Energy Storage Targets 2030 and 2050

Ensuring Europe’s Energy Security in a Renewable Energy System

European Association for Storage of Energy

Executive Summary

As Europe accelerates its ambitions to achieve climate neutrality by 2050, the energy system is set to look very different from the one we see today. Driven by ambitious climate targets, the electricity sector especially is taking great strides in reducing greenhouse gas emissions by replacing fossil fuel generators with renewables. However, the inherent variability of wind and solar generation brings with it new challenges. The electricity system needs to become much more flexible than it is today to accommodate the rising share of renewables and new flows of electricity that come with it. Variable production of wind and solar means renewable deployment alone will not eliminate fossil fuel dependence, as backup gas generators are used to cover renewables energy shortfalls at times of low production. If the EU is to meet its climate targets in time and integrate even higher shares of renewables as stated in the REPowerEU plan, reliance on fossil fuel imports and backup gas generation must be replaced with alternative low emission solutions.

Energy shifting and flexibility services provided by energy storage are indispensable for system reliability and securing supply of energy to cope with moments of low renewables and also maximise renewable utilisation at times of high production. While flexibility services can also be provided by other technologies, energy storage is the only solution able to provide the essential energy shifting service which is one of the key solutions to minimising curtailment of renewable energy. *This will ensure a self-sufficient European energy economy by maximising utilisation of local renewables, reducing reliance on external fossil fuel imports, in turn alleviating the high electricity prices seen today.* REPowerEU clearly acknowledges this and the important role of energy storage to reduce the use of gas power plants in the energy system [1]. It is therefore critical that the role of greenhouse gas (GHG) emitting flexibility from fossil fuel generators is reconsidered especially by 2030*.

However, storage uptake today is seriously lagging behind wind and solar deployment. The EU risks being unable to integrate the rapidly growing renewables and in turn being locked into fossil fuel backup, if storage deployment does not go in parallel with renewable uptake. With this paper we assess the energy storage requirements as a whole for Europe and propose estimates of energy storage targets for 2030 and 2050 based on a review of existing scientific literature, official documents from the European Commission (EC) and input from relevant stakeholders. We find that many studies do not address all key energy storage technologies and durations, often undervaluing low emission technologies and energy shifting resources and overvaluing the use of GHG emitting baseload plants especially in the 2030 time horizon [2]. Many studies are based on outdated climate targets which leads to an underestimation of flexibility needs in the energy system. Furthermore, the rapidly changing storage technology and innovation landscape means new cost projections need to be included in energy system planning today to accurately reflect technologies available [3] [4].

We estimate <u>energy storage power capacity requirements at EU level will be approximately 200 GW by 2030</u> (focusing on energy shifting technologies, and including existing storage capacity of approximately 60 GW in Europe, mainly PHS). <u>By 2050, it is estimated at least 600 GW of energy storage will be needed in the energy system.</u> This is based on the needs in terms of bi-directional contribution from Power-to-X-to-Power solutions (i.e. for energy shifting), estimated at around 435 GW as a no regret option for 2050, being complemented by 165 GW of power-to-X technologies providing one-directional system flexibility. This will require a massive ramp-up in storage deployment of at least 14 GW/year in the next 9 years, compared to 0.8 GW/year of battery storage deployed in 2020 according to the International Energy Agency (IEA). This is an ambitious goal but it is in line with existing non-binding national targets in Spain for example, which is targeting 20 GW by 2030 and further highlights the urgent need to start deployment now. The required storage capacity (hours of rated power during discharging) will largely depend on the fraction of annual energy from variable renewables in the generation mix, which means some member states will already require large amounts of storage even before 2030 (see Figure 4). There is an urgent need for EU-level energy storage targets and strategy that are compatible with the energy storage needs related to current EU climate policy. Establishing these values as energy storage targets at EU-level backed by the promise of meaningful future policy and regulation, provides the clearest signal to the energy storage industry to begin building the infrastructure needed to drive true scale, reducing costs and enabling the success of the EU's climate goals.

*Low-carbon non-variable generation such as nuclear, bioenergies or CCUS can also make very meaningful contributions to the GHG reductions target; their different projected growth trajectories however are not part of the scope of this current paper.

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1. Introduction: Why Do We Need Energy Storage Targets?

As highlighted in the REPowerEU initiative, the European Commission plans to increase renewables and electrification of the energy system. This means there will be a growing need for technologies which can support high levels of electrification by storing and giving electricity back to the system. Setting energy storage targets in line with existing climate targets and best practice in the EU today is critical. We focus on the key applications of energy storage providing system flexibility and energy shifting services crucial to enabling the rising integration of renewables. Formalising energy storage targets will provide the necessary long-term vision to market players, utilities, investors and policy makers to make strategic decisions with confidence, in a context of global uncertainty about market growth, technologies and cost. Such a vision must be based on a comprehensive rationale taking into account decarbonisation goals and resulting structural changes needed in the energy system.

1. 1. Energy Storage Definition

In this work we follow the energy storage definition established in the Clean Energy Package, Article 2(59) of Directive (EU) 2019/944 of the European Parliament and of the Council. We distinguish storage solutions providing system flexibility (i) in one-direction i.e. not giving electricity back to the system, by Power-to-X technologies and (ii) bi-directional i.e. electricity is stored and given back to the electricity system (energy shifting), provided by Power-to-X-to-Power technologies, as illustrated below.

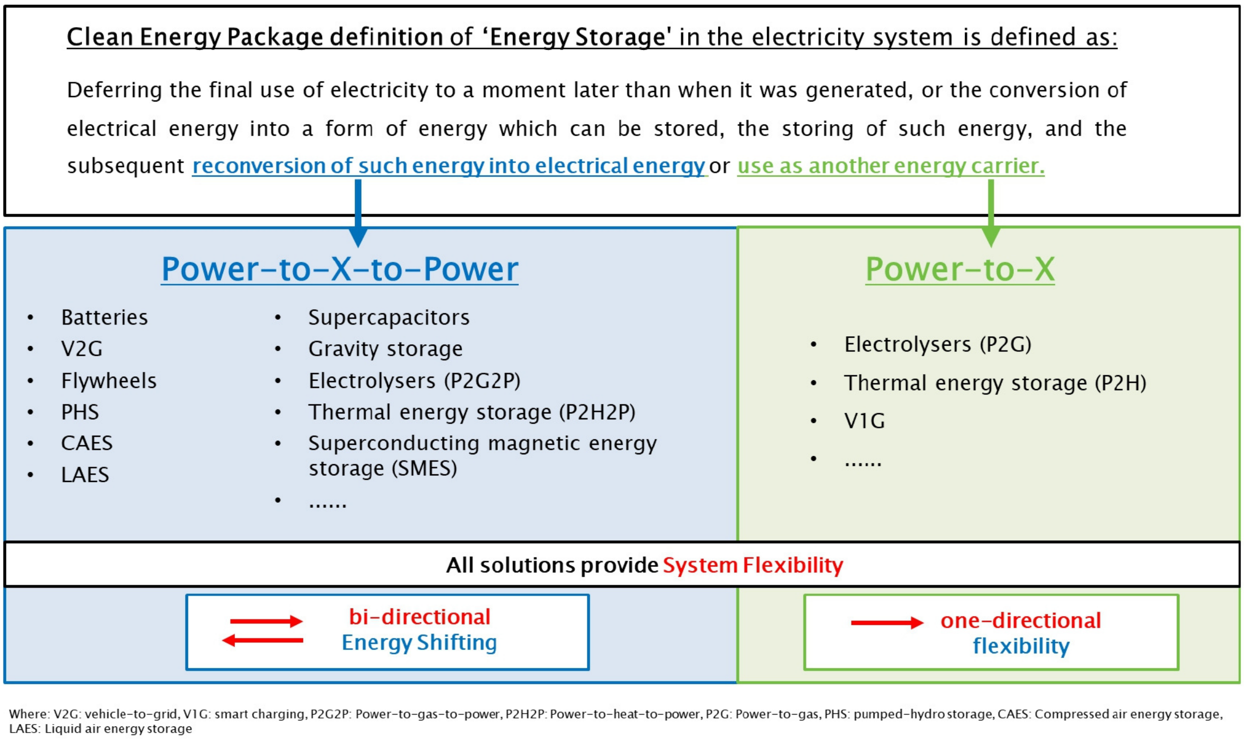


Figure 1: *Clean Energy Package definition of energy storage providing system flexibility from Power-to-X-to-Power technologies providing bi-directional flexibility (energy shifting) and Power-to-X solutions providing flexibility in one-direction.*

Power-to-X: includes technologies which provide flexibility in '**one-direction**', meaning the electricity flows in one direction and is not given back to the system, it is converted to another energy carrier, which can then decarbonise other parts of society (e.g. heating, cooling, transport etc.). Storage technologies which fulfil this role mainly include among others: **Power-to-X technologies** e.g. Power-to-Gas (P2G, i.e. electrolysers which produce hydrogen not reconverted back to electricity), Power-to-heat (P2H) and V1G (i.e. smart charging of electric vehicles where electricity is not reinjected back into the grid).

Power-to-X-to-Power (Energy shifting): refers to storage technologies which shift electricity and store this electricity for different durations (seconds, minutes, hours, weeks, months, seasons), releasing it back to the system when it is needed [5]. **Energy shifting** can be considered **'bi-directional'** meaning the electricity which is shifted is given back to the system. Technologies which are more geared to providing this service include among others batteries, flywheels, supercapacitors, SMES, PHS, gravity storage, CAES, LAES, V2G, electrolysers (P2G2P), thermal energy storage (P2H2P). Figure 2 illustrates the concept of energy shifting based on the case of seasonal energy shifting, excess electricity produced in summer months where the demand is low is stored and used to meet higher demand peaks in winter months – electricity use is therefore 'shifted' from summer to winter using energy storage.

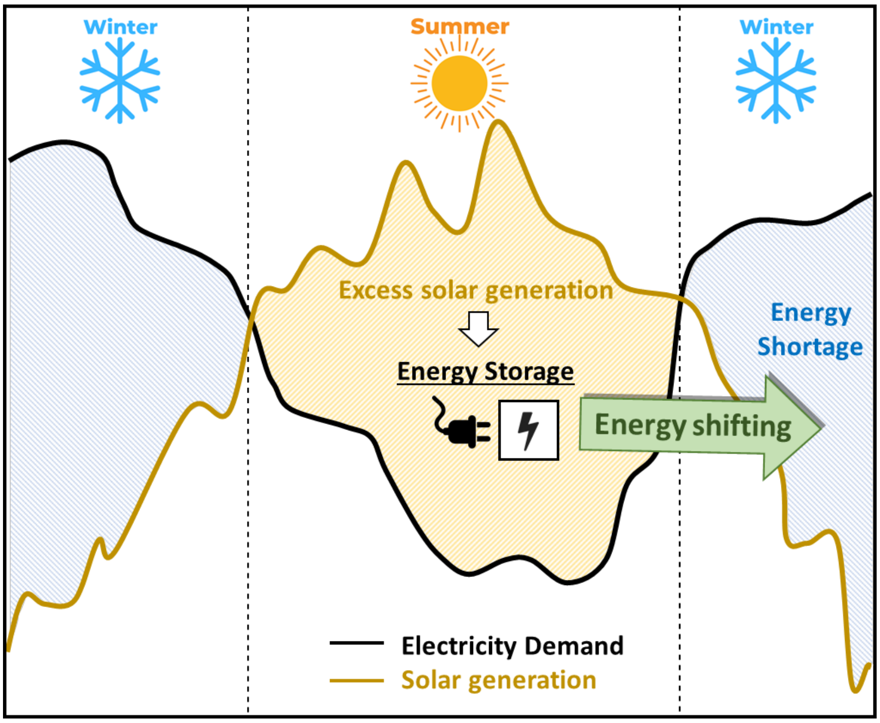


Figure 2: *Seasonal correlation of electricity demand (black line) and solar generation (yellow line) for Europe over a single year. Yellow shaded are indicates excess solar generation stored using energy storage technologies. The use of this electricity is 'shifted' to meet high demand in winter.*

1. 2. Accelerated Renewables Uptake in Europe – What Does This Mean for Energy Storage?

Figure 3 shows wind and solar growth in Europe in TWh per year: both the historic trajectory (black line) and the latest national energy and climate plans (orange line) will fail to meet the 55% GHG reduction target by 2030 at current growth rates. Wind and solar growth need to almost triple in the next decade to reach their needed contribution to the 55% reduction target by 2030. This will require a massive ramp-up in wind and solar electricity generation between 93-100 TWh/year, corresponding to variable renewables share as high as 69% already by 2030 [6]. In light of REPowerEU this build out of renewables will be accelerated meaning he energy system must become much more flexible and capable of energy shifting than it is today to accommodate this high share of wind and solar generation.

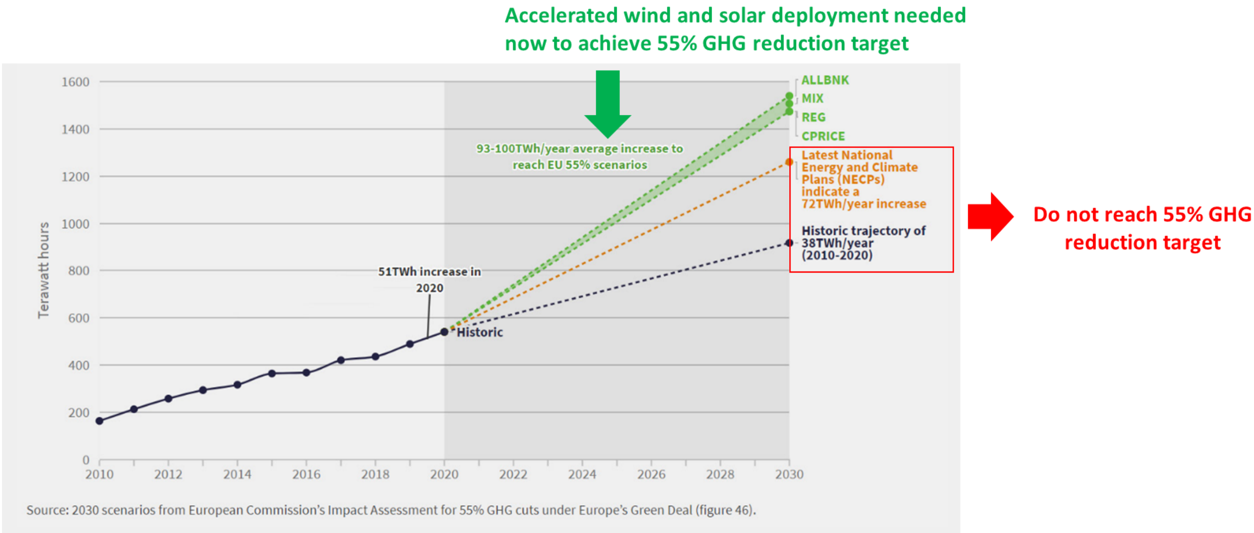


Figure 3: *Wind and Solar Growth required to reach EU's 55% Emissions Target by 2030, (adapted from EMBER, Agora Energiewende, The European Power Sector in 2019)*

The key issue for the integrating wind and solar in the energy system is their variable, non-dispatchable generation. This means the system requires technologies able to stabilise electricity flows ensuring reliable energy supply. Furthermore, on low wind or cloudy days energy production from variable renewables alone cannot meet demand. In these instances, dispatchable backup supply typically from fossil fuel gas generators is used to cover these energy shortfalls. Therefore, building more and more renewables will not in itself reduce reliance on fossil fuels. The need for backup supply to account for variable generation will only increase as more renewables are introduced in the system. The role of alternative clean energy storage solutions able to fill this role must also be considered over GHG emitting counterparts.

Curtailment also becomes an issue the more renewables are integrated in the system. When there is excess production on very windy or sunny days and there is no demand for this electricity or there are capacity constraints from the system itself, electricity is curtailed. This is a massive waste of the EU's indigenous renewable energy resources. Storage provides a solution to this, creating energy independence by maximising EU's own renewables utilisation in line with climate targets, minimising curtailment and providing critical system flexibility and energy shifting services over different timescales. Figure 4 illustrates increasing wind and solar in the electricity mix mainly requires hourly storage (<10 hrs) up to a 60 % share of renewable generation in any given EU region. Beyond 60%, there is a sharp increase in the need for more daily and weekly storage [7] [4]. Seasonal storage becomes more critical beyond 80% variable renewables in the generation mix and will be important especially by 2050. This means by 2030 already the role of energy storage for system flexibility and energy shifting will be critical to integrating high shares of wind and solar [8].

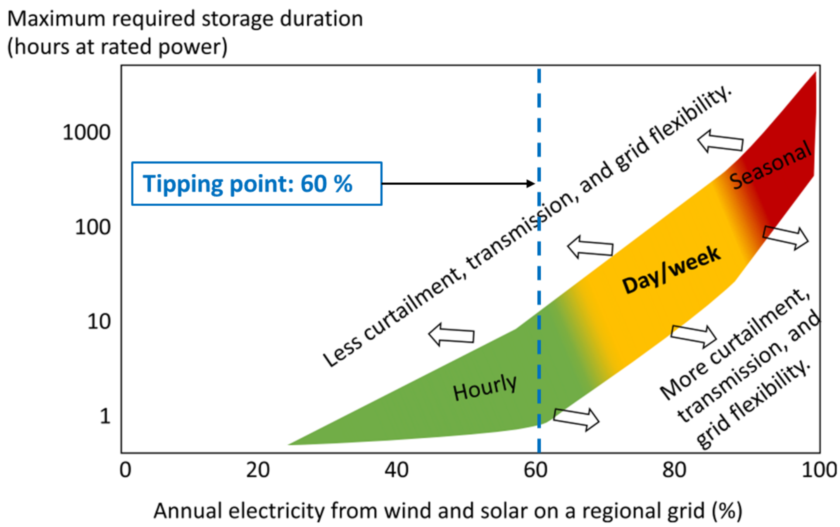


Figure 4: *Y-axis shows maximum duration of electricity storage needed to ensure demand is met at all times (logarithmic scale) versus fraction of annual energy from variable renewable generators (wind and solar) on a regional/local level. The arrows indicate either more restrictive (to the left) or aggressive (to the right) assumptions for curtailment, transmission and grid flexibility. For example in a system where curtailment is minimised (arrow to the left), storage duration required is longer than in the case where more curtailment is allowed (arrow to right). Adapted from ref [7].*

Despite the important benefits storage brings to the system, deployment of storage technologies is severely lagging behind wind and solar uptake today. Given the further cost reductions expected for wind and solar, even 45% RES target may be easily exceeded in some countries. Spain for example is already targeting 74% renewables in the power sector by 2030 which further illustrates the need to deploy storage now, as some member states are already ahead of others. It is important therefore that energy storage requirements are assessed on a regional/local level. If we achieve the EU average of 67% vRES by 2030, this means some countries will have greater than 67% vRES and already require days/weeks of energy storage according to Figure 4. If storage uptake does not catch up to wind and solar deployment rates, we will see more and more costly curtailment and the EU risks being locked into fossil-fuels and rising electricity prices for years to come. If market growth of energy storage remains at current rates, it will be impossible to meet the requirements of a variable renewable energy system in Europe by 2030 and 2050. It is critical that the market prepares and reflects these energy storage needs in the next decade. Without sufficient energy shifting measures via energy storage, the EU will be (i) locked into 100% fossil fuel power backup and (ii) continue curtailing homegrown renewable generation in turn incurring costly redispatch. Storage deployment must start now and setting energy storage targets is important for achieving this.

1.3. Setting EU Energy Storage Targets in Line with Best Practice

Setting sector targets is in line with best practice in the EU today as climate targets exist already in many sectors for example 40% RES target, 55% GHG reduction targets, 2x40 GW Hydrogen electrolyser targets. Similarly, energy storage targets are needed at EU level that are compatible with the energy storage needs related to the current EU climate policy. Targets will help stimulate investment, driving down storage technology costs and accelerating deployment as was the case for both wind and solar technologies [8]. Storage targets will complement existing climate targets acting as a guiding objective for member states to estimate their needs for storage as part of their National Energy and Climate Plans (NECPs), and to incentivise the development of market-based mechanisms [9]. Targets drive learning-by-doing among utilities, regulators, and agencies and help orchestrate updates to rules and processes that are often required to bring energy storage onto the electricity grid.

Energy storage targets are already in place in a number of regions including California (among other states in the US) and Spain (among other member states) in the EU. California recognised early on that Storage targets are necessary complements to state clean energy and environmental policies. They successfully established the first energy storage target in the nation in 2010 of 1,325 MW of energy storage by 2020 for the state's three investor-owned utilities (IOUs). Spain quantified storage needs in its dedicated Energy Storage Strategy in line with decarbonisation targets established in the national energy and climate plan (NECP). Spain already foresees the critical role for energy storage to support renewable deployment and is targeting 20 GW by 2030 and 30 GW by 2050 considering both large-scale and distributed storage, these targets are non-binding and are part of long-term plans and strategies, which are meant to provide investment signals to the storage industry. EU countries have different trajectories for achieving decarbonisation goals according to their National Energy and Climate Plans (NECPs). Of course, this means the energy mix and amount of renewables differs for each member state and in turn so do energy storage needs. Nonetheless, establishing energy storage targets at EU level will ensure a holistic approach to driving storage uptake to support renewable deployment and speed-up the energy transition, as has been the case for renewables where the targets were also set at EU level.

2. Overview of Energy Storage Requirements in Europe by 2030 and 2050

Future energy storage requirements are typically determined by energy system and capacity expansion models based on different predefined scenarios [2][11][12]. These scenarios evaluate the impacts of policy decisions, climate targets (e.g. carbon emissions, energy efficiency, renewables shares), changes in energy demand, changes in energy supply (source, variations), prices of energy commodities and cost projections among others on the future energy system [2]. Flexibility for high variable renewable systems can be provided by different technologies including conventional flexible generation, interconnectors, demand-side management and energy storage technologies. Sector integration is also part of the solution landscape. Taking all these solutions into consideration makes energy system planning extremely complex, with numerous variables and assumptions which can greatly alter the final output for energy storage requirements.

Key drivers which influence how much storage is required in the system include but are not limited to: (i) the share of variable renewables in power mix (%vRES) (as well as the ratio of wind to solar generation in the mix), (ii) different storage technologies considered (iii) technology cost assumptions (iv) temporal and spatial resolution (v) competition from alternative solutions (vi) sector integration (vii) electric grid models (viii) political targets and (i) weather forecasts, uncertainties and variations in weather years (especially for longer duration storage this is very important). Other drivers impacting the future flexibility portfolio in Europe which should also be considered are related to social acceptance of grid development, social acceptance of certain generation technologies (e.g. nuclear, wind farms), social acceptance of demand side management and political or social ambitions for energy self-sufficiency [13]. Based on the numerous assumptions and inputs affecting the final output of these models, it is not surprising that there is a large variability in the reported power and energy capacity requirements for storage in 2030 and 2050 across the literature to date. It is important to critically evaluate each study based on its underlying assumptions to identify areas where information may be missing or outdated.

Figure 6 and Figure 7 below give an overview of installed power capacity values in the literature for Europe today. The literature covered here is not exhaustive, there is much value to be gained from looking into studies on a country-specific basis in Europe as well as regions outside Europe to understand the system planning needs. It is important that energy storage technologies are described in terms of both power capacity (GW) and energy capacity (GWh) to indicate power capability as well as storage volume and duration (hours, weeks, months). This is an area of the literature which needs to be addressed more clearly and streamlined for better comparison between technology capabilities and applications. Energy capacity values vary significantly in the literature depending on model inputs for example the renewables share, storage technologies considered and whether sector integration is included or not e.g. annual volumes of between 70TWh to 1000TWh are reported across studies for 2030 [14][4][15] and from 30 TWh to 4900 TWh for 2050 [16][15][17][14][18][19]. This order of magnitude variation across studies makes energy capacity a difficult metric for comparison. As such we identify studies reporting installed power capacities (GW) on the assumption that this covers a diverse range of technologies and durations both short and long-term as illustrated in Figure 5 which shows the different energy storage technologies based on power capacity and discharge duration which covers seconds, hours, days, weeks and seasonal timescales.

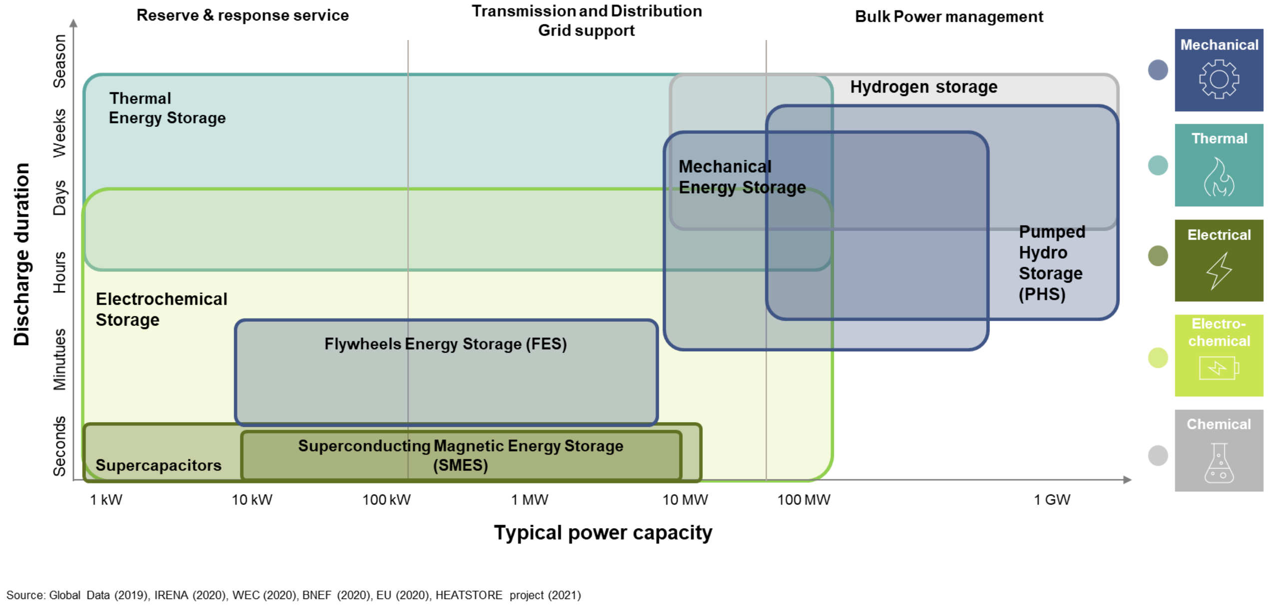


Figure 5: *Typical power ranges and discharge duration of different energy storage technologies.*

2. 1. Energy Storage: 2030-time Horizon

Energy storage power capacities reported for selected 2030 studies are shown in Figure 6 [20][21][13][18][10][6][4]. Most power capacity values reported for 2030 lie around 100 GW with the exception of values extrapolated from Cebulla et al. which look at storage needs based on either a wind or solar dominated system, correlating % variable renewables to GW storage needs [18] (see Annex 6.1). Solar dominated systems typically require more daily flexibility to cover day/night cycles (603 GW value), whereas wind dominated systems require longer duration storage for days or even weeks of low winds (268 GW value). We note significant shortcomings in the literature today which means energy storage requirements are underestimated at this time horizon and will be much greater than 100 GW in 2030 in the EU. A key issue is that most literature studies covered here for 2030 do not include the 40% RES target proposed in the REDII revision or the more recent 45% RES stated in REPowerEU today [20]. Furthermore, the 55% GHG reduction target is also not often included in studies today, and the role of GHG emitting backup generation in 2030 is significantly overestimated and must be reconsidered at the 2030-time horizon. This means the system will require much greater flexibility and energy storage needs in particular are underestimated.

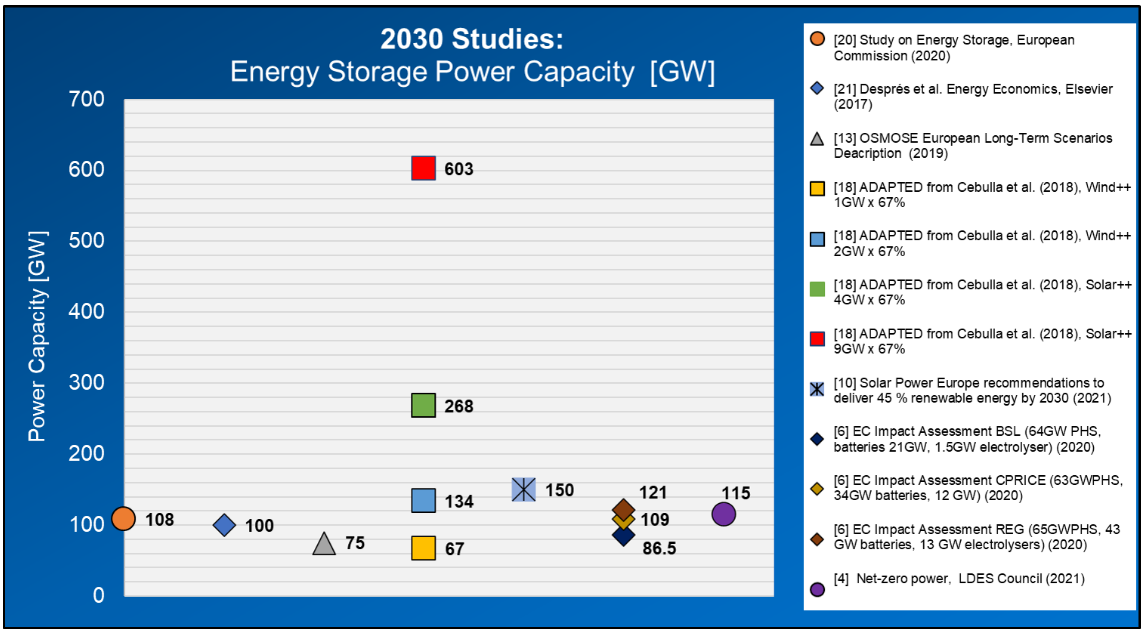


Figure 6: *Energy Storage installed power capacity requirements across different literature studies for 2030 focused on Europe.*

2. 2. Energy Storage: 2050-time Horizon

The 2050-time horizon is more difficult to model as it is highly dependent on policy decisions, market evolution and renewable scenarios in the next decades which are hard to predict. By 2050 the European power system will be dominated by variable energy sources with more than 85% variable renewables projected for 2050 [6]. This will require large amounts of energy shifting (days, weeks, months) and adequate long term seasonal storage, often not addressed in many 2050 studies today. Extreme weather conditions (e.g. Dunkelflaute) and other weather events must also seriously be considered to ensure a resilient energy system in the future [22]. Rolling blackouts are not an option and energy security and adequacy must be a top priority for European industry and societal well-being.

There is lacking a scenario in 2050 where all possible energy storage solutions able to address the system needs is covered, meaning in many studies energy storage is underrepresented and underestimated. Energy storage power capacity requirements for 2050 vary between 80– 720 GW across different selected literature reports, see Figure 7 [23][20][13][21][24][25][16][18][4][6]. Studies looking at storage for 2050 do not consider all storage technologies, typically covering only hydrogen electrolysers, batteries and PHS [26][9]. There are technologies available today and emerging innovations which must be considered, 2050 scenarios must not be limited only to technologies seen as cost competitive today. The variation between values in the literature is in part due to scenario and technology selection. The lower values reported for 2050 between 80-400 GW either exclude PHS or do not foresee its expansion [24] [25] [13] [23] or include significant grid expansion [16]. The values adapted from reference [18] (Annex 6.1) show extremes of the power system mix either solar dominated (320-720GW) or wind dominated (80-160GW) systems. This illustrates the effects of renewable generation technology on the system flexibility requirements. A more balanced mix of both wind and solar is expected according to European Long-Term Scenarios Description [13] and EC impact assessment [6]. Nonetheless the role of generation technology will be important at a country level for determining storage requirements and durations in the EU.

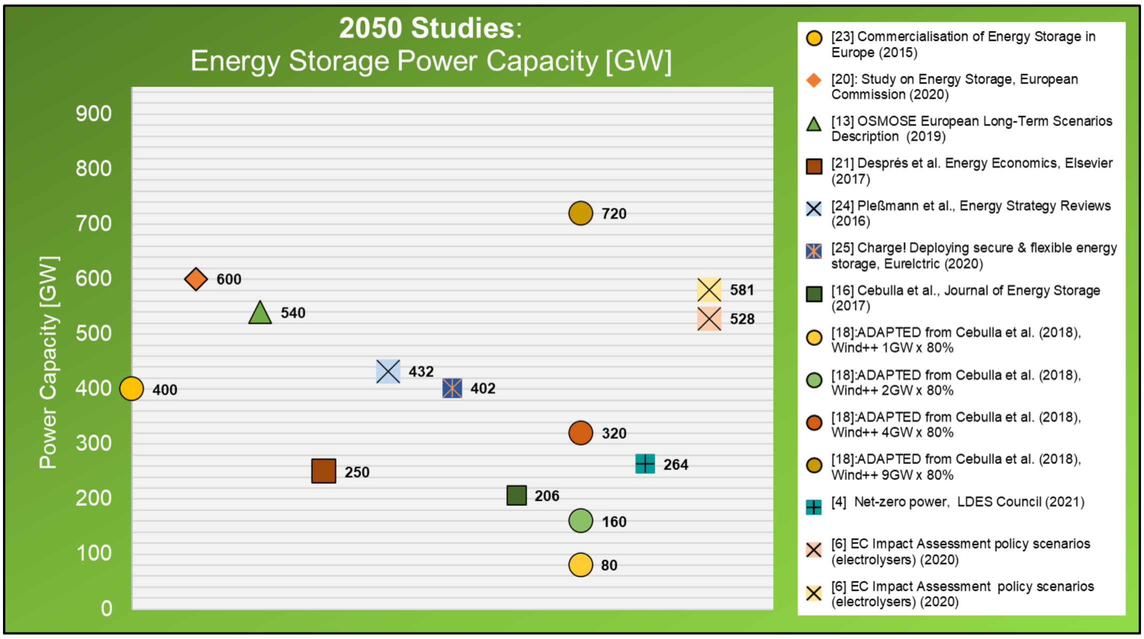


Figure 7: *Energy Storage installed power capacity requirements across different literature studies for 2050 focused on Europe.*

3. Why Energy Storage Needs Are Underestimated Today

Based on the analysis of existing literature, in all cases there is lacking a full comprehensive study including all technology options based on system needs accounting for up-to-date cost projections, revised climate targets and the importance of reducing reliance on fossil gas imports to ensure the EU's energy independence and security of supply. The following section identifies key inputs which must be updated and considered to accurately reflect energy storage needs in 2030 and 2050.

3. 1. Climate and Sector Targets do not Align with Energy Storage Uptake

All existing and proposed sector targets must be considered in energy system planning and this should be continually updated to capture and align all political, market and technical aspects of the future energy system. The recent REPowerEU plan has increased ambitions for RES targets to 45% RES, this will result in even greater system flexibility needs which includes energy storage [1]. Furthermore, hydrogen targets mapped out in the EU Hydrogen strategy in 2020, had already set an ambitious 40 GW Hydrogen electrolysers and production of up to 10M tonnes of Hydrogen intra EU by 2030 (~28 Mtoe, ~330 TWh), this ambition has also been further increased in REPowerEU plan to over 60 GW [27]. This requires huge amounts of additional renewable electricity in addition to realisation of the original revised REDII target, 40% RES [28]. It must be clearly understood how renewable energy generation will be allocated to hydrogen production in order to accurately determine the energy system needs and the energy storage technologies which are needed to provide system flexibility and energy shifting supporting higher shares of wind and solar generation. A holistic approach is critical to align targets across all sectors and define the energy system needs taking into account all variables.

3. 2. High Electricity Prices Today: Urgent Need to Reduce Reliance on Natural Gas

The European Climate Law sets binding targets to reduce net domestic GHG emissions by at least 55% by 2030 compared to 1990 levels. Europe cannot get anywhere near its climate targets without a steep reduction in fossil fuel use. As renewable penetration grows and traditional dispatchable generation assets such as coal are decommissioned and phased out, the need for flexible backup generation is becoming more critical. While gas-fired peak power plants can be used for dispatchable generation to cover instances of low production from wind and solar, phasing out one GHG emitting asset (coal, lignite plants) to replace it with another will only lock us into fossil fuels and hinder the success of sustainably reducing GHG emission in line with Europe's climate targets. This outlook might change if higher CO_2 prices, guarantees of origin and CO_2 certificates are considered, allowing green storage technologies to be recognised for their role in reducing GHG emissions. While it is possible to add carbon capture utilisation and storage to gas plants, the capture efficiency is less than 100% and CCS also increases gas plants OPEX and capital intensity and generally requires it to be installed close to a CO_2 storage or usage facility. This also does not eliminate the issue of Europe's dependence on third party imports of natural gas, the catastrophic effects of which we see today. Extreme costs of gas are dictating electricity prices and gas import dependence is a serious concern for the EU's security of supply. This issue must be considered as a driver for reducing flexibility provision from gas turbines. Europe must eliminate its reliance on external imports and create a reliable local energy supply.

This is already possible today, by maximising existing renewable energy production coupled with energy storage will minimise curtailment and create a low-emission, dispatchable backup energy reserve using technologies available today. Furthermore, storage technologies which use rotating generation (e.g. Carnot batteries, LAES, CAES, PHS) are able to provide critical system inertia and additional grid stability. Non-rotating storage technologies such as batteries (a grid connection power converter, power park module, or HDVC) provide near instantaneous active power output, replicating the effects of inertia, in case of frequency change in the system within a timeframe of up to 5 ms [29]. Energy storage is already a viable alternative for gas-fired peak power plants plants in the US. A recent study by the National Renewable Energy Laboratory (NREL) indicates the important role storage can play in future power systems by reducing generator starts (and associated emissions) and by increasing the use of low-carbon resources such as existing curtailed PV or wind generation [30]. Similarly in Australia, large-scale battery storage is now the superior choice for electricity peaking services, based on cost, flexibility, services to the network and emissions [31]. Long-duration energy storage (LDES) technologies have also been shown to be alternative options in the U.K. for replacing at least 50 TWh of gas in 2035. This study finds the total annual system costs could be reduced by £1.13 bn (2.5%) in 2035 if LDES is introduced [32].

3. 3. Minimising Curtailment with Energy Shifting

Curtailment occurs when there is overproduction of wind and solar exceeding demand, in which case the excess energy is curtailed and essentially wasted. Alternatively, when there are power system constraints renewable generators must ‘dispatch-down’, meaning electricity must be curtailed. When low carbon generation is curtailed, polluting generators such as natural gas are often required to ramp up to meet demand. In Ireland for example in 2020, 11.4% of the total available wind energy (1,448 GWh) was curtailed due to system constraints [33]. This figure has grown year on year as more wind and solar has come online. Curtailment is not only a waste of clean, locally produced energy but it is also costly. In the U.K. over 3.6T Wh of wind energy was curtailed in 2020 costing over £1.1 billion in constraint management. This clean energy could have been used to power over one million homes for the whole year had it been stored and used when needed.

Energy storage would be able to absorb the excess wind and solar energy that would otherwise have to be wasted. Storage can therefore minimise curtailment by shifting and storing excess renewable generation and using it to cover energy shortfalls traditionally covered by fossil fuel gas generators. In this way, storage maximises use of the EU’s own energy resources and reduces reliance on gas imports. Energy shifting is a service that can only be provided by storage technologies that store energy and deliver this energy back to the system. These technologies include among others batteries and also ‘long-duration energy storage’ (LDES) which covers: pumped-hydro storage, novel gravity storage, compressed air energy storage (CAES), liquid air energy storage (LAES), thermal energy storage (sensible, latent, thermochemical), chemical energy storage (power-to-gas-to-power) and electrochemical energy storage (flow battery). LDES technologies are expected to reach 128- 264 GW installed capacity by 2040. Of these technologies, pumped-hydro storage is the most mature means for GWh capacity storage of electricity. There is huge potential to add new capacity by retrofitting conventional hydro plants to make them reversible. These types of so called ‘brownfield’ projects which use existing dams have a much lower capex than ‘greenfield’ projects which are built from scratch. The EC Impact assessment foresees at least 65 GW PHS by 2030, an approximate 10% increase from today’s capacity. Furthermore, a joint study by the eStorage Project, a European Commission-funded consortium of major European stakeholders from the entire electric power value chain, identifies 2291 GWh of development-ready sites with existing reservoirs for new pumped hydro energy storage plants in the EU-15, Norway and Switzerland. The potential of PHS must be valued as a mature technology with a proven track record and is often not recognised enough in energy system and storage planning today.

Advantages of Energy Shifting Technologies

1. **Security of supply of energy in the EU**, relying on EU-produced renewable energy which has been stored. In this way, remove the dependence on third party electricity or gas imports, avoiding rising electricity and gas prices as is the case today. For example, clean energy stored in summer can provide peak capacity in winter instead of gas-fired peak power plants.
2. **Minimise curtailment and redispatch costs** by storing energy that would otherwise be curtailed to alleviate congestion in the grid or using this energy to cover shortfalls typically covered by expensive, polluting gas plants.
3. **Replace fossil-fuelled sources of flexibility such as gas turbines** with low emission energy storage solutions and reduce the need for additional peaking generation while also reducing GHG emissions in line with EU climate targets. Energy storage provides a modular, low emission alternative compared to gas-fired peak power plants which emit CO2 and require deployment of carbon capture and storage (CCS), increasing gas-fired peak power plants capital intensity and generally requires it to be installed close to a CO2 storage facility.
4. **Maximise utilisation of existing Renewable sources**, by storing excess energy generation that would be otherwise wasted and using this energy when needed, further reducing reliance on fossil generation.
5. **Support network constraint management**, and reduce the volume and cost of network reinforcements by shifting supply from congested to uncongested periods using energy storage.
6. **Provide storage over different durations** – intraday, inter-day and inter-seasonal, helping to balance the system across longer periods of lower generation (e.g. periods of low wind) or higher demand (e.g. colder periods when heating demand rises).

3. 4. Cost Projections and Technology Readiness Data Does Not Reflect Reality

Cost assumptions are particularly important as they are the key driver determining the future energy storage requirements in energy system models today. If costs projections are high, certain technologies will not be included, however current cost projections and technology innovations are constantly changing and must be kept relevant and up to date for system models. Technologies must also be recognised for the value they bring to the system and selection criteria should include benefits of energy security, low emissions and curtailment minimisation.

The LDES Council Net Zero looks at cost and performance data for novel LDES technologies based on storage duration, 8-24hr and >24hr (some technologies cover both ranges). Capex costs are expected to decline by 60% in future projections. This can be achieved by scaling production efforts and driving down costs as was the case for similar breakthrough technologies such as wind and solar. This requires investment signals to facilitate their widescale deployment [4], which is also dependent on enabling policy and legislation. System models should account for this uncertainty, as technologies are ready to be deployed but are limited by cost assumptions which in turn means they are not considered today as viable solutions for the future.

3. 5. Sector Integration and Seasonal Storage Considerations

Heating and cooling in buildings, businesses and industry consume around half of the energy produced and used in the EU. Thermal energy storage can provide an important flexibility lever helping balance demand and supply particularly on long duration seasonal timescales critical for balancing high renewables in 2050 [34]. Limited studies have been performed which evaluate the potential role of thermal storage technologies in sustainable European energy scenarios. A focus is typically applied on electricity and hydrogen storage options in most recent EU scenario studies, while overlooking the storage potential that other technologies may provide at competitive costs. High temperature- underground thermal energy storage (HT-UTES) and other thermochemical energy storage technologies for example provide valuable services to the electricity sector through sector integration as it absorbs electricity surpluses through power-to-heat solutions decoupling electricity production and heat demand from the short to seasonal timescales [35]. It is one of few long-duration storage technologies that can store vast amounts of energy up to tens of GWh per cycle on a seasonal timescale, see Figure 8. [36]

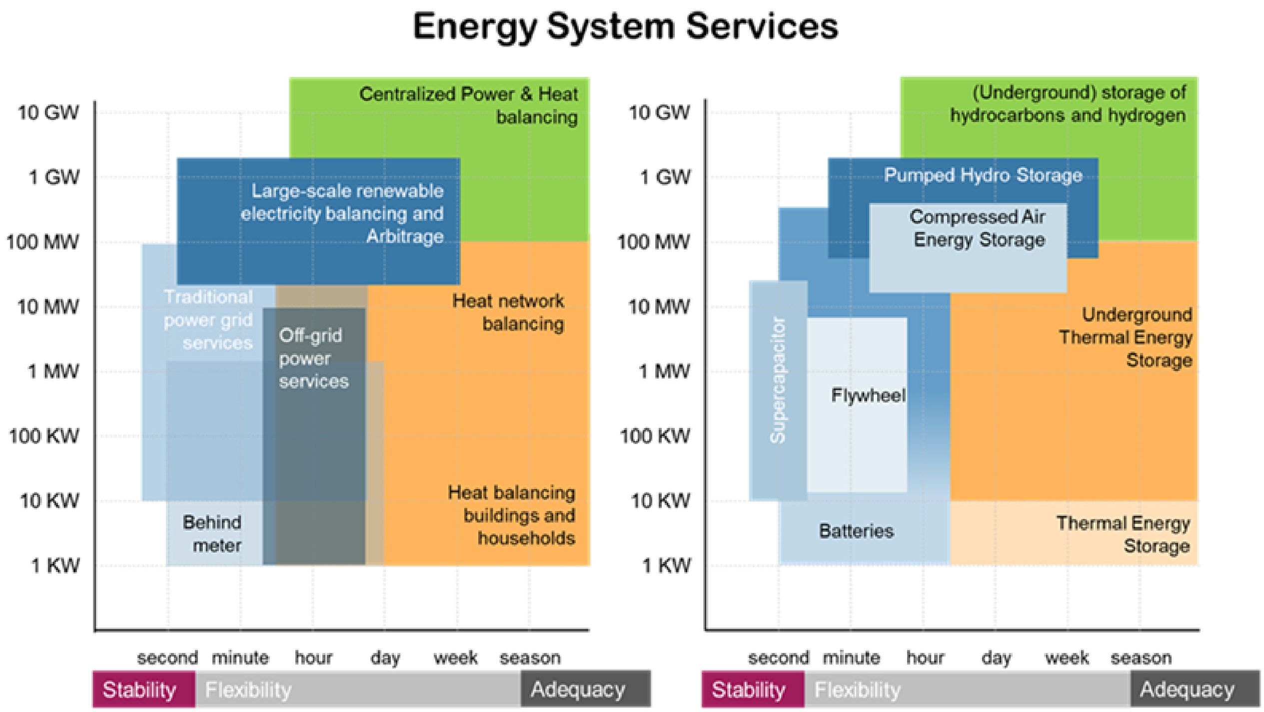


Figure 8: *Energy system services and storage options mapped according to their power (W) and relevant timescales for charging and discharging. Colours coding indicate in which infrastructure system the storage technology is implemented: blue = electricity grids, green = (renewable) gas infrastructure; orange is heat networks adapted from ref [36].*

Thermal energy storage (TES) technologies are developing at pace and can enable a higher share of renewable energy in industries and facilitate the recovery of heat that would otherwise go to waste. They can also play a key role in retrofitting existing fossil fuelled power plants, avoiding the combustion of fossil fuels. The integration of HT-UTES technologies in future energy scenarios and energy system planning will allow the demonstration of the crucial role that HT-UTES can play in the decarbonisation of the heat sector and benefit the electricity sector.

3. 6. Accounting for Extreme Weather Events and Adequate Temporal Resolution

IIn the case of prolonged periods without sufficient sun or wind, these imbalance periods could last days or even weeks [4] [37]. Dunkelflaute events occur on average 50 -100 hours per year between November to January for countries bordering the North and Baltic sea [38]. Shifting large amounts of energy from times when there is excess energy and storing it until needed will be central to balancing an variable energy system. Energy storage technologies can provide enhanced resiliency for extreme weather events. Researchers have recently begun to quantify the value that energy storage brings in terms of resiliency and there are several instances where tens of hours of energy storage would be sufficient for a system to remain online during a loss of power [7]. This function is traditionally served by fossil-fuelled generators, however, concerns regarding reliability, fuel supply and costs are driving operators of sites such as hospitals, data centres, and wastewater treatment facilities to explore alternatives. Energy storage could fulfil this role, with the added potential to provide additional revenue by participating in other markets e.g. ancillary services. System models should reflect real historical meteorological data accounting for extreme weather events so all energy shortfalls are captured and accounted for [37].

It is also important that all short and long duration flexibility needs are captured in energy system models to accurately reflect all the services storage can provide on all timescales, particularly for shorter durations <1 hour. Time resolution <1 hour are not typically included in models due to model complexity and computational cost [2]. This omits a significant application window for storage devices which provide critical system services including frequency response and balancing supply and demand in real time [2][39]. Often, simulations are run for only a single arbitrary year or several weather years which does not guarantee system adequacy in the worst year. Models should be careful with perfect foresight optimisation and allow for uncertainty to be factored in to the analysis.

3. 7. Maximising Existing Grid Infrastructure with Energy Storage

While grid capacity expansion reduces congestion risk, it is a capital-intensive process that requires long-term planning. The permitting requirements and complexity of transmission grid projects can cause projects to be delayed or even cancelled, not to mention public acceptance issues. As decentralised wind and solar projects are being sited where sun and wind resources are most abundant, this is often in areas where transmission lines weren’t designed to accommodate such power flows. As a result, networks are quickly becoming congested and in some cases solar and wind projects are forced to be curtailed because their output cannot reach load centres [40]. Copper plate assumptions which overestimate the ability to shift energy to other regions in the EU and underestimate grid congestion must be accurately addressed based on real data.

Storage solutions for maximising existing grid infrastructure provide a solution which allows large-scale integration of solar and wind power without grid congestion or redispatch, avoiding any immediate need for large grid infrastructure investments and thus reducing costs, noting that this is region dependent [41]. In Australia for example, deploying 100 MW of storage would take 24 months less than traditional solutions, realizing as much as $34 million AUD of savings for consumers during that period for specific interstate lines [40]. Energy storage is placed along a transmission line and operated to inject or absorb power, imitating transmission line flows, illustrated in Figure 9. Used in this way, storage can take the place of proposed system upgrades or lines that would otherwise have to be built. IRENA reports that Global needs for network investment deferral could reach 14.3 GW by 2026 and some countries including Italy and France are already piloting these solutions to reduce renewable power curtailment [41]. This valuable application of energy storage should be considered in energy system planning models as it may present an opportunity to maximise the use of existing lines and even to optimise grid expansion costs.

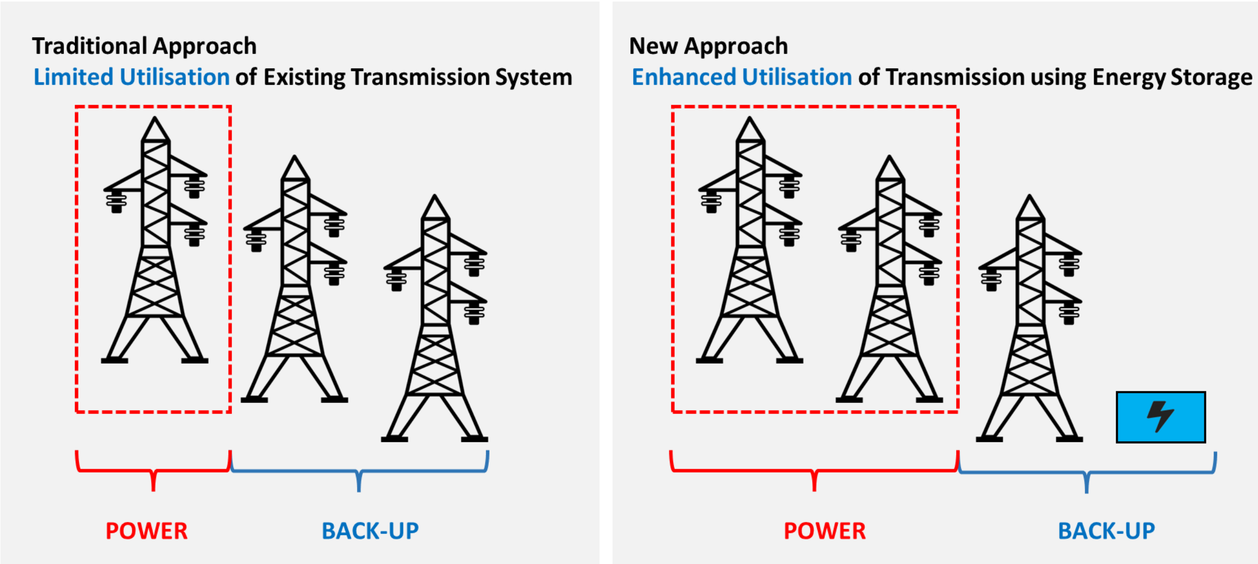


Figure 9: *Improving transmission grid utilisation with energy storage, adapted from [40].*

4. Energy Storage Estimates Based on Current Data and Assumptions

In the following section we estimate the EU energy storage needs for 2030 and 2050 based on the previous literature review, updated assumptions and revised climate targets. The flexibility needs were previously defined in official documents from the commission. We use the EC study on energy storage [20] and the more recent EC Impact Assessment [6] as a foundation for defining flexibility needs for 2030 and 2050. Yet, as highlighted in Section 3, key information needs to be updated to accurately reflect energy storage needs today. We consider 'energy storage' technologies as defined by the Clean Energy Package definition covered previously in Section 1.1. The storage needs defined here should be set as targets at EU level for 2030 and 2050 in line with best practice in the EU today.

4. 1. Flexibility Needs for 2030

The EC energy storage study finds that 456 GW of flexibility will be needed by 2030 [20], however this is based on outdated climate targets, therefore the total flexibility need will be even greater by 2030. Figure 10 adapted from this study shows that 76% of installed flexibility provision comes from gas turbines (open-cycle gas turbines, OCGT and closed cycle gas turbines (CCGT) without carbon capture utilisation and storage (CCUS) and only two storage technologies (PHS and batteries) are included in this scenario. This means many readily available storage technologies are underrepresented and the disproportionate amount of gas turbines providing flexibility is not in line with today's decarbonisation agenda and energy security plans.

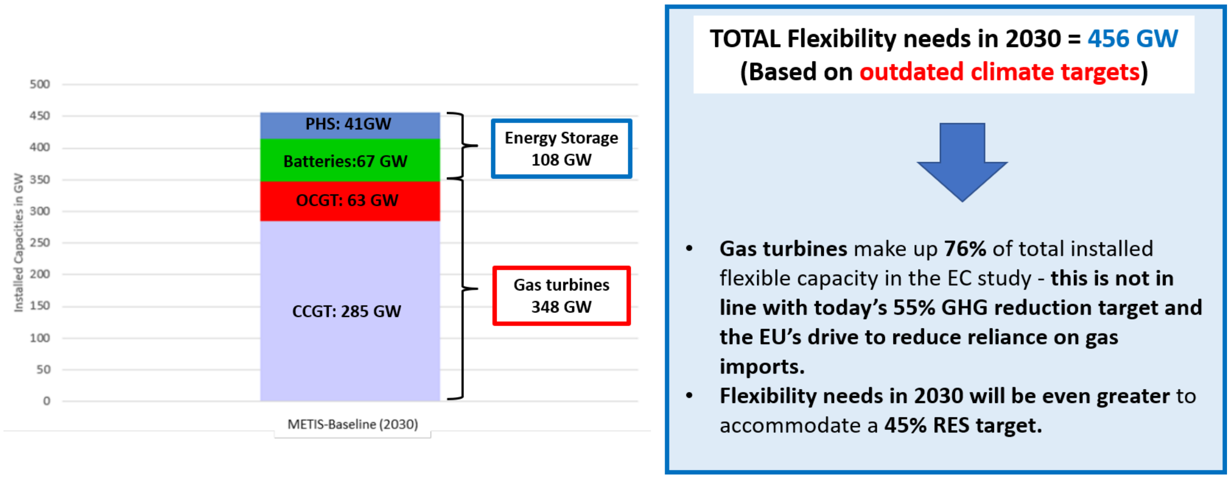


Figure 10: *Installed power capacities for flexibility solutions from METIS-baseline 2030 scenario adapted from the EC Study on energy storage [20].*

Flexibility provision for 2030 needs to be revised in light of the updated EU climate targets, the urgent need to reduce reliance on fossil gas imports as well as the advancement in storage technology innovation and cost assumptions as illustrated by other literature studies. We propose the following key revisions which should be taken into account to accurately determine energy storage needs for 2030.

1) Storage needs must be based on updated climate targets

- 45% RES as stated in the REPowerEU plan: higher RES target will inherently lead to greater need for system flexibility and energy shifting which could be provided by energy storage solutions. Thus, the total flexibility needs by 2030 will be greater than stated in the EC study which does not account for updated climate targets today.
- 55% GHG reduction by 2030: the role of fossil fuel power and flexibility plants must be reconsidered by 2030 and energy storage technologies provide a low emission alternative to gas-fired peak power plants flexibility.

2) Address system needs based on a technology neutral approach

- All storage technologies able to address the system needs providing system flexibility in either one-direction or bi-directional (energy shifting) must be considered based on the value they bring to the system particularly recognising (i) energy security, (ii) energy independence and (iii) low GHG emissions.
- Updated cost assumptions and technology readiness for all storage technologies must be included in energy system planning.

3) Urgent need to reduce reliance on gas imports and ensure Europe's energy independence

- The high share of gas turbines providing flexibility in EC study on energy storage 2030 scenario must be reconsidered in light of higher emissions reduction targets and the need to reduce reliance on external gas imports. This is elaborated in Section 4.1.1.

4. 1. 1. Reducing the EU’s Reliance on Natural Gas by 2030

Energy storage technologies are an alternative solution to gas turbines providing clean, reliable backup energy based on the EU’s own renewable energy resources as highlighted in the REPowerEU communication and other recent studies [1][30][32]. Batteries for example are already replacing gas turbines in the US and Australia today [30]. Recent studies for the U.K. have also shown that as much as 50TWh of gas could be replaced by long duration energy storage technologies by the 2030s, effectively reducing emissions, minimising curtailment and maximising renewables output [32]. We use the same rationale here for reducing gas use in the EU by 2030, based on data from the EC Impact Assessment we determine the amount of natural gas that must be eliminated from the power sector in 2030 to align with today’s 55% GHG reduction target (see Annex 6.2 for calculation details).

Key assumptions for replacing flexible capacity from gas turbines with energy storage

According to the METIS-Baseline 2030 scenario from the EC Study on energy storage, gas turbines are used to balance variable renewables on daily, weekly and seasonal basis by providing backup supply. We make the following assumptions for replacing a portion of gas turbine flexibility from the original EC study on energy storage, METIS-Baseline 2030 scenario with energy storage solutions:

1. We focus our analysis on natural gas used in the power sector in 2030 according to the EC Impact Assessment [6].

2. We consider replacing gas turbines which provide flexibility to balance variable renewables supply in 2030 with energy storage, this particular service relies on a dispatchable energy supply. While replacing gas turbines with more wind and solar generators would also reduce natural gas usage and GHG emissions, wind and solar are non-dispatchable and more wind and solar will only further increase flexibility needs.

3. We assume storage technologies including batteries, PHS and LDES (including novel gravity storage, compressed air energy storage (CAES), liquid air energy storage (LAES), thermal energy storage P2H2P (sensible, latent, thermochemical) and electrochemical energy storage) could replace gas turbines providing flexibility in 2030. Long duration storage technologies are already forecasted to be deployed at scale in the 2030’s. In light of the acceleration towards energy independence from gas imports, this deployment must be accelerated in the next few years already.

4. We assume there will be sufficient renewable energy generation and or curtailment in the EU to ensure storage technologies are able to provide the required flexible capacity provision in 2030. In the U.K. alone for example it is estimated that a maximum of 31 TWh energy will be available to be shifted from periods of excess renewable generation in 2035 [32].

5. We base our estimates on operational parameters for full load hours of OCGT (approx.1300 hr) [42].

Figure 11 summarises our analysis, the 2030 scenarios from the EC Impact Assessment are used based on outdated climate targets (BSL scenario) and revised climate targets (ALLBNK scenario). Our analysis based on natural gas usage in the power sector alone shows that an additional 188 TWh of natural gas must be eliminated by 2030 in order to align with the 55% GHG reduction target. This equates to replacing at least 55 GW of OCGTs providing flexibility according to the EC study on energy storage. This amount could be even more considering the low efficiency of OCGTs and their high emissions content. As such this is a minimum estimate of gas turbine replacement with energy storage in 2030 (See Annex 6.2 for further details).

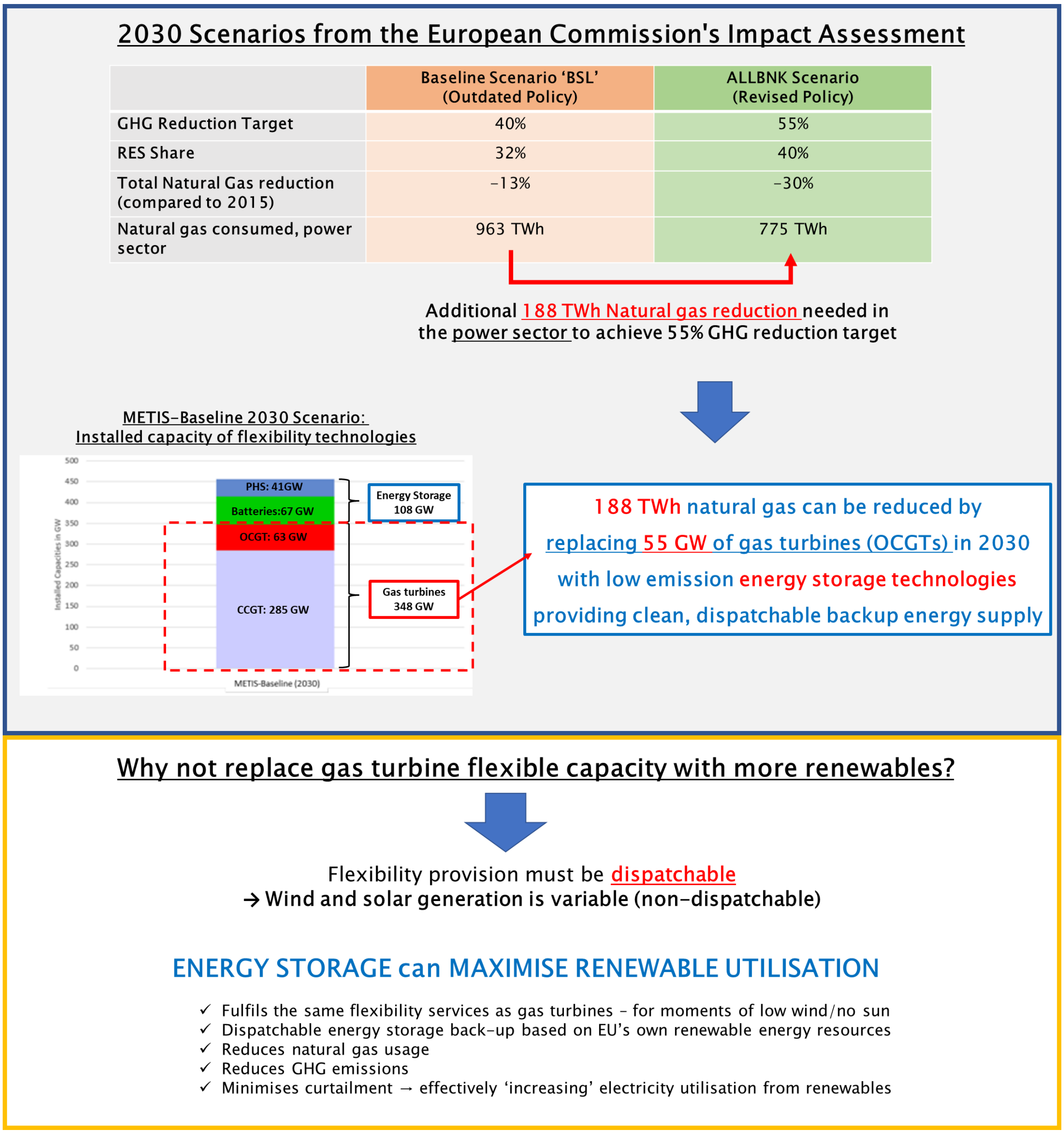


Figure 11: *Overview of rationale for replacing gas turbines using natural gas for flexible backup supply with energy storage in the power sector in 2030 based on data from the EC Impact Assessment and EC study on energy storage.*

4. 2. 2030 EU Energy Storage Target Estimation

Here we present our 2030 EU target estimate based on the flexibility needs as defined in the EC study on energy storage including assumptions on replacing gas turbines (detailed in Section 4.1.1.) in line with updated GHG reduction targets and including inputs from other literature studies. Our assumptions take into account the EC Impact Assessment for fit-for-55 scenarios which reach around 55% GHG reductions as much as 69% variable renewables (wind and solar) in electricity generation by 2030 [6]. While REPowerEU increases the RES ambition to 45%, this corresponds to the total energy production across all sectors from all renewable energy sources. The variable renewable sources (i.e. wind and solar) share in electricity generation are projected to increase to 67% in REPowerEU. This is in line with the most ambitious scenario in the fit-for-55 impact assessment (scenario ALLBNK which sees 69% variable renewables by 2030) nonetheless the generation mix must be considered and a dedicated model study is needed to account for the impacts of all the different variables on energy storage needs. Our assumptions and estimate on energy storage needs therefore represents a no regret option for 2030.

Assumptions included in our assessment of target estimates for 2030, Figure 12:

1. We include the 67 GW batteries stated in the EC study on energy storage: we assume inclusions of other short duration solutions under this 67 GW such as: V2G, flywheels, supercapacitors and Superconducting Magnetic Energy Storage (SMES).

a. V2G is estimated to be 33 GW according to the 2021 EU-Sysflex study. V2G is assumed to overlap with services provided by batteries and is therefore included under the 67 GW (see Annex 6.3).

2. 65 GW PHS as stated in the recent EC Impact Assessment (includes new and existing PHS) in line with 55% GHG reduction by 2030 is included. The continued expansion of PHS must be considered in line with PHS capacity potential already established by the Commission and in other studies already mentioned (Section 3.3).

3. 55 GW energy storage (Power-to-X-to-Power) to replace a portion of gas turbine flexibility in 2030

a. At least **55 GW** of gas turbines (OCGTs) providing flexibility in the EC study on energy storage is replaced by Power-to-X-to-Power solutions which include among others: batteries, PHS and LDES (including novel gravity storage, compressed air energy storage (CAES), liquid air energy storage (LAES), thermal energy storage P2H2P (sensible, latent, thermochemical) and electrochemical energy storage.

4. The 40 GW electrolyser target as stated in the European Hydrogen Strategy is taken into account and it is assumed that the role of electrolysers at this time horizon could overlap with other technologies providing system flexibility.

a. REPowerEU has also updated ambitions on hydrogen electrolysers to over 60 GW by 2030 which is included in its own dedicated hydrogen strategy.

b. We note that most hydrogen production at this time-horizon will be used for industrial use cases, therefore electrolysers are assumed here to provide flexibility in one-direction (P2G) and the contribution to other services provided by energy shifting P2X2P technologies is limited.

5. V1G and P2H is included qualitatively in Figure 12, under P2X solutions in 2030.

Based on these assumptions, Figure 12 shows the total installed energy storage requirements by 2030 to be at least 187 GW,. Power-to-X technologies are highlighted in blue and provide system flexibility in one-direction. Power-to-X-to-Power technologies are shown in green and provide system flexibility that is bi-directional i.e. electricity is given back to the system, these technologies provide critical energy shifting services. Since we are unable to predict an exact technology mix, we emphasise that this value of 187 GW is an estimate which depends on different scenarios and assumptions.

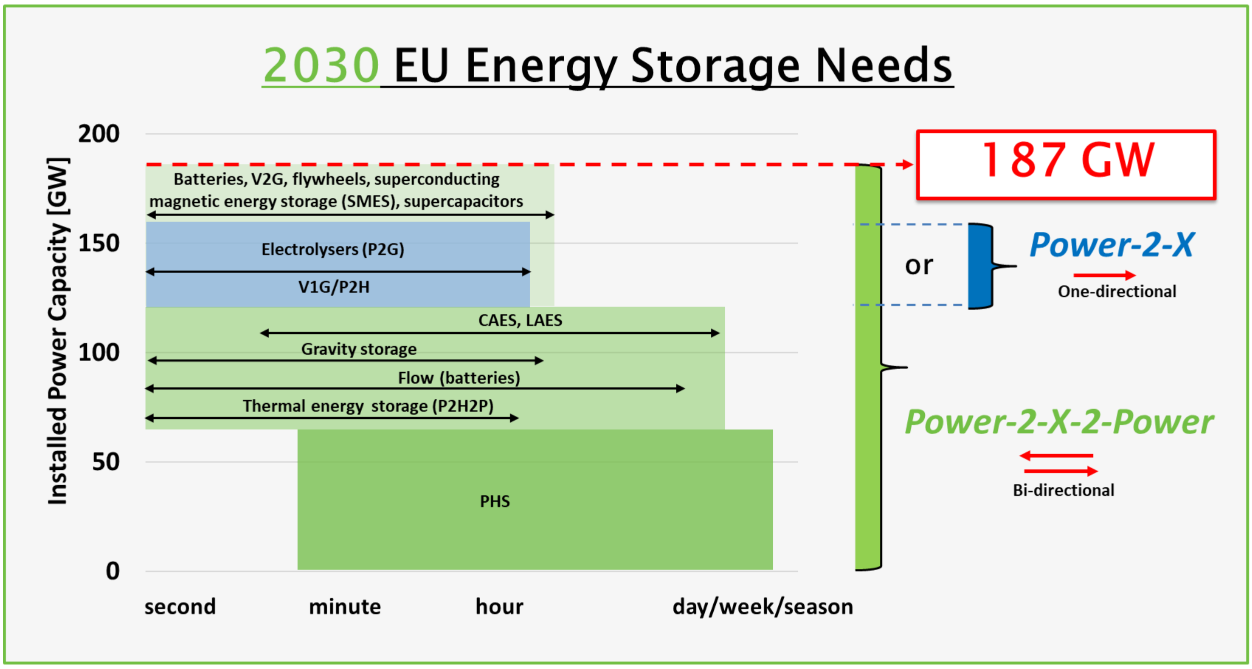


Figure 12: *Total energy storage requirements by 2030. The Y-axis shows installed power capacity (GW) for different energy storage technologies based on total flexibility as defined in the EC study on energy storage values, assumptions on replacing gas turbines by 2030 and other literature studies. Power-to-X technologies are highlighted in blue and provide system flexibility in one-direction. Power-to-X-to-Power technologies are shown in green and provide system flexibility that is bi-directional i.e. electricity is given back to the system, these technologies provide critical energy shifting services. The total energy storage needs are indicated by the red dotted line and are at least 187 GW in 2030, this includes new and existing storage installations (where existing installations in Europe are approximated to be 60 GW including 57 GW PHS [43] and 3.8 GW batteries according to IEA Energy Storage 2021 report*).*

4. 3. Flexibility needs for 2050

The EC study on energy storage 2050 scenario (METIS-1.5C 2050) foresees a total system flexibility need of 811 GW by 2050 of which 600 GW is covered by energy storage technologies and 211 GW by gas turbines. The 2050 scenarios covered in the EC study on energy storage mainly focus on electrolysers, which is only one of many storage solutions available. This leads to an underrepresentation of other critical storage technologies which could provide necessary flexibility and energy shifting services at this time horizon. PHS capacity for example, remains frozen from the 2030 scenarios indicating no PHS expansion is foreseen to 2050, which is not in line with studies on potential PHS expansion capacity in Europe mentioned previously. Since most energy system models are driven by least cost solutions, only the system needs should be addressed based on best technological fit. Cost assumptions and technology innovations today are constantly changing and must be updated to provide an accurate picture of storage needs especially by 2050. Given the timeframe from now to 2050 (>25 years) it is impossible to predict technology innovation and cost reductions or policy and market changes. Other clean technologies (e.g. wind and solar) have already seen dramatic cost reductions over even shorter timeframes. Similar cost reductions will likely occur in the timeframe up to 2050 for more nascent storage technologies. A sensitivity analysis based on best case scenario cost assumptions for all technologies should be accounted for in models today. While we do not dispute the quantity of flexibility needed by 2050 as stated in the EC study energy storage, other literature studies indicate that this flexibility need will be filled by a number of different technologies.

* https://www.iea.org/reports/energy-storage

4. 4. 2050 EU Energy Storage Target Estimation

Here we present our target estimate for energy storage in 2050 based on up-to-date figures from the literature for different storage technologies and assumptions for system flexibility based on Power-to-X-to-Power technologies providing energy shifting and Power-to-X technologies providing system flexibility in one-direction (See Annex 6.4 for detailed references). Since it is not possible to predict absolute scenarios and technology mix in 2050 we base our estimate on the following ranges and assumptions.

<u>Assumptions included in our assessment of target estimates for 2050, see Figure 13:</u>

Power-to-X-to-Power technologies providing energy shifting flexibility where energy is given back to the system (bi-directional)

1. We include **65 GW PHS** from the EC Impact assessment, which is a conservative estimate considering potential PHS capacity expansion highlighted previously (Section 3.3).

2. Long duration energy storage technologies are expected to reach between 128 GW and 264 GW installed capacity by 2040 in the EU, we take an average of **200 GW LDES in our estimate**. This includes among others: CAES, LAES, gravity storage, thermal energy storage (P2H2P), electrochemical storage and electrolysers (P2G2P) (Electrolysers providing P2G2P according to EC study is 12 GW).

3. **120 GW of V2G** based on scenario of European EV deployment (French TSO RTE provides an estimation of 1,7 GW of V2G for 1,1 million of EV, with the hypothesis of 77 million EV in Europe in 2050) [44] (See Annex 6.4)

4. The Commission's staff working document from 2021, states that stationary batteries will reach an installed capacity over 100 GW in 2050 [45]. The role of batteries in the EC study on energy storage ranges between 1-70 GW in 2050 dependent on sensitivities to deployment and costs of other competing technologies including V2G and electrolysers. We therefore take an average of these values (1-100 GW) and make a conservative estimate to include **50 GW of batteries** in the 2050 estimate.

Power-to-X technologies: Power-to-X storage technologies providing system flexibility in one-direction will also play a role in 2050.

1. To meet the total energy storage flexibility needs in 2050 as stated in the EC study, as much as **165 GW** could be filled by P2X solutions which provide system flexibility in one direction (energy is not given back to the system).

Our estimate is based on energy storage needs for system flexibility in terms of bi-directional contribution to the system (power-to-X-to-power energy shifting) which ranges between 315-550 GW and are estimated around 435 GW as a no regret option for 2050 in Figure 13. An additional 165 GW of power-to-X storage technologies are necessary for system flexibility, leading to a total of 600 GW. Lastly, the role of gas turbines could equally be filled by alternative cost competitive storage technologies in 2050 and could further increase storage needs at this time-horizon. Nonetheless based on these assumptions total energy storage needs of at least 600 GW will be required by 2050. This is illustrated in Figure 13 where power-to-X technologies are highlighted in blue and provide system flexibility in one-direction. Power-to-X-to-Power technologies are shown in green and provide system flexibility that is bi-directional i.e. electricity is given back to the system, these technologies provide critical energy shifting services.

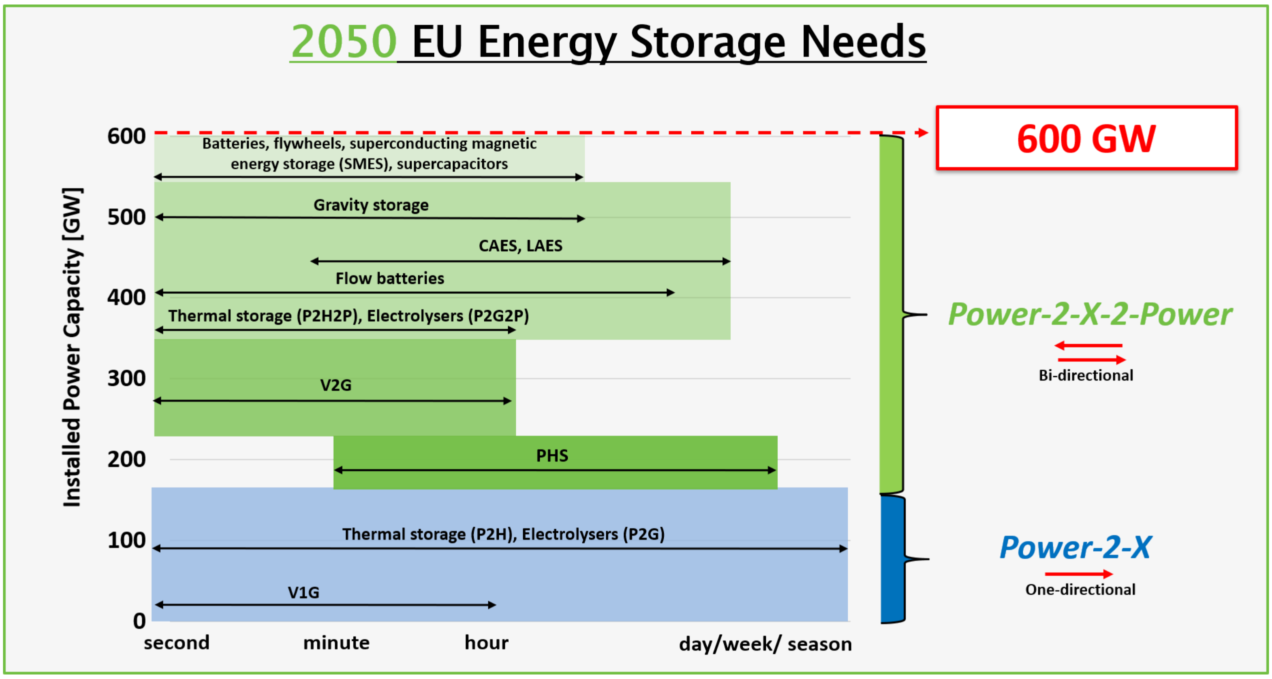


Figure 13: *Total energy storage requirements by 2050. The Y-axis shows installed power capacity (GW) for different energy storage technologies based on total flexibility needs as defined in the EC study on energy storage and values from other literature studies. Power-to-X technologies are highlighted in blue and provide system flexibility in one-direction. Power-to-X-to-Power technologies are shown in green and provide system flexibility that is bi-directional i.e. electricity is given back to the system, these technologies provide critical energy shifting services. The total energy storage needs are indicated by the red dotted line to be at least 600 GW in 2050.*

5. Conclusions

The EU energy system risks being unable to support the ambitious renewable energy integration foreseen in REPowerEU today if we do not act now. Accommodating the growing shares of renewables in the energy system requires energy storage to provide critical system flexibility and energy shifting services. Current market projections severely underestimate energy storage requirements and a massive boost in deployment is critically needed to go in parallel with renewables uptake. *A massive ramp-up in storage deployment of at least 14 GW/year is required in the next 9 years*, compared to 0.8GW/year of battery storage deployed in 2020 according to the International Energy Agency (IEA). Relying on fossil fuel generation and flexibility is not an option for the future if we are to ensure energy security and reduce reliance on third party imports, especially when low emission storage technologies are already available today.

With this paper we have highlighted the rationale for estimating EU-level energy storage targets based on an extensive review of numerous scientific studies and analyses of the energy system in Europe. We do not forecast the storage technology mix itself, as evolving costs, technologies and innovation landscapes will inevitably change in the future making it impossible to predict. However, we look at the system needs as a whole considering all technologies including both Power-to-X-to-Power and Power-to-X-solutions according to the Clean Energy Package definition of energy storage.

Taking into account inputs from numerous studies and assumptions on replacing a portion of gas turbine flexibility with low emission energy storage technologies, *we estimate energy storage needs of approximately 200 GW as a no regret option for 2030 (including existing storage capacity in Europe). By 2050, it is estimated at least 600 GW of energy storage will be needed in the energy system. This is based on the needs in terms of the bi-directional contribution from Power-to-X-to-Power solutions (i.e. for energy shifting) estimated at 435 GW as a no regret option for 2050, being complemented by 165 GW of Power-to-X technologies providing one-directional system flexibility.* As highlighted in the REPowerEU communication, energy storage reduces the use of gas power plants in the energy system and as such the role of gas turbines providing flexibility could further be filled by storage technologies in both 2030 and 2050, meaning energy storage needs could be even higher in both cases.

Establishing these 2030 and 2050 values as energy storage targets at EU level with a dedicated energy storage strategy will provide a clear signal to the energy storage industry and investors to begin building the infrastructure needed to drive large-scale deployment in parallel with supporting renewables integration. *Energy Storage targets are a necessary complement to existing EU climate targets and will allow Europe to foster a local, sustainable green energy system independent of external energy imports.*

6. Annex: Supporting Information

6.1. Relationship Between Variable Renewables Share and Energy Storage Requirements in GW

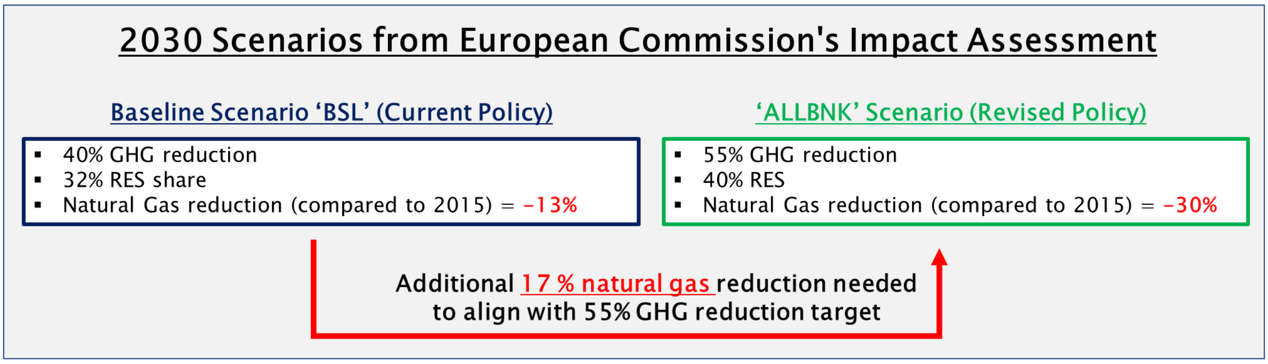
Looking only at the needs of a high variable renewable system which is a key question, one notable study looks at the relationship between variable renewables energy (vRE) share in the power mix and the GW of energy storage needed for flexibility and energy shifting. This study highlights the importance not only of the generation technology (wind or solar) but also the ratio of the two in the power mix on the subsequent energy storage requirements and durations. This study reviews over 400 different scenarios from the literature, narrowing down the scope to Europe [18]. Higher amounts of solar generation typically require more daily energy shifting flexibility from batteries (4-9 GW/% vRE), whereas wind dominated systems need longer term energy shifting to account for days or weeks of low winds (1-2GW/%vRE) [12][9][18][3]. In Table 1 we illustrate the energy storage needs for either a wind or solar dominated power mix in Europe. The share of variable renewables is take from the EC impact assessment scenarios, 67% vRE in 2030 and approximately 85% by 2050 [6]. These values indicate that more storage is needed for systems with higher solar generation to account for daily system flexibility and energy shifting whereas wind dominated systems require more longer-term storage to account for days or weeks of low winds (values are included in Figure 5 and Figure 6). This is an important observation and will affect storage needs based on generation technology (wind or solar) which will vary country by country in the EU and must be considered. Note here that these results will also depend on the storage durations, longer durations would mean lower installed capacity and vice versa.

Table 1: *Energy Storage power capacity calculated using reference [18] for a 67 % vRE share in 2030 and 85 % in 2050*

	2030	2050
Wind Dominated System 1-2GW/%vRE	LOW case:1GW x 67% = 67 GW HIGH case 2GW x 67% = 134 GW	LOW case:1GW x 85% = 85 GW HIGH case 2GW x 85% = 170 GW
Solar Dominated System 4-9GW/%vRE	LOW case:4GW x 67% = 268 GW HIGH case 9GW x 67% = 603 GW	LOW case:4GW x 85% = 340 GW HIGH case 9GW x 85% = 765 GW

6.2. Calculation of Natural Gas Reduction Needed in Power Sector by 2030 to Align with 55% GHG Reduction Target

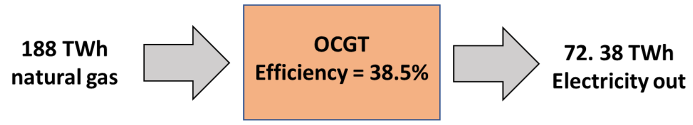
The EC Impact assessment study shows that a 30% reduction in total natural gas use (compared to 2015) is needed to achieve the revised 55% GHG reduction target in the ALLBNK scenario. This means an additional 17% reduction in total natural gas usage is required by 2030 compared to the baseline scenario (BSL) in order to reach the 55% GHG reduction target. As previously mentioned, the EC study on energy storage from 2020 is based on the outdated targets and therefore sees a disproportionate amount of gas turbines still providing flexibility in 2030. We look at how much natural gas must be removed from the power sectors (approx. 30% of natural gas is used in power sector). We propose substituting a portion of gas turbines (OCGTs) providing flexibility in the EC study on energy storage (METIS-Baseline scenario 2030, where OCGT = 63 GW and CCGT = 285 GW) with energy storage technologies. The key assumptions are elaborated in section 4.1.1. and calculations are summarised below (OCGT parameters taken from IEA-ETSAP (energy technology systems analysis program) ref [42]). Further to note that ALLBNK is the most ambitious Fit-for-55 scenario in the EC Impact Assessment and aligns with 55% GHG reductions and 40% RES (69% variable RES i.e. wind and solar in electricity generation).



Data from EC Impact assesment - 2030 Scenarios			
	BSL	ALLBNK	
TOTAL NG consumption in 2005 [Mtoe]	311.494		Color code
% reduction compared to 2005	0.13	0.3	*values from EC impact assesment*
TOTAL NG consumed 2030 (Mtoe)	271	218	*Calculated values*
NG consumed POWER sector - approx 30% of total (MtOe)*	83	67	
Additional NG reduction needed from power sector to align with 55% reduction (Mtoe)	16.2		difference (271-218 MtOe)
Additional NG reduction needed from power sector (TWh)	188.2		1MtOe = 11.63 TWh

**(EC states 91 Mtoe all gases in power sector under baseline, subtracted the 9% of other gases mentioned in the study to get NG alone)*

OCGT operational parameters			
	OCGT		
		Average	
efficeincy %	*35-42%*	0.385	
Load Capacity Factor %	*10-20%*	0.15	
Full load hours/yr	-	1314	(load capacity Factor*8760h)



$$\textit{GW Installed}\ \textbf{OCGT to produce 72.38 TWh electricity} = \frac{72.38 * 1000\ GWh}{1314\ h} = 55\ GW$$

6.3. 2030 Summary of Inputs and References for Energy Storage Targets Estimate

Table 2 summarises key inputs and sources used for 2030 energy storage estimates. We include the EU SySflex study in the table for contribution of V2G noting that we see this as being a competitive solution to batteries for short-term flexibility [22]. While of course not all applications of batteries can be filled by V2G, as we are unable to separate each contribution, we include 33GW V2G under the 67 GW system flexibility provided by batteries and other short duration technologies.

Table 2: *Summary of Key Data and Sources used for EU Energy Storage Estimates in 2030*

	Energy Storage Technology	Source	Ref#	Installed Power Capacity (GW)
POWER-TO-X-TO-POWER	Batteries	METIS-Baseline 2030 EC study, [March 2020]	**[20]**	**67 GW**
	Pumped-Hydro Storage (PHS)	[1]EC study, [March 2020] [2]EC Impact assessment, [Sept 2020]	**[20], [6]**	**41 GW[1] – 65[2] GW**
	*batteries, PHS and LDES (including novel gravity storage, compressed air energy storage (CAES), liquid air energy storage (LAES), thermal energy storage P2H2P (sensible, latent, thermochemical), electrochemical energy storage (flow battery)	Assumptions for replacing gas turbines in 2030 (see Annex 7.2)	-	**55 GW**
	Vehicle-to-Grid (V2G)	EU SysFlex, [Sept, 2021]	**[22]**	**33 GW**
POWER-TO-X	Thermal Energy Storage (P2H)	-	-	Included qualitatively
	Hydrogen Electrolysers (P2G)	Sector Target, EC Hydrogen Strategy, [July 2020]	**[28]**	**40 GW**
	Grid-to-Vehicle (V1G)	-	-	Included qualitatively

6.4. 2050 Summary of Inputs and References for Energy storage Target Estimate

Table 3 summarises key inputs and associated references for 2050 energy storage estimates detailed in Section 4.3 and 5.4.

Table 3: *Summary of Key Data and Sources used for EU Energy Storage Estimates in 2050*

	Energy Storage Technology	Source	Ref#	Power capacity (GW)
POWER-TO-X-TO-POWER	Vehicle-to-Grid (V2G) - 120 GW based on scenario of European EV deployment (French TSO RTE provides an estimation of 1,7 GW of V2G for 1,1 million of EV, with the hypothesis of 77 million EV in Europe in 2050)	RTE "Energy Pathways to 2050," [October, 2021]	**[42]**	**120 GW**
	Batteries	[1]METIS-1.5C (2050), EC study, [March 2020] [2]EC SWD Progress on competitiveness of clean energy technologies 6 & 7 - Batteries and Hydrogen Electrolysers [2021]	**[19], [43]**	**[1]1–[2]100 GW**
	Pumped-Hydro Storage (PHS)	EC Impact assessment, [Sept 2020]	**[5]**	**65 GW**
	Novel gravity storage, compressed air energy storage (CAES), liquid air energy storage (LAES), thermal energy storage (sensible, latent, thermochemical), electrochemical energy storage and chemical energy storage (power-to-gas-to-power technologies)	LDES Council input and Net Zero Report [Nov 2021] excl. U.K.	**[3]**	**128 - 264 GW**
POWER-TO-X	P2X technologies	An additional 165 GW of power-to-X storage technologies are deemed necessary for system flexibility based on total flexibility needs of 600 GW	**[19]**	**165 GW**

7. List of Acronyms

Acronym	Definition
CAES	Compressed Air Energy Storage
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and storage
CCUS	Carbon Capture Utilisation and storage
CO2	Carbon-dioxide
EC	European Commission
EU	European Union
FES	Flywheel Energy Storage
GHG	Greenhouse Gas
HT-UTES	High temperature- underground thermal energy storage
IEA	International Energy Agency
IOU	Investor-owned utilities
LAES	Liquid Air Energy Storage
LDES	Long duration energy storage
NECP	National Energy and Climate Plans
NREL	National renewable energy laboratory
OCGT	Open Cycle Gas Turbine
OPEX	Operating expenditure
P2G	Power-to-Gas
P2H	Power-to-Heat
P2X	Power-to-X
P2X2P	Power-to-X-to-Power
PHS	Pump-Hydro Storage
REDII	Renewable Energy Directive II
RES	Renewable Energy Sources
RTE	Réseau de Transport d'Électricité
SMES	Superconducting Magnetic Energy Storage
TES	Thermal Energy Storage
TSO	Transmission system operator
V1G	Grid-to-vehicle (also G2V), denotes smart charging
V2G	Vehicle-to-Grid
vRES	variable Renewable Energy Sources

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Notes

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The European Association for Storage of Energy (EASE) is the leading member - supported association representing organisations active across the entire energy storage value chain. EASE supports the deployment of energy storage to further the cost-effective transition to a resilient, low-carbon, and secure energy system. Together, EASE members have significant expertise across all major storage technologies and applications. This allows us to generate new ideas and policy recommendations that are essential to build a regulatory framework that is supportive of storage.

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