As explained in Section 2, the integration of variable RES and cross-sector electrification will drive up the needs for flexibility of the power system at various timeframes. This effect is compounded by the decommissioning of conventional thermal power plants (coal, nuclear in some countries), reducing the availability of assets that can provide flexibility to the system.

This section will provide a qualitative and quantitative assessment of the evolution of flexibility needs until 2050 and the potential solutions to be deployed in the Penta countries to meet these needs. Country level-analyses allow to consider the impact that local specificities (availability of resources, different decarbonization pathways) have on flexibility needs, and on the solutions to be implemented.[19]

Key insights of the evolution of flexibility in the Penta region

- The integration of renewables will drastically change the operation of power systems, **significantly increasing flexibility needs** at all timeframes. Daily and weekly flexibility will be most impacted, increasing by up to 6 times by 2050 compared to 2020.
- The composition of **flexibility portfolios** will drastically change, shifting from conventional thermal power generation to a major role of **cross-border exchanges and demand side flexibility**. Significant investments will be needed in low-carbon flexibility assets and cross-border interconnection capacities. In particular, EVs and batteries will be needed for short term flexibility (daily and weekly timeframes). The flexible operation of electrolysers may provide flexibility at all time-scales if hydrogen storage and grid infrastructure are available.
- **Regional cooperation** is a key enabler for flexibility, with interconnections allowing to reduce flexibility needs across states and market coupling facilitating liquidity and efficiency. The cross-border exchange of flexibility can allow to fully utilise the potential of local assets, such as hydropower in the Alps region or hydrogen storage.

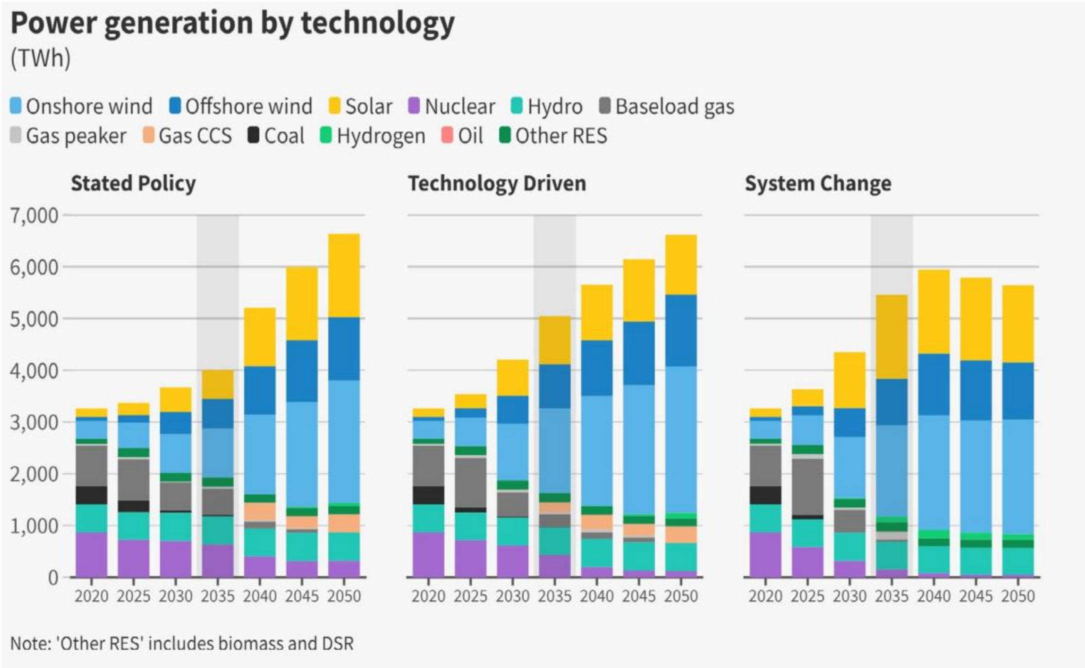
The Ember study

Quantitative analyses are based on the prospective scenarios developed in the "New Generation: Building a clean European electricity system by 2035" from Ember for which the modelling was carried out by Artelys (here on the Ember study)[20]. This study proposes three decarbonisation pathways for the European power system, shown in Figure 3-1, all achieving carbon neutrality by 2050 or earlier, with

[19] The identified solutions were derived from the Ember study and computed specifically for the three scenarios analysed in the context of the study. They should hence be considered as indicative orientation as results may look different for alternative scenario assumptions.
[20] The modelling exercise consisted in long term energy operation and capacity pathway optimisation using Artelys Crystal Super Grid.

different levels of ambition on the speed of renewable energy penetration and on energy efficiency, amongst others[21,22].

Figure 3-1: Evolution of power generation by technology in Europe for the three scenarios of the Ember study[23]



It should be noted that the qualitative analysis carried out using the Ember study data is not meant to provide an exact number or recommend the deployment of a specific technology, but to highlight main **trends and possible futures** in the Penta power systems.

3.1 Evolution of flexibility needs

This section presents a quantitative and qualitative assessment of the evolution and drivers of flexibility needs in the Penta region. Flexibility needs were assessed at the **sub-hourly, daily, weekly and seasonal** timeframes.

Quantitative assessment of the evolution of flexibility needs using the Ember study is performed only for the daily, weekly and seasonal timeframes. Sub-hourly needs were assessed only through a literature review.

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[21] The Ember study was selected over ENTSO-E's TYNDP scenarios due to more ambitious targets on decarbonization, varying RES penetration and power demand pathways and a full availability of underlying data and results till the 2050 horizon in 5-year steps, due to the consultant's participation in the study.
[22] The Ember study did not consider the current energy crisis in the modelling, as scenarios were set beforehand.
[23] The Stated Policy scenario follows government plans until 2035. After that, the power system is optimized to reach zero emissions by 2050 at least cost. Demand grows significantly due to cross-sector electrification, including hydrogen demand.
The Technology Driven scenario is consistent with a 1.5°C warming. The pathway of the power system is optimised from 2025 onwards, reaching zero emissions by 2050 and with limited carbon budget over the period (<9 GtCO2 between 2020-2050). Electricity demand grows faster than in the Stated Policy scenario, but reaches the same level by 2050.
The System Change scenario is the most ambitious one, reaching zero emissions by 2040, while also being compatible with 1.5°C warming. Investments in CCS and new nuclear energy are not considered, as opposed to the Stated Policy and Technology driven scenarios. Significant efforts in energy savings see the electricity demand peaking by 2040 and reducing slightly by 2050.

3.1.1 Sub-hourly flexibility needs

Sub-hourly flexibility is required to maintain demand and supply balance in real-time. This consists in two complementary requirements:

- **Maintaining grid stability** against unforeseen events, such as forced outages. This consists in the ability of the system to withstand shocks, maintaining the system frequency within the established range. These phenomena require action in the range of seconds or under.
- **Maintaining system balance** against uncertainties in forecast errors, including demand and renewable generation forecasts. These phenomena require action in the range of minutes.

Maintaining grid stability

Supply and demand need to be balanced at all times in the power system. This is reflected in the system frequency, for which the nominal value in Europe is 50 Hz. If there is an excess in supply (or lack of demand), the frequency goes up, and if there is an excess in demand (or lack of supply) the frequency goes down. The frequency needs to be maintained in a narrow band around 50 Hz to ensure the stability of the system.

The grid stability is ensured by the **inertia** of synchronous rotating machines, like conventional generators (thermal, hydro, nuclear) or large industrial motors. In case of disturbances in the system, such as the unexpected outage of a generator, the inertia limits the speed and degree of deviation from the nominal frequency. This temporary response of inertia lasts a few seconds and gives flexible assets the time to adapt their output to balance demand and supply through **frequency containment response (FCR)**[24].

Variable RES, which are connected through power electronics and not through synchronous rotating machines, do not provide inertia to the system. The integration of high levels of variable RES into power systems and the decommissioning of conventional generators **will reduce the amount of inertia** available in the system, requiring the development of adapted technologies and services.

The Penta countries are part of the Continental Europe Synchronous Area (CESA), which ranges from Portugal to Ukraine and from Italy to Denmark-West. Given the large size of the CESA, high levels of inertia are present and no inertia-related issues are expected in the near future. Issues can arise, however, at long term horizons (2040-2050)[25].

Given the large inertia present in the CESA, the frequency containment response is required to be activated in under 30 seconds, as the frequency deviations after an event are slow. However, smaller synchronous systems already experience low-inertia issues, requiring **fast frequency reserves.** In the Nordics[26] and the UK[27] fast frequency response is already required to be activated in less than 1 second. Thus, new fast frequency response services may need to be developed in the CESA in the long term.

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[24] Also known as primary frequency response.
[25] Local stability issues, related to voltage support, can arise earlier in areas without enough inertia. See IEA and RTE (2020) Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050
[26] https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/fast-frequency-reserve/
[27] https://www.nationalgrideso.com/industry-information/balancing-services/Frequency-Response-Services/dynamic-containment?technical-requirements

Technology allows power electronics-based assets (wind, solar PV, batteries) to provide frequency response with faster response times than conventional generation, thus enabling them to provide fast frequency containment services. For example, in the ERCOT system (Texas) and in Ireland, wind generators are already able to provide frequency response services. RES and batteries can also have **grid-forming** capability, emulating the role of inertia of synchronous machines. Grid-forming RES set the frequency of the system, instead of just following it, and can provide other non-frequency related services such as voltage support. However, the conditions for a 100% RES system using grid-forming capabilities are still under research.

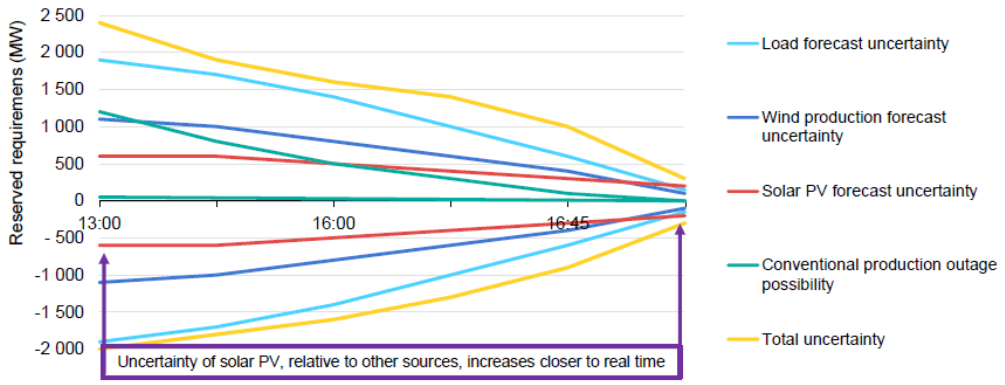
Maintaining system balance

The supply and demand balance is not only impacted by large disturbances such as outages, but also by errors in forecasts of demand and power production, in particular from solar and wind. To cope with forecast errors in real-time, TSOs need to ensure that sufficient flexible capacities will be available to respond quickly enough. For this purpose, **operational reserves** (FCR, FRR, RR) are procured by TSOs in advance (usually day-ahead), which are then activated in real-time according to the system conditions. The activation of reserves is also used to balance demand and supply within a given market period (imbalance settlement period, ISP), which is 15 to 30 minutes for generation, depending on the country, and 1 hour for interconnections. The timeframe for the activation of operational reserves is 30 seconds for FCR and 5-30 minutes for FRR and RR.

The sizing of operational reserves depends on the quality of forecasts. High forecast uncertainty requires a larger volume of reserves to cover all probable states of demand/generation. Demand forecasts are a well-known tool by TSOs, and the associated forecast errors should not significantly increase in the future. Additionally, the development of demand response can reduce the risk of large demand forecast errors. On the other hand, wind and PV forecasts errors are expected to increase (in absolute terms, in GW) due to the increase in connected capacities. Thus, **improving the accuracy of variable RES forecasts is needed to limit the increase of reserve requirements**.

Wind and PV production forecasts depend on weather forecast and on real-time monitoring of facilities. In particular, a large share of PV generation has no real-time monitoring (due to its decentralised installation), limiting the quality of forecasts. Overall, forecast uncertainty decreases as they approach real-time, but significant improvement only occurs in the last hours, as shown in Figure 3-2.

Figure 3-2: Operational reserve requirements when getting close to real-time, according to the 98% confidence interval of forecasts affecting supply-demand balance.[28]



Projections of operational reserve needs

Frequency containment reserves (FCR) are sized based on the CESA reference contingency, which represents the outage of the two largest generators, equivalent to 3GW. This amount of reserve is shared among all CESA members. The size of FCR is not expected to increase significantly due to the integration of RES, as the size of the reference contingencies is not expected to increase. However, faster reserves might be needed in the long term, as explained above.

On the other hand, FRR and RR, which are needed to cover for forecast errors, are expected to increase significantly with high RES integration. Elia, the Belgian TSO, foresees an increase of around 10% in reserve requirements already by 2032[29], and RTE, the French TSO, foresees an increase in reserves by a factor of 2 to 3 by 2050, depending on the RES integration scenario (see Figure 3-3)[30].

It should be noted that not all the need for sub-hourly flexibility is to be contracted through reserves. Part of the sub-hourly flexibility can be obtained implicitly by providing the market players with mechanisms and incentives to self-balance. This includes allowing trading closer to real time, when forecasts are more accurate, providing imbalance pricing, and reducing imbalance settlement periods (ISP), which are currently being aligned to 15 minutes in Penta countries. It should be noted that already ISPs of 5 minutes can be found in some markets such as PJM in the US and AEMO in Australia.

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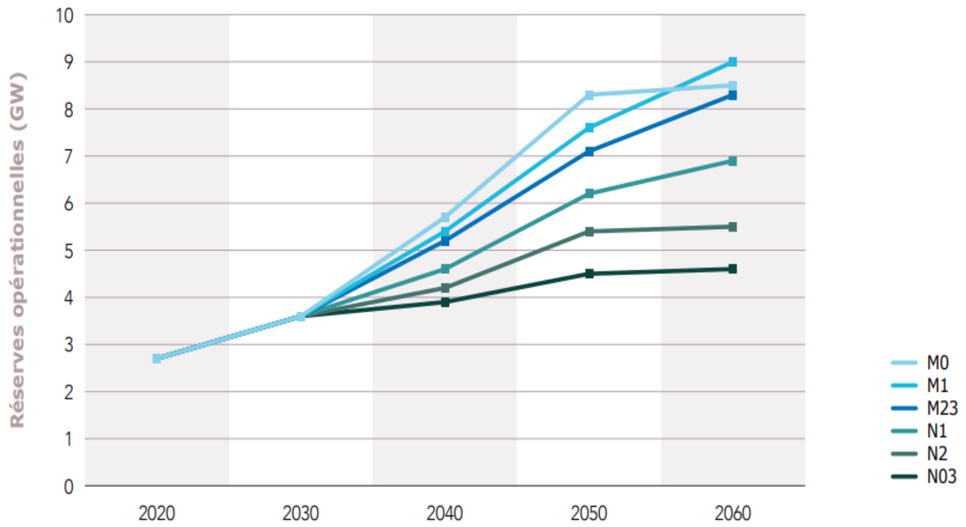
[28] IEA and RTE (2020) Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050
[29] ELIA (2021) Adequacy flexibility study
[30] RTE (2022) Futurs énergétiques 2050

Figure 3-3: Evolution of total operational reserve needs in France for different scenarios. Scenarios N1 to N03 consider different levels of nuclear generation development in France, whereas scenarios M0 to M23, consider 100% RES system by 2050, with different shares of distributed vs. large-scale farms.[31]



3.1.2 *Daily, weekly and seasonal flexibility needs*

A quantitative assessment of the daily, weekly and seasonal flexibility needs was performed using the results of the Ember study. This analysis was carried out for three prospective scenarios, for the years 2020, 2030, 2040 and 2050.

Metrics for flexibility needs

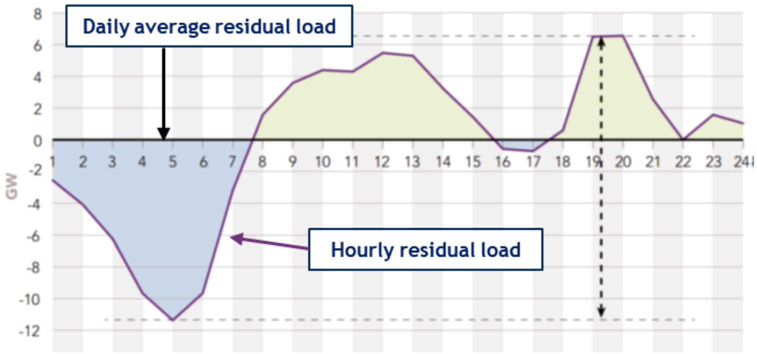
To quantify the flexibility needs, an indicator was computed for each of the flexibility timeframes. The flexibility needs indicator is computed on the basis of the **residual load**, which is the total system load less the production from variable RES. The flexibility needs for a given timeframe will be the absolute difference between the residual load and the average residual load, as illustrated in Figure 3-4 for the daily timeframe. In this case, the daily flexibility need will be the sum of the green and blue areas.[32] Flexibility needs are computed at the daily timeframe (comparing the hourly residual load with daily averages), the weekly timeframe (comparing the daily averages with the weekly averages) and the seasonal timeframe (comparing weekly averages with the annual average).

The flexibility need indicator **represents the variability of demand (or excess RES generation) that has to be met with flexible solutions**. Thus, this indicator aims to capture the dynamics of the residual load for different timeframes, where a flat residual load would require no flexibility need and a highly variable residual load would require a higher flexibility need.

[31] RTE (2022) Futurs énergétiques 2050

[32] Detailed description and computation methodology of the flexibility needs metrics can be found in: European Commission (2019) Mainstreaming RES: flexibility portfolios. Design of flexibility portfolios at Member State level to facilitate a cost-efficient integration of high shares of renewables

Figure 3-4: Illustration of daily flexibility needs[32]



Evolution of flexibility needs at the Penta level

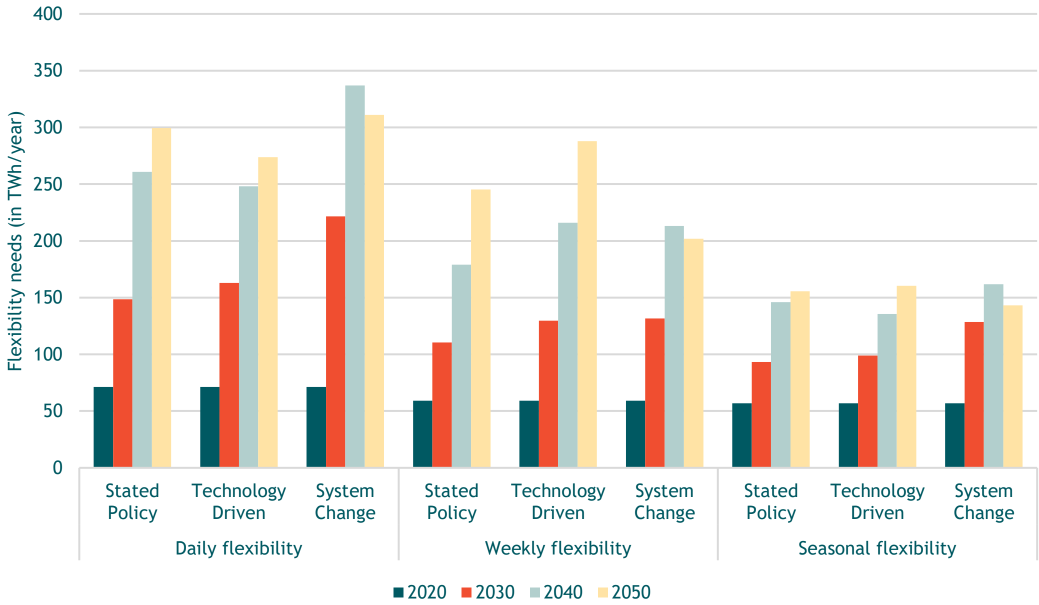
The aggregated flexibility needs of the Penta countries[33] are presented in Figure 3-5, for the 2020[34] until 2050 horizons and the three scenarios of the Ember study. Results show that in the next decades the **flexibility needs are expected to increase across all timeframes, and in all scenarios considered, by a factor of 1.5 to 3 by 2030 and from 3 to 6 in 2050** with respect to 2020.

The daily and weekly flexibility needs feature stronger increases than the seasonal ones. They increase by a factor 4 to 6 by 2050, depending on the scenario, whereas seasonal needs increase by a factor of 3. This can be explained by the fact that daily flexibility needs are mainly driven by increased solar PV power generation whereas weekly needs grow due to rising wind power generation. At the seasonal level, PV generation, with higher production during summer, and wind generation, with higher generation during winter, can partly counter-balance each other. Therefore, seasonal needs increase less significantly.

Differences in flexibility needs across scenarios result from the different decarbonization pathways of the electricity system. The Technology Driven scenario features a higher share of wind generation and slightly lower share of PV generation. This translates in slightly higher flexibility needs at the weekly timeframe, and lower needs at the daily timeframe. The System Change scenario is the most ambitious scenario in terms of RES shares and reduced energy demand (from 2040 onwards), reaching decarbonization by 2035. This translates into higher flexibility needs at the 2030 horizon for this scenario, but decreasing needs after 2040.

[33] The cumulated flexibility needs are calculated as the sum of the individual flexibility needs of each Penta country.
[34] The results for the 2020 horizon are model results and are not based on 2020 statistical data.

Figure 3-5: Cumulated flexibility needs of Penta countries for the three different scenarios, 2020 to 2050 (without regional cooperation)[33]



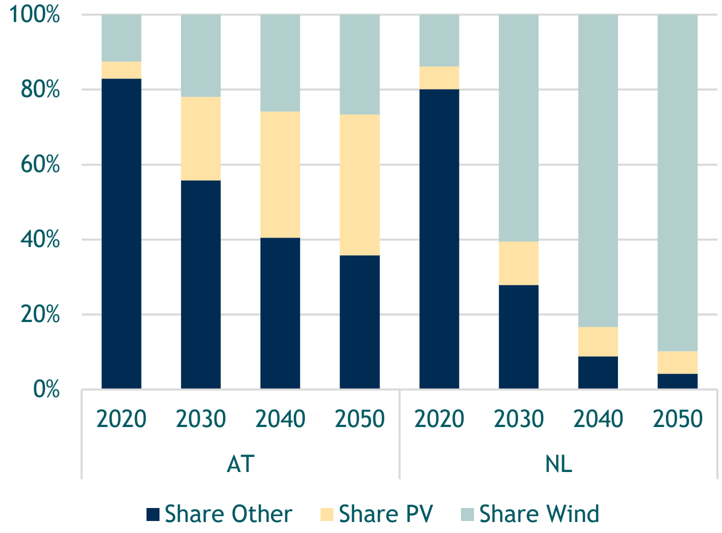
Contrasting evolutions of flexibility needs at the country level

The evolution of power systems will differ significantly across Penta countries, due to the available potentials for RES development and geographical constraints, as well as technological choices and strategies. Therefore, the flexibility needs evolve differently across countries.

This effect can be showcased for Austria and the Netherlands, as shown in Figure 3-6 for the Technology Driven scenario[35]. The two countries have similar power generation mixes in 2020, with a share of PV plus wind reaching 20% of production, but diverge afterwards. In Austria, a significant development of PV generation is observed, reaching 38% by 2050, while the share of PV remains relatively constant in the Netherlands. On the other hand, in the Netherlands the RES development is driven almost exclusively by wind energy (mainly offshore), rising up to 90% of total power generation by 2050, while it increases only up to 27% of total power generation in Austria.

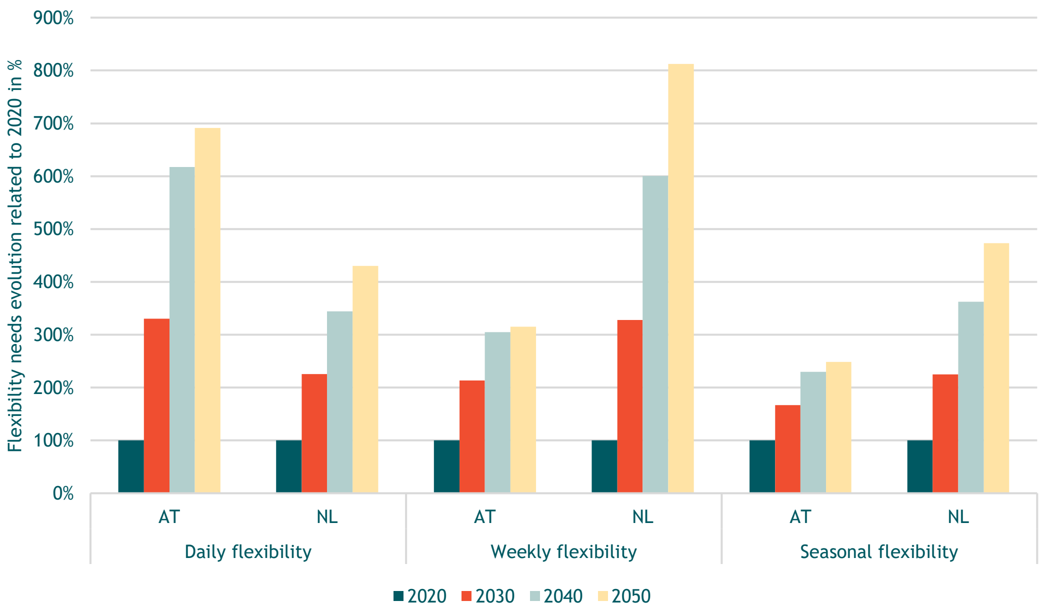
[35] Only the Technology Driven scenario is shown here. Details on electricity generation capacity mix and flexibility needs for all countries and scenarios can be found in Annex 6.2.

Figure 3-6: Electricity production by source for Austria and the Netherlands in the Technology Driven scenario



The contrasting evolution of the Austrian and Dutch power systems affects their flexibility needs, which are shown in Figure 3-7 in percentage with respect to 2020. Daily flexibility needs increase more significantly in Austria (x7 by 2050) than in the Netherlands (x4 by 2050), mainly driven by the stronger uptake of PV. On the other hand, weekly flexibility needs increase is much more pronounced in the Netherlands (x8 by 2050) than in Austria (x3 by 2050), driven by the preponderant role of wind generation. Finally, the evolution of the seasonal flexibility needs is less pronounced in Austria (249%) compared to the Netherlands (473%), as there is a more balanced share of solar PV and wind power generation in the power generation mix in 2050.

Figure 3-7: Evolution of flexibility needs for Austria and the Netherlands for the three flexibility timeframes and for the Technology Driven scenario. Flexibility needs are shown in percentage relative to the 2020 needs of each country.



Regional cooperation

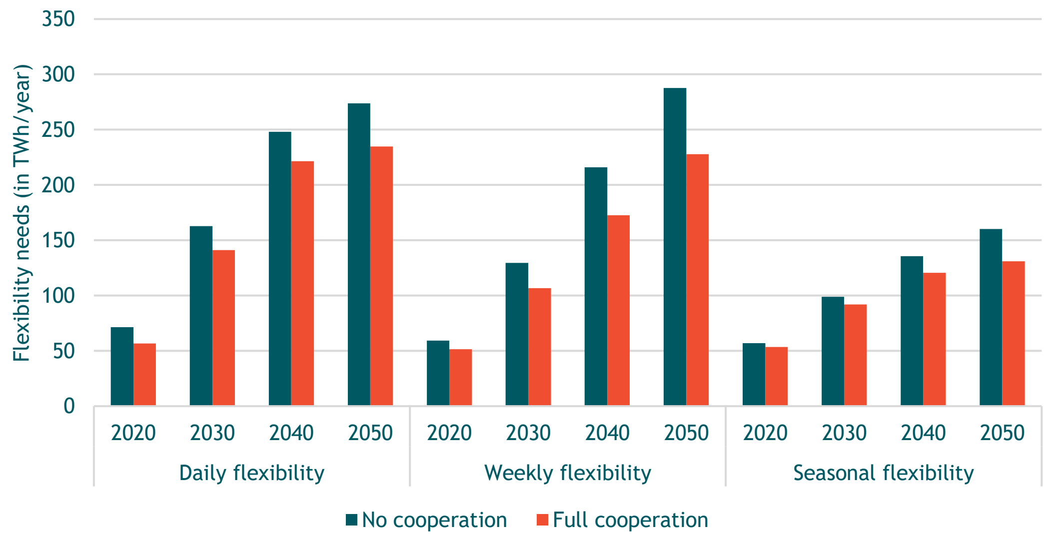
As it was mentioned previously in Section 2 Definition and common understanding of flexibility, the interconnections between countries allow to shift power generation across space, smoothing variability in RES generation and demand across large areas, and thus reducing the need for flexibility at the regional level. The Penta region is highly interconnected, which enables a reduction in flexibility needs through regional cooperation.

In order to evaluate the impact of regional cooperation on flexibility needs, the latter were computed using two methods. In the case without regional cooperation, flexibility needs are computed at the country level, considering they would operate in isolation, and then aggregated at the Penta level (corresponding to the flexibility needs shown in Figure 3-5). The second method considers full regional cooperation (copper plate, neglecting grid constraints within the Penta region), with flexibility needs computed using the residual demand aggregated at the Penta level.

The flexibility needs for the Penta region, with and without cooperation, are shown in Figure 3-8 for the Technology Driven scenario[36]. Regional cooperation brings benefits at all flexibility timeframes, as **flexibility needs are reduced between 10% to 20%** depending on the time horizon and flexibility timeframe. The reductions of flexibility needs are more important in high-RES systems (i.e., by 2050).

The benefits of regional cooperation are slightly more pronounced at the weekly timeframe with a flexibility need reduction of 19% in 2050, and 14% for the daily and seasonal. This difference is partly explained by a higher diversity in wind generation patterns (which drive weekly needs) across Penta countries whereas PV generation (which drive daily needs) strongly correlates across the Penta region, lowering the possibilities to "smooth" variability in RES production.

Figure 3-8: Flexibility needs of the Penta region for the Technology Driven scenario without cooperation and with full cooperation.



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[36] Comparisons for the two other scenarios are shown in in Annex 6.2.

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3.2 Flexibility potentials and portfolios

In order to meet the flexibility needs identified in the previous Section 3.1, a portfolio of flexibility solutions is needed. Several flexibility solutions were introduced in Section 2.2, consisting of generation, storage and demand technologies. This section aims to illustrate possible flexibility portfolios and the role of the different flexibility solutions in the individual Penta countries.

The assessment of flexibility portfolios relies on the results of the Ember study for the Technology Driven scenario[37,38]. Two indicators are analysed which capture the level of participation of each technology to its host country: the installed capacity of flexible assets and their contribution to meet flexibility needs. These indicators were computed for the following flexibility solutions: flexible generation, RES curtailment, demand side response (including EVs and electrolysis) and storage technologies (batteries, PHES).

It should be noted that these indicators are used to illustrate the trends of different flexibility assets, which depend on the hypothesis of the scenarios and the scope of the modelling exercise, and not to provide exact values or targets.

3.2.1 Installed capacities of flexible assets

The installed capacities of flexible assets in the Penta countries are presented in Figure 3-9 and Figure 3-10. These figures do not include EVs or variable RES (solar PV, wind) capacities.

The installed capacities of flexible assets remain relatively stable or exhibit moderate increases by 2050 in all Penta countries[39]. The increase of flexible capacities (14% at the Penta level) is modest in comparison to the increase in flexibility needs (between 300% to 600% at the Penta level). This implies that the operation of assets in the future needs to be much more flexible than currently.

The composition of the flexibility solutions portfolios is completely different when comparing 2020 to 2050. The phase-out of unabated fossil generation in (coal by 2030, gas by 2050) as well as nuclear generation (Germany, Belgium, Switzerland, reductions in France[40]), is compensated by an uptake of flexible demand-side assets (batteries, EVs, heat pumps, electrolysers) and hydrogen-based power generation, and in a few cases fossil gas with carbon capture and storage (CCS). Hydro maintains a major role in some countries (Switzerland, Austria, France to a more limited extent).

Hydrogen-related assets can become a major flexibility source if installed in wind-rich countries, such as Germany, the Netherlands, Belgium and France. Electrolysers reach 23 GW by 2030 and 138 GW by 2050[41], corresponding to 7% and 38% of the total installed capacity of flexible assets (without RES and EVs) in the Penta region. Hydrogen generation and gas with CCS is mainly developed in countries with high dependency on gas generation in their current power system (the Netherlands, Germany, Belgium), reaching 94 GW by 2050 respectively.

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[37] Similar trends are observed in the other scenarios. Detailed results for all scenarios can be found in Annex 6.2.
[38] Additional flexibility solutions to existing ones were determined endogenously using the Artelys Crystal Super Grid pathway model, a least-cost optimisation model for energy systems.
[39] The Ember study did not consider the provision of reserves to handle sub-hourly needs. The requirement for flexible assets could be higher if sub-hourly needs were considered.
[40] The reduction of nuclear capacities in France is part of the scenario hypothesis, which may not correspond to the country's policy.
[41] Electrolysers capacity was determined endogenously (i.e., optimised) during the modelling exercise.

Figure 3-9: Installed capacities of flexible assets in Austria, Belgium, Switzerland, Luxembourg and the Netherlands in GW from 2020 to 2050 for the Technology Driven scenario (legend available in the next figure)[42]

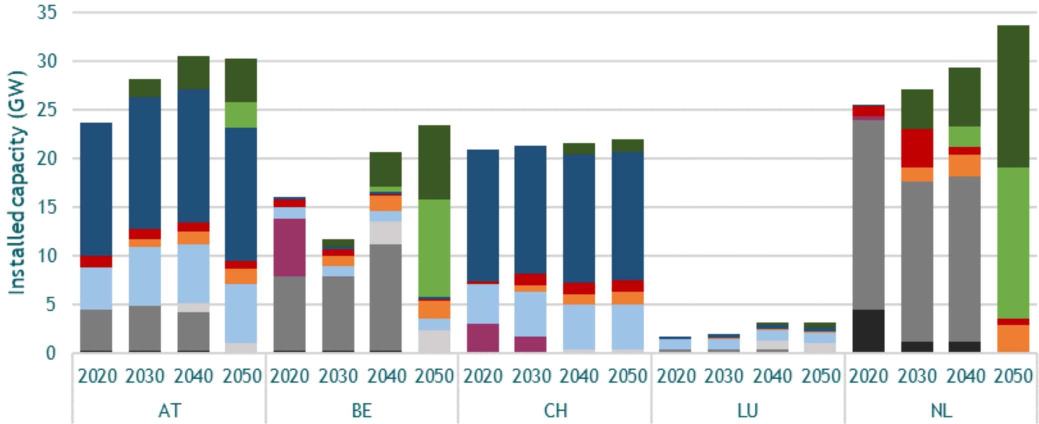
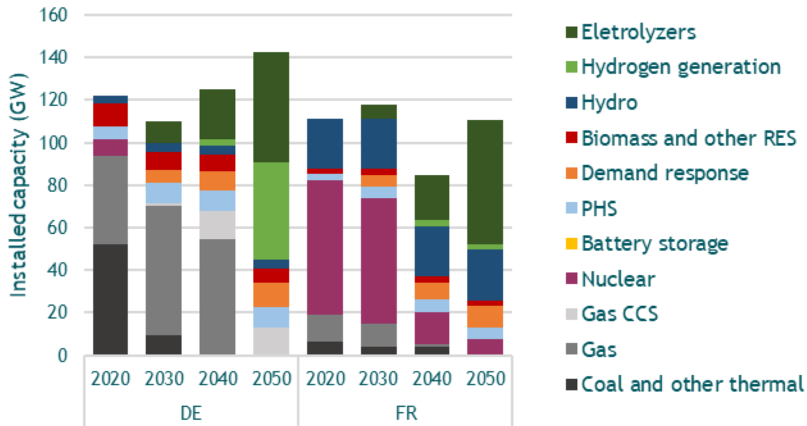


Figure 3-10: Installed capacities of flexible assets in Germany and France in GW from 2020 to 2050 for the Technology Driven scenario.



Almost no batteries are installed in this scenario, due to the consideration of rapid uptake of EVs coupled with market/grid-friendly charging (smart charging and V2G). EVs will represent a major potential for flexibility, with tens of millions of EVs on the streets expected from 2035 onwards in the Penta countries alone. This can represent several tens of GWh of storage capacity and tens of GW of power capacity for flexibility. Stationary batteries could be developed for other flexibility needs not covered in the modelling exercise, such as local congestion management, voltage support or balancing reserves. These batteries could also provide flexibility to the energy market (daily and weekly flexibility), competing with other flexibility solutions.

The investment in flexibility assets needs to be complemented by investments in grid interconnection capacities, as shown in Figure 3-11[43]. The total cross-border interconnection capacity in the Penta countries increases by a factor of 3 by 2050 (from 54 GW in 2020 to 144 GW in 2050[44]), allowing increased exchange of RES generation and flexibility, required to successfully integrate large amounts of renewable energy into the system.

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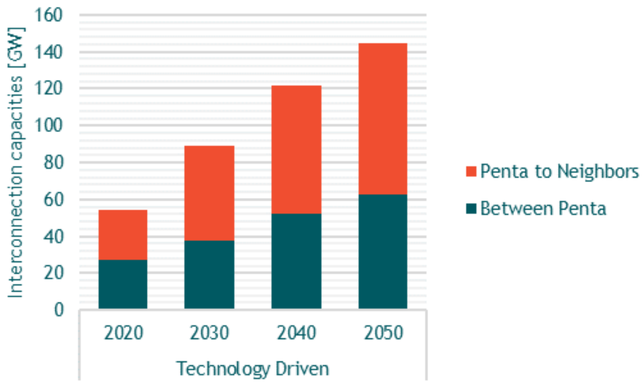
[42] Switzerland installed capacities include 4.1 GW of hydro run-of-river for all years.
[43] Interconnection capacities were determined endogenously (i.e., optimized) during the modelling exercise.
[44] The interconnection needs are in the same order of magnitude to ENTSO-E's System Needs study for 2030 and 2040 (https://needs.entsoe.eu/)

Figure 3-11: Cumulated interconnection capacities between Penta countries and with their neighbours, for the Technology Driven scenario

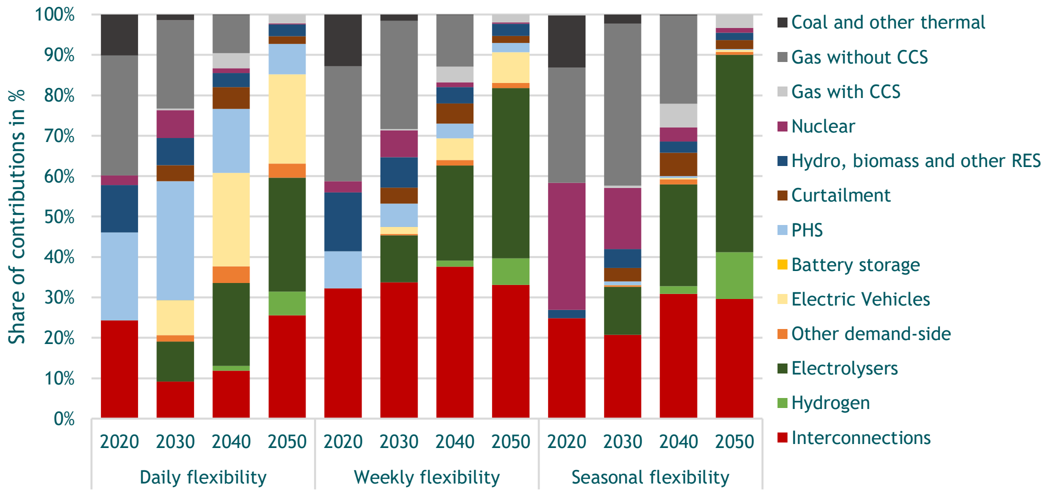


3.2.2 Contribution to flexibility needs

Flexibility contributors at Penta level

The shares of contribution to flexibility needs in Penta countries are presented in Figure 3-12[45], for the Technology Driven scenario. It shows the contribution per technology in percentage (and not in energy, i.e., TWh), to facilitate reading, as needs increase by a factor of 3 to 6 from 2020 to 2050. The contribution of flexibility needs are computed for each country independently, and then summed at the Penta level.

Figure 3-12: Share of technologies providing system flexibility in the Penta countries for daily, weekly and seasonal timeframes, Technology Driven scenario.[46]



The main technologies contributing to flexibility depend on the time horizon and flexibility timeframe. However, **interconnections**, both within Penta countries and with neighbours, **will keep playing a major role in flexibility at all timeframes and at all time horizons.** The share of contribution to flexibility is around 25% of the needs at the Penta level. This contribution is given by both allowing the smoothing of RES variability across space (i.e., reducing the flexibility needs) and by allowing cross border exchange of flexibility.

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[45] Contributions to flexibility needs are computed at the country level, considering the technologies available in the country, and the aggregated at the Penta level.
[46] “Electrolysers” refer to the production of hydrogen from electricity, whereas "hydrogen” refers to power generation using hydrogen turbines (P2G2P). This requires hydrogen transport and storage infrastructures.

Conventional technologies provide the bulk of flexibility needs in 2020, with hydro and pumped hydro storage providing a significant share at the daily and weekly timeframe. Coal, gas and nuclear (mainly at the seasonal level) provide most of the remaining flexibility needs.

The flexibility contributors change drastically by 2040 and 2050, with demand-side flexibility becoming the major contributor at all timeframes (EV batteries, electrolysers, heat pumps and others), compensating the decommissioning of conventional generation technologies. In particular, battery storage technologies (mostly EVs) provide around 25% of flexibility needs at the daily timeframe, and around 7% at the weekly timeframe, highlighting their importance for short-term flexibility.

Electrolysers appear as the major contributor to flexibility at all timeframes by 2050, and complemented by hydrogen-based power generation at a minor level (power-to-gas-to-power, P2G2P). To achieve this, flexible operation of electrolysers is required, meaning that the capacity of electrolysers would be oversized for the expected demand. The flexible operation of electrolysers, and in particular the possibility of P2G2P (i.e., hydrogen generation) is also enabled by the availability of long-term hydrogen storage capacities. These two conditions are still uncertain and correspond to assumptions of the modelling exercise.

Contrasting flexibility contributions

A stark contrast between the flexibility contributions at each country can be observed, as each country has its own power generation mix, dependent on geographical constraints and political choices. This can be observed in the flexibility contributions of Switzerland and the Netherlands, shown in Figure 3-13 and Figure 3-14, respectively. Negative contributions mean that the operation of a given asset goes against the flexibility needs of a country, increasing the needs instead of contributing to fulfil them. This can be the case of interconnections, if the country exports large amounts of flexibility to a point that the local needs are increased.

Switzerland's hydro assets represent the main flexibility contributors at the daily and weekly timeframes, even exceeding national needs by a factor of 2 to 3. EVs and electrolysers complement daily and weekly flexibility from 2030 onwards. Switzerland becomes a major exporter of flexibility (thus the negative values for interconnections), tapping in the flexible operation potential of its hydro reservoirs and PHES and highlighting the importance of regional cooperation.

On the other hand, the Dutch power system is the opposite of the Swiss one, which relies mainly on gas by 2020 and on wind power by 2050, without any hydro or nuclear generation plants. The Netherlands meet their flexibility needs in 2020 through the use of gas-fired power plants at all timeframes, even exporting flexibility at the seasonal timeframe, while interconnections contribute significantly at the daily and weekly timeframe. The rise of flexibility needs and the decommissioning of gas generation is compensated by EVs (daily timeframe) and flexible electrolysers. The high availability of wind generation and the potential for hydrogen storage allow the development of flexible electrolysers and P2P2G.

This section provides an example of two countries that have different flexibility contributors in order to meet with their national flexibility needs. It is important to emphasize the importance of cooperation between countries and that individual flexibility portfolios depend on each country's peculiarities. The shares of technologies providing system flexibility are presented in the Annex 6.2 for all Penta countries.

Figure 3-13: Share of technologies providing system flexibility in Switzerland for daily, weekly and seasonal timeframes.

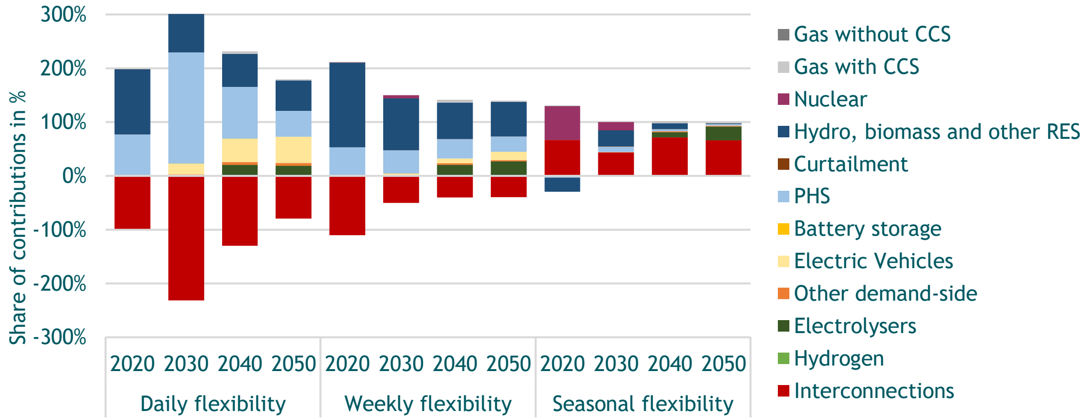
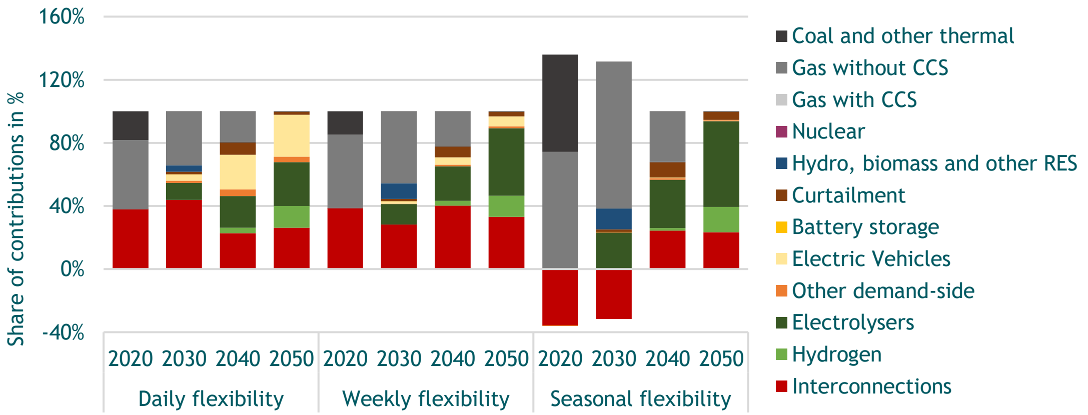


Figure 3-14: Share of technologies providing system flexibility in the Netherlands for daily, weekly and seasonal timeframes.



3.2.3 Summary

The diverse portfolios built for each country in order to meet the flexibility needs show that different technologies are needed to provide flexibility at different timeframes. This can be seen with battery storage (including EVs), which provide flexibility mostly at daily timeframes, or PHES that provides flexibility at both daily and weekly timeframes, due to larger storage capacities than batteries. Also, the availability of local resources will play a major role in the developed solutions, which was shown with the role of hydro in Switzerland and the availability of long-term storage for P2G2P in the Netherlands.

A summary of the status of flexibility contributors in Penta countries is shown in Table 3-1. Each row indicates the role that a given technology may play in a Penta country.

Table 3-1: Status of flexibility contributors in Penta countries

	Austria	Belgium	Switzerland	Germany	France	Luxembourg	Netherlands
Coal	× (red)	× (red)	× (red)	✓ (orange)	✓ (orange)	× (red)	✓ (orange)
Nuclear	× (red)	✓ (orange)	✓ (orange)	✓ (orange)	✓ (green)	× (red)	✓ (blue) (in discussion)
Gas-fired power plants	✓ (green)	✓ (green)	● (orange)	✓ (green)	✓ (green)	✓ (blue)	✓ (green)
Hydropower	✓ (green)	× (red)	✓ (green)	● (orange)	✓ (green)	✓ (green) ● (orange)	× (red)
Pumped Hydro Storage (PHS)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	× (red)
Hydrogen storage (P2G2P)	✓ (blue) ● (orange)	✓ (blue) ● (orange)	× (red)	✓ (blue)	✓ (blue) ● (orange)	× (red)	✓ (blue)
Electrolyzers	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)
Demand-side response	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Battery storage	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)

Status of flexibility contributors
- ✓ (green) Can provide system flexibility from 2020
- ✓ (orange) Can provide system flexibility but will phase-out before 2040
- ✓ (blue) Can provide system flexibility in the future but it does not at the moment
- ● (orange) Limited contribution to system flexibility
- × (red) Unavailable or marginal contribution to system flexibility

A **green tick** symbolizes the fact that it is possible for a certain flexibility asset to provide flexibility from today until at least 2050. A clear example of this status is the pumped-hydropower storage that is able to provide flexibility in all countries of the Penta region up to 2050 with the exception of the Netherlands, due to geographical constraints. Yet, it should be noted that the PHES potential is already exploited to a large extent.

Orange ticks are attributed to the flexibility assets that currently provide flexibility but that will phase-out in the country at most in 2040. This is the case of nuclear phase-out in Belgium, Switzerland and Germany before 2040 and the phase-out of coal power plants in Germany, France and the Netherlands.

The **blue tick** represents the flexibility solutions that could be deployed in the future, but are not ready yet to be deployed at scale. This tick is mainly associated to future deployment of flexible electrolysers and hydrogen storage to provide system flexibility.

An **orange dot** represents that the technology can provide flexibility, but with limited contribution to the country's needs. This is the case of gas-fired power plants in Switzerland, which are not needed due to the availability of hydropower. This also represents uncertainty in the role of hydrogen-fuelled power generation in countries lacking hydrogen storage capacities such as Austria and Belgium[47].

Finally, the **red cross** symbolizes the unavailability of a technology to provide system flexibility. This includes technologies that have not been developed or have already been phased-out in the country, such as nuclear power in Austria. It also encompasses the unavailability of developing these assets given the geographical context, such as hydropower and PHES in the Netherlands.

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[47] The most promising options for large scale hydrogen storage are saline caverns, which are located mainly around the North and Baltic seas. Source: Caglayan et al (2019) Technical Potential of Salt Caverns for Hydrogen Storage in Europe, International Journal of Hydrogen Energy

4 Regulatory status quo, identified barriers and recommendations to foster flexibility

This chapter identifies and compares existing regulations enabling or hindering the deployment of flexibility solutions in the electricity sector in the Penta countries. Planned regulations to be implemented in the short-term are also included.

It is important to note that if a Penta country is not specifically mentioned, it does not mean that it does not have regulatory provisions for the respective topic; the study does indeed not aim to provide an exhaustive overview but rather focuses on the most relevant national and cross-border provisions and practices.

4.1 Summary of the regulatory status quo and related barriers

Flexibility needs of the power systems in the Penta countries are expected to increase significantly with the further deployment of renewable electricity sources and the electrification of end-uses, but the need for flexibility is already today a pressing issue. The European Council agreed in September 2022, based on a Commission proposal, to an obligation for Member States to reduce the power demand by at least 5% in peak hours. Member States should define peak hours to comprise at least 10% of the hours from 1 December 2022 to 31 March 2023.[48] With the current energy prices and supply risks, all measures that can reduce peak demand can provide significant benefits. Some Penta countries moreover already face significant structural grid congestions[49] and several network operators struggle to timely connect renewable energy projects or new consumers to the grid, threatening the cost-effective achievement of the climate and energy targets.

Flexibility is a complex issue which relates to spot and balancing markets, as well as non-frequency ancillary and congestion management services procurement. The flexibility solutions also vary significantly, including dispatchable power generation, energy storage, demand-side flexibility and conversion (hydrogen) technologies, being capable of providing both implicit as well as explicit flexibility.

It is thus necessary to scope the analysis. The following topics affecting flexibility solutions have been selected following discussions with the Steering Committee:

- ✓ Day-ahead and intraday markets;
- ✓ Electricity balancing;
- ✓ Congestion management;
- ✓ Network tariffs and contracts;
- ✓ Independent aggregators;
- ✓ Network planning;
- ✓ Value stacking;

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[48] Council of the European Union (2022) Proposal for a COUNCIL REGULATION on an emergency intervention to address high energy prices (12249/22 INIT)

[49] According to article 2(6) of the Electricity Regulation 219/943, 'structural congestion' means congestion in the transmission system that is capable of being unambiguously defined, is predictable, is geographically stable over time, and frequently reoccurs under normal electricity system conditions

- ✓ Collective self-consumption.

The analysis reveals that the **day-ahead and intra-day markets** are in the Penta countries in general well advanced in allowing the participation of flexibility sources, aggregated or not. There remains nonetheless significant benefits from further cross-border integration, with among others ensuring the availability of existing interconnectors to market parties across all timeframes, and developing additional interconnection capacities where economically justified.

The **balancing markets** in the Penta countries are largely compliant with the Electricity Target Model. Nonetheless, barriers remain for new and small actors (such as storage or small loads) especially due to specific market rules. Further balancing market design changes could improve incentives to implicit or explicit flexibility solutions. For example, imbalance charge components and ‘adders’ to prices paid to BSPs could improve signals to market parties.

Compared to spot and even balancing markets, **congestion management** through the procurement of redispatching services by network operators presents more barriers to the participation of new and small flexibility providers, both at the TSO and DSO levels. Nonetheless, progress is being made in several Penta countries, through the adaptation of the regulatory framework and specific market rules. Also, platforms for procurement of congestion management services are being developed, sometimes in conjunction with the procurement of balancing services. There is however no harmonised approach for deciding on market- vs cost-based procurement of redispatching services, nor transparency requirements on the decision-making process.

Network tariffs are another aspect significantly influencing flexibility solutions, with large differences in design between Penta countries. Time-differentiated transmission and distribution tariffs are used to varying extent across the Penta region. Interest in dynamic network tariffs is growing, but there is yet no practical case of implementation and it is not sure that dynamic grid tariffs would be an adequate solution for market operators. Flexible (interruptible) grid connections for generators are recently being considered or implemented in some Penta countries, while interruptibility schemes are since long being used for large off takers in some Penta countries.

For small actors such as households or other users connected to the LV and MV networks, **aggregators** (can) play an important role to enable their active participation in the electricity markets. The role of aggregators has been clarified or will be in most Penta countries. However, even without a formal definition, aggregators are able to participate in different electricity markets anyway. **Independent aggregators** are however still facing barriers due to the lack of a regulatory framework enabling their access to all electricity markets, but this is expected to be addressed in the coming years. Nonetheless, barriers for independent aggregation of small loads will remain in some countries due to e.g. the lack or incomplete roll-out of low-voltage smart meters or high transaction costs.

Network development plans (NDPs) detail the proposals of TSOs and DSOs for investments and refurbishment projects within their grids. NDPs define the main flexibility assets possible for consideration in future network development as alternatives for grid expansion and reinforcement. The plans’ implementation also directly influences the potential availability of flexibility in various markets. NDPs in the Penta region are broadly in line with the EU TYNDP. However, NDPs often do not include storage or power-to-x facilities, nor consider these and other flexibility solutions as alternatives to network development. There is in general still limited or no coordination between NDPs for electricity and other energy carriers (such as natural gas and hydrogen).

Value stacking allows flexibility asset operators to maximise their revenues and thus increases the flexibility resources available to the system. Using a flexibility asset to provide two or more flexibility services at different moments is often allowed in the Penta countries, but providing services simultaneously is more often forbidden. Moreover, selecting the assets that will provide the flexibility service in (near to) real-time (called dynamic pooling) in the Penta countries is often not allowed for the relevant flexibility services.

Finally, concerning **collective self-consumption**, and more specifically **energy sharing**, in the context of citizen and renewable energy communities, a regulatory framework is in place in most Penta countries. However, the regulatory changes have often been introduced only recently, and their effects on flexibility are limited and not yet fully clear.

4.2 Overview of potential barriers to flexibility

This section assesses the different challenges and barriers for utilisation of flexibility sources as well as cross-border cooperation. The most relevant barriers were identified based on desk research (incl. the most recent publications, industry reports and Penta background documents) and previous project work undertaken by the consultants, while also incorporating stakeholder's views gathered during and after the project workshops.

We have grouped the barriers for deployment of flexibility sources in those related to the categories listed in Table 4-1Table 4-2. Based on this review and discussions with representatives from the Pentalateral Energy Forum, we have selected the topics for in-depth analysis in this chapter.

Table 4-2: High-level challenges and barriers to flexibility

Aspect	Challenges and barriers
Governance	• There may be a lack of clear decarbonisation scenarios, which properly take into account the current developments • No clear strategy and measurable targets for different flexibility sources to meet flexibility needs, in part due to the complexity of the topic • Lack of analysis of flexibility needs and potential at a regional level for the Penta / CWE region • The participation of Switzerland in the EU market platforms depends on an EU-CH agreement
Market design	• Implementation of the Clean Energy Package is not yet complete in some countries, for example regarding a framework for the procurement of flexibility by DSOs • Limited competition and liquidity in forward and spot markets in some European countries, including Penta countries • Barriers to market access for distributed flexibility sources still exist (metering requirements, pre-qualification and participation rules, lack of harmonised products)

Aspect	Challenges and barriers
	• Rules for some national capacity remuneration mechanisms (CRMs) may block or disadvantage some flexibility solutions such as storage and hinder cross-border trade • Remaining barriers to participation of all flexibility solutions in balancing markets, including specific market rules for (aggregated) small actors, and imbalance charges often not producing adequate incentives • Cross-border integration of balancing capacity markets mainly limited to the FCR cooperation initiative • Procurement of congestion management services is still not fully open to non-conventional flexibility solutions • Interlinkages between market timeframes (such as intra-day and balancing) is still largely not accounted for in market clearing algorithms, reducing synergies and increasing opportunity costs for flexibility providers • Value stacking is also unduly constrained, without clear and objective rules for when it is allowed/forbidden • Market and network models used for planning and market operation need to be improved, including need for inter-vector coordination and sector interlinkages, consideration of non-conventional flexibility solutions, and availability of interconnectors
Supply-side flexibility	• Decreasing available dispatchable power generation capacity in CWE, which will have to be substituted by other flexibility sources at supply or demand side • Lack of profitability of highly flexible peaking power generation plants in normal market conditions (without CRM) • Uncertainties regarding profitability of fossil fuel based power generation technologies employing CCU/S given need for development of CO2 transport infrastructure, decreasing load factors of conventional power plants and current high gas prices
Demand-side flexibility	• Dynamic retail prices are not yet (easily) available in all Penta countries • Relies on the large-scale deployment of technical solutions at end-users' premises (e.g. smart technologies, home energy management solutions, etc.). • Difficulties to access the market linked with a lack of standardisation (e.g. different technology requirements across markets), lack of a clear framework for DR providers, limited access to and exchange of data, … • Rules for market entry affect flexibility providers in different ways based on their nature, the main affected solutions are dispatchable generation, electrolysers, storage and demand-side solutions • Role and potential participation of aggregators not yet clearly defined in all countries. • Absence of large-scale electricity smart meter roll-out for low-voltage users in some European countries • Price regulation remains in some European countries, including Penta countries, distorting competition and hampering effective price formation
Energy storage	• Although the cost of battery storage technologies has been decreasing over the past decade, they still involve large upfront investments. • Double network charging (injection + take-off) is in place in some countries

Aspect	Challenges and barriers
	• Double taxation is in place in most countries
Grid infrastructure	• Increasing interconnection capacities requires high levels of collaboration between countries and/or jurisdictions • Insufficient cross-zonal capacity is made available to the market to facilitate trade and exchange of flexibility across market timeframes, remaining under the CEP 70% target • Internal congestion hindering the connection of RES and flexibility resources (while congestion management represents potential revenue streams for flexibility resources) • Bidding zones configuration may not properly reflect structural congestions, and the 1st bidding zone review process was deemed deficient by ACER • Flexibility options are not yet considered as an alternative to grid reinforcement in some Penta countries' regulatory frameworks (e.g. Austria)

4.3 Day-ahead and intraday markets

Summary of the topic

- Electricity spot markets facilitate the entry and participation of flexibility sources;
- Rules for market entry affect flexibility solutions in different ways based on their nature; the main affected solutions are dispatchable power generation, electrolysers, storage and demand-side solutions;
- Most barriers for direct participation of small market operators in DA and ID markets have been lifted in the Penta countries;
- Metering requirements still hamper end-user engagement in certain cases;
- Harmonisation of product definitions and timeframes is advancing in the Penta countries;
- Cross-border cooperation has proven to be highly beneficial and should further continue, with among others ensuring a higher availability of existing interconnection capacity to market parties across all timeframes, and developing additional interconnection capacities where economically justified;
- Further assessment and removal of prevailing barriers is recommended. Improvements are expected from the exchange of good practices, as well as from maximising cross-border flows and the harmonisation of national regulations to avoid market distortion.

4.3.1 Relevance of day-ahead and intraday markets to flexibility

Well-functioning, cross-border energy markets can contribute to the optimal utilization of flexibility by allowing (in conjunction with balancing markets) BRPs to adjust their positions, facilitating the entry and participation of flexibility sources and providers, and by integrating various national markets. This improves both efficiency and liquidity as well as spurs competition, by ensuring that the most cost-effective flexibility solutions are deployed.

The main challenges impacting flexibility solutions that occur on spot markets are related to adequate rules and regulations for participation of small operators, as well as some aspects of product design. Participation of small actors is still hampered by some factors, such as limited market liquidity or the lack of harmonised trading windows for low-granularity flexibility products. These barriers can be overcome with suitable regulation and market design, an inclusive market structure and adequate network operations. Harmonised product definitions for standard services that apply universally ease the procurement of flexibility services.

Access to liquid and well-functioning spot markets is mainly important to facilitate flexibility solutions (such as dispatchable generation, electrolysers, storage and demand-side assets) that are owned and operated by small and independent (not-integrated) operators.

4.3.2 Current regulatory frameworks in the Penta countries

Participation of small operators

Active participation of small operators can help to reduce congestion and system costs[50] by providing balancing and other ancillary services to improve system flexibility. However, the participation of small actors in electricity markets is still hampered by multiple factors. ACER has identified several barriers to efficient price formation and market entry for these actors in 2020[51], categorizing them as follows:

Table 4-3: Barriers to efficient price formation and market entry for small entrants (excerpt)

Category	Barrier
Regulation and market design	Complex, lengthy and discriminatory administrative and financial requirements
	Lack of a proper legal framework to enable new entrants and small actors
	Restrictive requirements to participate in capacity mechanisms and interruptibility schemes
	End-user price interventions
	Limited incentive to contract dynamic retail prices
	Restrictive requirements in prequalification and/or the design of products
Market structure and performance	Limited competitive pressure in the retail markets
Network services and operations	Lack of incentives to consider non-wire alternatives
	Insufficient information provided by system operators

In the Penta countries, most of the barriers for access to electricity markets have already been lifted, however some remain. For example, France and Belgium still have limited competition/high concentration on their wholesale markets[52], and there are often lengthy administrative requirements to

[50] A good example from DE (Baden-Württemberg) presents EUR 280 million in savings via the utilization of small flexibility assets like EVs and heat pumps: https://www.transnetbw.de/de/newsroom/presseinformationen/mit-e-autos-und-waermepumpen-die-energiewende-voranbringen
[51] ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume.pdf (europa.eu) p.84, Table 7
[52] ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume.pdf (europa.eu)

meet for smaller actors to participate. The transaction costs are in some countries also a barrier to direct participation of small operators.[53]

Adequate product definition and market design

To ease the entry for flexibility providers, spot market products should be further adapted where appropriate and harmonised as much as possible to accommodate all actors on the market, including smaller non-vertically integrated players, and enable them to conduct effective cross-border trade of electricity, in particular to balance their portfolio. The increased granularity and complexity of the DA/ID products and the enactment of various other technical features ensures adequate functioning of these markets.

Market price signals in the wholesale and retail markets are key to motivate changes in supply and demand, and thus for fostering flexibility. In some Penta countries, price caps or regulated retail prices have been introduced on electricity markets to mitigate the economic effects of an increase in the wholesale prices. These are detrimental to price formation[54] and thus the participation of flexibility sources, as they give no scarcity signals and so reduce the opportunities for flex to minimize the system stress. This results in potential revenue loss for flexibility providers and reduces incentives to participate.

Besides price caps or floors, price formation on wholesale markets may be constrained by certain features of the imbalance settlement mechanism too, distorting wholesale price signals and increasing the cost of providing flexibility for these players. The EU target model (Electricity Balancing Guideline, Electricity Market Regulation and Directive) set out for the Imbalance Settlement Period to be harmonized to 15 minutes in all MSs to support ID trading and foster the development of more trading products. The development and harmonization of trading products with this granularity on both DA and ID markets for all Penta countries would improve the ability of Balancing Responsible Parties (BRPs) to adjust their positions and reduce their imbalances in these market timeframes in reaction to updated generation and load forecasts, ahead of real-time balancing, thereby also increasing the cost reflectivity of imbalance prices as well as enable these actors to further contribute to frequency restoration[55].

The cross-zonal intraday gate closure time being set to 15 minutes before market start also contributes to liquidity[56]. Continuous trading of cross-border ID products coupled with lower granularity products like the 15-minute one makes the market design better suited for RES generation as well[57]. In 2020, from the Penta countries France still had a longer ISP period than 15 mins (namely 30 minutes), with a plan to implement it by 2025[58].

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[53] https://op.europa.eu/en/publication-detail/-/publication/4944efcd-4071-11ed-92ed-01aa75ed71a1/language-en

[54] As pointed out in ACER's Market Monitoring report and current events on electricity markets is countries where there are price caps

[55] https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER%20Market%20Monitoring%20Report%202020%20%E2%80%93%20Electricity%20Wholesale%20Market%20Volume.pdf

[56] 200617_6.5_EFET_ID_MarketDesign paper.pdf (azureedge.net)

[57] 200617_6.5_EFET_ID_MarketDesign paper.pdf (azureedge.net)

[58] https://energy.ec.europa.eu/system/files/2021-04/france_market_reform_plan_0.pdf

Metering requirements

The wider use of smart metering is imperative for efficient demand-side management, and the slow roll-out of electricity smart metering for low-voltage users in some European countries (including Austria, Germany, Switzerland and Belgium) still poses a barrier for demand-side flexibility. Low penetration of smart metering hampers engagement from small end-users, as there are often specific metering requirements and synthetic load profiles (SLP) needed for qualification and participation in flexibility markets. In France and Austria, small consumers can provide DR without smart metering, in the former via an aggregator[59] and in the latter using an SLP. The standardization of asset interfaces and a wider smart meter roll-out could also benefit the participation of DR.

Cross-border importance of wholesale markets and interlinkages with other market timeframes

The efficiency of cross-border trading has a profound impact on electricity prices and social welfare, and is hence a key factor in enabling flexibility. Coupled markets help mitigate the potential price impacts of renewable electricity production and reduce demand disturbances, delivering substantial economic benefits at the same time (according to ACER[60] EUR 34 billion in 2021[61] and further EUR 1 billion per year with the integration of short-term electricity markets). Maximising cross-border exchanges is thus essential for all Penta countries. It is only with the fine-tuning of product definition and granularity as pointed out above that interconnectors can be fully utilised once markets are coupled, and national surpluses and deficits can be tackled with greater resilience via trading, close to real-time.

In the Penta countries, Belgium is a good example for meeting its generation shortfall in 2018 via imports to a significant extent compared to earlier, while France's recent nuclear power outages in 2021 made it a net importer from a net exporter, with cross-border interconnections playing an important role in mitigating electricity prices volatility and providing security of supply too[62]. The Dutch TSO TenneT also confirms that for the Netherlands to cost-efficiently ensure resource adequacy and cope with electricity demand until 2030, cross-border cooperation and trade with neighbouring Member States is essential.[63] Specifically, the further the integration of Switzerland in the different European electricity market segments (especially the day-ahead timeframe) would be an essential next step towards full cross-border efficiency. ACER already reported significant additional welfare gains from the cross-border coupling of CH-IT North markets in 2021 for example[64].

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[59] https://publications.jrc.ec.europa.eu/repository/handle/JRC129745 https://publications.jrc.ec.europa.eu/repository/handle/JRC129745

[60] https://www.acer.europa.eu/sites/default/files/documents/Publications/Progress_report_European_wholesale_electricity_21.pdf

[61] https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER%26%23039%3Bs%20Final%20Assessment%20of%20the%20EU%20Wholesale%20Electricity%20Market%20Design.pdf https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER%26%23039%3Bs%20Final%20Assessment%20of%20the%20EU%20Wholesale%20Electricity%20Market%20Design.pdf

[62] https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER%26%23039%3Bs%20Final%20Assessment%20of%20the%20EU%20Wholesale%20Electricity%20Market%20Design.pdf https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER%26%23039%3Bs%20Final%20Assessment%20of%20the%20EU%20Wholesale%20Electricity%20Market%20Design.pdf

[63] https://www.tennet.eu/tinyurl-storage/detail/international-dependency-on-security-of-electricity-supply-calls-for-more-cross-border-coordination https://www.tennet.eu/tinyurl-storage/detail/international-dependency-on-security-of-electricity-supply-calls-for-more-cross-border-coordination

[64] https://www.acer.europa.eu/sites/default/files/documents/Publications/Progress_report_European_wholesale_electricity_21.pdf

The interlinkages between forward, spot and balancing markets should also be properly considered. While easy access of flexibility providers to the different market segments is important and should in general be facilitated, the access rules and practices should contribute to the overall optimisation of the energy system also taking into account the availability of cross-border capacity.

As cross-border electricity trade in the forward time frame is extremely important to enhance market competition and liquidity and to cover electricity demand at least cost, market rules should prioritise the use of available cross-border transmission capacity for long-term contracts. In principle, all available cross-border capacity (resulting from the long-term capacity calculation process) should hence be allocated in the forward time frame as far in advance as possible via long-term transmission rights. The TSOs should regularly update their capacity calculation and offer any additionally available or released capacity in subsequent auctions to market operators for long-term contracts. To ensure an optimal market functioning, transmission capacity should in principle not be reserved ex-ante for flexibility transactions in the short term market segments, but any remaining capacity in the day-ahead and intra-day time frame (determined by using a flow-based calculation method) should be made available to market operators to adjust their portfolios. TSOs can in the short term time frame also use any remaining transmission capacity to balance their system, including via netting.

However, TSOs are according to the Electricity Balancing Guideline (Regulation (EU) 2017/2195) entitled to allocate cross-zonal capacity for the exchange of balancing capacity and the sharing of reserves, when supported on the basis of a cost-benefit analysis. To this end, they can apply one of the 3 following methods: the co-optimisation method which is to be performed on a day-ahead basis, the market-based allocation process where the contracting is carried out not more than one week in advance of the provision of the balancing capacity, or the allocation based on an economic efficiency analysis where the contracting is done more than one week in advance of the provision of the balancing capacity, provided that the volumes allocated are limited and that an assessment is carried out annually. EU TSOs have opted in their proposal for a harmonised cross-zonal capacity allocation methodology not to include the third approach of allocation based on an economic efficiency analysis.[65] Therefore, cross-border transmission capacity should in principle be by priority allocated to wholesale market parties. The Electricity Balancing Guideline allows an exception for reserve capacity, but TSOs have opted to maintain (in addition to the co-optimisation approach to cross-zonal capacity allocation) only the market-based allocation approach, and should thus in principle not negatively affect the overall efficiency of the market.

4.3.3 Recommendations

The recommendations on electricity market design and participation of flexibility services in the Penta region primarily aim at **improved cross-border markets' functioning and coordination/harmonisation of trading products**. The following recommendations would facilitate more efficient cross-border trading and market accessibility for flexibility providers:

- Resolve and improve any remaining **spot markets' coupling** issues that still hinder cross-border trading in order to capture the full benefits of markets' integration. Interconnection capacities need to be increased where appropriate to enable using the most competitive production (e.g. hydro in Switzerland in the summer) and flexibility assets (e.g. large-scale storage) available at regional level.

[65] ACER is due to take a decision on the proposal by June 2023. See https://acer.europa.eu/news-and-events/news/acer-will-consult-proposal-harmonised-cross-zonal-capacity-allocation-methodology

This requires high levels of collaboration between the respective national authorities and grid operators. Next to further extensions of the physical cross-border interconnection capacity where economically justified, a higher share of the existing capacity needs to be made available to the market to reach the CEP target of 70%.

- Create **suitable and harmonised product definitions for non-standardised trading products** to facilitate (real-time) participation of small actors in national and local markets and also further improve cross-border trade. **Revise bidding zone configurations** where appropriate to better reflect structural congestions. Where congestion occurs occasionally, grid operators should be incentivized to procure flexibility via market-based mechanisms, where appropriate. Structural grid congestion should preferably be addressed by adequate investments in additional grid capacity.
- **Exchange good practices** between Penta countries on the **participation of small demand response, administrative frameworks and aggregation**, and revise where appropriate the **metering and other rules for flexibility providers** to facilitate and encourage participation of small operators in the spot markets.

4.4 Electricity balancing

Summary of the topic

- Balancing markets enable system operators to manage system imbalances and allocate (at least part of) the costs to the parties causing the imbalances;
- Balancing markets in the Penta countries are largely compliant with the Electricity Target Model;
- However, barriers still remain for new and small actors (such as storage or small loads) especially due to specific market rules;
- Further balancing market design changes could improve incentives to implicit or explicit flexibility solutions. For example, imbalance charge components and 'adders' to prices paid to BSPs could improve the economic signals;
- In contrast, designing cost-reflective network charges for recovering balancing capacity procurement costs is challenging and would require further research;
- Penta countries should harmonise pre-qualification requirements for balancing markets as well as employ ex-post verification of compliance of assets with technical requirements combined with administrative pre-qualification as an alternative to full pre-qualification, when adequate, in line with the upcoming network code on demand response.

4.4.1 Relevance of electricity balancing markets to flexibility

Balancing markets[66], together with spot markets, allow market participants to adjust their positions in (close to) real time considering updated information – especially renewable energy forecasts but also increasingly the availability of demand response resources such as electric vehicles or smart appliances – as well as allow system operators to contract the balancing services needed to manage remaining imbalances. Therefore, both balancing and spot markets (and their interlinkages) are relevant for flexibility.

[66] We include in this reference not only organized balancing markets where TSOs procure balancing reserves and energy, but also bilateral agreements between market participants to address their primary imbalances

Balancing markets provide balancing responsible parties information on the system imbalance and direction, and allow also system operators to procure balancing services in order to address the system imbalance at least cost. Therefore, balancing markets provide signals to stimulate not only implicit flexibility but also signals for the investment in and activation of explicit flexibility solutions.

Significant progress has been made in Europe in developing balancing markets and removing entry barriers. However, a number of barriers for the provision of signals to implicit flexibility and participation of new flexibility solutions in balancing markets may still exist. Many are specific to small flexibility assets, especially for demand response, where the role of aggregators is critical (discussed in section 4.10). Others affect all flexibility sources, such as the challenges in recovering balancing capacity costs in a cost reflective manner.

4.4.2 Current regulatory frameworks in the Penta countries

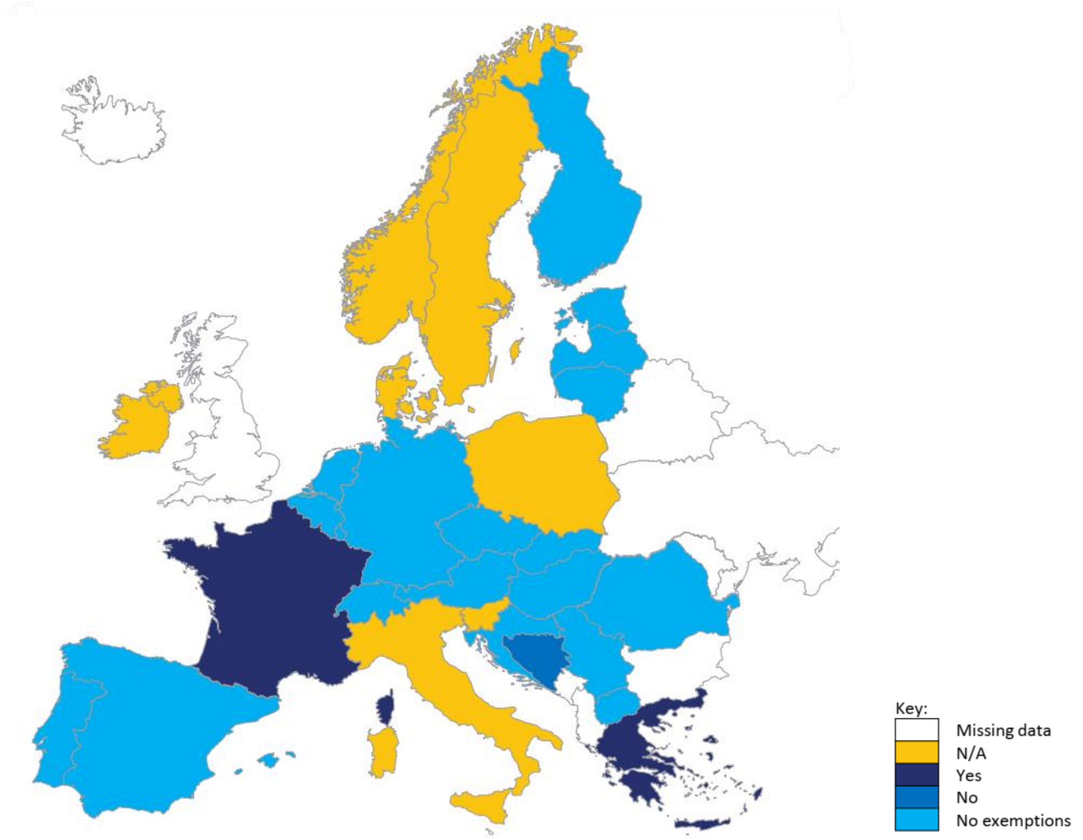
Balancing responsibility for RES

The majority of ENTSO-E members for which information is available do not exempt renewable energy producers from balancing responsibilities, as shown in the figure below.[67] The exception among the Penta countries is France, where producers participating in the feed-in tariff scheme are exempted, while those participating in the feed-in premium scheme bear balancing responsibility.[68]

Exempting large-scale renewable energy producers from balancing responsibility disincentivises them from managing their own imbalances, including through minimising deviations in their generation forecasts, and provides a competitive advantage vis-à-vis other RES producers in the same regional market that are subject to balancing responsibility. However, as the majority of Penta countries do not exempt RES producers from balancing responsibility and as RES producers are still supported by non-harmonised national schemes, the exemption from balancing responsibility has a limited potential for distortion of competition between renewable energy producers located in different Penta countries.

[67] ENTSO-E (2022) Survey on Ancillary services procurement Balancing market design 2021
[68] CEER (2021) Status Review of Renewable Support Schemes in Europe for 2018 and 2019

Figure 4-1: Exemption to renewable energy producers of balancing responsibility[69]



Role of TSO/DSO for managing residual system imbalances and other system functions

This section looks at the allocation of responsibility for managing residual imbalances[70] to the TSO and/or DSO. Currently, TSOs have the responsibility for balancing in their load frequency control area (which includes the distribution systems located there), as well as for other functions at the transmission level, for example managing congestions, maintaining voltage levels within limits and assuring other non-frequency ancillary services such as the availability of black-start capacity. However, DSOs have to increasingly take actions to ensure the stability of their grids, by providing or procuring a number of non-frequency ancillary services, while TSOs maintain the responsibility for managing imbalances of BRPs. This set-up is constantly evolving, driven by the growing deployment of distributed energy resources and their participation in energy markets at transmission and distribution level, as well as integration of national energy markets.

The current set-up thus allocates responsibilities between TSOs and DSOs according to system functions, instead of only network voltage levels, with DSOs being responsible for some but not all functions in their networks. In theory, DSOs could be assigned the responsibility to address also residual imbalances for their network once local smart grids sufficiently develop,[71] thus being responsible for all services at distribution level. For this, the load-frequency control area would be defined as the DSO's network.[72]

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[69] ENTSO-E (2022) Survey on Ancillary services procurement Balancing market design 2021
[70] That is, the imbalance after balancing responsible parties have adjusted their primary positions
[71] Ecorys (2014) The role of DSOs in a Smart Grid environment
[72] Schittekatte et al. (2022) Distributed energy resources and electricity balancing: visions for future organisation

Managing balancing at the local level to a certain extent could thus occur due to the further decentralisation of electricity production and limited connection capacities to the transmission system. It could also contribute to reducing distribution network expansion needs[73] (by better considering network constraints for any balancing actions) and providing more opportunities for distributed flexibility resources.[74] However, there is limited analysis on the advantages and disadvantages of centralised vs local balancing, and to our knowledge no DSO in the Penta countries is currently responsible for managing residual imbalances in its entire network, despite several pilot projects existing on the balancing of local smart grids. It must be noted that this would not necessarily be the most advantageous option, as sharing balancing resources at a national and even regional level significantly increases the allocative efficiency. Rather, this theoretical discussion highlights the different allocation of responsibilities to TSOs and DSOs per system function.

Pass through of balancing capacity procurement costs

As can be seen below, all Penta countries recover the balancing energy costs from the balancing responsible parties through the imbalance settlement process. Moreover, most Penta TSOs socialize the balancing reserve costs and recover them from all network users. Concerning balancing reserve costs, Switzerland has a specific charge to recover ancillary service costs including for balancing reserve in order to provide greater transparency on the allocation of these costs, but these are still recovered from all consumers.[75]

Usually off-takers – DSOs and consumers connected directly to the transmission system – bear most of the balancing charges. In contrast, in Austria, capacity costs for FCR are recovered from generators and for FRR via grid tariffs.[76] In Belgium, electricity generators pay balancing charges[77], while generators in France and the Netherlands do not have to pay such charges.[78]

Table 4-4: Cost recovery of balancing services in the Penta countries

<table>
<tr><th></th><th>FCR</th><th>FRR</th><th>RR</th><th>Balancing energy</th></tr>
<tr><td>Austria</td><td>Other charge</td><td>Main transmission tariff</td><td rowspan="5">N/A</td><td rowspan="7">Imbalance settlement / BRPs</td></tr>
<tr><td>Belgium</td><td colspan="2" rowspan="4">Main transmission tariff</td></tr>
<tr><td>Germany</td></tr>
<tr><td>Luxembourg</td></tr>
<tr><td>Netherlands</td></tr>
<tr><td>France</td><td colspan="3">Main transmission tariff</td></tr>
<tr><td>Switzerland</td><td colspan="3">Other charge</td></tr>
</table>

Sources: ACER (2019) ACER Practice Report on Transmission Tariff Methodologies in Europe; Swissgrid (2019) Costs for using the Swiss transmission grid; Swissgrid (2022) Tariffs - Status 22 March 2022.

[73] Pierre et al. (2021) Local Balancing of the Electricity Grid in a Renewable Municipality; Analysing the Effectiveness and Cost of Decentralized Load Balancing Looking at Multiple Combinations of Technologies
[74] Schittekatte et al. (2022) Distributed energy resources and electricity balancing: visions for future organisation
[75] Swissgrid (2022) Tariffs - Status 22 March 2022
[76] E-Control (2022) Regelreserve und Ausgleichsenergie. https://www.e-control.at/marktteilnehmer/strom/strommarkt/regelreserve-und-ausgleichsenergie
ACER (2019) ACER Practice Report on Transmission Tariff Methodologies in Europe
[77] https://www.elia.be/-/media/project/elia/elia-site/customers/tarrifs-and-invoicing/tariffs-and-invoicing/en/grille-tarifaire-2020-2023-toegang-en-v3.pdf
[78] National Grid ESO (2020) Final Report - Second Balancing Services Charges Task Force

Ensuring cost reflectivity of balancing charges (both energy imbalances charges and charges for reservation and activation of balancing reserves) can incentivise implicit and explicit flexibility by motivating market parties to adjust their imbalances in order to reduce the system imbalance, and by providing balancing services. However, it is not possible to ensure full cost reflectivity of balancing charges. The recovery of balancing energy costs from BRPs and the socialisation, in most Penta countries, of balancing reserve costs reflect the difficulties in defining cost causality for balancing reserves, as these reserves are contracted beforehand and are thus not linked to the actual imbalances of BRPs. Hence, the approved methodology for the rules and processes for the exchange and procurement of balancing capacity of the FCR cooperation initiative does not address the question of recovery of the costs of each TSO from network users (it only addresses TSO-TSO settlement for exchanged capacity).

A study led by the British TSO on redesigning the balancing charges in the UK (BSUoS)[79] recommended treating balancing costs on a cost recovery basis – i.e. having cost recovery as the main driving principle of balancing charges design, rather than cost reflectivity. Specifically, the study found that:

- ✓ The existing UK balancing charges did not provide “any useful forward-looking signal which influences user behaviour to improve the economic and efficient operation of the market”, as “the current BSUoS charges are hard to forecast, complex, increasingly volatile, that other market signals are more material and so take precedence, and the current BSUoS charge applies to all chargeable users of the transmission system on an equal basis”
- ✓ None of the four potential design options considered to improve the balancing charges “would not or could not provide a cost-reflective and forward-looking signal that would drive efficient and effective market behaviour”, even if some theoretical benefits existed. This is due to residual balancing costs incurred by the system operator varying significantly, it being unclear how to define marginal costs caused by parties, the existence of risks of double-counting with other cost components such as the main transmission tariffs, and the overall complexity of balancing services.

System services, including the residual costs of balancing, can constitute a significant share of the TSO’s transmission tariffs, being even the largest component of TSO-related costs in Belgium, Germany and the Netherlands.[80] Note that other systems services, particularly congestion management, can represent a larger share of the system service costs than balancing, for example as was the case in Germany in 2022.[81] Therefore, in theory it would be appropriate to recover these costs in as cost-reflective manner as possible. However, for the reasons detailed above this is not straightforward.

Imbalance charges design

Providing adequate incentives to (implicit) flexibility solutions through the design of imbalance charges is comparatively simpler than through the design of (residual) balancing charges. Two parameters are particularly relevant in this regard: the settlement rule (whether there is only a single or different prices for BRPs whose imbalance positions are short or long in respect to the system position - single or dual pricing) and the position (whether injection and withdrawal imbalances for each BRP are settled

[79] National Grid ESO (2019) Balancing Services Charges Task Force - Final Report
[80] ENTSO-E (2022) Overview of Transmission Tariffs in Europe: Synthesis 2020
[81] Bundesnetzagentur and Bundeskartellamt (2023) Monitoringbericht 2022

jointly or separately - single or dual positions, respectively). ACER indicates that single pricing and single position are the standard in the Electricity Target Model.[82]

According to ACER, prices under dual pricing are often capped or linked to other market prices, distorting incentives for BRPs to reduce the system imbalance, besides discriminating against smaller market actors which may not have the same possibility to manage their imbalances as large actors. A single position facilitates the participation of small (aggregated) flexible units, as they do not need to separate their production and consumption positions. Some stakeholders support the use of dual pricing, especially for security reasons, as dual pricing reduces the possibility for overshooting by BRPs and incentivizes them to use high-quality production plans.[83]

All Penta countries use single pricing and position, with the exception of the Netherlands, where dual pricing applies in some cases ("where both positive and negative balancing energy is activated and where a preferred direction cannot generally be determined")[84,85] and of Switzerland, where dual pricing is in place.[86] In Belgium, dual pricing has been applied during a certain time period, but has meanwhile been abandoned.

Another relevant issue is the use of scarcity or incentivising components when defining imbalance prices, as is currently the practice in multiple Penta countries as shown in Table . Allowed by the imbalance settlement harmonisation methodology[87] article 9(6), the purpose of the components is generally to provide adequate signals to BRPs to adjust their primary imbalances, in scarcity situations in the case of the scarcity component, and in other situations in the case of the incentivising component (particularly to incentivise them to adjust their imbalances near to real time e.g. via transactions on the intra-day market).

Table 4-5: Use of scarcity and/or incentivising components in imbalance prices in the Penta countries[88]

	Scarcity component	Incentivising component
In use in	AT, DE, CH	BE, FR, DE, CH
Potential impacts on flexibility solutions	- Reduce TSO's need for balancing services - Increase BRP flexibility needs from other market participants in short-term (intra-day and balancing timeframes)	

Belgium for example employs the alpha parameter (considered an incentivising component) to adjust imbalance prices. A modification of the parameter was approved in 2022 by CREG,[89] in order to reduce its importance to the formation of the imbalance prices, especially after high imbalance prices were observed in 2021.

[82] ACER and CEER (2021) ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume
[83] ENTSO-E (2018) Imbalance settlement harmonization - Informal workshop pursuant the EBGL Art. 52(2). Notes of the informal workshop https://eepublicdownloads.entsoe.eu/clean-documents/events/2018/20180323-Workshop_imbalance_settlement-Summary.pdf
[84] ACER and CEER (2021) ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume
[85] ACM (2022) ACM/UIT/570957 https://www.acm.nl/sites/default/files/documents/goedkeuring-dubbele-prijsstelling-voor-onbalansverrekening.pdf
[86] Swissgrid (2022) General Balance Group Regulations
[87] ACER decision 18/2020
[88] ENTSO-E (2022) Balancing Report 2022
[89] https://www.creg.be/sites/default/files/assets/Publications/Decisions/B658E77NL.pdf

The same consideration applies when defining the settlement rule (single or dual pricing) and the position (single or dual) for these components: how to incentivise parties to not only manage their imbalances but also to eventually contribute to minimising the system imbalance in a cost-effective manner. Here, as indicated above ACER considers that single pricing and position is the most adequate design as it does not penalise smaller BRPs whose imbalance is against the system position or who could further contribute to reducing the system imbalance. Once could consider also increasing the remuneration perceived by BSPs with the scarcity or incentivising components when providing balancing services. The European Commission has in 2021 invited for example Belgium to consider bringing this measure to the Belgium alpha parameter.[90]

These components to the imbalance price can impact the exchange of balancing energy and imbalance netting between countries. Therefore, it could be interesting to dedicate further attention to the analysis of the impact of such components on procurement of balancing services, imbalance settlement and imbalance netting, particularly as several Penta countries make use of them.

Procurement of balancing services

In 2020 a number of new and small market actors were not eligible to participate in different markets in the Penta countries. ACER noted that in some Penta countries active consumers, (independent) aggregators and energy communities were not eligible to participate in most market timeframes (day-ahead, intraday, balancing and congestion management services, as well as other services to TSOs and DSOs).

Since then, progress has been achieved for balancing as well as other market timeframes. Active consumers are increasingly eligible to participate in DA, ID and balancing markets directly, or through aggregators. The participation of independent aggregators is still more challenging and is covered in section 4.10, while citizen energy communities (with collective self-consumption) are covered in section 4.11). The provision of congestion management and non-frequency ancillary services to TSOs and DSOs also remains a challenge; congestion management is specifically covered in section 4.6. Due to the challenges with independent aggregation, the participation of small loads in balancing markets is still restricted.[91]

Generally the balancing market design in the Penta countries is compliant with the Electricity Target Model (ETM). However, some countries were in 2020 not yet fully compliant on a few features relevant for flexibility sources:[92]

- ✓ **Minimum capacity required in the prequalification process** was above 5 MW in France for mFRR and RR (ETM requirement is 1 MW or lower)
- ✓ **Minimum bid size for balancing energy** above 5 MW in France for mFRR and RR (ETM requirement is 1 MW or lower)

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[90] https://energy.ec.europa.eu/system/files/2020-05/adopted_opinion_be_en_0_1.pdf
[91] JRC (2022) Explicit Demand Response for small end-users and independent aggregators
[92] ACER and CEER (2021) ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume;
RTE, Manual frequency restoration reserve and replacement reserve terms and conditions Version in force on 1 January 2023. https://www.services-rte.com/files/live//sites/services-rte/files/documentsLibrary/2023-01-01_MFRR-RR_TERMS_AND_CONDITIONS_4507_en

- ✓ **Minimum bid size for balancing capacity** was above 5 MW in France for mFRR and RR (ETM requirement is 1 MW or lower)
- ✓ **Settlement rules for the balancing energy market:** regulated prices were used in France (aFRR), pay-as-bid in Austria (mFRR, until connection to MARI), Belgium and Germany (aFRR and mFRR), while the ETM requirement is marginal pricing
- ✓ **The activation rule** used in France for aFRR was pro-rata, instead of the merit order

Moreover, barriers can still exist for participation in balancing markets, even if the market design is compliant with the ETM. The JRC (2022) notes some barriers for the Penta countries, including non-adapted qualification procedures for e.g. EVs, the requirement to specify exactly which actor (in case of aggregation) or asset is providing the balancing service, high administrative charges for establishing balance groups, and disproportionate penalties for non-delivery.[93]

Arrangements are necessary to check the compliance of resources and their service providers with service requirements and grid availability and ensure adequate functioning of flexibility markets, but can indeed represent a barrier. The prequalification process can include requests for 1) operator qualification, where market operators prove being a suitable flexibility resource provider for a given market themselves (involving financial checks); 2) product qualification for each unit providing flexibility (validating technical requirements); as well as 3) grid qualification for certain products like inertia, FCR and aFRR to see if they cause congestion.[94]

Often these procedures are lengthy and discouraging smaller participants, or include measurements that don't adequately address the specific properties of DR. Where pre-qualification is done at the level of a pool (by aggregators), and not on the single end-user level, it can encourage participation of smaller loads, as is the case in France[95]. Moreover, a simplified administrative pre-qualification can be combined with the verification of compliance of the assets with the product technical requirements ex-post upon delivery, instead of full qualification being conducted ex-ante. This is not commonly done yet among EU Member States as noted by ACER[96] but could significantly lower the barrier for entry to balancing markets while ensuring delivery of the contracted services in the long-run.

4.4.3 Recommendations

This section analyses several issues regarding the design of national balancing markets which can be further explored in the future, such as increasing the cost-reflectivity of charges to recover balancing capacity costs. However, these issues will require further reflection and experimentation given the complexity of achieving cost-reflective charges. Therefore, the most immediate improvements that Penta countries can consider, concern measures to remove any remaining barriers for the participation (including cross-border), of flexibility solutions in balancing markets by among others **harmonizing pre-qualification requirements for balancing markets** as well as **considering ex-post verification of** compliance of assets with technical requirements combined with administrative pre-qualification as an

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[93] JRC (2022) Explicit Demand Response for small end-users and independent aggregators
[94] VITO (2021) Analyse van het wettelijk, reglementair en regulerend kader van de flexibiliteitsmarkt
[95] https://op.europa.eu/en/publication-detail/-/publication/4944efcd-4071-11ed-92ed-01aa75ed71a1/language-en
https://op.europa.eu/en/publication-detail/-/publication/4944efcd-4071-11ed-92ed-01aa75ed71a1/language-en
[96] ACER (2022) Wholesale Electricity Market - Monitoring 2021 Prequalification processes for the provision of balancing services
https://acer.europa.eu/news-and-events/news/acer-sees-scope-grid-operators-simplify-their-prequalification-processes-enable-small-scale-demand-response-provide-balancing-services

alternative to full pre-qualification, when adequate, in line with the upcoming network code on demand response.

4.5 Cross-border balancing platforms

Summary of the topic

- Cross-border energy balancing platforms, mandatory under the Electricity Balancing Regulation[97], are being implemented in Europe, allowing the exchange of balancing flexibility across countries;
- Cross-border capacity balancing platforms have been implemented to a lesser extent, on a voluntary basis by TSOs. The main example is the FCR cooperation, in with all Penta countries are participating;
- The balancing platforms provide several benefits to their participating members, including harmonization of products, imbalance netting and cross border activation of flexibility. The added value provided by each platform is estimated at several hundred million € per year, depending on the type of reserve and the geographical scope;
- Main recommendations lie in continuing and strengthening collaboration in cross-border balancing platforms, both mandatory and voluntary.

4.5.1 Relevance of cross border balancing platforms to flexibility

The implementation of cross border balancing platforms provides a number of benefits on the procurement of balancing flexibility. First, they allow for imbalance netting between TSOs. A flexibility need of one TSO can be offset by an opposite need of another TSO, not requiring the activation of flexibility. Second, they allow the cross-border exchange of flexibility, where a need situated in the zone of one TSO can be answered by a flexibility activation in another TSO's area, improving the liquidity and efficiency of flexibility markets. And third, they provide a harmonization of products and rules, simplifying trading and lowering learning barriers for participants.

Overall, the different flexibility market platforms can provide benefits of several hundred million Euro per year for the countries involved. The FCR cooperation has an estimated socio-economic welfare increase of 184 million € per year, and TERRE, the platform for replacement reserves (RR) reported an increase in socio-economic welfare of ~480 million € from March to December 2021. Additionally, the IGCC, the platform for imbalance netting, provided savings of over 300 million € in 2021[98,99]. When fully operational, the PICASSO and MARI platforms, which will allow cross-border trading of FRR energy, should provide significant benefits as well.

4.5.2 Current development in the Penta countries

Balancing markets are usually organised in two stages. First, a procurement for **balancing capacity** is performed between one day before delivery (D-1) up to one year before (Y-1). And then, in real-time, the **balancing energy** is activated according to the system needs. The balancing capacity aims to ensure that there will be enough resources to provide balancing energy in real-time, as a shortage of balancing energy providers can put at risk the system.

[97] Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing
[98] Note that socio-economic welfare gains are not the same as savings.
[99] ENTSO-E (2022) Balancing report 2022

The activation of balancing energy can be automatic or manual. For FCR, all balancing providers selected in the capacity market participate on the service based on the frequency of the system in real-time, in a continuous manner. For FRR and RR, activations are performed in a market-based manner as defined in the EB Regulation, meaning that they are selected according to **energy bids.** Balancing providers that were not selected in (or that did not submit bids to) the balancing capacity market can still participate in the balancing energy market.

The European balancing platforms

The Electricity Balancing Regulation (EB Regulation) of 2017 sets out the obligation of establishing market platforms for the cross-border exchange of balancing energy. This comprises the development of four platforms:

- The **IGCC** (International Grid Control Cooperation) is the European platform for the imbalance netting process. The imbalance netting allows TSOs to avoid simultaneous and opposite activations of aFRR. This means that a need of a TSO can be complemented by an opposite need from another TSO, without any activation. This provides savings for TSOs and increases the security of the system, by not using reserves when not needed. This platform started in 2011 and now covers 24 countries in Continental Europe, including all Penta countries.
- **PICASSO** (Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation) is the platform for the exchange of aFRR balancing energy. This platform has the approval of all ENTSO-E members. The GO-live for PICASSO was in June 2021. It operates currently only in Germany, Austria and Czechia. Accession for the rest of members (including Penta countries) is expected by 2023-2024.
- **MARI** (Manually Activated Reserves Initiative) is the platform for the exchange of mFRR balancing energy, covering 30 countries in Europe. The Go-live was in October 2022, with only Germany and Czechia in operation. Accession for the rest of members (including Penta countries) is expected by 2023-2024.
- **TERRE** (Trans European Replacement Reserves Exchange) is the platform for the exchange of RR balancing energy covering 7 countries in Europe. The Go-live was in January 2020, with 6 countries operational and the expected accession of Poland in 2023. Among Penta countries, only France and Switzerland participate in the platform, as the other countries do not procure RR.

Cross-border exchange of balancing capacity is voluntary, thus balancing capacity markets remain mostly at a national level. Two main platforms exist in the Penta region which allow the cross-border exchange of balancing capacity. These platforms have been put in practice on a voluntary basis:

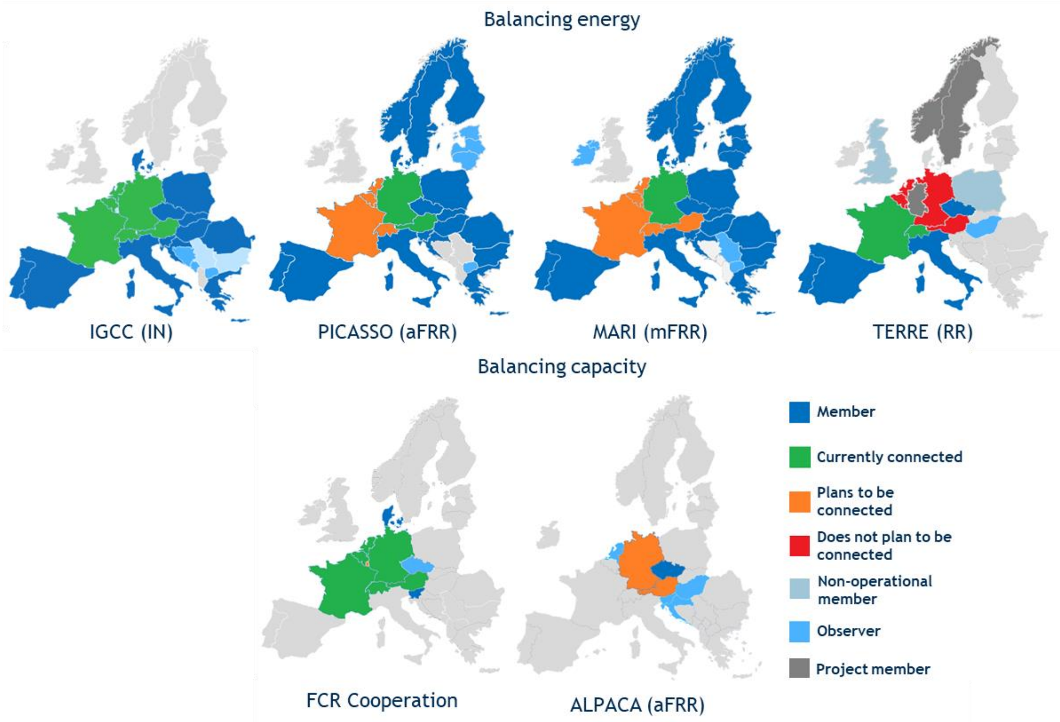
- **FCR Cooperation**, is a cross-border exchange platform for FCR capacity, which currently covers 8 countries[100], including all Penta members[101]. Participating countries need to cover part of their demand internally (core demand), and the remainder can be procured from other countries as long as they respect transfer capacities.
- **ALPACA,** is a platform for joint procurement of aFRR balancing capacity between the TSOs of Austria and Germany. The platform started operating in February 2020, and estimates savings of 16 million € in 2021. In 2022 the TSO of Czechia signed a Memorandum of understanding to

[100] Czechia will join the FCR cooperation in March 2023.
[101] Not considering Luxembourg, which is part of the German balancing zone.

join the platform. Four other TSOs are assessing joining the cooperation, including TenneT NL.[102]

The participating members in the 6 platforms are shown in Figure 4-2.

Figure 4-2: Members and connection status of Penta countries to the European platforms[103]



As the platforms are quite recent, they are not operational yet in all countries. The timeline for accession of Penta members is shown in Table 4-6.

[102] ENTSO-E (2022) Balancing market report 2022.
[103] Adapted from ENTSO-E Electricity balancing.

Table 4-6: Accession timeline to European balancing platforms for Penta countries. ✓ represents the countries that are currently connected to each platform, ✓ the ones that plan to be connected in the future and ✖ the ones that do not plan to be connected to the platforms

	Balancing energy				Balancing capacity	
Country	IGCC	PICASSO	MARI	TERRE	FCR Coop.	ALPACA
Austria	✓	✓	✓ Q2 2023	✖	✓	✓
Belgium	✓	✓ Q4 2024	✓ Q4 2023	✖	✓	✖
Germany	✓	✓	✓	✖	✓	✓
France	✓	✓ Q2 2024	✓ Q3 2024	✓	✓	✖
Luxembourg	✓	✓[104]	✓[104]	✖	✓	✖
Netherlands	✓	✓ Q3 2024	✓ Q3 2024	✖	✓	✓ In study
Switzerland	✓	✓[105]	✓[105]	✓	✓	✖

Products and sequential clearing

One of the benefits of the cross-border platforms is the harmonization of products, which facilitates trading. An overview of the key product parameters is provided in Table 4-7. IGCC is not considered as it is not a market platform, but a cooperation platform among TSOs without any traded products.

Table 4-7: Main parameters of balancing energy platforms and product definition

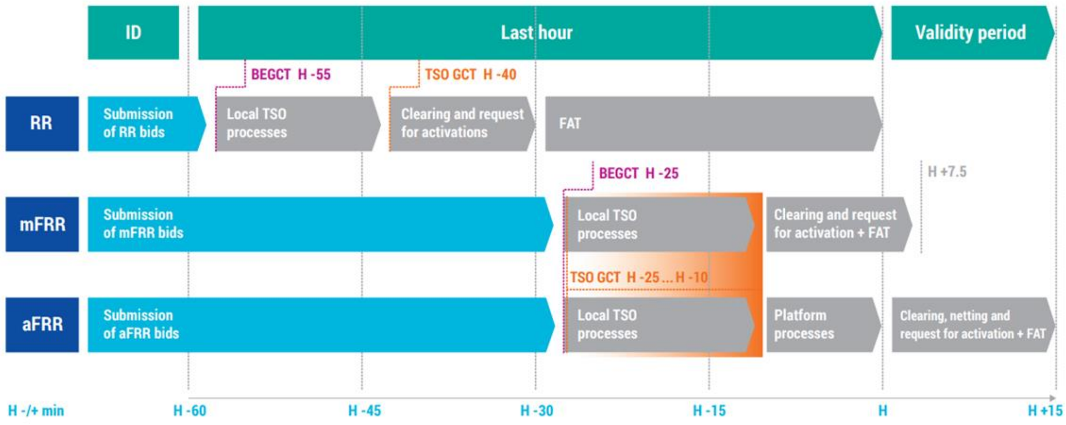
	Balancing energy			Balancing capacity	
Parameter	PICASSO	MARI	TERRE	FCR Coop.	ALPACA
Gate closure time	T-25	T-25	T-55	D-1 (8:00)	D-1 (9:00)
Full activation time	5 min.	12,5 min.	30 min.	30 sec.	5 min.
Product length	15 min.	15 min.	15 - 60 min.	4 hours	4 hours
Min bid volume	1 MW	1 MW	1 MW	1 MW	1 MW
Bid granularity	1 MW	1 MW	1 MW	1 MW	1 MW
Pricing scheme	Marginal	Marginal	Marginal	Marginal	Pay as bid

Two major advantages of product harmonization can be identified. First, the reduction of minimum bid sizes to 1 MW eases the entrance of new actors, such as RES or distributed demand response aggregators. However, this parameter level can still be considered as high[106] and could be further reduced (500 kW or less).

Second, the gate closure times (GCT) of balancing energy platforms have been aligned to provide a sequential clearing between intraday, RR and FRR markets, as shown in Figure 4-3.

[104] Luxembourg operators are connected to German markets since the load frequency control area is Creos (Luxembourg) / Amprion (Germany).
[105] The technical readiness of Swissgrid has been acknowledged. The participation of Switzerland in the aFRR-and mFRR Platforms is regulated based on article 1.6 and 1.7 of the EB Regulation and currently the subject of litigation by Swissgrid at the General Court of the European Union.
[106] ENTSO-E (2021) Options for the Design of European Electricity Markets in 2030, Stakeholders' Responses to the public consultations

Figure 4-3: Gate Closure Time (GCT) for different products and stakeholders[107]



The intraday market closes at T-60 (one hour before delivery). Then, market actors have 5 minutes to submit their bids for RR, which are the slowest reserves. TSOs processes the bids and computes their needs (demand bids), and sends them to the central platform (TERRE). The market outcome is obtained at T-30, with corresponding accepted bids (i.e., requests for activations) and rejected bids. After the results of the RR market, market actors have 5 minutes to submit bids to the FRR market (either automatic or manual, depending on the technical capabilities and preferences). TSOs again process the bids, formulate their demand and send the bids to the respective platforms (PICASSO and MARI). The market outcome is obtained at T-15, with corresponding accepted bids (activations) and rejected bids.

Having GCT close to real time for the balancing energy markets allows actors to submit bids with better forecasts of their production/demand. This is particularly important for RES-based actors, for which forecasts improve only in the last hours (see Section 3.1.1). This way, an actor who would not be able to participate in the day-ahead capacity market due to low certainty on their perimeter, can participate in the balancing energy market when their forecasts have improved.

Sequential clearing also allows actors to participate in all balancing markets (if technically possible), as results from one market (ID or RR) are obtained 5 minutes before the next one (RR or FRR). It should be noted that sequential clearing is not the only possibility to improve the efficiency of markets. Co-optimisation of energy and reserves, which is carried out in some US markets such as PJM, can also be performed.

4.5.3 *Recommendations*

The recommendations regarding cross-border balancing platforms aim to encourage collaboration among Penta countries and with their neighbours, and to continuously improve the market platforms:

- **Push for accession to mandatory platforms** (balancing energy, PICASSO, MARI). In several countries, discussions between NRAs and TSOs are time consuming, with risks of delays of accession to the platforms beyond 2024. In particular for Switzerland, the lack of a agreement between Switzerland and the EU on electricity market integration can put in danger its participation in balancing platforms.

[107] ENTSO-E (2020) Balancing Report 2020

- **Continue cooperation in voluntary platforms** (balancing capacity platforms), establish mechanisms of cooperation where non-existing, and encourage Penta and non-Penta countries to join existing platforms, when deemed efficient. Cross border balancing capacity platforms can increase the pool of assets available to provide balancing capacity, but have additional operational and implementation costs (such as the need to reserve interconnection capacity).
- **Push for ambitious objectives in product design**. In the FCR platform, assess the impacts of increasing the granularity of products to 1 hour (currently 4-hour products), and asymmetric provision. Overall, assess the impacts of lowering the minimum bid threshold.
- **Ensure continuous improvement of the technical functioning of platforms**, such as the rules used to define cross-border capacity limits. Assess the impacts and requirements for the use of updated flow-base domains for energy balancing platforms, instead of the use of previous-day NTCs.[108]

4.6 Congestion management

Summary of the topic

- Congestion management services will be increasingly required, especially at the distribution level, and can constitute a relevant revenue stream for flexibility providers;
- Significant barriers still exist for the provision of congestion management services to TSOs and DSOs by new and small players, directly or through aggregation;
- Nonetheless, progress is being made in several Penta countries, through the adaptation of the regulatory framework, with for example the creation of the Congestion Management Service Provider (CSP) figure as well as the adaptation of the detailed market rules;
- Also, platforms for procurement of congestion management services are being developed, sometimes in conjunction with the procurement of balancing services;
- There is however no harmonised approach for deciding on market- vs cost-based procurement of redispatching services, nor transparency requirements on the decision-making process;
- Given the incipient state of mechanisms to procure congestion management services compared to balancing markets, several areas for improvement are identified, including:
  - Develop harmonised approach/principles for deciding on market- vs cost-based procurement of redispatching services, and transparency requirements on the decision-making process;
  - Assess and remove barriers for (voluntary) participation of small and new actors in existing markets, including aggregators, with exchange of good practices;
  - Work towards harmonised definitions of (national) products;
  - Gradually evolve towards increasing coordination/integration of markets at TSO/DSO levels.

4.6.1 Relevance of congestion management to flexibility

Grid congestion restricts the exchange of flexibility, and should therefore be addressed to ensure market outcomes are feasible and whenever cost-effective (i.e. when the benefits of addressing the congestion are greater than the costs of any remedial measures required). Remedial actions may be

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[108] Girod et al. (2022) Improving cross-border capacity for near real-time balancing, EEM 18

required in order to comply with the Electricity Regulation 2019/943 rule requiring that at least 70% of the cross-zonal capacities be made available to the market (and even more, if cost-effective), as well as to resolve grid congestion at the transmission and distribution level.

Distribution-level congestions are expected to increase in the future with the increased deployment of distributed energy resources. Penta countries already face significant structural grid congestions[109] and several network operators struggle to connect further renewable energy projects or new consumers to the grid, threatening the timely and cost-effective achievement of the climate and energy targets. Such structural grid congestions should be addressed primarily through network expansion and the efficient operation of the grid, and in the case of internal congestion through reconfiguration of the bidding zones if adequate. However, network expansion has a long lead time and in some cases flexibility solutions may be a more cost-effective alternative, enabling the deferral of grid investments.

This section discusses barriers in the Penta countries and recommendations regarding the provision of congestion management services by flexibility solutions, primarily redispatch at the transmission and distribution level. Flexible connection agreements are discussed in Section 4.7. Network planning is discussed in Section 4.8, and covers network expansion and the consideration of alternatives to investment.

4.6.2 Current regulatory frameworks in the Penta countries

According to ACER various small and new actors – active consumers, (independent aggregators) and citizen energy communities - were not eligible in 2020 to provide congestion management (and other) services to TSOs and DSOs in some Penta countries. However, although significant barriers still exist (with e.g. demand response not eligible to provide redispatch services to DSOs in most of the EU)[110] with the implementation of the new EU electricity market design the situation is changing fast (with developments observed also in Switzerland), as shown below.

In the Netherlands, producers with a connection of 60 MW or above are obligated to provide up or downward bids that can be used for congestion management. Complementing this, aggregators and active consumers are able to voluntarily offer congestion management services to the TSO as well as DSOs through the GOPACS platform. Currently GOPACS is available to parties trading in the existing electricity exchanges and to large consumers.[111] Users are also allowed to trade flexibility bilaterally.[112] Also, tests were ongoing to use public charging points as flexibility providers in GOPACS.[113]

Recently, the Dutch NRA has amended the electricity network code to introduce the concept of the capacity limitation product (‘*capaciteitsbeperkingsproduct*’) and the figure of the congestion management service provider (CSP).[114] The capacity limitation product is a market-based long-term bilateral contract between the TSO or DSOs and the CSP, offering the possibility for the network operator to activate the CSP in case of congestion and representing an alternative to solving congestion

[109] According to article 2(6) of the Electricity Regulation 219/943, ‘structural congestion’ means congestion in the transmission system that is capable of being unambiguously defined, is predictable, is geographically stable over time, and frequently reoccurs under normal electricity system conditions
[110] JRC (2022) Explicit Demand Response for small end-users and independent aggregators
[111] https://www.gopacs.eu/informatie-zakelijke-grootverbruikers/wat-is-het-congestiemanagementportaal/
[112] CERRE (2022) The active distribution system operator (DSO). An international study
[113] https://www.gopacs.eu/proefproject-met-laadpalen-via-gopacs/
[114] https://www.acm.nl/nl/publicaties/codebesluit-congestiemanagement

through the redispatch market. The CSP can act as an aggregator, representing multiple connected network users, as well as offer congestion management services through countertrading.[115] The revised network code also contains requirements on cooperation between the TSO and DSOs on congestion management (although it does not specify if this has to include joint procurement of redispatch services or can be restricted to exchange of information).[116]

Furthermore, there is an agreement by sector parties following a proposal in the Dutch Market Facilitation Forum (MFF) by Dutch electricity network operators for the development of standardised market processes for congestion management, facilitating the market-based procurement of congestion management services from assets regardless of their size.[117]

TenneT furthermore employs interesting measures to minimise the risk of strategic behaviour in market-based redispatch. As SmartEn (2021) indicates, "first a Cost-Benefit Analysis (CBA) is performed in order to assess the grid's needs. If grid reinforcements are not viable or would require additional time, market-based congestion management is introduced. To avoid gaming, a series of requirements are introduced in the market design: A minimum of three competing market participants; DR participation, together with generation and storage; Intervention in case of suspicious bids; Penalties and bidding-zone splitting might be applied".[118]

In Germany, the Act on the Acceleration of the Expansion of the Energy Transmission Grid required "all conventional and renewable generators above 100 kW to be integrated in the redispatch process starting October 2021".[119] To that end, a data exchange platform was jointly developed by the 4 TSOs and 16 more relevant DSOs: "Connect+".[120] Connect+ is as single point of contact to exchange data from market / market parties and between TSOs and DSOs (with a Grid Operators coordination concept). Connect+ integrates the required structural, scheduled data (including forecast) to run Redispatch 2.0; as well as supports the exchange of limitations/conditional reservations and request.

There is another example of one implementation project that is interoperable with Connect+ by TransnetBW (Germany) called: "DA/RE".[121] DA/RE is a platform jointly developed, owned and operated by TransnetBW (TSO) and NetzeBW (DSO) in TransnetBW's control area (but it can also be used in other German control areas). The platform supports the functioning of a regulated and mandatory participation of power generation units and storage > 100kW and < 10MW into a congestion management mechanism, called Redispatch 2.0, that involves especially DSOs. Congestions are solved on the basis of a cost-based approach that searches to minimise the cost of the solution and at the same time allows the assessment of the connecting network operators of the power generation modules selected in the redispatch.

Two important features of DA/RE comprise:

a) The redispatch action includes a counterbalancing of the action.

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[115] https://zoek.officielebekendmakingen.nl/stcrt-2022-14201.html
[116] https://smarten.eu/wp-content/uploads/2022/07/Spotlight-Local-Flexibility-Markets.pdf
[117] Private communication with Dutch network operator
[118] https://smarten.eu/wp-content/uploads/2021/07/smartEn-Inc-Dec-Gaming-Position-paper-FINAL.pdf
[119] Poplavskaya (2021) Balancing and redispatch: the next stepping stones in European electricity market integration
[120] Kooperation – Connect+ (netz-connectplus.de)
[121] https://www.dare-plattform.de/erleben/

b) The calculation of the solution takes into account, besides cost-criteria, a certain representation of the network. The level of detail of the network representation is up to the network operator. At least one node representation is required.

DA/RE applies an interface to the above mentioned Connect+ platform and facilitates then the aggregation of data (potential of redispatch), for a coordination of both: the consideration of the needs from TSOs (allowing a coordination with DSOs) and the integration/coordination with TSO of DSOs solutions perhaps outside DA/RE.

In addition to that a 'Redispatch 3.0' concept is currently under discussion, where a voluntary participation of demand (market based) would be integrated on a hybrid redispatch model considering a combined merit order list (cost-based + bids).[122]

Furthermore, German TSOs support that development of a voluntary redispatch market framework to include also flexibility solutions below this threshold.[123] 50Hertz and TenneT Germany are also collaborating on an international level. TenneT Germany and the Netherlands, TransnetBW, Swissgrid, Terna and APG are members in the "Equigy" project[124] that is developing the so called "crowd balancing platform". This platform "enables aggregators to seamlessly participate with smaller flexibility devices in electricity balancing markets across Europe while allowing the market to operate within grid limits"[125]. 50Hertz and TenneT Germany are also using the "Crowd Balancing Platform" to procure redispatch services.[126] Several DSOs are involved in projects to source flexibility solutions to address congestions in their network or at the high-voltage networks.[127]

4.6.3 Recommendations

In order to facilitate market-based procurement of redispatching services by transmission and distribution network operators, further efforts are required to **enable the participation of new and small flexibility providers, either directly or via aggregators**. Progress is being made in several Penta countries, through the adaptation of the regulatory framework and specific market rules. Platforms for procurement of congestion management services are also being developed, sometimes in conjunction with the procurement of balancing services. These 'good' practices in some Penta countries can serve as an example for other countries. Where barriers for participation of small and new actors in these platforms still exist, they should be removed.

Moreover, the implementation of the Core CCR methodology for coordinated redispatching and countertrading should be continued. Also, **a more harmonised approach for deciding on market- vs cost-based procurement of redispatching services would be appropriate**, as well as **more transparency on the decision-making process**. In situations where local congestion can only be addressed by a very limited number of sources, cost-based procurement of the required services should be preferred to avoid undue price setting by the concerned providers.

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[122] https://www.transnetbw.de/de/newsroom/presseinformationen/studie-zu-redispatch-3-0-vorgestellt
[123] https://www.transnetbw.de/de/newsroom/presseinformationen/studie-zu-redispatch-3-0-vorgestellt
[124] https://equigy.com/about/#team
[125] https://equigy.com/the-platform/
[126] https://equigy.com/the-platform/
[127] https://cdn.eurelectric.org/media/5561/local-flexibility-benchmark-summary_eurelectric_2021-11-10-vf-h-87F24155.pdf

While structural congestion should be addressed by grid investments, **occasional (limited) congestion can be addressed by flexibility options, including redispatching and flexible connection agreements**. This option can also be used to avoid that new renewable energy plants would not be able to connect to the grid; however, an adequate legal framework should oblige the concerned grid operators to properly remunerate flexible grid users for curtailments exceeding an agreed level. This remuneration should incentivize grid operators to timely invest in capacity reinforcements allowing to offer firm connection agreements and to avoid structural congestion.

4.7 Network tariffs

Summary of the topic

- Network tariff structures and levels impact the costs and revenues of flexibility solutions connected to transmission or distribution grids.
- These impacts appear across various flexibility solutions, including large-scale (e.g. industry) and small-scale (e.g. electric mobility) electricity users, generators, and storage devices (e.g. batteries and pumped hydro).
- Time-differentiation of transmission and distribution tariffs is used to varying extent across the Penta region, and could be further extended to reduce actual or potential grid congestion. The implementation of dynamic network tariffs is being considered, but there is yet no practical case and it is not sure they would be an adequate solution.
- The range of costs recovered by distribution network tariffs is different per country, which makes it difficult to compare national tariffs and draw conclusions based on specific practices. There is more harmonisation in the costs recovered by and structure of transmission network tariffs.
- Capacity- and energy-based tariff approaches differ across countries for both network levels.
- Flexible (interruptible) grid connections for generators and/or large consumers are being considered or implemented in several Penta countries.
- Storage solutions in the Penta region usually benefit of exemptions from either injection or withdrawal charges. The approach for these exemptions varies greatly based on national specificities.
- Changes to further increase the cost-reflectiveness of network tariffs could be considered, including by increasing the share of costs recovered by capacity-based tariffs, by properly separating withdrawal and injection costs and recovering them via specific tariffs, and by recovering costs not directly related to network usage (e.g. public support) via other means.
- While time-differentiation of network tariffs is implemented in all Penta countries, location-differentiation is at present implemented in only 1 Penta country. Both tariff options can improve the economic signals sent to flexibility providers and further enhance the cost-reflectiveness of network tariffs.

Transmission and distribution network (or “grid”) tariffs and contracts allow to recover costs related to the management of the network and procurement of system services. This section surveys the different aspects of cost and revenue agreements between network operators and users, which are relevant for flexibility solutions.

4.7.1 *Relevance of network tariffs and contracts to flexibility*

Network tariffs and contracts are the primary means by which TSO and DSO network investments and operational costs are recovered. Most flexibility assets are connected to the grid and hence directly impacted by these tariff structures and levels. Other flexibility assets that are not directly connected are indirectly influenced by the network tariffs.

The implementations chosen for network tariffs and contracts affect a wide array of flexibility solutions. At the transmission system level, many large-scale flexibility options are impacted, including dispatchable power generators (to the extent that they are subject to G-charges), large-scale storage solutions (such as pumped hydroelectric storage), wind energy turbine farms, and large users connected to the high-voltage grids. At the distribution system level, impacts on flexibility range from the demand side (electric mobility, medium- and low-voltage demand) to the supply side (distributed generation) and in between (i.e. storage).

To adequately address the current and future system challenges in the Penta region, network tariff approaches and structures may need to be further adapted. Time- and location-differentiation (and possibly dynamic network tariffs) may be considered to accurately price (and thus encourage efficient usage of) flexibility solutions. While energy related charges are an adequate means to recover variable costs, capacity-based tariffs may be more appropriate to recover network capex and to reduce investment needs by stimulating load shift. Interruptible grid access contracts for withdrawal and injection of energy also find various interest in Penta countries. Lastly, tariff conditions for storage are particularly important, as these assets increase in importance and value in an energy system with an increasing share of non-dispatchable renewable (and thus more volatile) electricity production.

4.7.2 *Current regulatory frameworks – Transmission system*

In this subsection, we review the following topics related to transmission network tariffs:

- Primary network access agreement, which is usually referring to a network tariff
    - Capacity- versus energy-based tariffs
    - Time-differentiated and location-differentiated network tariffs
- Interruptible grid connections
- Specific network tariffs and discounts for energy storage

Transmission network tariffs recover the costs related to capital and operational expenditures, including transport and transformation losses, infrastructure-related compensations, system services, and sometimes other non-TSO costs (including stranded assets, support schemes for renewables, cogeneration of heat and power, and security of supply).[128] In Europe, generally a primary transmission tariff recovers most of these costs, while the remainder is covered by separate charges depending on the country.

The focus of the analysis is on transmission tariffs; distribution tariffs are also mentioned when specific relevant information related to flexibility is identified for the Penta countries.

[128] ACER (2019), Practice report on transmission tariff methodologies in Europe.

In some countries, **grid tariff discounts** are applied for specific consumers. In the Netherlands, large discounts (up to 90%) are granted to large industrial consumers with relatively flat load profiles.[129] Similar discounts are granted to large consumers in Germany and France as well.[130] Discounts for flat load profiles make sense to the extent that they effectively reflect lower network costs, which are mainly CAPEX driven. However, in a power system where renewable energies have a dominant share, flexible loads which can react to price signals would comparatively increase more the overall system flexibility. These grid tariff signals can reflect the (renewable) supply and (electrified) load profiles, as well as the consequent grid congestion. Hence, assessing the adequacy of discounts for flat load profiles should weigh the incentives it provides to reducing network and overall system costs in a context of increasing flexibility needs and network congestion.

Capacity- vs energy-based network tariffs

Generally, two types of tariff charges are used for recovering transmission grid costs. Energy-based tariffs set a per-kWh rate that recovers costs per kWh transported via the grid. Power- (or "capacity-") based charges price a user's contribution to the system peak (coincident peak load), and/or the user's own peak network power usage during a prespecified time period (non-coincident peak load).

Both tariff designs have benefits and limitations and affect the flexibility potential. Energy-based grid charges create incentives for energy efficiency but are less cost-reflective. This is because grid costs are mostly capex-driven and depend on the maximum capacity used in each part of the network, while the amount of electricity transported via the grid has limited impact on the overall network costs. Consequently, applying only volume-related tariffs would lead to charges that do not reflect the actual cost of delivery, resulting in welfare losses. However, if used in a time-based format (e.g. higher tariffs during peak load periods), these differentiated charges can encourage demand flexibility. Such time-differentiated tariffs can encourage load shifting, potentially leading to grid investment deferrals, higher grid reliability, and lower overall system costs.

On the other hand, capacity-based charges are more cost-reflective, in particular if the tariffs are based on the users' contributions to a coincident peak demand. In reality, users face often difficulties in reducing these coincident peaks (due to late announcement, disinclination to reduce capacity factors due to the economic impact of an intervention in industrial processes, among other reasons), leading to less flexibility. Non-coincident peak capacity pricing, where a user's individual peak is priced, is sometimes used as well, e.g. in Belgium. Insofar as this individual peak matches the coincident peak demand, it can be cost-reflective and help reduce not only the peak generation needs but also congestions arising in those moments. But individual peaks may not match the system peak for certain categories of consumers. Also, it may be difficult to forecast changing system peaks accurately.[131] Hence, this scheme does not necessarily incentivise implicit flexibility from all users. Moreover, for coincident and non-coincident peak capacity pricing, users may be less inclined to help alleviate positive system imbalances (system supply > demand), as it may potentially increase their peak power withdrawal. This can inevitably make congestion management more difficult, as more resources and products need to be applied to address network congestion.

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[129] https://publications.tno.nl/publication/34639482/Gliqt5/TNO-2022-P10368.pdf
[130] ACER (2019), Practice report on transmission tariff methodologies in Europe.
[131] Schittekatte et al. (2018) Least-cost distribution network tariff design in theory and practice

Both energy-based and power-based charges are used in transmission grid tariffs. Most Penta countries (Austria, Belgium, France, Germany, and Luxembourg) use a mixture of energy-based and power-based charges, while one country (the Netherlands) uses almost entirely power-based charges. Switzerland uses a mix of energy, power and fixed tariff components.[132] The level of charges differs based on voltage level, coincident peak load, non-coincident peak load, and more uncommonly, area.

Time-differentiated and location-differentiated network tariffs

Time-differentiated network tariffs are used to provide suitable economic signals to stimulate a more cost-efficient use of the network. Given that most network expenditures (investments, losses, and congestion) depend on peak capacity and usage times, some Penta countries, namely Belgium and France, have implemented time-differentiated network tariffs (for France: except for users connected to the 400 kV grid). The tariff designs of both these countries contain seasonal, diurnal, and peak/off-peak time elements, and especially focus on higher pricing during peak hours in winter months. Time-differentiated (transmission) network tariffs are not in place in Germany[133].

Network tariffs are in general pre-set, and not determined in a dynamic manner based on the actual grid situation. This is primarily to provide predictability to grid users for their grid charges, and to grid operators for their cost recovery. Dynamic network tariffs could be considered however, to set prices at any given time for network use. These tariffs are more cost-reflective, and could for example reduce congestion risk. Although some pilots exist in Europe, these tariffs have generally not met widespread usage.[134] For these tariffs, setting prices is often difficult and complex for grid operators, and the sacrificed cost predictability is highly important for grid users. Simpler time-differentiated static tariffs are often preferred, which were discussed in the previous paragraphs.

Dynamic *network* tariffs should be distinguished from dynamic commodity prices, which price the commodity component of electricity supply, and were intended by the Electricity Directive (2019/944). The price variations in supply contracts with dynamic prices generally coincide with wholesale spot market prices, while dynamic network tariffs are intended to represent local grid congestion.[135] Time-differentiated network tariffs and spot market prices can hence provide conflicting economic signals to market operators in general and flexibility providers in particular.

Location-differentiated network tariffs can also provide suitable economic signals for capacity investments (including in power generation and storage) and consumption based on the location-dependent aspect of network costs.[136] This differentiation can make tariffs more cost-reflective but less predictable; this practice also impacts costs for existing network users, and has been considered difficult to implement in Europe.[137] Only Austria in the Penta region uses locational transmission network tariff components. These locational network charges are integrated within the energy- and

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[132] Swissgrid (2022) Tariffs - Status 22 March 2022
[133] https://www.ikem.de/wp-content/uploads/2021/01/IKEM-Netzentgelte-Broschu%CC%88re.pdf
[134] ACER (2019), Practice report on transmission tariff methodologies in Europe.
[135] CEER (2020), Paper on Electricity Distribution Tariffs Supporting the Energy Transition.
[136] Ambrosius, M., Grimm, V., Sölch, C., & Zöttl, G. (2018). Investment incentives for flexible demand options under different market designs. Energy Policy, 118(July), 372–389. https://doi.org/10.1016/j.enpol.2018.01.059
[137] European Commission (2017), Study supporting the Impact Assessment concerning Transmission Tariffs and Congestion Income Policies.

power-based components of withdrawal charges.[138] Locational signals are also being discussed in France for the transmission tariffs.

Remuneration for interruptibility (injection/offtake)

Some network operators offer lower grid access tariffs for connections whose injection or offtake can be interrupted for short periods of time. Other network operators explicitly contract interruptibility services or offer flexible connection contracts (for example in heavily congested network areas). These interruptible tariffs or contracts offer flexibility to the system operator during moments of network congestion, and interruptibility schemes can also serve to address supply scarcity issues. TSOs also cite balancing and other frequency-related ancillary services as uses of interruptible connections.

We first discuss interruptibility schemes and interruptible connection contracts intended for offtake of electricity from the TSO grid. Some TSOs in the Penta countries provide specific remunerations for interruptible grid connections.[139,140] The French grid operator, RTE, contracts interruptibility services via individual contracts.[141] German TSOs also previously offered various interruptibility contracts, but have stopped doing so since mid-2022.[142] Both service operators use auctions to remunerate this flexibility, which was activated more commonly in Germany than in France in 2016-2020.[143] A pilot project by the Luxembourgish TSO (Creos) named “Feeder Flex” is worth mentioning. Feeder Flex allows large end-users to have two power off-take options with different limits for base and peak times, with possible curtailment should loads exceed the agreed limits. In Belgium, the TSO can during a limited number of hours activate reserve capacity contracted with interruptible end-users. To our knowledge, other Penta countries do not yet have set up interruptible connection contracts for offtake. However, discussions are ongoing in the Netherlands (for new offtake contracts) for interruptible connections.

For injection of energy, some grid operators contract flexible connections with renewable energy producers, if the existing network capacity is insufficient to offer a firm connection agreement and if the required investments to extend or reinforce the grid cannot be timely realised. This is for example the case in Belgium for some wind energy projects, whose injection can be curtailed during a limited number of hours per year (e.g. for maintenance works). These contracts are usually intended as a temporary solution, as the grid operator will in principle reinforce its network capacity to apply a regular contract in the future. Some regions (such as Belgian Wallonia) even legislate financial compensation by TSOs (and in some cases DSOs) for missed revenue due to curtailment. However, this compensation setup is still uncommon.

These interruptibility schemes provide direct beneficial services for grid operators. However, these schemes may create other market issues, as ACER notes that “…[these contracts] may weaken the competitive and direct participation of consumers into congestion management, balancing markets or

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[138] ACER (2019), Practice report on transmission tariff methodologies in Europe.
[139] ACER (2019), Practice report on transmission tariff methodologies in Europe.
[140] Swissgrid – Raccordement au réseau. https://www.swissgrid.ch/fr/home/customers/topics/legal-system.html#raccordement-au-reseauhttps://www.swissgrid.ch/fr/home/customers/topics/legal-system.html#raccordement-au-reseau
[141] https://www.services-rte.com/fr/decouvrez-nos-offres-de-services/l-appel-d-offres-interruptibilite.html https://www.services-rte.com/fr/decouvrez-nos-offres-de-services/l-appel-d-offres-interruptibilite.html
[142] http://www.gesetze-im-internet.de/ablav_2016/index.html
[143] ACER and CEER (2021), ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume

network reserves by establishing a separate, DR specific, procurement channel for these services."[144] Generally, participation in these schemes is limited to specific grid users, and this can fragment markets for grid services. Moreover, separate interruptibility contracts potentially prevent the establishment of newer and/or better-functioning alternatives, such as demand-side response programs, balancing markets, or other capacity mechanisms. Lastly, these schemes are not necessarily technology-neutral, and thus may require further adjustment to ensure interruptibility services are efficient while being effective. [145]

Specific tariff conditions for storage (to avoid double charging)

Storage assets play an increasing role in providing flexibility to the electricity system; while pumped hydro is historically being used in several Penta countries to provide flexibility, batteries are now increasingly being installed behind the meter (internal installation) or connected to the public grid and operated based on grid tariff and market price signals.

Storage assets can face specific network tariffs different from assets that only withdraw electricity from or inject it into the grid. These tariffs are listed in Table 4-8. For tariffing, storage is sometimes categorized into pumped hydroelectric storage (PHES) assets and other assets (mainly batteries). In countries where large-scale storage assets exist and are connected to the transmission grid, injection costs are usually energy-based, while withdrawal charges are in most cases both energy- and power-based.

Table 4-8: Transmission grid-level injection and withdrawal charges for storage, per country and storage Source: [146]

Country	Storage type	Injection	Withdrawal
AT	PHES	Energy-based	Energy- and power-based
AT	Non-PHES	N/A	N/A
BE	All	Energy-based (only transmission-connected)	Energy- and power-based (only transmission-connected)
CH[147]	PHES	N/A	No
CH	Non-PHES	N/A	Fixed, energy- and power-based
DE	All	No	Energy- and power-based
FR	PHES	Energy-based (only transmission-connected)	Energy- and power-based (only transmission-connected)
FR	Non-PHES	Energy-based (only transmission-connected)	Energy- and power-based (only distribution-connected)
LU	All	No	N/A
NL	All	No	N/A

(PHES = pumped hydroelectric energy storage; Non-PHES storages are e.g. batteries and cold storage; N/A means no such network user group exists)

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[144] ACER and CEER (2021), ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume
[145] ACER and CEER (2021), ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume
[146] https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER%20Practice%20report%20on%20transmission%20tariff%20methodologies%20in%20Europe.pdf
[147] ENTSO-E (2021) Overview of Transmission Tariffs in Europe: Synthesis 2020; Swiss Federal Electricity Supply Act articles 4(1b) and 15

For countries with storage assets connected to the transmission network, national regulatory authorities (NRA) have approved exemptions on some or all network tariff components. Reasons for network tariff reductions or exemptions for storage include:

- Storages demand low grid capacity requirements, and the administrative burden may not be worth additional charges.
- Promotion and support of new technologies.
- Better cost-reflectiveness, e.g. to avoid double-charging.
- Specific benefits of storage for grid operation, such as ensuring system adequacy.

Table 4-9: Exemptions for transmission grid injection and withdrawal charges (for assets connected both at transmission and distribution grid level; N/A are those with no charges currently). Source: [148]

Country	Storage type	Injection	Withdrawal
AT	PHES	Only network losses are charged	Reduced energy- and power-based charges
AT	Non-PHES	N/A	N/A
BE	PHES	New or substantially increased storage facilities receive 80% tariff reduction for 10 or 5 years (from 2020; only transmission-connected).	-
BE	Non-PHES	-	-
CH[149]	PHES	N/A	N/A
CH	Non-PHES	N/A	-
DE	PHES	N/A	PHES whose pump capacity or turbine power increased by at least 7.5% or whose storage capacity increased by at least 5% after 04.08.2011 are fully exempted for the first 10 years.
DE	Non-PHES	N/A	Non-PHES storage facilities built after 31.12.2008 and put into operation within 15 years from 04.08.2011 are fully exempted for the first 20 years of operation.
FR	PHES	Storage connected under 150 kV are fully exempted (only transmission-connected).	Some are partially exempted (tariff reduction; only transmission-connected).
FR	Non-PHES	Storage connected under 150 kV are fully exempted (only transmission-connected).	-
LU	All	N/A	N/A
NL	All	N/A	N/A

4.7.3 Current regulatory frameworks – Distribution system

In this section, we review topics related to tariffs and contracts in the distribution system which are relevant for flexibility solutions. In the distribution system, the following cost components are commonly charged to network end-users:[150]

- Energy commodity costs
- Miscellaneous costs of delivery, such as sales, general and administrative costs, specific taxes, levies and value-added tax recovered via the electricity suppliers
- Distribution network tariffs
  - Distribution network costs
    - Distribution system operation, expansion, and maintenance costs

[148] https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER%20Practice%20report%20on%20transmission%20tariff%20methodologies%20in%20Europe.pdf

[149] ENTSO-E (2021) Overview of Transmission Tariffs in Europe: Synthesis 2020

[150] ACER (2021), Report on Distribution Tariff Methodologies in Europe.

  - Cost of system losses
- Transmission system costs (passed on from transmission grid tariffs)
- System services costs (e.g. congestion management, voltage control, and reserves)
- Metering costs
- Non-network related policy costs (e.g. taxes and other levies, costs of renewable support schemes) recovered via the DSOs

The term “distribution network tariff” refers to different components depending on the countries and their regulatory authorities. This variety is a persistent challenge in Europe and complicates comparisons between countries. In the Penta region, all countries recover their distribution system operation and system loss costs via distribution network tariffs. Costs for system services are also recovered similarly, except in France. For metering costs, all countries recover these entirely via the network tariffs, except for some cases in the Netherlands and Germany where the metering activity is partially deregulated. For non-network related policy costs, there is a wide divergence of methods and approaches. As examples, public service obligations (Belgium) and renewable energy support (Austria) are funded via distribution network tariffs.[151]

Distribution network costs are recovered via injection and withdrawal tariffs. Table 4-10 shows distribution-level injection and withdrawal tariffs per country in the Penta region. Unlike transmission network tariffs, distribution network tariffs have a wide variety of components and tariff levels. Energy-based, power-based, or lump sum payments, or a combination of the three, are used across the Penta countries. Costs usually shift from a high energy related share to a high capacity related share, as users a) consume more electricity, b) consume at higher capacity levels, and/or c) install power metering. Moreover, each country with power-based charges uses a different pricing scheme.[152] For example:

- ✓ In the Netherlands, both the contracted amount of power and the actual peak power used within a week or a month is used.
- ✓ In France, the contracted amount of power is used.
- ✓ In Wallonia (Belgium), the actual maximum power per month is used, unless this information is unavailable (i.e. power is not metered).

Other differences in tariff setting also exist. Withdrawal tariffs vary based on voltage level (in AT, BE, FR, DE, LU, and NL).[153] Some time- and location-differentiation also exists in distribution network tariffs, which is discussed in the later subsection.

[151] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[152] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[153] ACER (2021), Report on Distribution Tariff Methodologies in Europe.

Table 4-10: Distribution network injection and withdrawal tariffs per country/region. Source: ACER (2021)[154]

Country	Injection			Withdrawal			
	Energy	Power	Lump sum	Energy	Energy + Power	Energy + Lump sum	All 3
Austria	x				Most users	Some LV users	
Belgium (Flanders)	x			Households	Non-households		
Belgium (Wallonia)		x			Users w/ power meters	Users w/o power meters	
Belgium (Brussels)	-	-	-		HV users	LV users	
France			x				All
Germany	x[155]	x			Power metering & non-LV users	Exceptional cases for LV users	
Luxembourg			x		Non-LV users	LV users	
Netherlands			x				All
Switzerland	-	-	-	All[156]	(Optional)[157]	(Optional)	

National regulatory authorities and network operators generally prioritize tariff stability over other tariff design principles. Thus, significant changes to distribution tariff methodologies are uncommon. Nonetheless, changes are being considered or implemented in a few Penta countries, with a strong focus on moving towards a higher share of power-based network charges, for example in France and Flanders (Belgium). In the latter, the regulator has decided for example that low-voltage users will as of January 2023 pay most (80%) of their grid costs via power-based charges, based on their monthly peaks over a 12 month time horizon.[158] This tariff change has led to criticism from the political level (due to its presumed negative impact on small and vulnerable end-users) and its implementation has therefore been delayed twice.[159] The German and Luxembourgish regulatory authorities aim to develop or extend network tariff options that stimulate flexibility from electric vehicles and heat pumps.[160]

Exemptions for network charges

Generally, all injecting grid users are responsible for paying injection charges. The exception to this is Belgium, where prosumers (producer-consumer) with net metering do not pay injection charges. Similarly, withdrawal costs are charged to all grid users, with notable exemptions in:

- Austria (discounts for pumped hydro units + negative balancing reserve + new pumped storage power plants and plants for converting electricity into hydrogen or synthetic gas)
- Brussels (full exemptions for ancillary services of generators, and storage)
- Wallonia (full exemptions for ancillary services of generators)
- Germany (some newer storage and pumped hydro facilities, for a limited number of years)
- Luxembourg (full exemptions for ancillary services of generators)
- Switzerland (exemption to pumped hydro when pumping)

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[154] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[155] Germany actually applies negative network charges for injection at the distribution level, equivalent to the avoided network costs. This incentive will be phased out from 2023 on. https://www.bundesnetzagentur.de/EN/RulingChambers/Chamber8/RC8_06_Network%20charges/67%20Avoided%20network%20fees/RC8_Avoided%20network%20fees.html
[156] For 'base' users, see above
[157] Meaning the structure can be used by network operators
[158] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[159] https://www.brusselstimes.com/262869/flanders-to-take-energy-regulator-to-court-over-potential-bills-increase
[160] ACER (2021), Report on Distribution Tariff Methodologies in Europe.

For the few countries (or regions) providing data (the Netherlands, Flanders, Wallonia and Switzerland), withdrawal charges covered almost 100% of the costs of the distribution system.[161]

Time-differentiated and location-differentiated distribution network tariffs

For distribution network tariffs in the Penta countries, this practice is non-existent for injection tariffs and uncommon for withdrawal tariffs. Austria, Belgium's three regions, France, and Switzerland apply some form of time-differentiation for network tariffs. Details of these tariffs can be found in the table below, which highlights the differences in terms of which tariff component they apply to, whether they are mandatory, and what form of time differentiation they set.[162]

Table 4-11: Details of time-differentiated distribution network tariffs in the Penta region. Source: ACER (2021)[163] and Swiss Federal Electricity Commission[164]

Country	Tariff Component	Mandatory?	Time-differentiation
Austria	Energy	Yes	Daily + Seasonal
Belgium	Energy	No	Daily
France	Energy + Power	Only at MV	Peak[165] + Seasonal
Switzerland	Energy + Power *	No	Daily + Seasonal *

**: varies per Canton*

The time differentiation for these tariffs differs in how they are set. In Belgium, for example, daily time horizons are set as 6-21 or 7-22 on working days (with lower tariffs at other hours during night-time and weekends). Seasonal tariff settings generally differentiate between winter and summer, where winter tariffs are higher. The ratio of tariffs in different times also differs depending on the country and DSO.[166] Examples:

- Brussels, Belgium: the night tariff amounts to 60% of the day tariff.
- Wallonia, Belgium: the ratio between day and night tariffs differs per DSO, reaching as high as 2.
- Flanders, Belgium: the ratio has been similar to Brussels, Belgium, but the tariff structure has recently been changed following the regulatory authority's decision[167]).
- France: at low voltage levels, grid tariffs during winter peak hours are 4 times higher than during summer peak hours, and winter non-peak hours are 3 times higher than summer non-peak hours.[168]

In Switzerland, certain requirements are established in the existing regulation regarding the tariff structure for 'base' users at networks below 1 kV and annual consumption of 50 MWh or less, for whom the energy component should be at least 70%, except if it is possible to measure their offtake, according to Art. 18 of the Swiss Federal Electricity Supply Ordinance. Moreover, for all consumers "according to Art. 14 of the Electricity Supply Act, grid usage tariffs must be simple in structure and

[161] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
Swiss Federal Electricity Supply Act articles 4(1b) and 15
[162] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[163] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[164] https://www.elcom.admin.ch/elcom/en/home/topics/electricity-tariffs/basic-data-for-tariffs-of-the-swiss-distribution-network-operato.html
[165] Peak/off-peak periods usually, but not necessarily, coincide with day/night cycle.
[166] ACER (2021), Report on Distribution Tariff Methodologies in Europe.
[167] https://www.vreg.be/nl/tariefmethodologie-2021-2024
[168] ACER (2021), Report on Distribution Tariff Methodologies in Europe.

reflect the costs incurred by end consumers, be set independently of the distance between the point of injection and the point of withdrawal and be based on the withdrawal profile. They must also be uniform per voltage level and customer category for the network of the same operator and take account of efficient network infrastructure and electricity use."[169] The Swiss regulator is of the opinion that network operators are free to define flexible network tariffs, including time-of-use or even dynamic ones, as long as the above and other requirements are respected.[170] Time-differentiated distribution tariffs are available in Switzerland and differ per canton.[171]

Dynamic network tariffs are another possible option for pricing network usage based on network congestion. These tariffs use real-time information about the status of the network to price network usage. Although commonly discussed, to our knowledge dynamic network tariffs at the DSO level are currently not implemented or considered in any Penta country.

Location differentiation for distribution network tariffs (independent of the specific DSO the user is connected to) is to our knowledge only practiced in Austria, where tariffs are set per network area, with several DSOs possibly operating in the same area. Tariffs in Penta countries with more than one DSO can vary per distribution network, such as in Belgium, the Netherlands and Switzerland. However, this tariff differentiation is related to the actual overall DSO cost level differences and not to the location of the concerned grid users.[172]

4.7.4 Recommendations

Our recommendations for distribution and transmission network tariffs include:

- Generally, initiatives can be taken to increase the cost-reflectivity of network tariffs at both the distribution and transmission levels, while not creating obstacles to flexibility.
    - **The share of power (or "capacity") based components in the overall network charges could be increased** in some Penta countries to more accurately reflect the actual structure of network costs, which are largely CAPEX-driven. While this measure would contribute to the cost-reflectivity of the tariffs, the other main principles for tariff design – transparency, predictability, and non-discrimination - should also be respected.
    - **The costs for grid injection and withdrawal should be allocated and charged separately**, and not mixed with each other. This alignment was less important while there was little demand flexibility; but misalignment can become distortionary as more flexibility assets come online. For these assets, double-charging can rapidly become a problem – a problem that was solved with tailored exemptions in the past. For electric vehicles (as an aggregated asset) and power-to-X facilities, for example, these charges need to be cost-reflective and transparent.
    - **Costs that are not related to network usage should be recovered via other means and budgets**. Recovery of some cost categories, such as pension schemes, policy costs, and renewable energy support, via the electricity network tariffs can be highly distortionary.

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[169] Conseil Fédéral (2021) Consommation d'électricité. Quelle quantité annuelle d'électricité les appareils pilotés par les fournisseurs d'électricité tels que les chauffe-eau électriques, les chauffages à accumulation, les pompes à chaleur, les installations de pompage-turbinage, etc., consomment-ils en Suisse?
[170] ElCom (2019) Tarifs nouveaux et dynamiques d'utilisation du réseau et de fourniture d'énergie : questions/réponses
[171] https://www.elcom.admin.ch/elcom/en/home/topics/electricity-tariffs/basic-data-for-tariffs-of-the-swiss-distribution-network-operato.html
[172] ACER (2021), Report on Distribution Tariff Methodologies in Europe.

These practices are not cost-reflective and discourage (or indirectly distort) investment in and activation of flexibility assets, as well as overall electrification of end-uses.

- **Dynamic network tariffs** can send accurate economic signals to actual and potential flexibility owners and are being evaluated across the Penta region. There are however **multiple concerns with dynamic network tariffs**, namely that these tariffs would require advanced metering infrastructure for billing, and advanced TSO/DSO SCADA and ICT infrastructure for monitoring and tariff-setting, and automated control infrastructure for end-users to activate flexibility. Without a large basket of these infrastructures, dynamic network tariffs can prove to be too complex, untransparent and unactionable. Moreover, the lack of predictable tariff signals may hinder market actors to take well-informed operational decisions to activate their flexibility.
  Given the drawbacks of dynamic network tariffs, other suitable time-differentiated tariffs can be considered. For example, **predetermined time-of-use tariffs** can give simpler signals about the cost of network use at any given time, such as in peak versus off-peak or winter versus summer periods. Such signals can give clear, and actionable information to grid users for investing in and utilizing their flexibility.
- Network tariffs should be designed with consideration for their influence on flexibility solutions and to **avoid competition distortion between different technologies**. A minimum level of **cross-border harmonization** is also required to avoid unfair competition between market operators that are located in different countries but active in the same regional market.
- **Network tariffs can also be differentiated based on location**. Similar to time-differentiated signals, which give signals about *when* flexibility is most needed, these signals inform about *where* flexibility is needed most. As flexibility, in a network management context, is partly a locational challenge, these signals form an inseparable part of cost-reflective network tariffs. They are thus a possible approach for developing a clear and functional market for implicit flexibility provision. These locational signals do not necessarily need to be integrated into network tariffs, but can instead be integrated into power market prices.[173]

4.8 Network planning

Summary of the topic

- Network development plans (NDPs) outline the main investments proposed by TSOs and DSOs for the development of their grid in a 10- to 15-year time window.
- NDPs should properly take into account the different current and planned flexibility assets at supply and demand side, especially as possible offsets for considered grid expansion and reinforcement projects. NDPs are important in the context of flexibility as they influence the access of flexibility assets including storage, (aggregated) demand response, and power-to-x facilities, to the various markets.
- NDPs in the Penta region are broadly in line with the EU ten-year NDP, and with each other (including between TSOs and DSOs). Although some small DSOs are not yet publishing an NDP, their absence does not present a significant risk for alignment between NDPs. However, the cross-border impact of projects could be considered in more detail in the NDPs; moreover, thresholds for this impact could be better aligned across NDPs and with the EU TYNDP.

[173] Examples exist in ISOs in the United States, where locational-marginal nodal prices reflect both the supply and demand of electricity, and the scarcity of transmission capacity in each network node.

- NDPs often do not include storage projects, also as network operators do in general not own or operate storage, and the inclusion of third-party storage projects in NDPs is still limited. At present, NDPs also include limited information on power-to-x facilities.
- A recent development is the coordinated or even joint development of NDPs for electricity and other carriers (such as natural gas and hydrogen) in Europe. Authorities in the Penta region should stimulate or even impose this cross-vector coordination/cooperation, especially as it further improves investment clarity and market access for power-to-x facilities.
- NDPs should ensure a non-discriminatory treatment of flexibility versus investments in network capacity. Network operators should be encouraged to timely reinforce their grid to enable the connection of new generation and off-take capacity while properly considering non-wire alternative or complementary options to grid expansion, in particular flexibility assets such as storage and power-to-X facilities.
- NRAs should have approval rights to NDPs. Together with transparent and clear public consultations, this right can ensure that a) NDPs consider the optimal bundle of technologies and investments for development and b) discriminatory access to markets for flexibility is avoided.

Network planning refers to the expansion and maintenance of distribution and transmission networks by their respective DSOs and TSOs. This activity is commonly reported and described in network development plans (NDPs), which are updated on a multi-year basis. NDPs are in most cases (but not always) overseen by NRAs and other regulatory bodies. ACER also regularly reviews NDPs of most European countries to assess consistency with the TYNDP.

4.8.1 Relevance of network planning to flexibility

NDPs have a significant influence on flexibility solutions and their possible use by TSOs and DSOs. The consideration of all flexibility solutions (as alternatives to grid expansion) in NDPs has been emphasized within the Electricity Directive (2019/944) under Articles 51 (for TSOs) and 32 (for DSOs). The scoping of TSO and DSO NDPs (every 2-4 years) defines which flexibility solutions are considered in network development with a 10-15 years (or more) horizon.

The scoping of NDPs, and how flexibility options are considered in them, can have a large impact on the eventual availability of different flexibility options. Depending on which technologies and assets are considered in TSO and DSO NDPs, and with which attributes, these options may or may not be available as alternatives to grid expansion.

Moreover, networks are the main access point of many flexibility options to markets for flexibility. Thus, network development plans play a large role in ensuring sufficient network capacity is available for the connection of flexibility options and exchange of flexibility in a non-discriminatory manner.

NDPs can impact flexibility providers on other networks regarding the trade of their flexibility products. Grid expansions and other projects related to network development can have cross-border or cross-zonal impact on users connected to other networks. Moreover, TSO projects can influence the market access and trade of flexibility providers connected to a DSO network, and vice versa. Therefore, coordination and harmonization of NDPs across regions and levels is also an influential matter for flexibility provision.

Lastly, network operators are forbidden to own and operate flexibility assets other than interconnections (with the possibility of some exceptions for storage). The development process of NDPs also serves as engagement with NRAs and other stakeholders to ensure that all perspectives and interests are adequately considered in the network planning.

4.8.2 Current regulatory frameworks in the Penta countries

Network planning often depends on the production of an NDP, which are not always published (or sometimes there is no NRA oversight). All TSOs in the Penta countries release NDPs on a 2-year basis (excluding Switzerland, where the TSO Swissgrid does so every 4 years). However, not all DSOs release NDPs. In some countries, all DSOs do (Belgium, the Netherlands, Luxembourg); in others, only some DSOs do (France, Germany, Switzerland), while in Austria the DSO does not release an NDP (as of May 2021). Nonetheless, ACER reports that the alignment between TSO and DSO NDPs in Penta countries is quite high.[174] Given the differences in the various countries regarding DSO NDPs, for a clear comparison and discussion, the following text generally refers to TSO NDPs, unless stated otherwise.

An important matter for flexibility provision concerns the consideration of flexibility options in NDPs. Previous reports have mentioned that in many EU MSs, NDPs rarely consider energy storage assets to a sufficient degree. The European TYNDP includes storage assets at and above 225 MW of capacity. Moreover, scenarios developed by ENTSO for the TYNDP consider multiple types of flexibility, including residential-scale and utility-scale batteries, demand response and EV charging, and electrolysers.[175] However, these flexibility assets may not be and often are not considered within the NDPs of TSOs and DSOs of the Penta countries as alternatives to network expansion.

Generally, the largest missing flexibility asset in the NDPs is storage. TSOs and DSOs are not allowed by law to own storage assets (unless it is established that no market interest exists). They thus have indirect incentives to consider network expansion over other options for security of supply and resource adequacy, and do not include storage in their NDPs. There may be cases where storage is a cheaper option than network expansion, but is not considered and evaluated within NDPs.[176] In the Penta region, to our knowledge the NDPs do not explicitly consider storage.

Other infrastructure can facilitate or allow for flexibility options to be used instead of network expansion. These include works for DSO connection requests, non-copper infrastructure (such as ICT, cybersecurity, and supervisory control and data acquisition systems), power-to-X facilities, and smart grids. Table 4-12 shows how each Penta country includes these infrastructure types in its NDPs. Most countries include works for DSO connection requests, but inclusion of non-copper infrastructure and smart grids is more varied. Third-party projects (i.e. projects developed by entities other than the grid operator) are also generally included, except in the Netherlands, where they are not allowed.[177]

[174] ACER (2021), Opinion 05-2021 on electricity national development plans.
[175] EnTEC (2022), Study on Energy Storage.
[176] EnTEC (2022), Study on Energy Storage.
[177] ACER (2021), Opinion 05-2021 on electricity national development plans.

Table 4-12: Inclusion of various infrastructure projects in TSO NDPs. Source: ACER (2021)[178]

Country	Works for DSO connection requests	Non-copper infrastructure	Smart grid	Power-to-X facilities and storage	Third-party projects
AT	x				X*
BE	x	x			X
CH	x	(allowed)	(allowed)		X*
DE	x	(allowed)	(allowed)		x
FR	x	x	x		x
NL	x	x	(allowed)		
LU	(allowed)	x	x		x

*: Third-party projects in Austria receive no assessment, and those in Switzerland receive a different assessment than TSO-managed projects.

Network development can also include projects with significant cross-border impact in the Penta region, and in Europe more broadly. Such projects are for instance interconnections that can be Projects of Common Interest[179], and domestic transmission projects with major investments. The cross-border effects of such projects are published in Austrian, German, and Belgian NDPs for most or all projects. However, the French and Dutch NDPs only publish this info for interconnector projects, but not for internal projects with potential cross-border impact. The Swiss NDPs contain information for some projects, but this information is not included in the Luxembourgish NDP.[180] The lack of information regarding projects with cross-border impact can create a vague investment environment for flexibility assets with potential cross-border value. Clear information about cross-border impacts would also improve the clarity of the EU TYNDP. Nonetheless, ACER considers that the European NDPs are broadly in line with the EU TYNDP in terms of inputs and methods.[181]

Another important matter for flexibility is the co-planning of the network development of multiple energy carriers. ACER's findings in 2021 are repeated from observations in 2020 and 2018 that no country in the Penta region appears to conduct NDPs for multiple energy carriers in a coordinated fashion.[182] A more coordinated or even joint planning of the network investments for different energy carriers is especially important in light of the further coupling of energy carriers via power-to-X facilities and the increasing options for electrification (and hydrogenification) of various end uses. To properly take into account the development of power-to-X flexible assets, scenarios and assumptions in the NDPs of electricity and gas networks should be harmonized. The further growth of these assets will make coordinated NDPs of multiple energy carriers more important.

The NDPs also differ in the rights of approval granted to national regulators. ACER finds regulatory oversight of NRAs necessary for NDPs, since NDPs define the investment choices of TSOs, and costs are often eventually passed through to grid users, including of suboptimal choices in case those are not identified by the regulator. In most countries in the Penta region, NRAs have approval or amendment

[178] ACER (2021), Opinion 05-2021 on electricity national development plans.
[179] https://energy.ec.europa.eu/topics/infrastructure/projects-common-interest/pci-examples-and-their-benefits_en
[180] ACER (2021), Opinion 05-2021 on electricity national development plans.
[181] ACER (2021), Opinion 05-2021 on electricity national development plans.
[182] ACER (2021), Opinion 05-2021 on electricity national development plans.

rights to the NDP, with weaker or no powers of scrutiny in two countries (Belgium and Luxembourg).[183] TSOs directly control and benefit from grid expansion plans, whereas they are often barred from flexibility asset investments by regulation. Given the financial and indirect incentives to consider grid expansions, these network development solutions can thus take precedence over the use of flexibility assets.

NDPs also differ in the level of stakeholder consultation and transparency. For flexibility options, especially those assets expecting significant deployment in the coming years, public consultations are an important venue by which the opinions and viewpoints of flexibility owners can be communicated and considered in NDPs. These consultations are often done by NRAs (Austria, Germany, and France), and less commonly by TSOs (in Belgium and the Netherlands). In Luxembourg, NDPs are partially open to consultations, and Switzerland's NDP process includes no consultations. Public and transparent consultation processes can improve the consideration of flexibility investments in NDPs, and lead to a more optimal portfolio of investments presented in NDPs. Moreover, these consultations can create clarity for flexibility product owners regarding their market access, as this market access can be detailed in the NDP based on the viewpoints shared in the consultations.

4.8.3 Recommendations

The recommendations regarding the development of NDPs in the Penta countries primarily relate to those that improve market accessibility and non-discriminatory procurement of flexibility services by network operators. These improvements should mainly reduce the risks for market distortion and information asymmetry:

- National authorities should ensure that the **procedures for TSOs and DSOs to establish NDPs are fully in line with the Electricity Directive** Articles 51 and 32, which aim for market access and clarity for all potential grid users. Given that networks serve as a gateway to market access for most flexibility options, NDPs contain crucial information that stakeholders need for investments in flexibility options.
- Grid operators are required via the Electricity Directive to consider in their NDPs **non-wire solutions as alternatives to network expansion**. Operators should be encouraged by policymakers and regulators to properly consider these options, especially projects of flexibility aggregators, energy storage, and power-to-X facilities.
- **NDPs for electricity networks should be aligned and possibly developed together with plans for other energy carriers**. In the context of increasing electrification of end-uses and decarbonization via power-to-X facilities, coordination is especially important for properly taking into account the interactions. A few EU countries (Italy and Denmark) have begun developing gas and electricity NDPs together, and Belgian and French grid operators are likewise in discussion to align NDPs.
- **NDPs need more harmonization at supra-national level**. Much progress has been realised in recent years to align NDPs with each other and with the EU TYNDP. However, space remains to further align assumptions and inputs, especially regarding projects with cross-zonal/cross-border impact. These projects should be reported consistently in NDPs, to ensure their cross-border impacts can be adequately considered by grid operators and other stakeholders (for

[183] ACER (2021), Opinion 05-2021 on electricity national development plans.

example flexibility owners) in other regions. The EU TYNDP and its methodology and scenarios provide a good framework for harmonizing NDPs across countries and regions.

- **NRAs should have approval rights to the NDPs.** This regulation can ensure that NDPs consider an optimal bundle of assets, including where appropriate flexibility assets as alternative to grid reinforcements or expansions. Moreover, NRAs can more readily ensure market access and clarity for flexibility providers.
- A transparent means of assuring this market access and clarity is by developing NDPs in a manner accessible to the relevant stakeholders. **Public consultations for NDPs** can allow to ensure that all stakeholders' concerns and perspectives are properly taken into account in the plans.

4.9 Value stacking

Summary of the topic

- While value stacking is a complex issue, it allows flexibility asset operators to maximise their revenues and thus increases the flexibility resources available to the system.
- Using a flexibility asset to provide two or more system services in different moments in often allowed in the Penta countries, but providing services simultaneously is more often forbidden.
- Selecting the assets that will provide the flexibility service in (near to) real-time (called dynamic pooling) in the Penta countries is often not allowed for the relevant flexibility services.
- Each Penta country should assess the possibilities and interest to reform the market rules in order to allow stacking for multiple services. Penta countries could also exchange good practices in this regard.
- Penta countries could also review the level of penalties for non-delivery, in cases where they are deemed excessive and represent a barrier for the participation of flexibility sources, including by exchanging practices within the Penta region.

4.9.1 Relevance of value stacking to flexibility

Value stacking is the provision of two or more flexibility services by the operator of a flexibility resource to one or more parties.[184] This can include not only balancing and other ancillary services, but also distribution grid deferral services or arbitrage in wholesale energy markets. By stacking revenues from different value streams, operators of these resources are able to increase their revenues and thus achieve profitability for flexibility solutions that would be unprofitable if they had to rely on a single value stream. Allowing for value stacking whenever possible thus facilitates the deployment of flexibility assets.

USEF identifies three types of values stacking:[185]

1) Value stacking in time: participating in different markets in different timeframes (e.g. morning and evening);

[184] USEF (2018) Flexibility Value Stacking
[185] USEF. (2021). Flexibility Deployment in Europe. White Paper. https://www.usef.energy/app/uploads/2021/03/08032021-White-paper-Flexibility-Deployment-in-Europe-version-1.0-3.pdf

2) Value stacking in pools: activating assets for different services;
3) Double serving: Providing multiple services at the same time by stacking activation from one asset.

However, some forms of revenue stacking such as double serving are highly complex, requiring more sophisticated strategies from flexibility operators and increasing the risk of non-delivery. Moreover, such value stacking also requires a high level of coordination between actors in order to e.g. agree on the baselines for the different markets and identify the net balancing position of an end-consumer whose assets were activated by an independent aggregator to provide flexibility in multiple markets. Therefore, restrictions to value stacking may be warranted for security of supply if non-delivery would unduly affect system adequacy or reliability.

Flexibility operators can stack revenues from spot, balancing, non-frequency ancillary services, redispatch as well as other markets. Therefore, barriers to value stacking can affect all types of flexibility solutions, from supply- to demand-side as well as storage.

4.9.2 *Current regulatory frameworks in the Penta countries*

The possibilities for value stacking depend on the national rules for the provision of flexibility services in the different markets. Generally, there are no restrictions in spot markets (day-ahead and intra-day) for stacking of revenues. However, rules for provision of balancing, non-frequency ancillary, redispatch and capacity services frequently still contain restrictions to value stacking in many European countries.

Exclusivity clauses for the provision of flexibility services (barring the operator to employ the same asset for other purposes) represented a main barrier to flexibility. This is gradually improving, with exclusivity clauses being removed when not justified by security of supply requirements, and replaced by penalties for non-delivery.

According to USEF (2021), in early 2021 all Penta countries surveyed (Belgium, France, Germany, the Netherlands, Switzerland) allowed value stacking. This indicates the Penta countries to be advanced in this regard compared to other European countries. However, multiple barriers remained, such as dynamic pooling frequently not being allowed as assets providing the services had to be identified significantly in advance, nor double serving for some combinations of services.

In Belgium, value stacking is already allowed for a number of services, especially for using the same asset to provide different services in different moments (contractual combo). However, using the same asset to provide multiple services at the same time (combo activation, or double serving) is less frequently allowed, as shown in the figure below. The Belgian TSI Elia is preparing measures to further allow value stacking, between spot and ancillary services market (using the Transfer of Energy framework, ToE, already employed to enable independent aggregation), as well as between aFRR and mFRR provision.[186]

[186] Elia (2022) Analysis of the possibility to offer different types of balancing products on DPpg – Report for Public Consultation

Figure 4-4: Allowed combination of services in Belgium spot and balancing markets as of October 2022[187]

Combo	Contractual Combo	Combo activation
FCR and aFRR	Is allowed and used	Is allowed and used
FCR and mFRR	Is allowed and used	Is allowed but not used
aFRR and mFRR	Is allowed but seldom used	Is not allowed
FCR and DA/ID with ToE	Is allowed but not used	Is allowed but not used
aFRR and DA/ID with ToE	Is allowed but not used	Is not allowed
mFRR and DA/ID with ToE	Is allowed but not used	Is not allowed

The same report overviews the possibilities for value stacking in France, Germany and the Netherlands. It indicates that value stacking in time (contractual combos) are allowed in all three countries, while double serving (combo activation) is allowed for all balancing products in France and Germany, and FCR + aFRR in the Netherlands.

Another issue is the definition of penalties for non-delivery of the flexibility services. Penalties are required to provide incentives for the delivery of the services by the operators. However, if set too high they may represent a barrier to the provision of flexibility, while if set too low they can increase the risk of non-delivery and eventually compromise security of supply. However, a comparison of the penalties for non-delivery in place in the Penta and other European countries has not been conducted, to our knowledge.

4.9.3 Recommendations

Revising market rules such as pre-qualification rules as well as terms & conditions for the delivery of ancillary, redispatch and capacity products can open up new revenue streams for flexibility asset operators. However, these rules can be quite complex as well as highly specific for the different Penta countries. Therefore, **each Penta country should assess the possibilities and interest to reform the market rules in order to allow for the stacking of additional services**. There is, however, the potential to **exchange best practices** with other Penta countries, as the ongoing process in Belgium shows.

The Penta countries could also **review the level of penalties for non-delivery**, in cases where they are deemed excessive and represent a barrier for the participation of flexibility sources. This could be done in the context of a regional study to assess current practices as well as the frequency of non-delivery for the different services in the Penta region.

[187] Elia (2022) Analysis of the possibility to offer different types of balancing products on DPpg – Report for Public Consultation

4.10 Independent aggregators

Summary of the topic

- Independent aggregators are expected to have an important role to unlock the flexibility potential as suppliers have been slow and reluctant to be active in the aggregation market.
- The role of aggregators has been clarified or will be in most Penta countries. However, even without a formal definition, aggregators are in general able to participate in different electricity markets.
- Independent aggregators face higher barriers due to the lack of a regulatory framework enabling access to all electricity markets, but this is expected to be addressed in the coming years.
- Nonetheless, barriers for independent aggregation of small loads will remain due to e.g. the lack or incomplete roll-out of low-voltage smart meters or high transaction costs.
- There is also a large variation in the models in place for independent aggregator-supplier compensation.
- Penta countries should continue the revision of regulatory frameworks and most importantly market rules for independent aggregators, including regarding the adequacy of different baseline methodologies and the supplier-independent aggregator compensation regulation across all markets.
- Penta countries should furthermore establish or further employ collaboration platforms (e.g. specific working group) to discuss these issues at Penta level, and consider further measures to address non-regulatory barriers, such as comparators for aggregators' offerings.

4.10.1 Role of aggregators to unlock flexibility potential

Independent aggregators are expected to have an important role to unlock the flexibility potential as suppliers have been slow and reluctant to be active in the aggregation market themselves.[188] USEF (2021)[189] identifies a number of aggregation models – from the integrated model (where the supplier exerts the aggregation activities) to models where the supplier and independent aggregator are distinct.

The JRC notes that while the regulatory framework for (independent) aggregators can be expected to be in place across the EU27 in the coming years, other barriers significantly affect the business case for explicit flexibility provision by (aggregated) small loads, such as the lack or incomplete roll-out of low-voltage smart meters or high transaction costs.[190]

4.10.2 Current regulatory frameworks in the Penta countries

Role clarified in national legislation?

The Electricity Directive (EU) 2019/944 defines in its art. 2(18) aggregation as "a function performed by a natural or legal person who combines multiple customer loads or generated electricity for sale,

[188] Schittekatte et al. (2021) The regulatory framework for independent aggregators;
Poplavskaya et al. (2020) Aggregators today and tomorrow From intermediaries to local orchestrators?
[189] USEF (2021) Flexibility deployment in Europe
[190] JRC (2022) Explicit Demand Response for small end-users and independent aggregators

purchase or auction in any electricity market", while art. 2(19) defines the independent aggregator as "a market participant engaged in aggregation who is not affiliated to the customer's supplier".

The roles of the aggregator are defined in Belgium (called Flexibility Service Provider), France (*operateur d'effacement),* Germany and Austria. A legislative proposal is due to be submitted to the Parliament in the Netherlands.[191] The specific function of aggregators is not defined in Switzerland, where they act as ancillary service providers or virtual generation units.[192,193]

The regulatory framework for the participation of independent aggregators of small loads was in place, fully or partially, at the end of 2021 in at least Austria, Belgium, France and Luxembourg. In Austria, at that moment only renewable and citizen energy communities were allowed to act as independent aggregators. The market for explicit participation of demand response of small loads was most advanced in Germany and France, with France offering the best environment, according to the JRC (2022). Independent aggregators were found to be active in Belgium, France, Germany, Netherlands and Germany.[194] However, across the EU in most countries independent aggregators for small loads did not have access to all electricity markets, except in France.[195]

Arrangements supplier (BRP) – independent aggregator

To avoid that actions of independent aggregators negatively impact the revenues of the concerned suppliers/BRPs, a perimeter correction can be employed. This means that the changes in energy supply/demand triggered by an independent aggregator are excluded from the concerned supplier/BRP's imbalance. Perimeter corrections are in place in most European countries, including Belgium, France, Switzerland and Germany (planned).[196]

When perimeter corrections are not implemented, for example if the energy activations of the aggregator are too infrequent and thus the perimeter correction implementation costs would outweigh its benefits, a financial compensation from the independent aggregator (or from the consumer) to the supplier can be implemented. This is the case in most EU Member States that have implemented regulatory frameworks for independent aggregation. Schittekatte et al. (2021) identify three models – the regulated, corrected and contracted compensation models as shown in Table 4-13. However, there is still no consensus for the need to require some form of compensation to suppliers for their missed revenues.

Regarding the regulated model, according to Schittekatte et al. (2021) "depending on the country, the calculated price can change hourly, as in Belgium, or is more static as in France. Another important difference between the Belgian and French implementation is that in France, the French TSO RTE has established a centralised platform to facilitate the financial flows and dispute settlements for the regulated model. This kind of implementation is sometimes also referred to as the central (regulated) settlement model (USEF, 2017). Similarly, in Switzerland, the aggregator is obliged to compensate the supplier for the difference in consumed energy with a payment that is determined by the TSO based on

[191] https://wetgevingskalender.overheid.nl/Regeling/WGK010483
[192] USEF (2021) Flexibility deployment in Europe
[193] https://www.e-control.at/documents/1785851/1811597/SoMa_1_V2_2-ab-1_7_2015_en.pdf/ed47caca-0fdc-3ba8-d00b-d48aae118984?t=1564385059611
[194] Poplavskaya et al. (2020) Aggregators today and tomorrow. From intermediaries to local orchestrators?
[195] JRC (2022) Explicit Demand Response for small end-users and independent aggregators
[196] Schittekatte et al. (2021) The regulatory framework for independent aggregators

the day-ahead spot price of the Swiss Electricity Index (Chacko et al., 2018; SEDC, 2017). In Belgium, the regulated compensation is settled bilaterally without any intermediary."[197]

In the contracted model, the supplier and the independent aggregator arrive at a bilateral agreement. Hence, the contracted model cannot be the only model available, as according to the Electricity Directive art 13(2) customers should be entitled to conclude an aggregation contract without the consent of their supplier. The provision that consumers do not need prior consent from their supplier is explicitly enshrined in the legislation in France and, for aFRR and mFRR markets, in Germany.[198]

One must note that different compensation models may be in place for different market timeframes, from wholesale to balancing and capacity markets. Hence, although the regulated and contracted models are available in Belgium, actions in the FCR market by the independent aggregator are uncorrected and not compensated.[199]

Table 4-13: Aggregation compensation models adapted from Schittekatte et al. (2021)

	No compensation model	Regulated model	Corrected model	Contracted model
What is the level of the compensation?	Not required by regulation	Determined by a methodology approved by the regulator	Retail price	Bilateral deal between independent aggregator and supplier
Who pays the compensation?	Not applicable	Typically, the independent aggregator	Typically, the consumer via the electricity bill, possibly passed through to the independent aggregator	Typically, the independent aggregator
Examples of countries	AT[200],UK	CH, SI, option in FR and BE	Large consumers in FR, planned for DE	Option in BE and FR

According to ACER's Draft Framework Guidelines on a demand response network code[201], the network code will need to specify the possible aggregation models as well as the associated compensation mechanism, if applicable. The draft framework guidelines also include the requirement for specifying a future European-wide process for further specifying and harmonising elements of the aggregation and compensation models, reducing the number of models if distortions are identified. The draft framework guidelines also require the future network codes to define aspects related to imbalance settlement, including perimeter correction.

4.10.3 Recommendations

Based on the above analysis, the following recommendations can be given to the Penta countries:

- ✓ Continue **revision of regulatory frameworks and most importantly market rules for Independent aggregators**

[197] Schittekatte et al. (2021) The regulatory framework for independent aggregators
[198] SmartEn (2022) The Implementation of the Electricity Market Design to Drive Demand-side Flexibility. 2nd edition.
[199] Nordic Energy Research (2022) The regulation of independent aggregators
[200] Poplavskaya (2021) Balancing and redispatch: the next stepping stones in European electricity market integration
[201] https://surveys.acer.europa.eu/eusurvey/files/e8f7b093-154c-4fda-bc95-14f4ef4c7d43/b21b37d1-2684-4bd6-b0c1-dae632a89d29

  - Pre-qualification and suitability of ex-post verification;
  - Adequacy of different baseline methodologies;
  - Supplier-aggregator compensation/transfer of energy regulation across all markets;
- ✓ Establish or further employ **collaboration platforms** (e.g. specific working group) to discuss these issues at Penta level;
- ✓ Consider further **measures to address non-regulatory barriers**, such as comparators for aggregators' offerings.

4.11 Collective self-consumption[202]

Collective self-consumption, and more specifically energy sharing, in the context of citizen and renewable energy communities "is a framework that enables pooling of energy generation which can be shared amongst a group of consumers, often with the aim of optimising self-consumption within the community"[203]. Collective self-consumption is allowed in Austria[204], Belgium, France, Germany, Luxembourg and Switzerland. It was furthermore allowed in the Netherlands as part of a regulatory sandbox.

In Belgium, energy sharing is in Flanders since January 2022 possible for residents of apartment buildings, which means that electricity from solar panels on the roof of an apartment building can be shared among the residents of the flats. Since July 2022, owners of solar panels can use the electricity themselves at another address (e.g. at their vacation home) or can sell it to another user.
As of January 2023, energy sharing is also possible within an energy community of citizens and a renewable energy community.[205]

[202] Although self-consumption and energy sharing are relevant to flexibility, they have a limited impact and are indirectly covered in the other sections. Therefore we have not further elaborated this section.
[203] smartEn (2022) European Market Monitor for Demand Side Flexibility
[204] Electricity Act 2010, as of 4 March 2022, paragraphs 16(a-c)
[205] https://www.vlaanderen.be/bouwen-wonen-en-energie/groene-energie/energiedelen

5 High-level regulatory recommendations

The Pentalateral Energy Forum can play an important role in facilitating and stimulating cross-border coordination and cooperation, including by exchanging information on good practices on how to activate and integrate flexibility, in particular from small electricity generators, demand side response and storage. Improving market design and rules, facilitating investments in flexibility assets and empowering prosumers/consumers will be required to cost-efficiently meet the increasing flexibility needs.

Based on our analysis, we have identified potential domains for enhanced cooperation at the Penta level and formulated concrete recommendations to steer the transformation of the Penta countries' energy systems. The recommendations are presented per main topic: governance of the energy system, electricity market design, and network aspects.

Governance of the energy system and collaboration within the Penta region

1. **Use existing or set up new platforms where appropriate for the exchange of experiences or good practices on specific flexibility measures, especially to facilitate demand side flexibility for normal market operation and emergency situations**
   In these platforms, information can be exchanged on a number of flexibility instruments or practices that are currently being used in some Penta countries, such as reliability options, flexible connection agreements, aggregation of flexibility sources at distribution level and the possibility to curtail consumption beyond a reference level in case of emergencies. It could serve not only to discuss measures to promote flexibility resources but also to discuss the flexibility needs of the Penta countries.

2. **Conduct on a regular basis a detailed flexibility and adequacy study at the Penta level (CWE region) to assess capacity and flexibility needs, gaps and potential for improvement of cross-border cooperation.**
   The present study focuses on the flexibility needs and sources at the Penta level, but as adequacy and flexibility are closely interrelated, a more comprehensive study could build on the present study and also include adequacy aspects as well as an analysis of the flexibility issues in more detail (e.g. ramping vs fast vs slow, upward or downward flexibility), and consider different scenarios/sensitivity analyses (for example different RES, electrolyser and interconnection deployment levels). Such a study could provide further guidance on the flexibility and adequacy needs and contributions of the different assets in the concerned countries, and also provide estimates on the need for additional interconnection capacity. This study would comprise useful input to elaborate national policies and investment plans (NDPs and NECPs).

3. **Identify and implement measures to foster the integration of Switzerland in the different European electricity market segments, including balancing platforms**

Significant socio-economic benefits can be derived from further electricity market integration with Switzerland, as highlighted recently by ACER.[206] Although it requires political agreements beyond the scope of this study, the Penta Forum is excellently positioned to highlight the benefits to the consumers of the concerned countries, and to stimulate this integration.

Implementation and review of the electricity market design

Several relevant developments are ongoing at the European level regarding the electricity market design. The Commission is expected to publish a first electricity market reform proposal in 2023. The upcoming network code on demand response is expected to further remove barriers to flexibility. These initiatives may present an opportunity for the Penta Steering Group members to actively participate in these debates. In this context, the following recommendations are proposed:

4. **The Penta countries should in their assessment of potential market design changes properly consider the impacts of these changes on flexibility.**
   Initiatives to decouple gas and electricity prices may dampen signals to explicit and implicit flexibility, depending on their format, with the highest risk associated with direct interventions in the electricity price setting mechanism on spot markets. But there are potential areas for improvement that may foster flexibility. These include reforms being discussed to develop (regional) liquid forward markets and other options to de-risking investments, such as capacity markets, which would improve the business case of solutions capable of providing not only adequacy but also flexibility services. Other potential reforms could consider how to expose consumers to market prices according to their risk preferences while protecting vulnerable consumers (see recommendation 7), and improving the bidding zone reconfiguration process based on experience from the ongoing process. Any required emergency measures should be coordinated at the Penta and European level and minimise market and competition distortions.

5. **Ensure the proper implementation of the electricity market design, including provisions of the Clean Energy Package and network codes/guidelines**
   This includes the implementation in the primary regulatory framework of provisions to enable the participation of flexibility sources in all electricity market segments, non-discriminatory network planning considering flexibility as alternative to network expansion, and other measures. Beyond primary regulation, it will be important to review national market rules, including on pre-qualification/ex-post verification and exclusivity clauses for the provision of ancillary and congestion management services in order to enable value stacking without compromising security of supply.

6. **Investigate ways to further link market places, such as shared balancing/redispatch order books and deployment of flexibility platforms and revising gate opening/closure time sequences**
   Market places should be increasingly interlinked. Some measures can be adopted in the short-term by the Penta (or more broadly European) countries and bring quick benefits, such as revising gate opening/closure time sequences or sharing balancing/redispatch order books

[206] ACER (2022) Progress report on European wholesale electricity market integration

where adequate. Other measures will require experimentation and exchange of good practices between Penta countries, such as the development of new flexibility markets and platforms. New or revised designs should consider the temporal sequencing of marketplaces, interactions between network levels and products traded/procured.

7. **Consider further measures to increase the participation of demand response, in particular at distribution level**
   There remains untapped flexibility potential across all voltage levels, with such potential due to increase in the future. While large end-users connected to HV grids are historically active flexibility providers, further measures could be foreseen. Specific measures are also warranted to foster the participation of demand response at distribution level. Penta countries should accelerate the roll-out of low-voltage smart meters where their coverage is still low, if required after having first conducted a new cost-benefit analysis. Measures to increase the offering of dynamic and new supply contract types exposing retail consumers to wholesale market prices fully or partly (i.e., only for a certain percentage of their demand) can be considered to enhance demand response.

8. **Work on cross-border harmonisation of definitions for non-standardised products**
   such as for non-frequency ancillary services and redispatch services, in order to reduce barriers to entry and facilitate the participation of flexibility providers in multiple national and local markets. Focus should be on harmonisation of the definitions, while the products themselves should be designed according to national/local flexibility needs and markets.

9. **Assess and adapt where appropriate support schemes to electricity producers and end-users in view of providing adequate incentives to flexibility**
   Policy measures should incentivise or at least not discourage the deployment of flexible assets. Support to renewable energy and end-use electrification (e.g., heat pumps), adequacy remuneration mechanisms and other support measures should not hinder the provision of flexibility but rather stimulate it.

Transmission and distribution network capacity and cross-border transmission capacity availability to the market

Further cross-border integration of electricity systems and markets reduces flexibility needs and increases the pool of flexibility solutions available, and should constitute a central objective of measures taken at the Penta and national level. Sufficient interconnection capacity and the elimination of domestic structural congestion with a cross-border impact are pre-conditions for efficient market integration. Distribution networks have also become increasingly important to connect distributed flexibility sources as well as to enable access to national and even cross-border markets – already, some Penta countries are facing significant network congestion and difficulties in connecting new users. The following specific recommendations are suggested:

10. **Monitor the timely deployment of planned transmission projects and identify further needs**
    This should cover interconnection and domestic transmission projects facilitating the exchange of flexibility and alleviating network congestions. Further needs could be identified, including through the regional adequacy and flexibility study indicated in recommendation 3.

11. **Maximise the availability of interconnectors where economically efficient, across all market timeframes**.
    To increase the interconnection capacity made available for market purposes, technical reforms could be undertaken such as flow-based coordinated capacity allocation in the balancing time-frame, and various other measures may be required. This includes the eventual reconfiguration of bidding zones where justified in order to more accurately reflect structural congestions.

12. **Electricity network planning should gradually evolve to integrate other vectors (methane, hydrogen), the transmission and distribution level, and consider new flexibility solutions**.
    Cooperation between TSOs and DSOs in the development of their network development plans should increase, and a gradual transition to integrated electricity-gas network development plans should be stimulated. Network operators should in their network development plans be obliged and incentivized to properly consider flexible network use as well as other flexibility solutions as possible alternative to investments in network reinforcement.

13. **Encourage grid operators to exchange information and best practices regarding technical options to maximise or optimize the use of existing grid capacity**
    This could lead to widespread adoption of practices by installing phase shifters in HV networks, and by using techniques, such as Dynamic Line Rating or advanced cable monitoring techniques to prevent or reduce grid congestion.

14. **Revise electricity network tariff methodologies to incentivise flexibility while maintaining them practical and considering interactions with market price signals.**
    Capacity-based and time-of-use network tariffs can achieve a better use of network capacity and reduce investment needs in reinforcements, and should hence be considered. However, the optimal tariff design and structure also depend on national and local characteristics.

15. **Allow the implementation of flexible grid connection agreements in order to avoid delays in RES deployment**.
    While flexible connection agreements can be used to accelerate RES deployment, an adequate legal framework should oblige the concerned grid operators to properly remunerate flexible grid users for curtailments exceeding an agreed level. This remuneration should incentivize grid operators to timely invest in capacity reinforcements allowing to offer firm connection agreements and to avoid structural congestion.

6 Annex

6.1 Technical characteristics of flexibility solutions

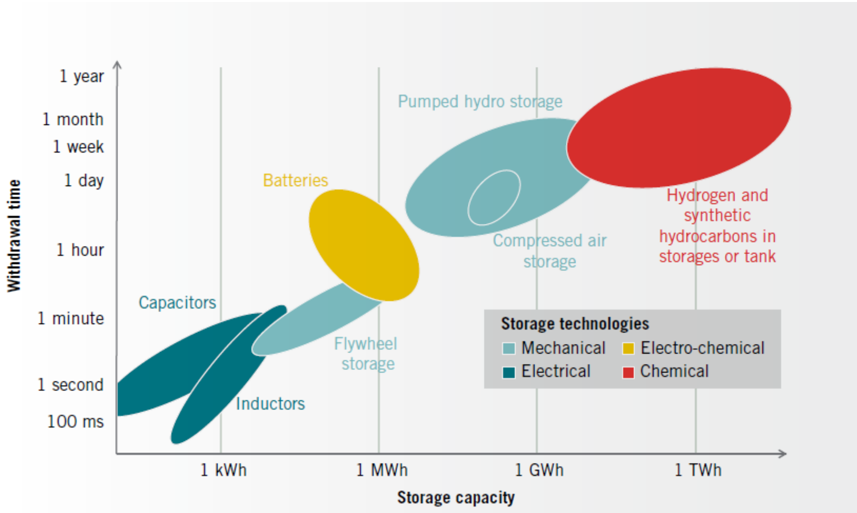
6.1.1 Load following capabilities of thermal power plants

Figure 6-1: Load-following ability of several dispatchable power plants[12]

	Start-up time	Maximal change in 30 sec	Maximum ramp rate (%/min)
Open cycle gas turbine (OCGT)	10-20 min	20-30%	20%/min
Combined cycle gas turbine (CCGT)	30-60 min	10-20%	5-10%/min
Coal plant	1-10 hours	5-10%	1-5%/min
Nuclear power plant	2 hours - 2 days	up to 5%	1-5%/min

6.1.2 Energy storage capacity versus power capacity of different storage technologies.

Figure 6-2: Difference in storage capacity and withdrawal time for various storage methods[207].



6.1.3 Technical characteristics of electrolyser technologies

Figure 6-3: Mapping of electrolysers and system services

	Alkaline		PEM		SOEC	
	Today	2030	Today	2030	Today	2030
FCR	Yes with limits	Yes with limits	Yes with limits	Yes with limits	No	Uncertainty about flexibility
aFRR	Yes with limits	Yes with limits	Yes	Yes	No	Uncertainty about flexibility
mFRR	Yes	Yes	Yes	Yes	No	Uncertainty about flexibility
RR	Yes	Yes	Yes	Yes	No	Uncertainty about flexibility
Voltage control	Electrolysers can provide reactive power, if they are equipped with self-commutated rectifiers.					
Congestion management	Yes	Yes	Yes	Yes	No	Uncertainty about flexibility

[207] ENTSO-E, Frontier Economics (2022) Potential of P2H2 technologies to provide system services

Figure 6-4: Flexibility characteristics of electrolysers

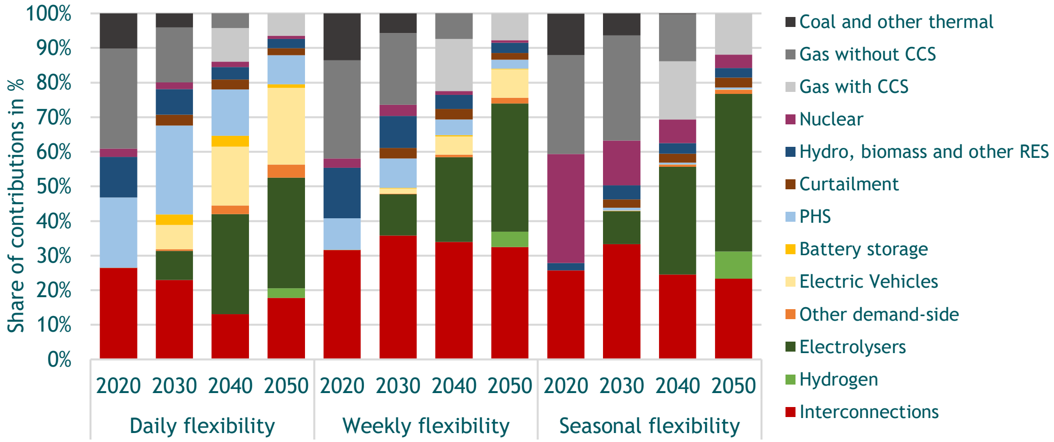
Characteristic	Time horizon	Alkaline	PEM	SOEC
Flexibility				
Load range (relative to nominal load) The overload condition can be kept for a limited amount of time, requires oversized equipment and entails efficiency losses.	Today	10–110%	0–160%	20–125%
	2030	Expected by 2050: 5–300%	Expected for 2050: 5–300%	Expected for 2050: 0–200%
Start-up time (warm, cold)	Today	1–10 minutes	1 second – 5 minutes	<60 minutes
	2030	Not available	Not available	Not available
Shutdown	Today	1–10 minutes	1 second – 5 minutes	Not available
	2030	Not available	Not available	Not available
Ramp-up / Ramp- down	Today	0.2–20% / second	100% / second	SOEC have a system response time of few seconds.
	2030	Not available	Not available	Not available
Reactive power	› Electrolysers cannot provide reactive power *per se* as they are a DC loads and limited reactive power is consumed by other equipment in the module. However, electrolysers may be able to provide voltage control through their converters.			

6.2 Flexibility needs and solutions

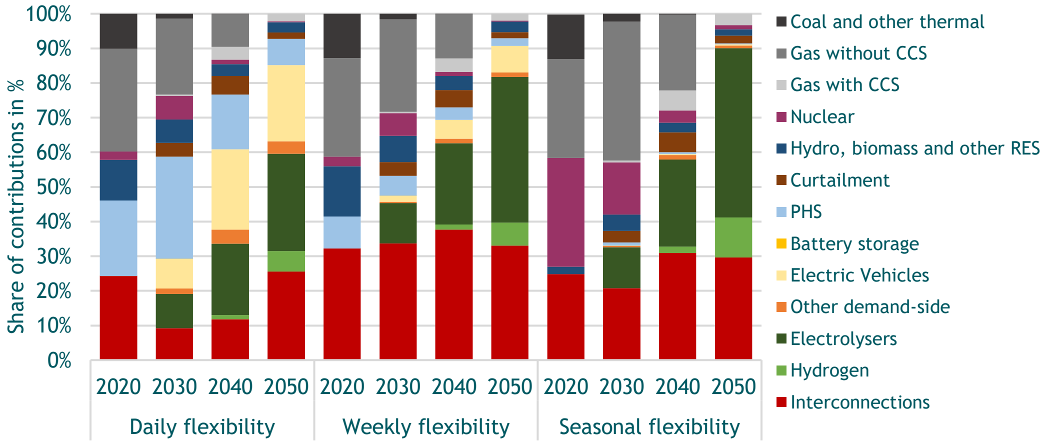
6.2.1 Penta region

Figure 6-5: Share of technologies providing system flexibility in the Penta countries for daily, weekly and seasonal timeframes for the three scenarios

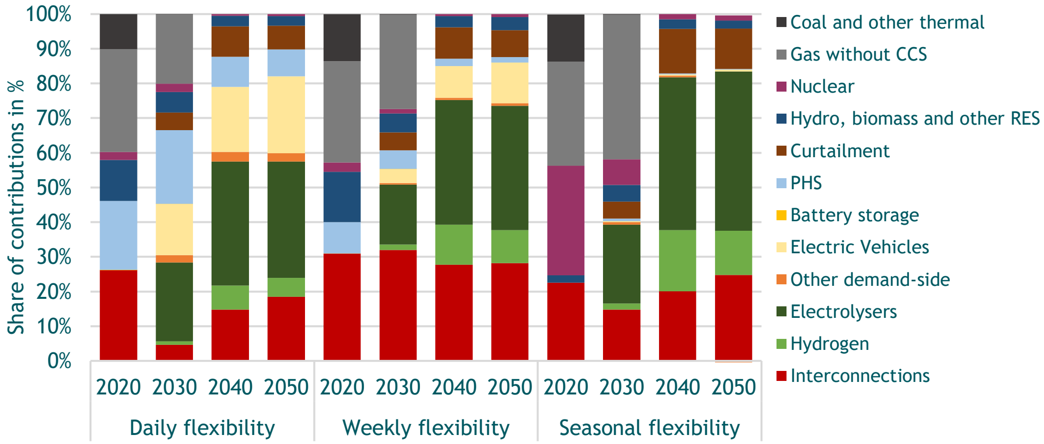
Stated policy



Technology driven



System Change



6.2.2 Austria

Figure 6-6: Flexibility needs of Austria for three different scenarios and three flexibility timeframes until 2050

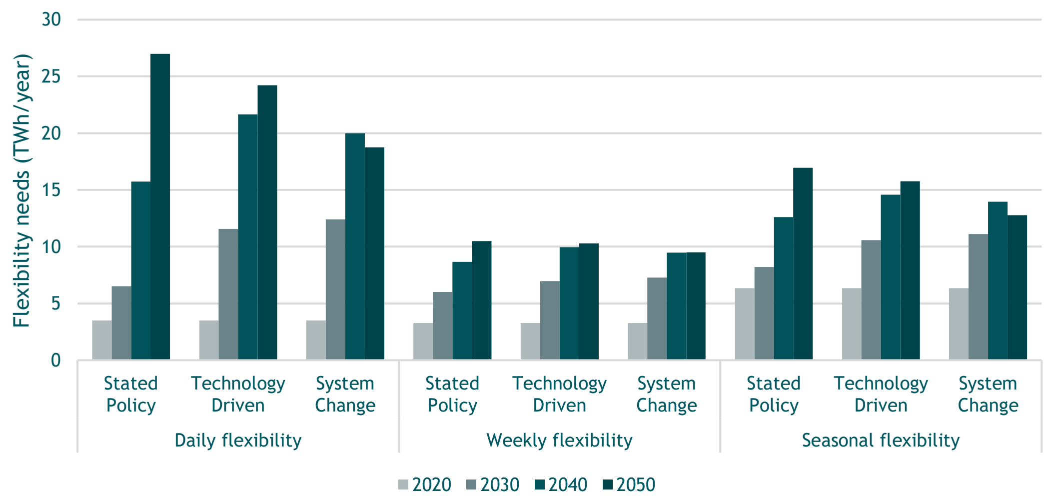


Figure 6-7: Electricity production by source for Austria for the Stated Policy, Technology Driven and System Change scenarios

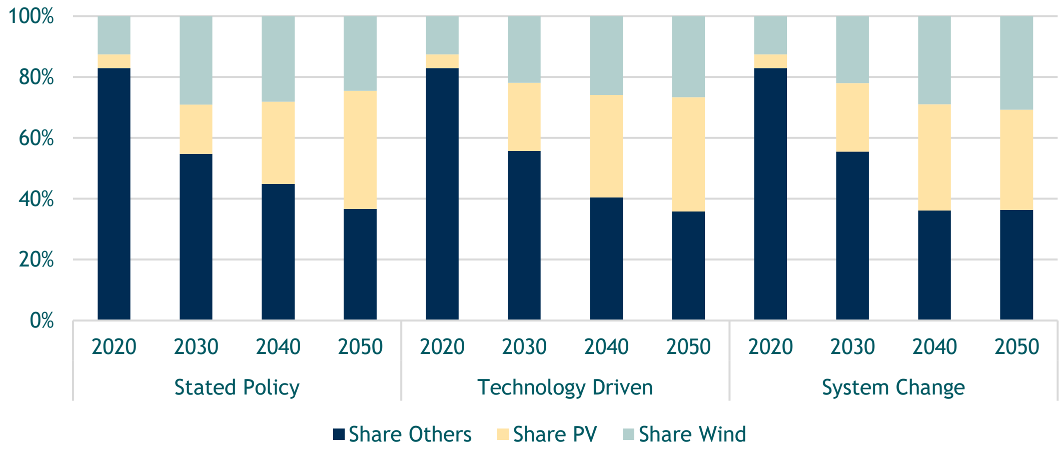


Figure 6-8: Installed capacities of flexible assets in Austria in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

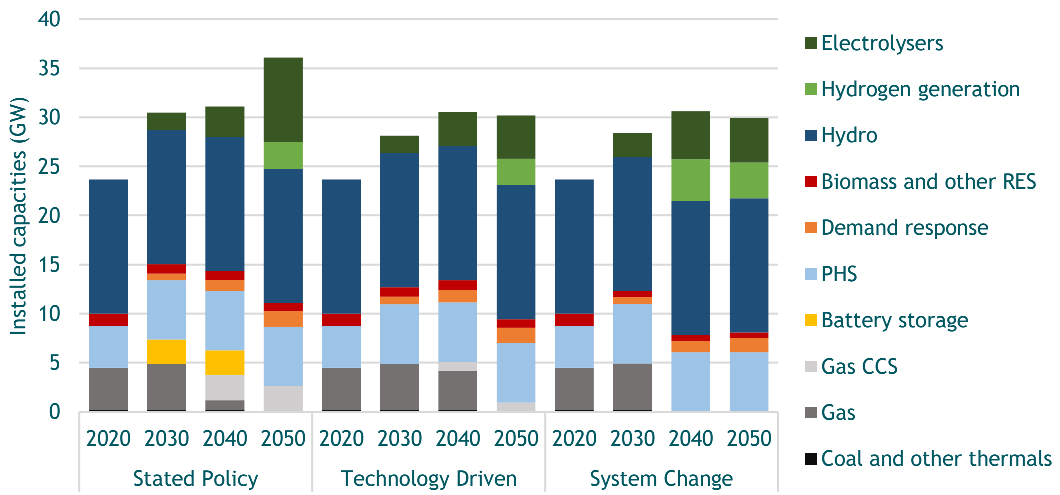
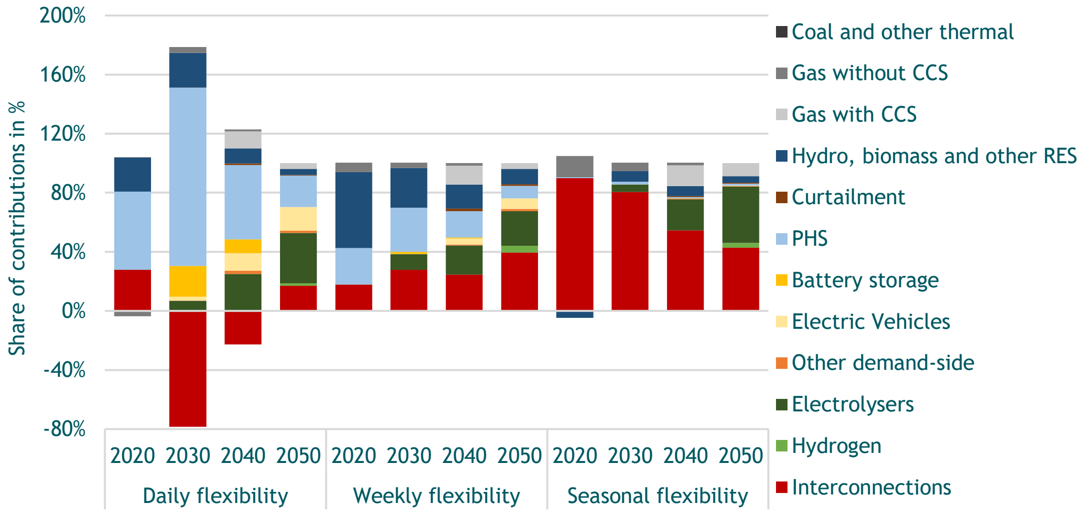
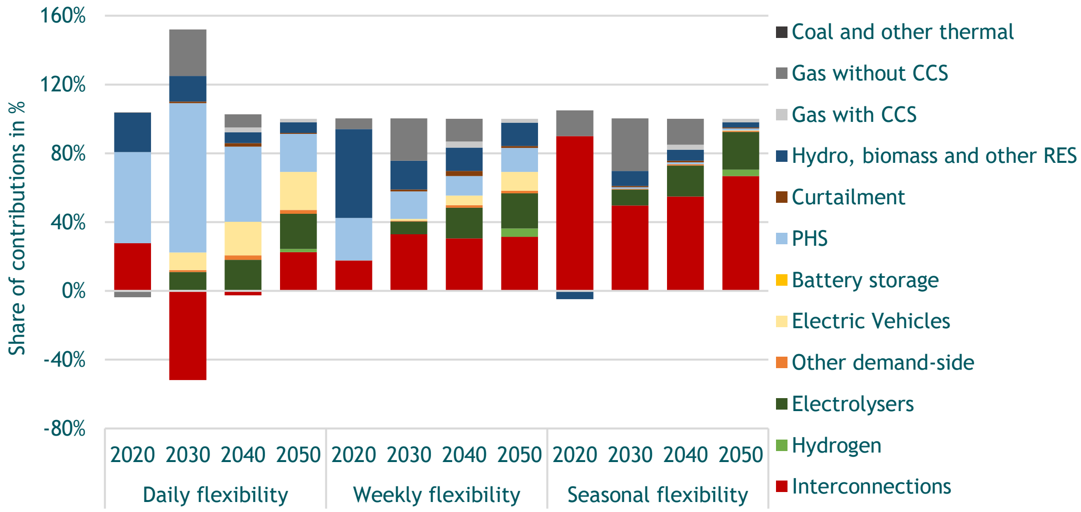


Figure 6-9: Share of technologies providing system flexibility in Austria for daily, weekly and seasonal timeframes for all three scenarios

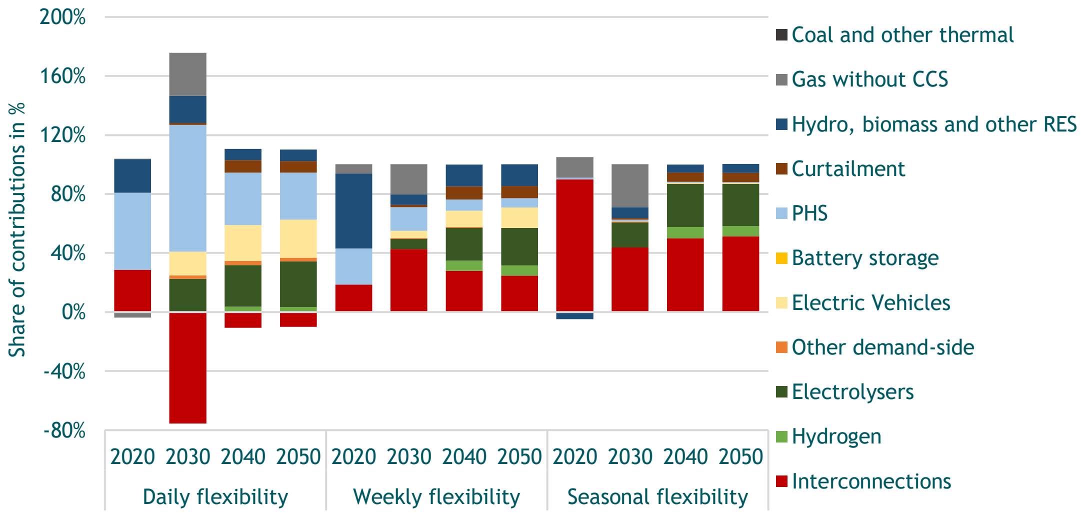
Stated policy



Technology driven



System Change



6.2.3 Belgium

Figure 6-10: Flexibility needs of Belgium for three different scenarios and three flexibility timeframes until 2050

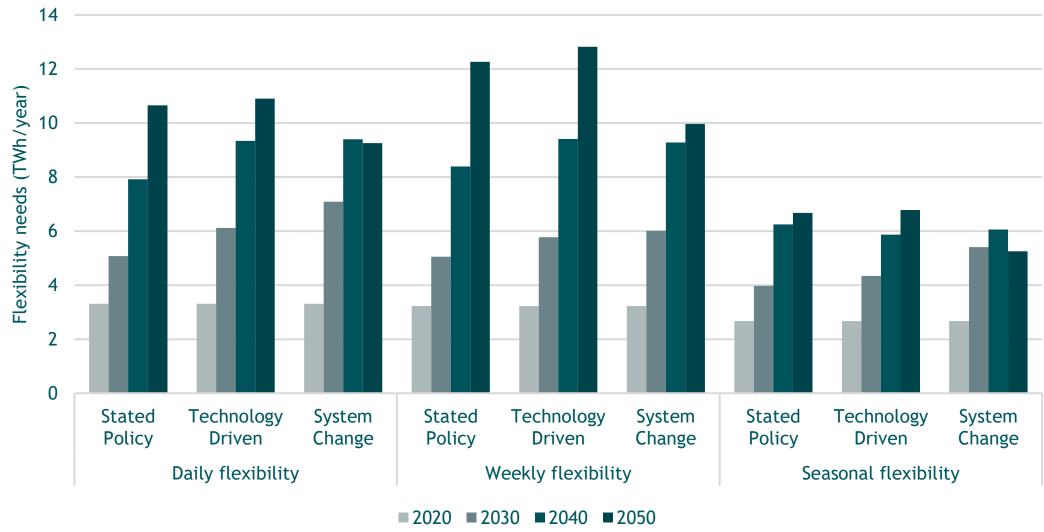


Figure 6-11: Electricity production by source for Belgium for the Stated Policy, Technology Driven and System Change scenarios

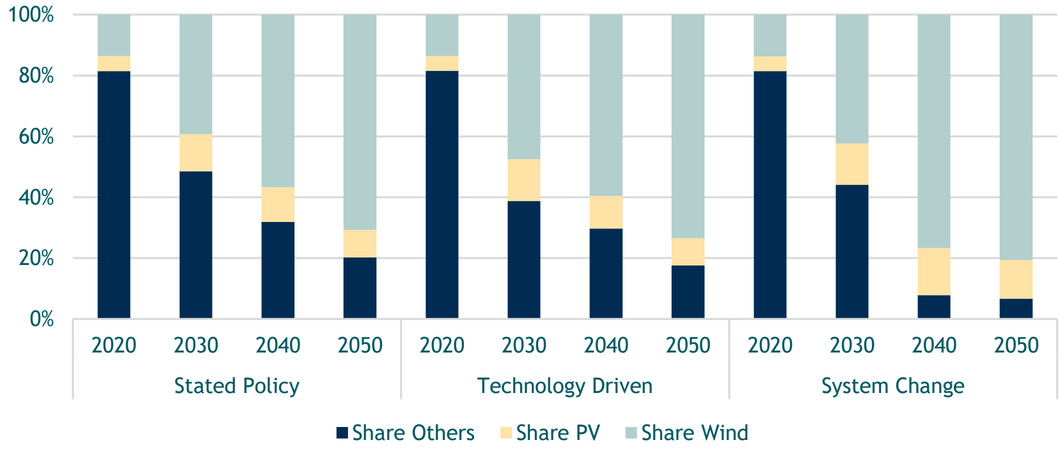


Figure 6-12: Installed capacities of flexible assets in Belgium in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

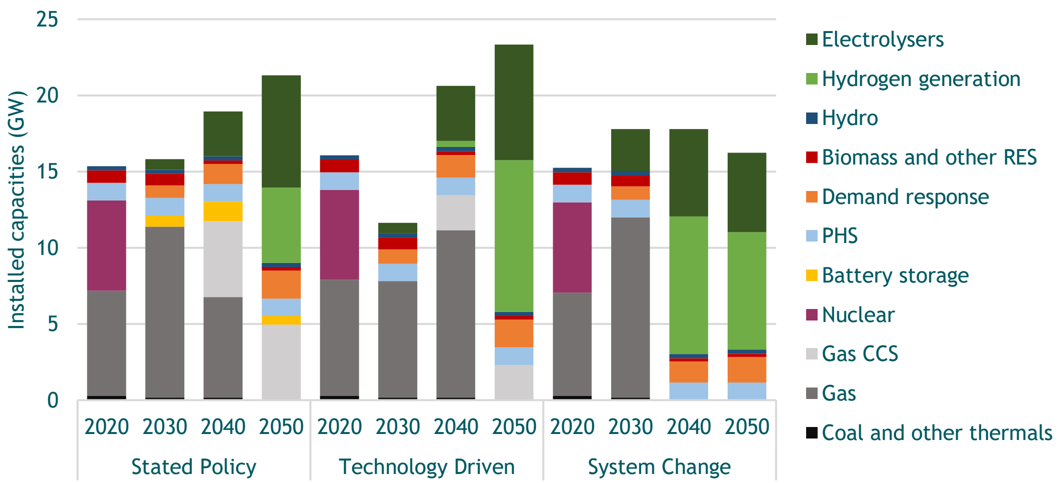
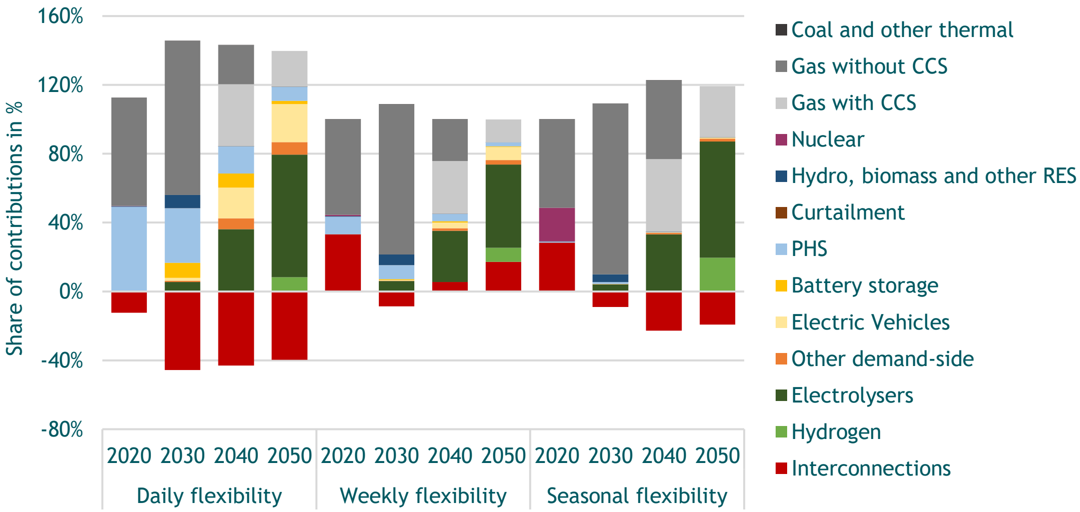
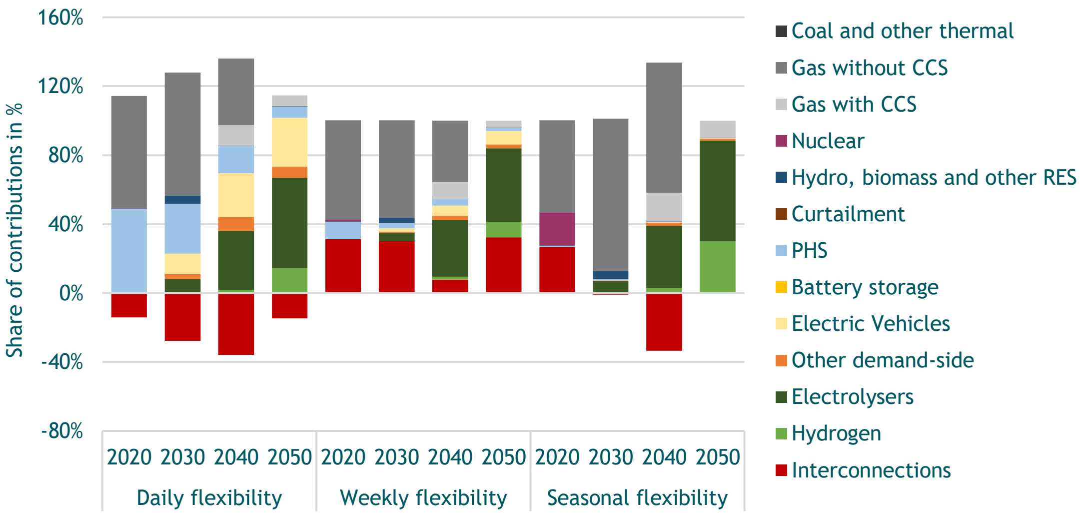


Figure 6-13: Share of technologies providing system flexibility in Belgium for daily, weekly and seasonal timeframes for all three scenarios

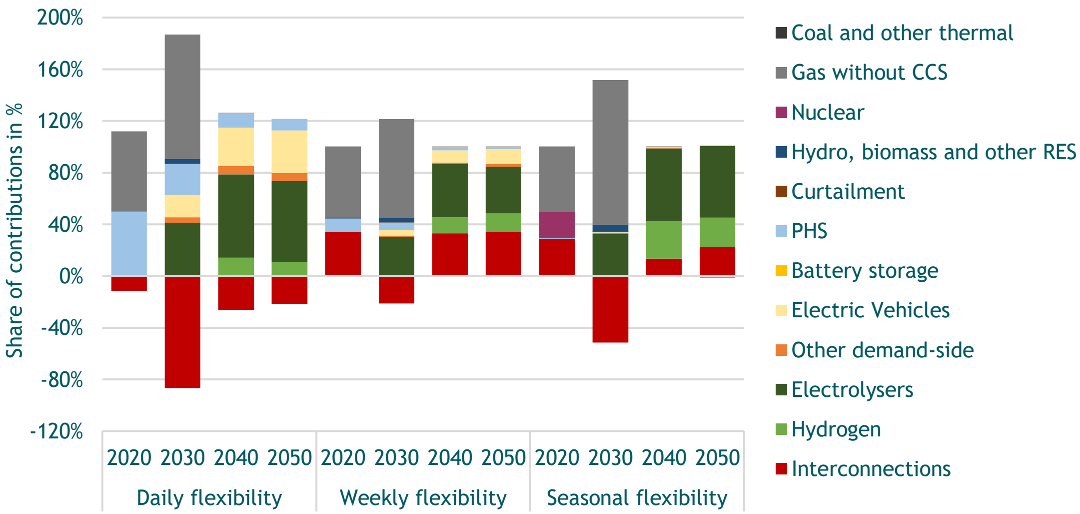
Stated policy



Technology driven



System Change



6.2.4 Switzerland

Figure 6-14: Flexibility needs of Switzerland for three different scenarios and three flexibility timeframes until 2050

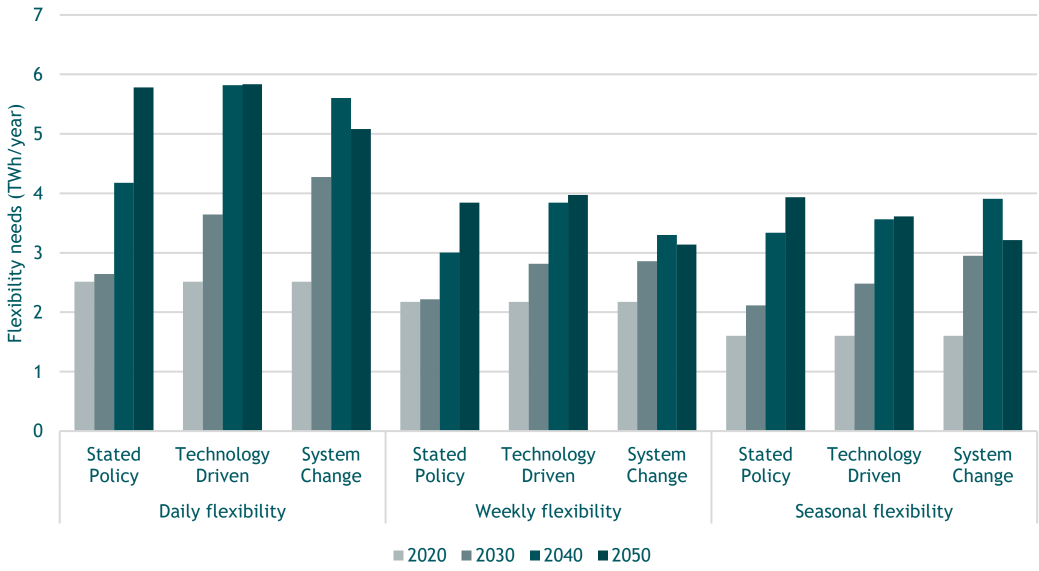


Figure 6-15: Electricity production by source for Switzerland for the Stated Policy, Technology Driven and System Change scenarios

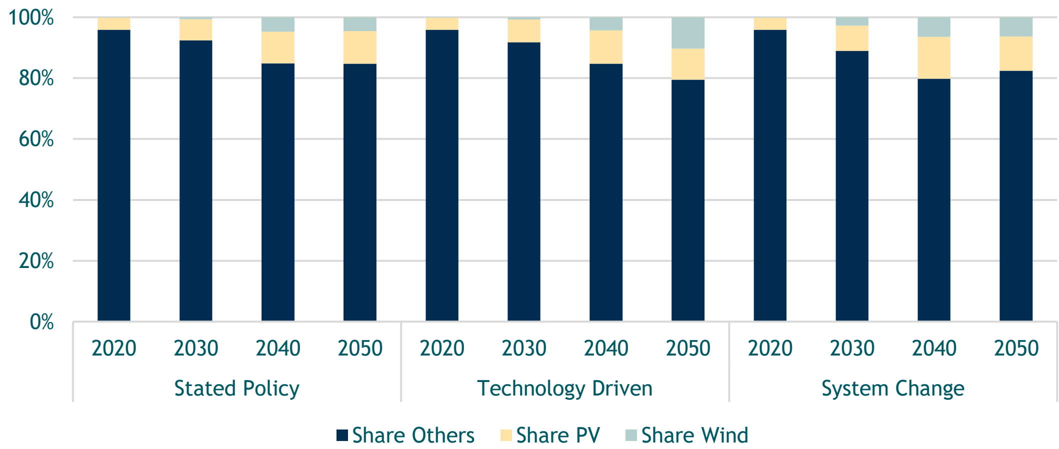


Figure 6-16: Installed capacities of flexible assets in Switzerland in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

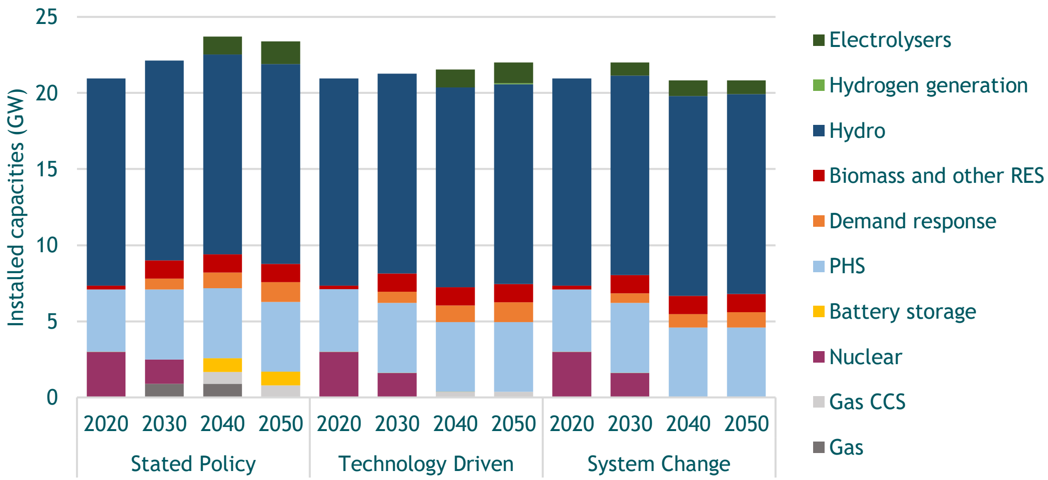
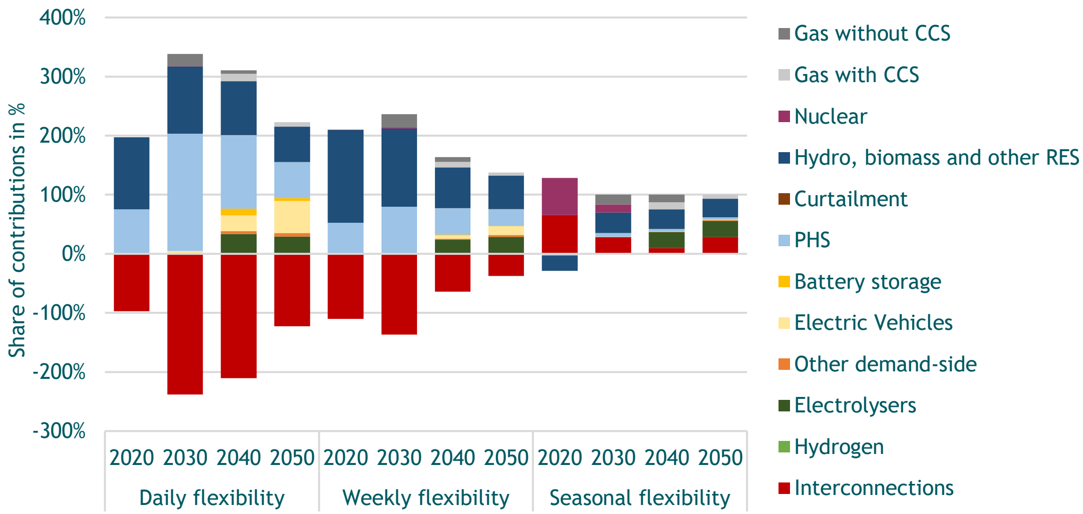
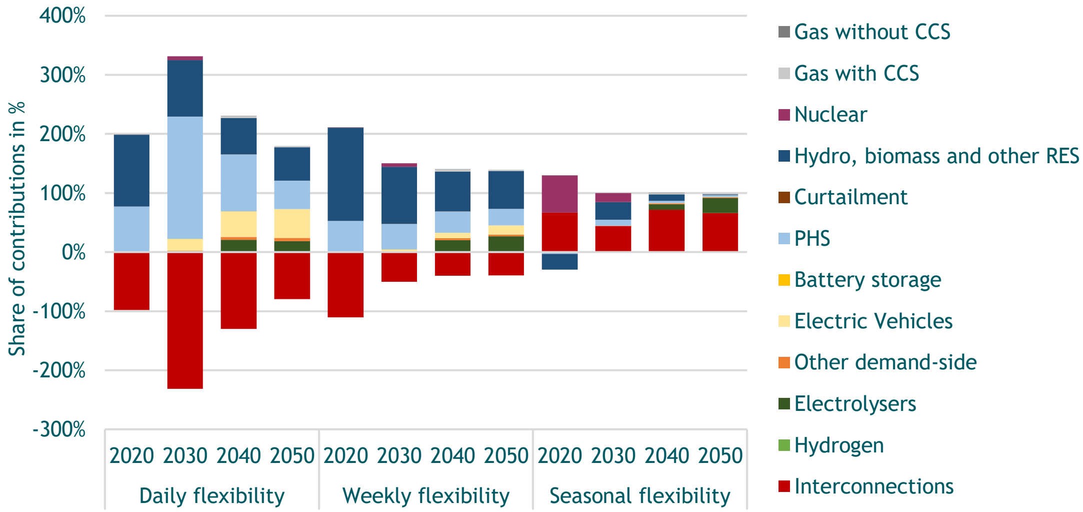


Figure 6-17: Share of technologies providing system flexibility in Switzerland for daily, weekly and seasonal timeframes for all three scenarios

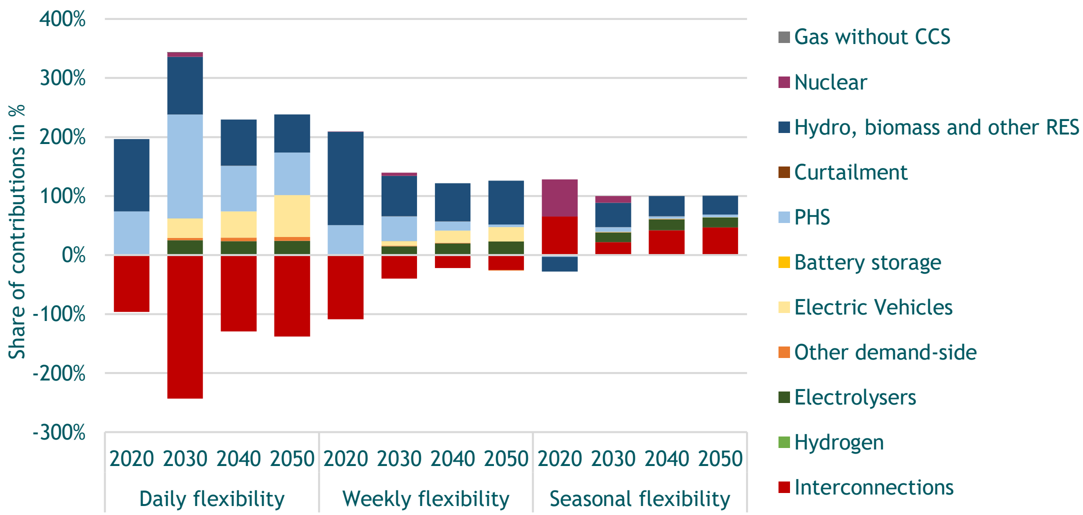
Stated policy



Technology driven



System Change



6.2.5 Germany

Figure 6-18: Flexibility needs of Germany for three different scenarios and three flexibility timeframes until 2050

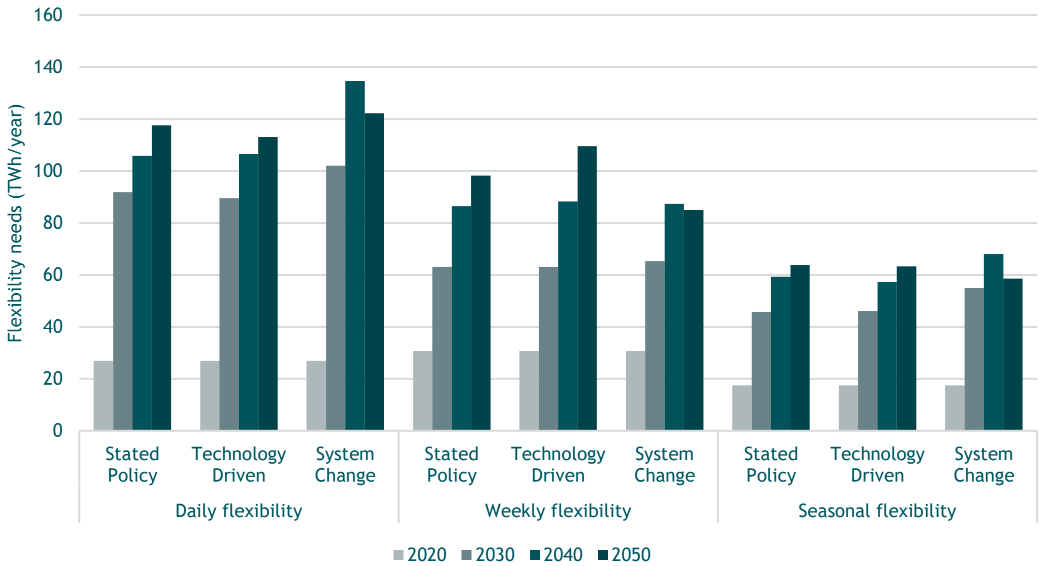


Figure 6-19: Electricity production by source for Germany for the Stated Policy, Technology Driven and System Change scenarios

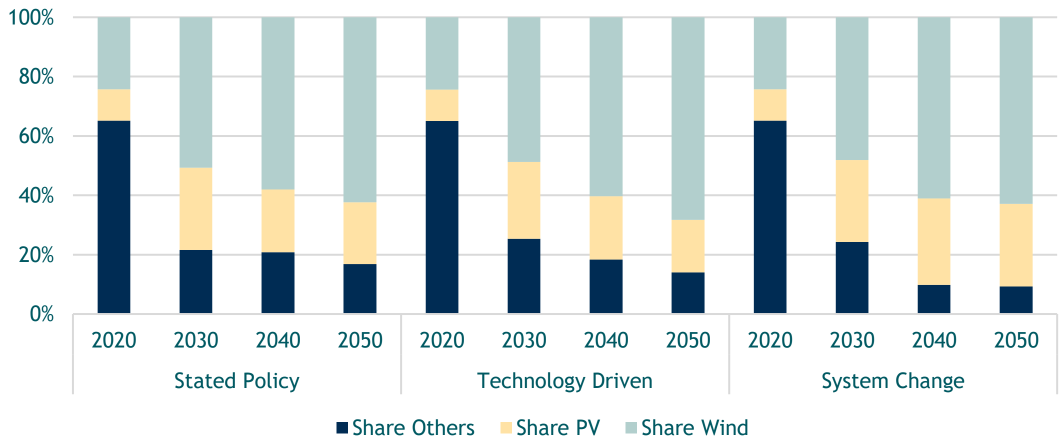


Figure 6-20: Installed capacities of flexible assets in Germany in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

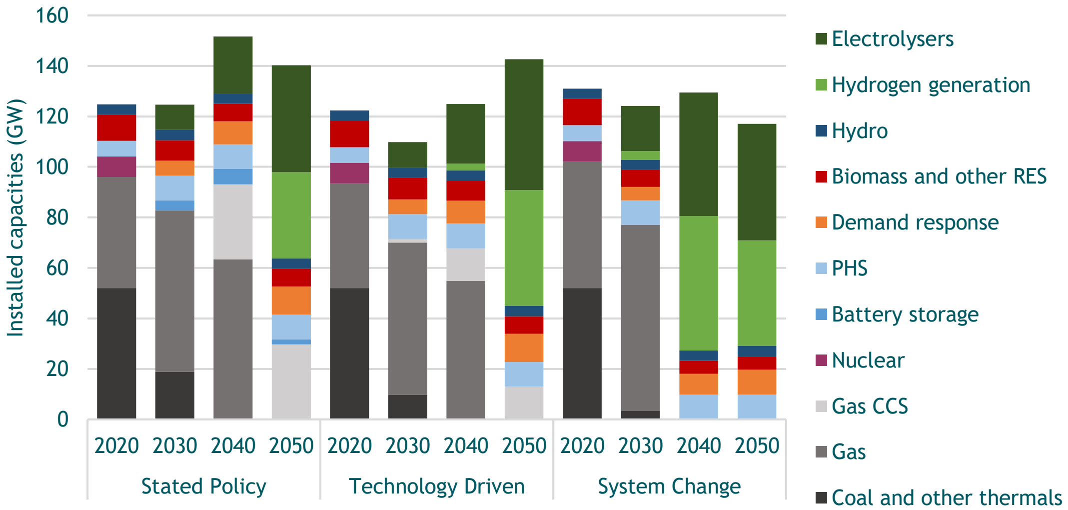
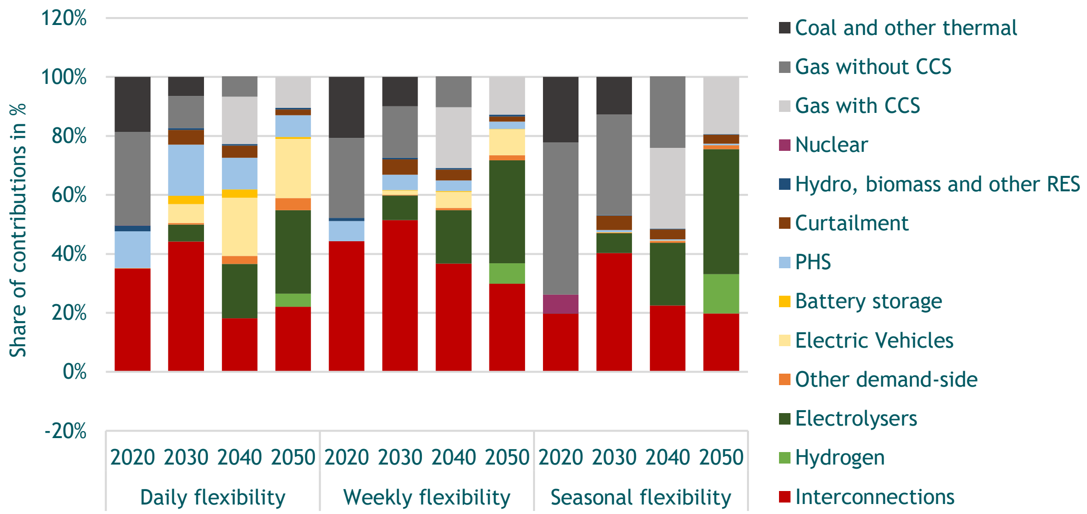
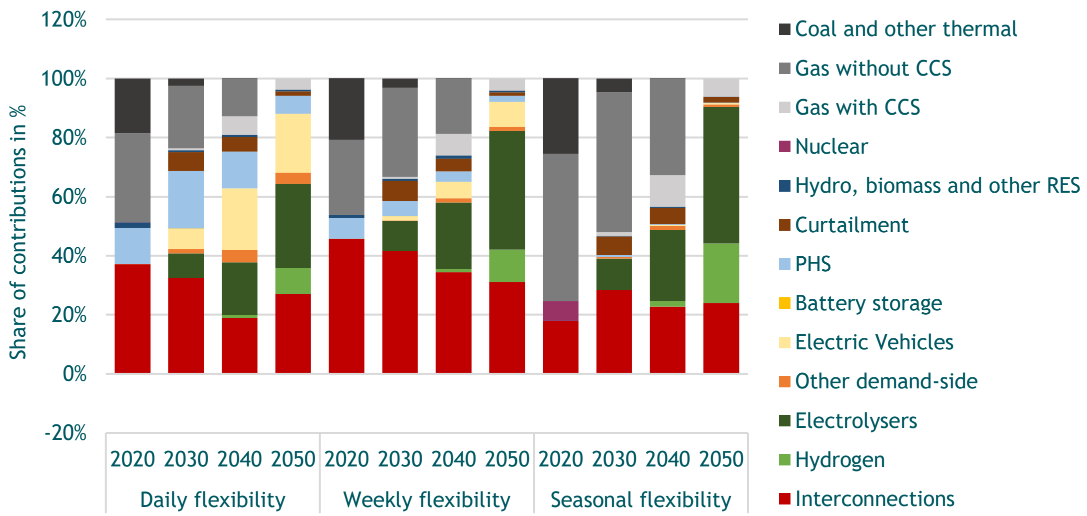


Figure 6-21: Share of technologies providing system flexibility in Germany for daily, weekly and seasonal timeframes for all three scenarios

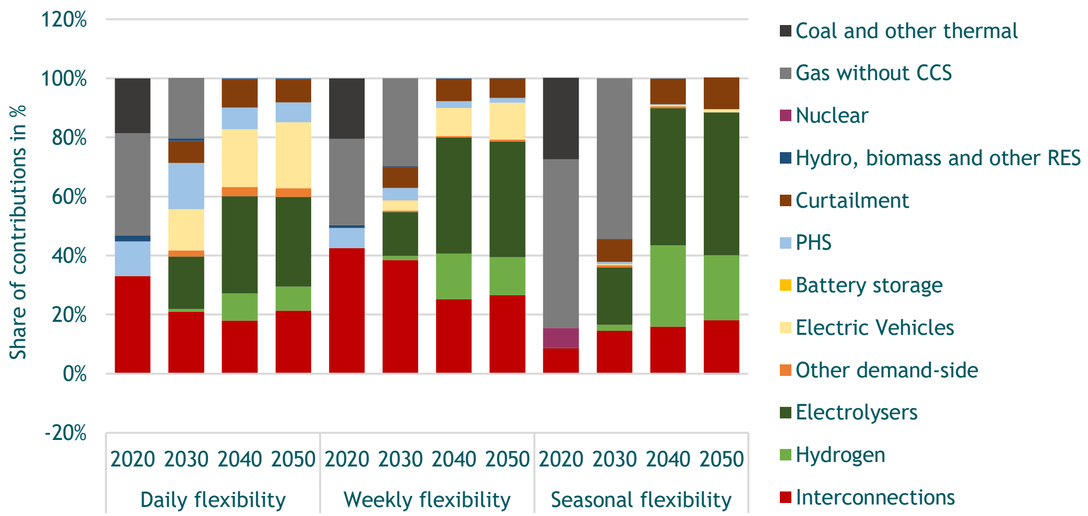
Stated policy



Technology driven



System Change



6.2.6 France

Figure 6-22: Flexibility needs of France for three different scenarios and three flexibility timeframes until 2050

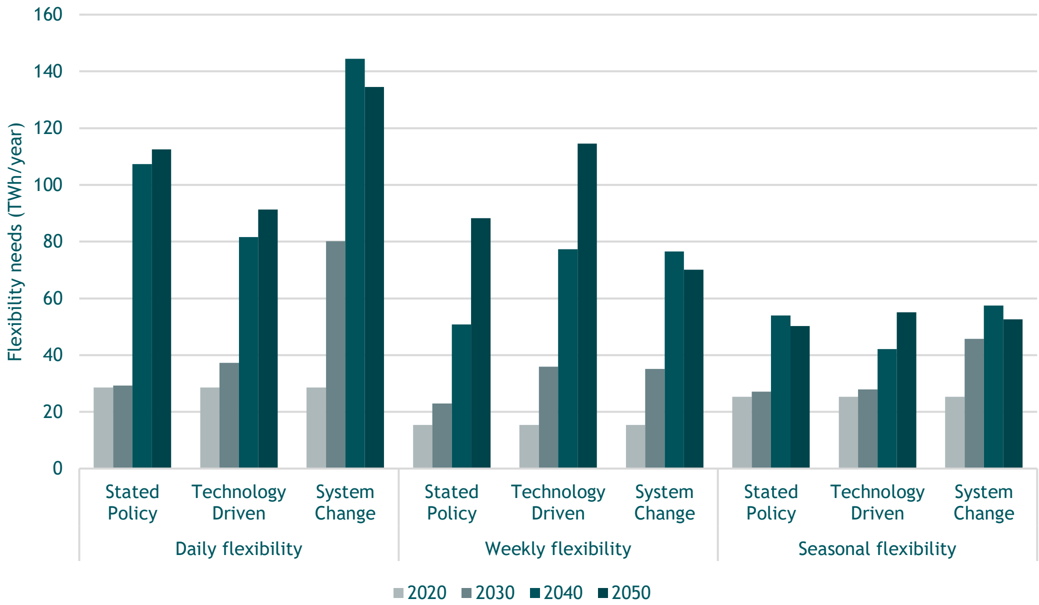


Figure 6-23: Electricity production by source for France for the Stated Policy, Technology Driven and System Change scenarios

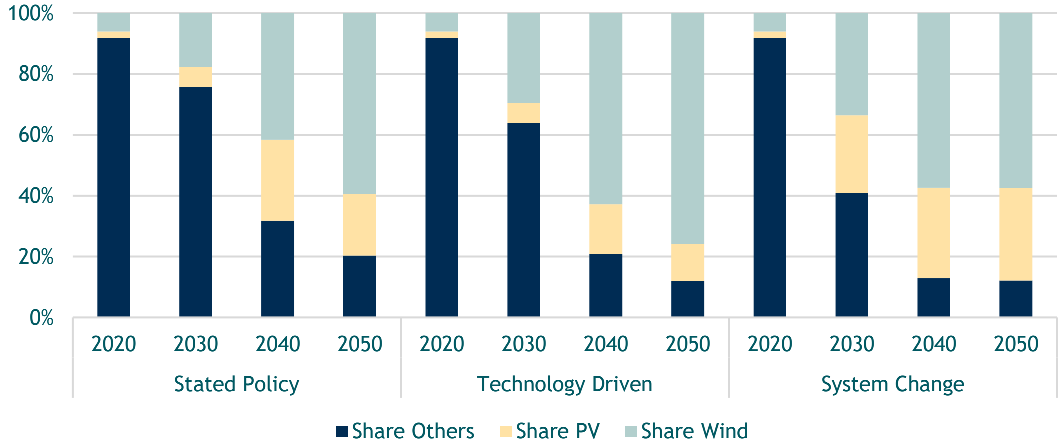


Figure 6-24: Installed capacities of flexible assets in France in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

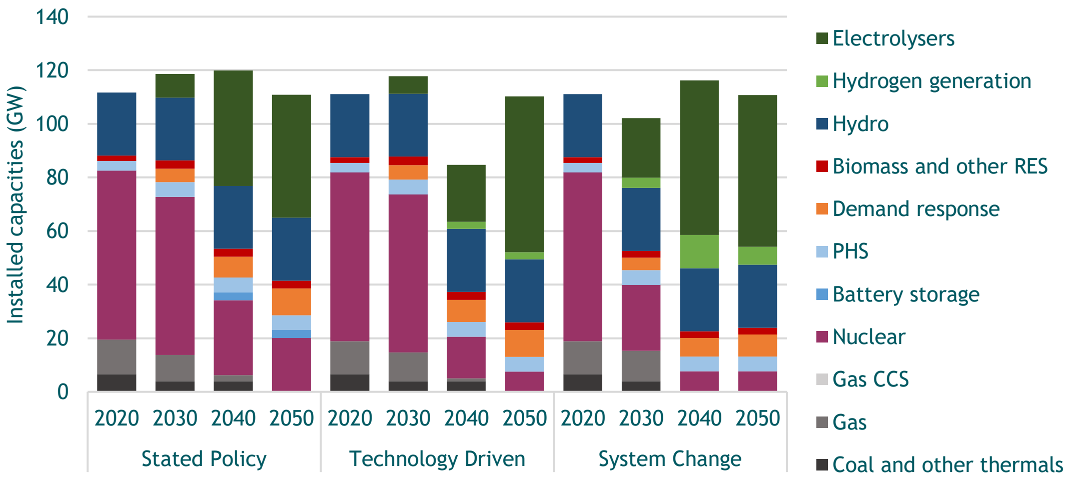
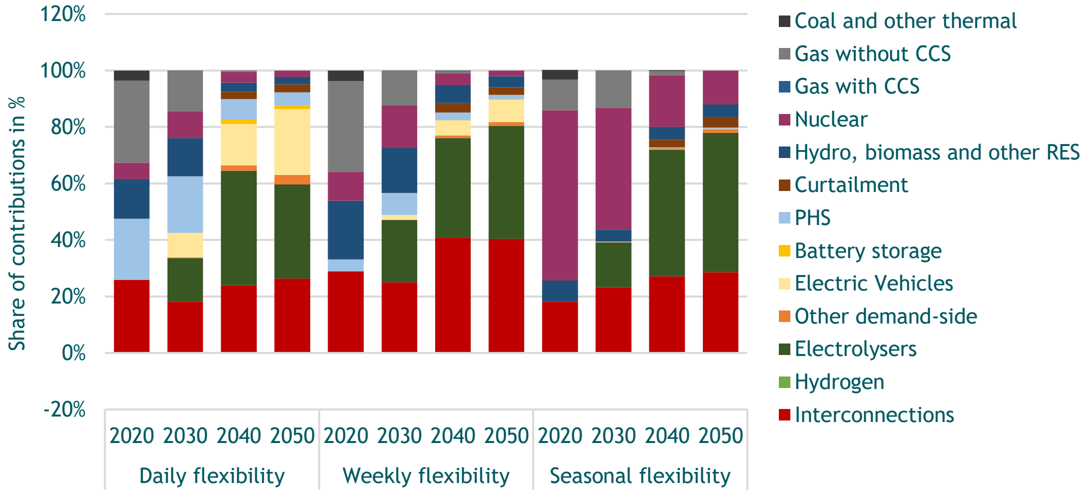
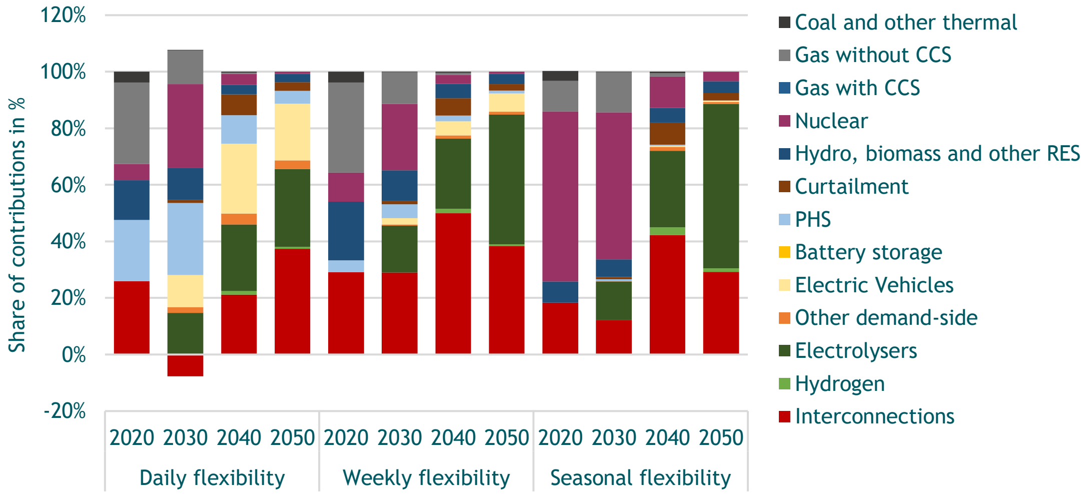


Figure 6-25: Share of technologies providing system flexibility in France for daily, weekly and seasonal timeframes for all three scenarios

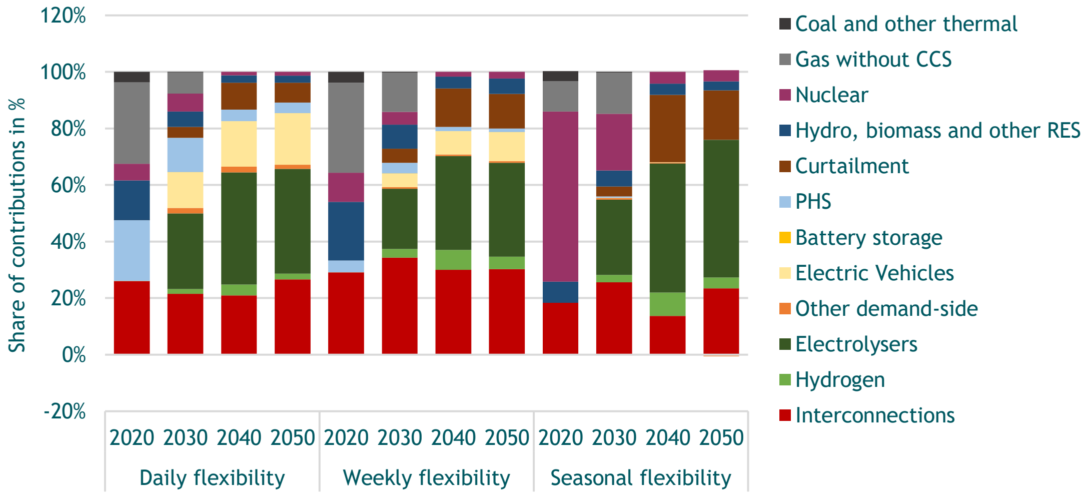
Stated policy



Technology driven



System Change



6.2.7 Luxembourg

Figure 6-26: Flexibility needs of Luxembourg for three different scenarios and three flexibility timeframes until 2050

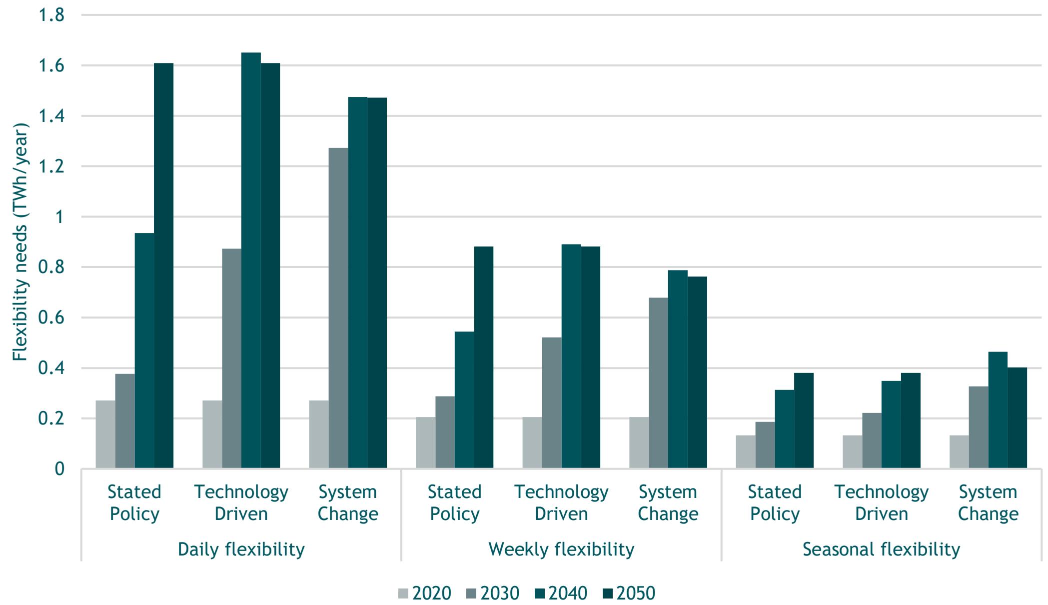


Figure 6-27: Electricity production by source for Luxembourg for the Stated Policy, Technology Driven and System Change scenarios.

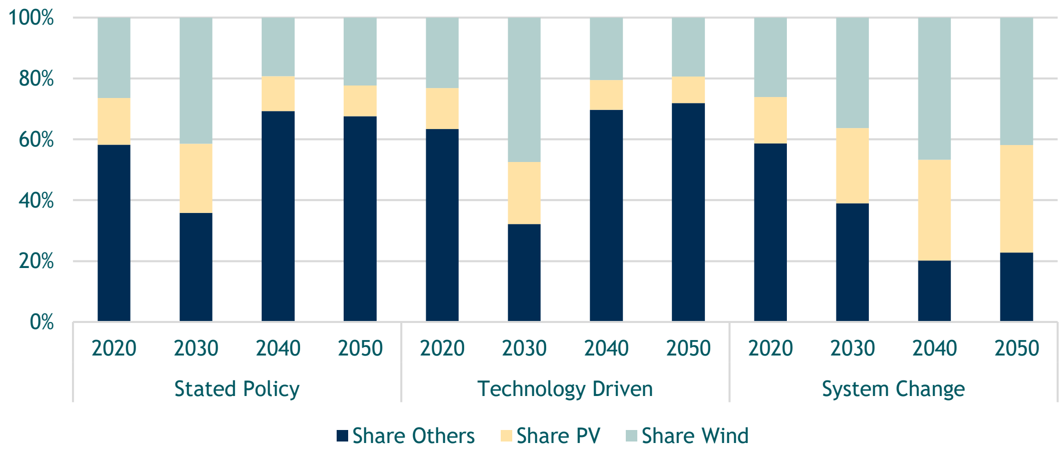


Figure 6-28: Installed capacities of flexible assets in Luxembourg in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

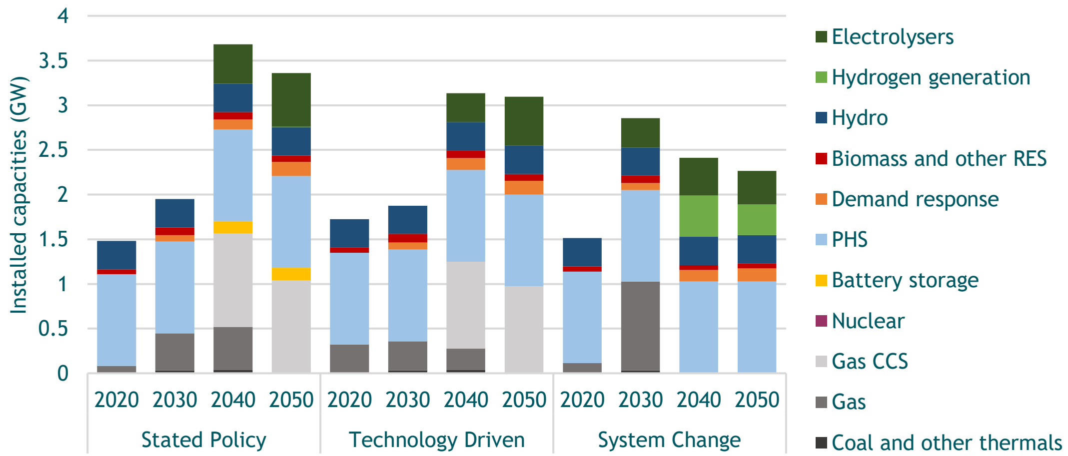
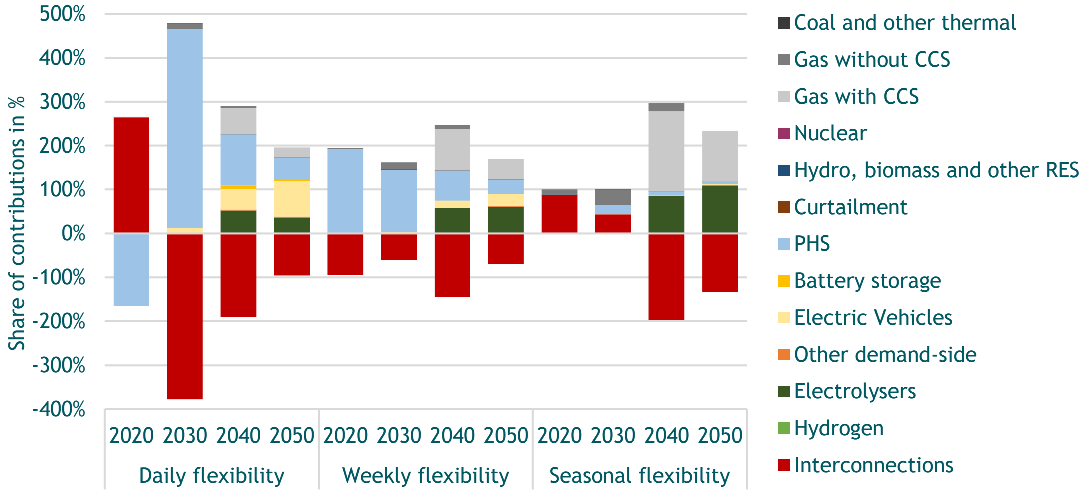
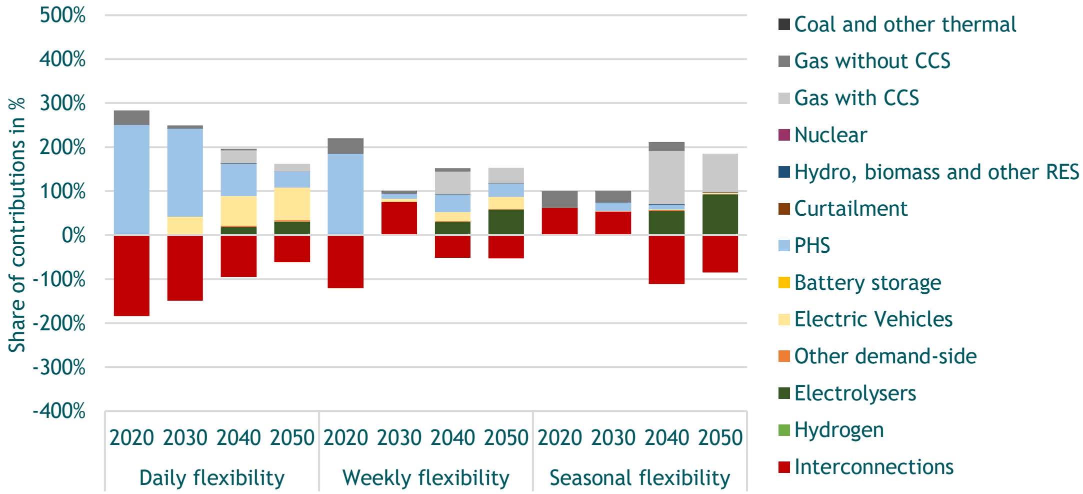


Figure 6-29: Share of technologies providing system flexibility in Luxembourg for daily, weekly and seasonal timeframes for all three scenarios

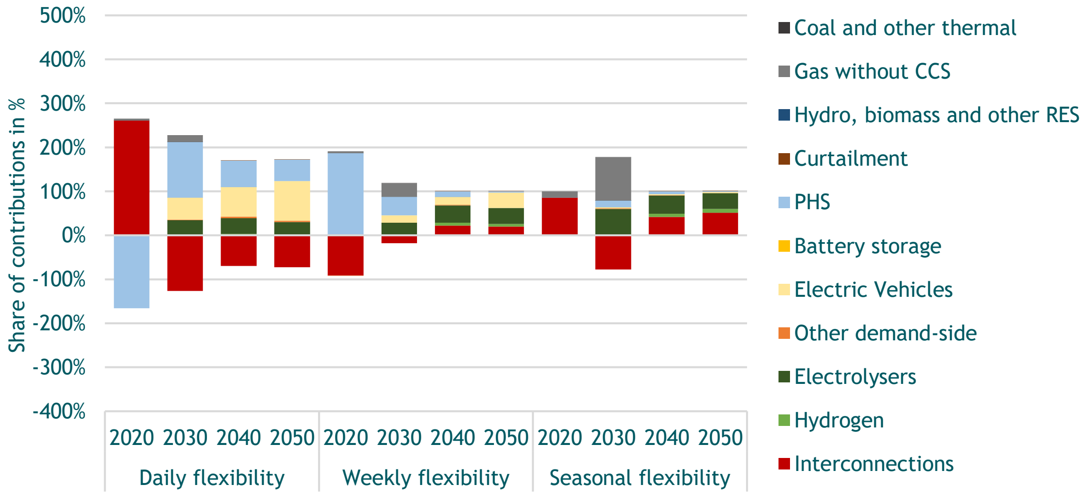
Stated policy



Technology driven



System Change



6.2.8 The Netherlands

Figure 6-30: Flexibility needs of the Netherlands for three different scenarios and three flexibility timeframes until 2050

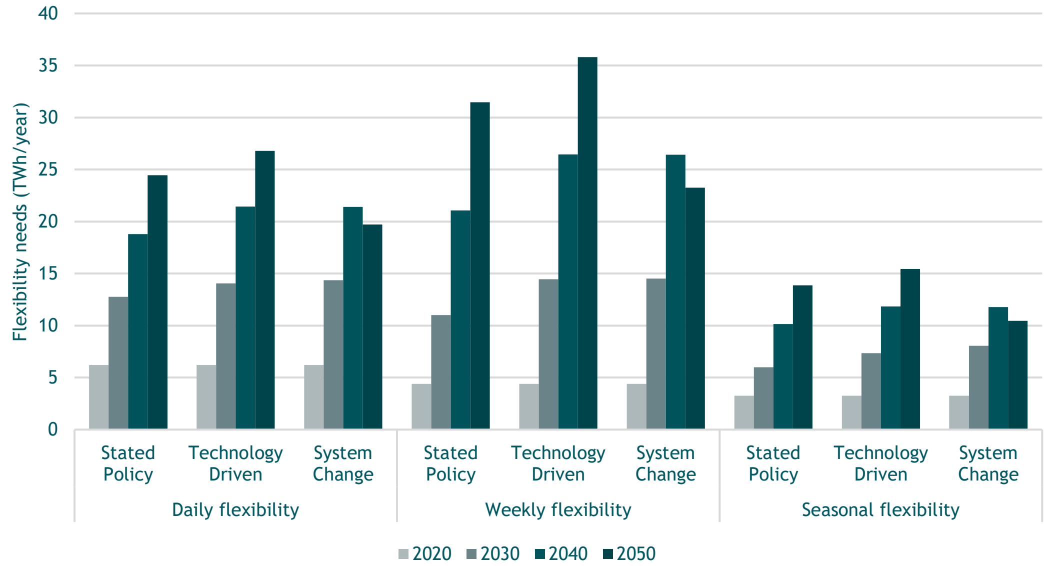


Figure 6-31: Electricity production by source for the Netherlands for the Stated Policy, Technology Driven and System Change scenarios

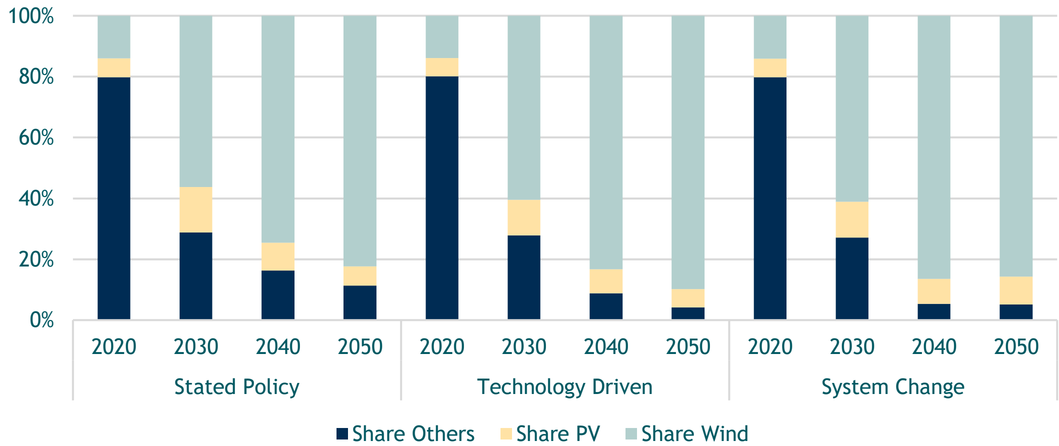


Figure 6-32: Installed capacities of flexible assets in the Netherlands in GW from 2020 to 2050 for Stated Policy, Technology Driven and System Change scenarios

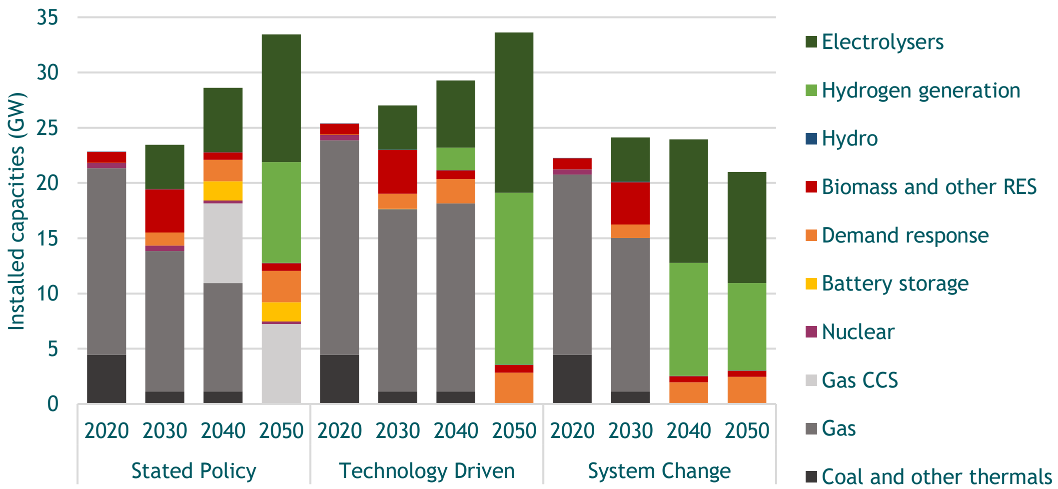
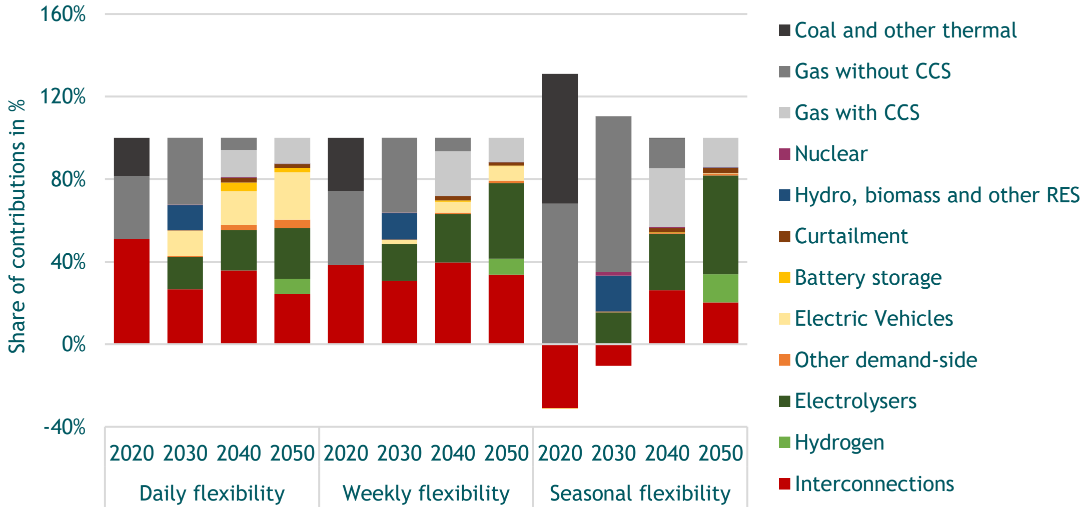
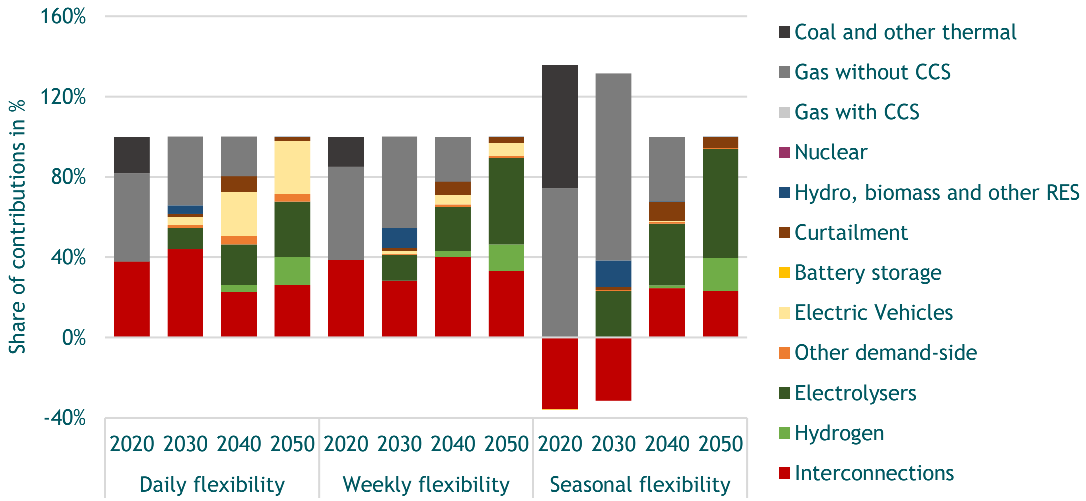


Figure 6-33: Share of technologies providing system flexibility in the Netherlands for daily, weekly and seasonal timeframes for all three scenarios

Stated policy



Technology driven



System Change