Long-Term Storage

CEER "European Green Deal" White Paper series (paper I)

relevant to the European Commission's Hydrogen and Energy System Integration Strategies

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Introduction

CEER[1] welcomes the European Commission's 2030 climate and energy framework[2] that facilitates the path towards decarbonisation while maintaining a non-discriminatory internal market. The increasing share of variable renewable energies will, due to their seasonal generation pattern, increase the need for solutions that provide seasonal adequacy and help to guarantee security of supply throughout the whole year. Traditionally, this has been done with fossil fuel power plants and gas storage. In a future, with a variable renewable energy source (vRES)[3] based power system, new (low carbon emitting) solutions will be needed. In this light, the European Commission's System Integration[4] and Hydrogen[5] Strategies are an important step to leverage synergies between the electricity and gas sectors, facilitating new solutions for seasonal adequacy.

As long-term storage is only one approach to achieve the overall goal of seasonal adequacy, this paper takes a more holistic view on solutions to match supply throughout the year. Therefore, first a rough estimation of the future regional electricity and gas long-term storage needs, based on historic data and predictions of the Ten-Year Network Development Plan (TYNDP) 2020, is performed. Afterwards, high-level principles to achieve seasonal adequacy (e.g. long-term storage, interconnectors, market-based curtailment and flexible demand) are compared. Finally, a brief look into the economic viability of Power-to-Gas (P2G) is taken[6].

This paper does not intend to provide answers similar to those given by others' more advanced and comprehensive adequacy analyses. The analysis provided in this paper follows the simplified method already applied in recent studies made for the Commission[7,8,9]. It uses historical data and aspired future generation mixes to estimate long-term storage needs, provide an overview on

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[1] CEER is the Council of European Energy Regulators which is the European association of energy national regulatory authorities, see www.ceer.eu.

[2] European Commission Communication on the 2030 Climate Target Plan - Stepping up Europe's 2030 climate ambition, COM/2020/562 final.

[3] For example, wind and photovoltaic generation.

[4] European Commission Communication on Powering a climate-neutral economy: An EU Strategy for Energy System Integration, COM/2020/299. Hereafter: EU Energy System Integration Strategy.

[5] European Commission Communication on a Hydrogen Strategy for a Climate-Neutral Europe, COM/2020/301 final. Hereafter: EU Hydrogen Strategy.

[6] For a more complete treatment of the topic of Power-to-Gas, see the ACER-CEER "European Green Deal" Regulatory White Paper Regulatory Treatment of Power-to-Gas, 11 February 2021.

[7] European Commission METIS study S07 on The role and need of flexibility in 2030: Focus on Energy Storage, August 2016.

[8] European Commission METIS study S11 on the Effect of high shares of renewables on power systems, April 2018.

[9] European Commission report on Mainstreaming RES – flexibility portfolios, 19 July 2017.

seasonal adequacy and derive a few high-level policy recommendations. Furthermore, it is important to state that the possible limitation linked to grid constraints on the availability of long-term storage capacities, at a given location, was not considered. In addition, the phase-out decisions and processes for nuclear and coal power plants were not examined in detail, thus, additional studies would be necessary for more detailed conclusions.

The term "storage" is used in alignment with the definition in Article 2 (59) of the EU Directive on common rules for the internal market in electricity[10]. In the scope of this paper, "long-term" refers to a timespan of several months.

Key conclusions and recommendations

The analysis performed in sections 2 and 3 shows that there are differences in the regional seasonality of gas and electricity demand. However, there is (from a technical point of view) no foreseeable additional demand for long-term storage of electricity until at least 2040 on an averaged European scale, as the remaining flexible fossil fuel power plants should be able to fill the (seasonal) gap[11]. This outlook might change if guarantees of origin along with higher CO_2 prices are considered. It might then be cheaper and thus more efficient to store in the long-term green gases to use in the wintertime instead of pure natural gases.

In case of a 100% RES scenario for 2040, the viable pumped hydro potential in Europe could only cover a limited amount of the storage needs. At present, the only technology that would possibly be able to provide the storage capacity necessary in that scenario is gas storage.

However, it is not clear whether long-term storing of renewable energy is the most economical solution for seasonal adequacy. Installing an excess of vRES generation assets, providing a surplus of energy most of the time, might also be a solution, with the benefit of providing cheap energy in many hours throughout the year. Today, demand side flexibility is of minor significance and only able to provide flexibility up to a few days. Through the increasing degree of electrification and growing hydrogen-based energy sectors, long-term flexibility potentials may arise.

Though not discussed in this paper, a METIS study[12] emphasised that an increase of interconnectors reduces the short-term (hours, days, weeks) storage demand, but it does not significantly reduce the demand for long-term storage.

The analysis performed in this paper also showed that there is a very strong correlation between the monthly wind power generation and the pan-EU electricity demand. Photovoltaic (PV) generation on the other hand, especially in the northern countries, does not correlate with the electricity demand pattern very well. Hence, the ratio between the installed PV and wind power capacities significantly influences the need for long-term storage.

Based on these findings, it is very likely that not one technology or solution will establish itself as the sole provider of seasonal adequacy; it will be a mix of many solutions. Hence, one basic recommendation is to provide a level playing field between all solutions providing seasonal adequacy and let the market determine the optimal share of technologies. Currently, transmission tariffs applied to (pumped hydro) storage follow a heterogeneous treatment across Europe[13], with tariff exemptions

[10] Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, Article 2, paragraph 59 states that *'energy storage' means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier*.

[11] It is assumed here that there will be no nuclear power plants in Belgium and Germany.

[12] European Commission METIS study S07 on The role and need of flexibility in 2030: Focus on Energy Storage, August 2016 and European Commission report on Mainstreaming RES Flexibility portfolios, 10 July 2017.

[13] See the ACER Practice Report on Transmission Tariff Methodologies in Europe, 23 December 2019.

in some countries. Market-based self-curtailment is not supported in any way and the regulation, taxes and levies schemes for demand side flexibility, especially Power-to-X, are just beginning to emerge.

A basic principle to achieve a level playing field is by applying tariffs, taxes and levies in such a way that they reflect the electricity or gas grid usage. Supporting new technologies, directly or indirectly, automatically discriminates against other solutions, possibly leading to a reduced total welfare. Furthermore, regulation, taxes, levies, and other incentives should not focus on certain technologies, but on services for the power system. Providing a stable, simple and cost-reflective-based regulatory environment is key to establishing a competitive market that yields an optimal mix of solutions and technologies for seasonal adequacy. A level playing field between different energy carriers was also deemed important on the 2020 European Gas Regulatory Forum (i.e. Madrid Forum)[14].

The second recommendation is to (better) model storage and sector coupling technologies in the TYNDP. Currently only pumped hydro storage connected at 110kV or above is modelled. The latest 2020 TYNDP used scenarios jointly built by ENTSO-E and ENTSOG, which is a very important step towards sector coupling. However, to better anticipate a sector-coupled energy system, planning tools need to extend their current system boundary.

Overview

When addressing the need and options for long-term storage, CEER recommends consideration of the following:

- Considering an efficient and well-planned phase out of the current thermal production, there should be no foreseeable additional demand for long-term electricity storage until 2040 on an averaged European scale;
- The EU's viable pumped hydropower potential only provides a limited amount of the long-term storage needs in a 100% RES scenario;
- The gas storages available today are enough to balance the EU gas and electricity consumption over a year. The current gas storage capacity widely exceeds the potential electricity demand for storage until 2040;
- Interconnectors help to reduce short-term flexibility needs but should not significantly reduce the need for long-term storage;
- The ratio between installed PV and wind power capacities has a significant impact on long-term storage needs; and
- P2G facilities, as purely market-driven long-term storage activities, will not be economically viable for a long time to come.

Given the simplifications made in this paper for the estimation of long-term storage needs, the figures and magnitudes obtained should be confirmed with the use of more advanced and thorough methods that include the consideration of geographical aspects.

Key recommendations

- Regulations should establish a level playing field between long-term storage and other seasonal adequacy approaches (i.e. excess generation assets, flexibility and storage); and
- Storage and sector coupling technologies should be integrated in a more detailed way in planning models (e.g. integrated electricity and gas market and network model, TYNDP).

[14] Conclusions from the 34th meeting of the European Gas Regulatory Forum on 14-15 October 2020.

1. Technologies and methodologies for seasonal adequacy

Matching the seasonally varying supply and demand of energy can in general be done in four ways: long-term storage, interconnectors, flexible (seasonally available) generation and (longer-term) flexible demand.

1.1 Long-term storage

With the increasing demand for storage in general, the elements of a broad portfolio like compressed air, cryogenic air, gravitational and thermal technologies are evolving. Most of them though, are suitable only for a short-term storage of hours, days and maybe a few weeks. The two main characteristics of a long-term storage technology are low costs per MWh and a very large storage capacity. Today, the only mature long-term storage technologies are pumped hydro storage and gas storage.

Pumped Hydro Storage (PHS)

Pumped Hydro Storage is the most mature storage technology, with a large share of its economically viable potential in Europe put into practice. Though the topology in many countries would facilitate some more PHS sites, the remaining potential projects often face environmental concerns. To give one prominent example, Norway has plenty of reservoirs (artificial lakes with dams and natural inflows) with a capacity of 86 TWh. These reservoirs balance the natural inflow's seasonality and ensure that 96% of Norway's electricity demand can be served with hydropower. The reservoirs could in theory (technical feasibility would need to be assessed case by case) be supplemented with pumped hydro storage facilities, but due to the current economics and price structure, investment has gone to economically more attractive projects in the short run. For example, NordLink and North Sea Link, two interconnectors to Germany and Great Britain, are becoming fully operational in 2021 and will, with their 1,400 MW each, further increase the import and export capacity between Norway and its neighbours.

The vast majority of the current PHS plants in Europe offer a duration capability, at maximum power, of several hours to days. Only a handful are designed to store energy for months. Thus, the installed amount and the additional potential for long-term PHS are much lower than the numbers presented in Table 1, which shows the total installed PHS storage capacity.

Gas storage

The portfolio of gas storage technologies is wide and the natural gas storage capacity is huge, about 1,000 TWh thermal. A minimum estimation of the additional potential can be made if just the depleted gas fields of Europe are considered as potential storage sites. From 2009 – 2019, about 17,000 TWh of gas was extracted in the EU27+UK.

Hydrogen competes with natural gas for storage locations. However, hydrogen diffuses more easily and therefore, needs adequately sealed reservoirs, typically depleted gas fields and aquifer formations with salt seals, or artificially constructed salt caverns[15]. Therefore, the storage capacity for pure hydrogen is smaller than the number presented in Table 1. When looking at the storage capacity of gas, one also has to consider conversion losses in order to compare it to the storage capacity of batteries or PHS. So the capacity theoretically available as "electrical" storage in the form of gas/hydrogen is smaller (around 60% for recent gas combined cycles when considering the conversion in one direction) than the number presented in Table 1.

Currently there is a surplus in gas storage capacity. Falling gas prices, a decreasing gas demand and the decreasing spread between summer and winter prices (due to the better integrated internal market) reduced the profitability of the storage assets, which is already forcing some to close. This

[15] Energy Storage Mapping and Planning (ESTMAP) Energy Storage Data Collection Report, December 2016.

trend might continue with the decreasing share of gas in the European primary energy mix. This situation could make some storage facilities available to hydrogen/green gases in the future.

Technology	Currently installed	Additional potential
Pumped Hydro Storage	14 TWh[16], 40 TWh[17]	Economic potential: 2.3 TWh[18] (54% of that in Norway) Technological potential: 5 – 123 TWh[19], 54TWh[20]
Gas Storage	1020 TWh (thermal)[21]	Multiple times the current storage capacity

Table 1 – Summary of the storage potentials

1.2 Interconnectors

A strongly interconnected European electricity grid can significantly reduce the demand for daily and weekly storage[22, 23], but interconnectors do not significantly reduce the demand for long-term storage. This can be explained by the fact that the seasonal generation and demand patterns of wind and PV across Europe do not differ too much between countries/regions. Hence, interconnectors cannot be used to balance the regional generation and demand patterns and, therefore, do not significantly reduce the demand for long-term storage.

1.3 Flexible generation

This is currently the main source of flexibility, where the market-driven dispatch of power plants forces technologies at the higher-priced end of the merit order curve to balance the seasonal differences. Today these are mainly fossil fuel power plants, especially coal- and gas-fired ones.

In a carbon-neutral society where fossil fuels have been replaced with renewable energies, the market will increasingly “force” renewable energy power to stop providing energy (through zero or negative wholesale prices). Although green energy may become lost this way, curtailing could be more economical than storing. The challenge for the transition phase in the coming years is to find a balance between removing incentive schemes for renewables and ensuring enough renewables come forward to sufficiently decarbonise the energy system.

The seasonal variations and market conditions will determine the remaining capacity of gas power plants necessary to convert the stored hydrogen/gas back into electricity.

[16] EU Open Data Portal - Database of the European energy storage technologies and facilities. The data was checked and extended by the NRAs for this paper.
[17] Lebelhuber, C., Steinmüller, H. How and to which extent can the gas sector contribute to a climate-neutral European energy system? A qualitative approach. Energy Sustain Soc 9, 23 (2019). https://doi.org/10.1186/s13705-019-0207-2
[18] eStorage’s Overview of potential locations for new Pumped Storage Plants in EU 15, Switzerland and Norway, 25 November 2015.
[19] European Commission’s Joint Research Centre report on the Assessment of the European potential for pumped hydropower energy storage, 2013.
[20] Gimeno-Gutiérrez, M., Lacal-Arántegui, R. Assessment of the European potential for pumped hydropower energy storage based on two existing reservoirs, Renewable Energy, Volume 75, 2015, Pages 856-868, https://doi.org/10.1016/j.renene.2014.10.068.
[21] Gie-AGSI Storage Data.
[22] European Commission METIS study S07 on The role and need of flexibility in 2030: Focus on Energy Storage, August 2016.
[23] European Commission report on Mainstreaming RES Flexibility portfolios, 10 July 2017.

1.4 Flexible demand

Flexibility options will be discussed in future CEER work. Most of the household and industrial consumption can only be shifted for some hours, maybe days, hence they do not offer a potential for seasonal adequacy.

The biggest potential for flexible demand lies in the conversion of power into gas, chemicals, heat, etc. This longer-term flexibility will become more and more available as more sectors are electrified or based on hydrogen.

2. Electricity and gas demand at European and regional level

The first step in this section is to illustrate the seasonality of the electricity and gas demand patterns and, at the same time, estimate the current seasonal gas and electricity storage needs.

For doing so, historical demand data[24] from 2008 to 2018, is used. Another assumption for this analysis is that interconnectors do not pose a bottleneck from a seasonal point of view. Thus, the grid constraints and generation and demand locations are not considered in this analysis.

Figure 1 shows the average monthly demand curve derived from the years 2008 to 2018 and the maximum and minimum within this period. It is possible to observe a clear seasonality in the demand pattern, with a lower demand in spring and summer months and a higher demand in autumn and winter.

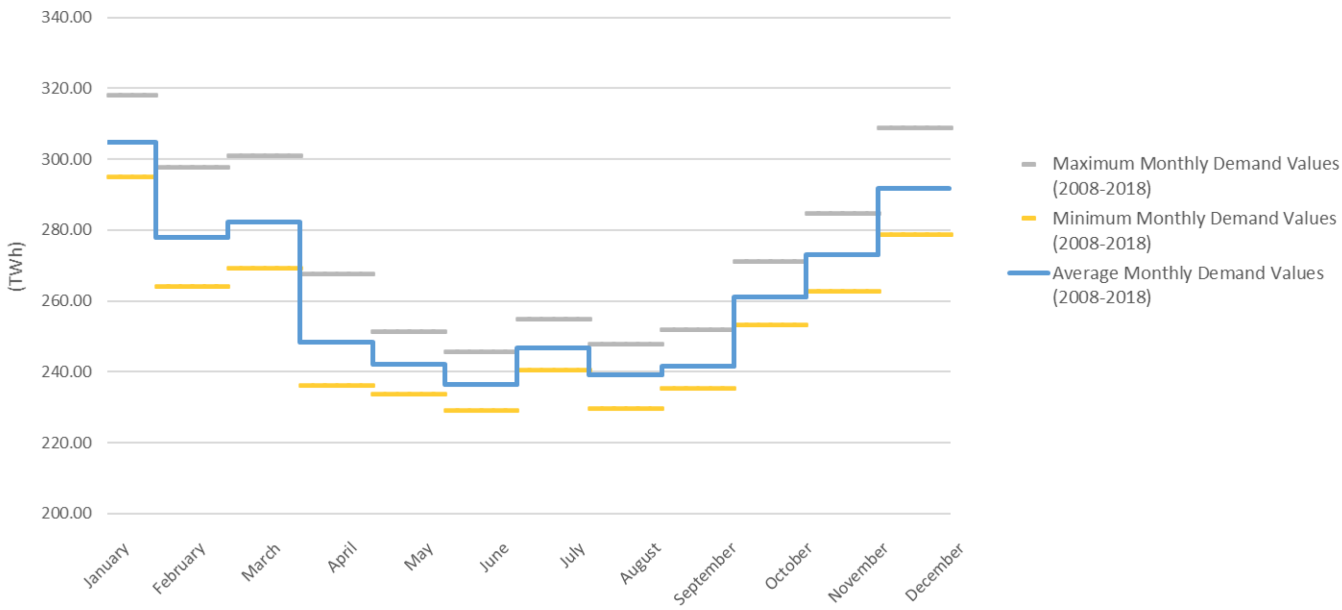

Figure 1 – 2008 to 2018 EU27+UK+NO electricity monthly demand

To get a better insight into the regional demand and generation patterns, 29 European countries were clustered in 3 regions (Northern, Central and Southern countries as seen in Figure 2).

[24] European Commission Eurostat Energy Database.

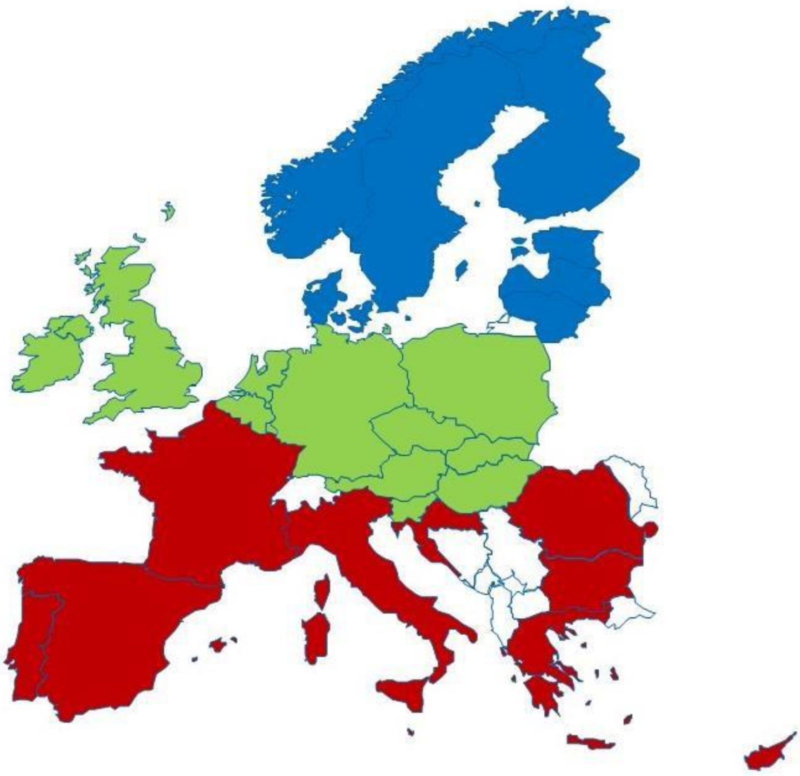

Figure 2 – Northern EU region (blue), Central EU region (green) and Southern EU region (red)

The regional results (shown in Table 2) for an "average year" (where each month value is equal to the average of the monthly values from 2008 to 2018), demonstrate similar variation values (between higher and lower monthly demand) for the central and southern regions and a more pronounced variation in Northern EU Region.

Region	EU27+UK+NO	Northern	Central	Southern
Maximum [TWh]	305	43	136	125
Average [TWh]	262	34	120	108
Minimum [TWh]	236	28	108	100
Variation	26%	45%	23%	24%

Table 2 – Electricity demand (monthly values for an average year)

Figure 3 shows normalised regional demand patterns (the values are normalised against each region's monthly demand average). The regional electricity demand patterns depend on many factors, such as different climates, different technologies and solutions used for heating/cooling purposes, level of industrialisation and even different consumption habits.

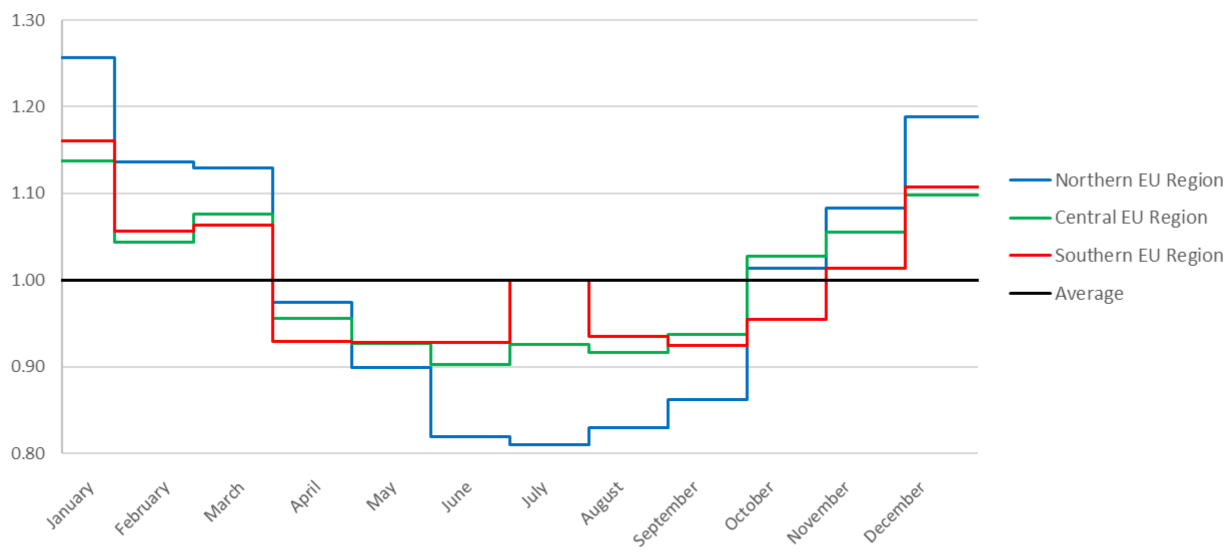

Figure 3 – Normalised electricity demand patterns Northern, Central and Southern EU regions (monthly values for an average year)

The gas consumption patterns show a seasonal trend similar to the electricity demand. They also demonstrate a pronounced seasonality, however, the overall variations (between maximum and minimum values) are even larger than the variations in electricity demand, with double the winter needs compared to those of the summer in the Central and the Southern EU regions (Table 3 and Figure 4).

Region	EU27+UK+NO	Northern	Central	Southern
Maximum [TWh]	656	23	388	245
Average [TWh]	431	17	253	161
Minimum [TWh]	271	12	156	102
Variation	89%	64%	92%	89%

Table 3 – Gas demand (monthly values for an average year)

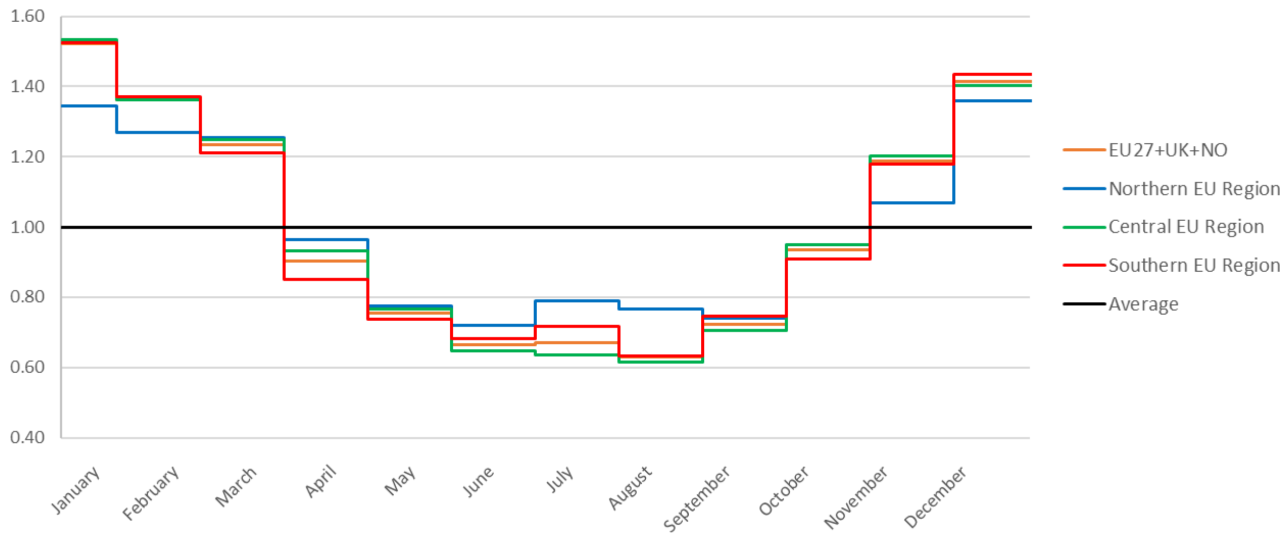

Figure 4 – Gas demand patterns (monthly values for an average year)

Assuming that months with a demand lower than the annual average demand represent storing periods, and, on the other hand, months where demand is larger than the annual average demand represent periods in which stored gas is being consumed, it is possible to approximate the annual gas storage needs.

Region	EU27+UK+NO	Northern	Central	Southern
Annual Load [TWh]	5169	200	3040	1929
Annual Storage Needs [TWh]	741	22	442	277
Share of total	14%	11%	15%	14%

Table 4 – Gas annual storage needs (monthly values for an average year)

The values estimated above represent the annual gas storage needs considering an average year. Doing the same estimation for the pan-EU annual gas storage, for each year between 2008 and 2018, the values vary from 613 TWh to 865 TWh, thus it is possible to observe that the currently available gas storage facilities, with their capacity of 1000 TWh, are easily sufficient to balance the EU gas consumption over the course of a year.

As previously stated, it should be noted that the approach used throughout this paper to estimate long-term storage needs is based on a simplified method already applied in recent studies made for the European Commission, and only intends to give rough estimations that allow high-level conclusions. For instance, as coal and nuclear generation should gradually disappear by 2040 (at least in most EU Member States), the effective use of the current gas storage capacities may be affected by the availability of regional appropriately located facilities.

3. European needs for long-term storage in electricity for 2030 and beyond

With the current European generation mix there is no actual need for long-term electricity storage, as the traditional power plants' (e.g. thermal and hydropower plants) dispatchability assures a well-balanced power system in the different timeframes from real-time balancing to seasonal adequacy. Additionally, these power plants are able to respond to demand fluctuation or to renewable energy plants' intermittency and variability. Therefore, the next step of this paper is to look forward to the coming years where a change towards a more renewable-based generation mix is pursued and, although not intending to do an extensive or very detailed adequacy analysis, try to roughly estimate future long-term storage needs for electricity.

In order to do so, historic EU power system data from the years 2016 to 2019[25] is used to extrapolate future monthly demand and generation patterns (lacking a better prediction with limited modelling efforts it is assumed that those patterns would be maintained in 2030 and 2040) by scaling demand and the share of generation assets according to the 2020 ENTSO-E TYNDP for 2030 and 2040[26]. The calculated residual load is the total load (total generation data in this case) minus the production of renewable energies (PV, wind and pure hydropower[27]).

Outlook 2030 TYNDP	Energy (TWh)	Share of Total
Total (Gen)	*3,420*	
Pure hydro power (Gen)	*625*	18%
Wind (Gen)	*1,030*	30%
Solar photovoltaic (Gen)	*395*	12%
Residual Load 2030	*1,370*	40%

Table 5 – ENTSO-E TYNDP 2030 scenario

Outlook 2040 TYNDP	Energy (TWh)	Share of Total
Total (Gen)	*3,893*	
Pure hydro power (Gen)	*561*	14%
Wind (Gen)	*1,697*	44%
Solar photovoltaic (Gen)	*548*	14%
Residual Load 2040	1,088	28%

Table 6 – ENTSO-E TYNDP 2040 scenario

Looking at the results in Tables 5 and 6, the key conclusion is that there is no foreseeable need for long-term storage in both TYNDP 2030 and 2040 scenarios since the residual load values for both scenarios are positive. This shows that the share of RES is not sufficient to cover the total demand, implying that there should be traditional generation technologies providing the availability for seasonal adequacy until 2040. The potential impact of this situation on decarbonisation will depend on the exact type of fuel. The phasing out of traditional generation technologies must, therefore, be carefully analysed.

The need for long-term storage arises, when we decide to consider, as a hypothesis, a 100% RES power system for the EU. This 100% RES scenario assumes that the total generation and pure hydro generation values would be equal to the ones of the TYNDP 2040 scenario. Then the values for wind and solar photovoltaic generation are scaled up in order to cover total demand, while maintaining the ratio between PV and wind similar to the one from the TYNDP 2040 scenario.

[25] European Commission Eurostat Energy Database.
[26] ENTSOs TYNDP 2020 Scenarios Visualisation Platform Electricity Data.
[27] Pure hydro power is non-dispatchable hydro plants powered by natural inflow.

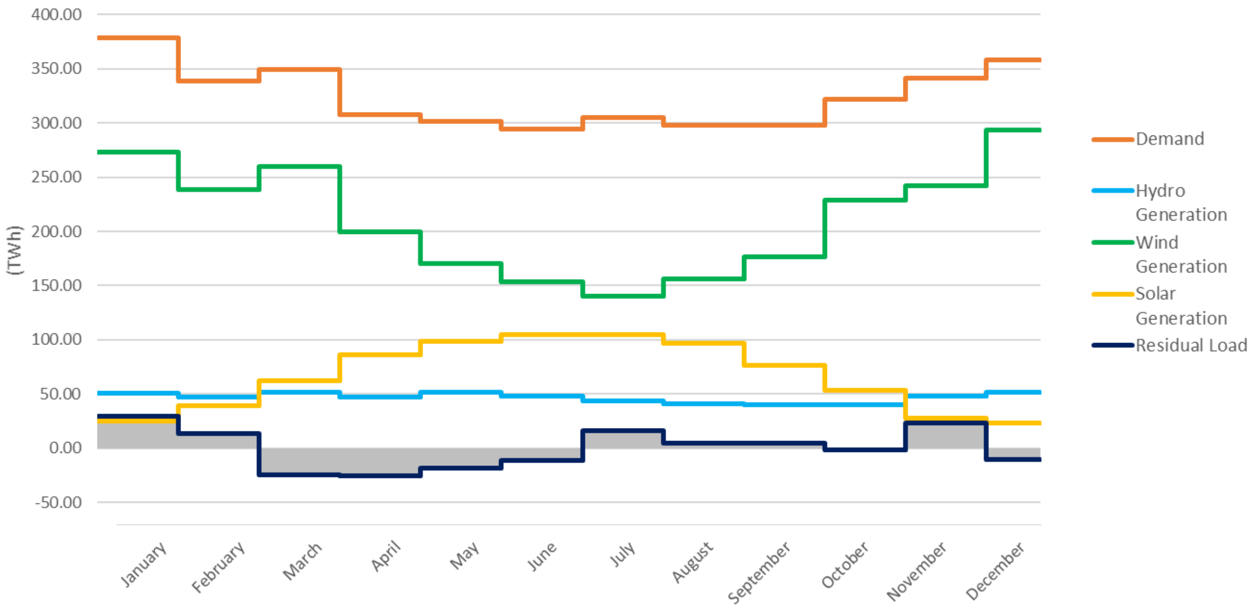

Figure 5 – 100% RES 2040 scenario

Using the residual load values and applying a methodology similar to the one followed in the demand analysis in section 2, while using the available generation data for the years 2017 to 2019 in order to analyse different generation patterns, it is possible to compute a range for the annual storage needs (the maximum value of the storage level, where the storage level is obtained by integrating the monthly residual load).

As we can see in Table 7 the EU27+UK+NO, annual electricity storage needs, for a 100% RES scenario, would be approximately between 75 TWh and 94 TWh, which represents less than 3% of the total annual generation value.

Performing a regional assessment, based on the same assumptions for generation, it is possible to see that the southern EU region is the one with the largest maximum annual storage needs - but this is still under 5% of the total energy demand. As we can see from the values in Table 7, the sum of each region's annual storage needs is larger than the EU27+UK+NO value, demonstrating that there is a balancing effect as all countries mutually compensate for a small part of each other's storage needs.

100% RES 2040	EU27+UK+NO		Northern		Central		Southern	
	Energy (TWh)	Share of Total	Energy (TWh)	Share of Total	Energy (TWh)	Share of Total	Energy (TWh)	Share of Total
Total (Gen)	*3,893*		*559*		*1,785*		*1,549*	
Pure hydro power (Gen)	*561*	14%	*245*	44%	*120*	7%	*195*	13%
Wind (Gen)	*2,532*	65%	*294*	53%	*1,349*	76%	*866*	56%
Solar photovoltaic (Gen)	*800*	21%	*20*	4%	*316*	18%	*487*	31%
Residual Load	0		0		0		0	
Annual Storage Needs	**75 - 94**	**< 3%**	**8 - 22**	**< 4%**	**48 - 66**	**< 4%**	**42 - 72**	**< 5%**

Table 5 – Regional electricity annual storage needs

A conclusion that arose whilst analysing the 100% RES scenario was that the needs for long-term storage have a strong correlation to the ratio between wind and solar photovoltaic generation. This is because solar PV supply is more greatly affected by seasonality than wind power supply and there is a greater correlation between demand and wind generation patterns.

Table 8 shows an example of a scenario for the EU27+UK+NO case, where the annual storage needs are lower than the original 100% RES 2040 scenario.

100% RES 2040	Energy (TWh)	Share of Total
Total (Gen)	*3,893*	
Pure hydro power (Gen)	*561*	14%
Wind (Gen)	*2,632*	68%
Solar photovoltaic (Gen)	*700*	18%
Residual Load	0	
Annual Storage Needs	**72 - 83**	**< 3%**

Table 6 – 100% RES scenario with lower annual storage needs

However, this scenario is only an example, intending to demonstrate the possibility of an optimisation of the storage needs. The measures taken by Member States within their National Energy and Climate Plan, the available resources and the market, will determine future generation mix and consequently the storage needs value.

4. Economic viability of P2G

Given that P2G is one possible element for the seasonal adequacy solution, it is worth having a short recap on its economic viability. As a technology in its early demonstration phase, it is unclear when and in which use cases P2G will become competitive compared to other conversion/storage solutions. It is not just costs and revenue opportunities which determine the economic viability. As CAPEX-intensive assets in the power system have amortisation times of many years, if not decades, a stable business case is important to investors. The dynamic market, technological, legal and regulatory environment currently causes risk-averse investors to refrain from financing P2G facilities, even though they might turn out beneficial toward the end of their lifetime.

For the following brief look at the economic viability of P2G, two use cases are explored.

Production of hydrogen

Currently most hydrogen is produced by processing methane (grey hydrogen). The hydrogen production by electrolysers allows for the obtaining of CO_2-free hydrogen (green hydrogen) if it uses RES electricity. The increasing prices for CO_2 certificates combined with continuously falling RES power prices may allow that P2G facilities become economically viable. In addition, the CAPEX costs for electrolysers are expected to diminish to somewhere between one half and one quarter of the current price levels by 2050, depending on the technology[28]. This is a prerequisite for the European Hydrogen Strategy.

The first stage of this European strategy identifies green hydrogen as a commodity. Based on the Hydrogen Europe report[29], once a 2030 carbon price is considered, green hydrogen must be produced at a cost between 1.5 to 3 €/kg to be competitive with conventional fuels in the industry and heavy-duty transport sectors. The same report states that the current cost for green hydrogen produced with the use of electrolysers is between 5 to 8 €/kg at an electricity price of 60 €/MWh. This total production cost is broken down to 45.9% CAPEX costs, 45.1% electricity costs and 9% in other Operation & Maintenance costs. The production of green hydrogen will need to become cost-

[28] Böhm, H., Zauner, A., Rosenfeld, D.C., Tichler, R., Projecting cost development for future large-scale power-to-gas implementations by scaling effects, Applied Energy, Volume 264, April 2020, https://doi.org/10.1016/j.apenergy.2020.114780.
[29] Hydrogen Europe Strategic Research and Innovation Agenda, July 2020.

optimised in many steps along the process chain. Let us assume for a moment, that the renewable electricity price (during sunny hours) can be reduced to about 10 €/MWh (as seen for example, in recent solar PV auctions in Portugal). This would still mean that the green hydrogen production cost would be between 3.12 and 4.99 €/kg. To assure that green hydrogen achieves a cost of 3 €/kg and, in order to be competitive with the other fuels in these sectors, the expected significant reduction in CAPEX costs mentioned before needs to be achieved.

The increase of electricity demand for green hydrogen production can level the electricity demand patterns, by adding flexibility to the power system, and thus reduce curtailment of RES.

Long-term storage

For a profitable operation of a P2G facility (in conjunction with gas/hydrogen storage and gas power plants/electrolysers) providing seasonal storage to the electricity system, the electricity price needs to be lower than the natural gas price during the summertime when excess (PV) energy would need to be converted to and stored in form of gas. Electricity may be cheaper than gas for some hours during the day, but the capacity factor should be as high as possible for an economically viable P2G facility operation. However, as long as natural gas power plants represent a big share of the generation assets in Europe and do often set the marginal price, the average electricity price will very likely remain higher than the natural gas price. A reduction in natural gas consumption in the path to a carbon-neutral society also most likely will lower the gas price and thus impair the economic viability of P2G as a crucial activity in long-term electricity storage process. These basic considerations lead to the conclusion that using green hydrogen as a long-term storage energy carrier will not be economically viable in the near future.

This outlook might change if guarantees of origin along with higher CO_2 prices are considered. It might then be cheaper to long-term store green gases to use them in the wintertime instead of pure natural gases. Guarantees of origin would allow the physical sharing of gas storage facilities and thus reduce the need for initial infrastructure investment to ensure successful green gases penetration.

Relevant Papers

1	European Energy Regulators' Overview Paper, "The Bridge Beyond 2025 Conclusions Paper", 19 November 2019
2	ACER-CEER Position Paper on Revision of the Trans-European Energy Networks Regulation (TEN-E) and Infrastructure Governance, 19 June 2020
3	ACER-CEER "European Green Deal" Regulatory White Paper #1 "When and How to Regulate Hydrogen Networks?", 9 February 2021
4	ACER-CEER "European Green Deal" Regulatory White Paper #2 "Regulatory Treatment of Power-to-Gas", 11 February 2021