STORY

Energy Storage

Our take on business models and regulation

Story Highlight
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Contents

1.1 Preface

The electricity landscape is in a state of flux, not least due to the increasing integration of renewable energy sources and distributed generation. In its wake is the growing attention for energy storage, arguably an important part of the renewable energy mix.

How can energy storage be used and integrated into existing power systems, in both residential and industrial environments? This is the key question the STORY project aims to address. Funded by the European Union's Horizon 2020 research and innovation programme, STORY is a 5-year research project analysing new energy storage technologies and their benefits. It features 6 demonstration case studies and involves 18 partner institutions in 7 European countries. One of these partner institutions is Vlerick Business School. In a context where several different actors can use storage assets it is essential to identify business models and regulation that will make energy storage sustainable, which is exactly where our expertise lies. We have taken the lead on the business cases supporting the rollout of electricity storage at the distribution level of the grid; more specifically, on those business cases revolving around the challenges of storage deployment and the interaction between the business models and the enabling market and regulatory context.

On 30 November 2018, Vlerick Business School therefore organised the STORY seminar on Business Models and Regulation for Storage (see Box 1) with the aim of providing a platform for researchers and industry players to meet and discuss the state of the art in research and practice on the integration of storage technologies. This white paper presents the findings and insights from studies conducted under the umbrella of the STORY project as well as from various experts at the November seminar.

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1.2 Acknowledgements

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Mathias Berger (ULiège), Kenneth Bruninx (KU Leuven, VITO and EnergyVille), Patrick Clerens (EASE), Alastair Currie (UK Power Network Services), Niels Govaerts (KU Leuven, VITO and EnergyVille), John Harrison (H2020 STORY and B9 Energy), Yannick Perez (LGI Lab CentraleSupélec), Ksenia Poplavskaya (AIT Austrian Institute of Technology and TU Delft), David Radu (ULiège), Tim Schittekatte (Florence School of Regulation, Université Paris-Sud XI and Vlerick Business School), Alan Thompson (UK Power Network Services) and Servaas Van Den Noortgate (FlexGrid)

Box 1: SEMINAR 30 NOVEMBER 2018: BUSINESS MODELS AND REGULATION FOR STORAGE

Venue: Vlerick Business School – Brussels campus

09.00 – 10.30	**Business models for storage** Moderator: Leonardo Meeus | Vlerick Business School Speakers: Patrick Clerens | European Association for Storage of Energy (EASE) Alan Thompson & Alastair Currie | UK Power Networks Services Servaas Van Den Noortgate | FlexGrid John Harrison | H2020 STORY & B9 Energy
10.30 – 11.00	Coffee break
11.00 – 12.30	**Potential of different storage technologies** Moderator: Ariana Ramos | Vlerick Business School Speakers: Yannick Perez | LGI Lab CentraleSupélec Kenneth Bruninx | KU Leuven, VITO & EnergyVille Mathias Berger & David Radu | University of Liège
12.30 – 13.30	Networking lunch
13.30 – 14.45	**Impact of regulation on business case of storage technologies** Moderator: Leonardo Meeus | Vlerick Business School Speakers: Tim Schittekatte | Florence School of Regulation, Université Paris-Sud XI & Vlerick Business School Niels Govaerts | KU Leuven, VITO & EnergyVille Ksenia Poplavskaya | AIT Austrian Institute of Technology & TU Delft
14.45 – 15.00	Closing remarks Leonardo Meeus | Vlerick Business School Patrick Clerens | European Association for Storage of Energy (EASE)

1.3 Market potential

Is there a business case for energy storage? Before we can answer this question, we must clarify why we need it. In addition to outlining some of the available technology options, we shall also briefly touch upon alternatives to storage.

1.3.1 Why do we need storage?

To support the transition to a low-carbon economy, the EU's Renewable Energy Directive sets a binding target: by 2030 renewables should at least make up 32% of the energy mix. However, the inclusion of renewable energy sources is not without its challenges.

Our electricity network requires that at any moment in time generation has to equal consumption. The intermittent character of renewables, such as solar and wind energy, now puts this system under pressure as availability and demand are no longer balanced 24/7. Solar energy is only available during daylight hours, while household demand may reach a peak in the evenings. And during the day, clouds may cause solar energy production to fluctuate. Wind turbines, in turn, only generate electricity when the wind blows.

To put things in perspective: the German Advisory Council on the Environment estimated that, in order to cover the maximum peak demand of approximately 86 GW, the installed capacity of renewables should amount to 300 GW, i.e. more than three times the peak demand[1]. Moreover, covering peak demand is not the only issue. Differences between forecasted and actual supply, and between forecasted and actual demand, as well as the resulting real-time differences between supply and demand also need to be addressed. Energy storage is capable of both reducing peak demand and providing flexibility, by balancing real-time differences, as it allows any surplus electricity to be temporarily stored in other forms of energy, in order to be made available again as electricity when needed. The industry has clearly picked up on this opportunity: the European energy storage market is expanding rapidly, having grown 40 to 50% year-on-year, from 0.6 GWh in 2015 to a forecasted 3.5 GWh in 2019[2].

1.3.2 Storage technologies

Talking about energy storage, the first thing that comes to mind is most likely a battery. There are, however, several methods of storing excess electricity until it is needed. Without wanting to be exhaustive, we briefly comment on a few storage technologies, three of which were discussed in more detail during the November seminar.

Pumped hydro storage

Pumped hydro or hydroelectric storage harnesses the potential energy of water at a height and has historically been the most common method of energy storage used worldwide. A pumped hydro system is comprised of two reservoirs at different heights. In periods of low demand and high availability, low-cost electricity is used to transfer water from the lower to the higher reservoir by means of a pump and a turbine or a reversible pump turbine. When electricity is needed, in periods of

[1] Source: TSO data as of 2016

[2] Source: Numbers include electrical, electrochemical and mechanical storage, with the exception of pumped hydro. European Market Monitor on Energy Storage 2.0 – EASE and Delta-ee

high demand, water can be released into the lower reservoir, driving the turbine, thereby generating electricity.

With an efficiency ranging from 70 to 85%, it is the most mature and one of the most efficient methods available to store large amounts of energy over a long period of time. Although the required electricity is not instantly available, reaction times are in the order of seconds with installations reaching their full power load in a matter of minutes. The most important downside of pumped hydro storage, however, is that it suffers from geological restrictions: not all locations are suitable as it requires large reservoirs at different heights.

Batteries

A battery consists of one or more electrochemical cells, which store electrical energy in the form of chemical energy and through electrochemical reactions convert that energy into electricity. Each electrochemical cell is made up of two electrodes separated by an electrolyte – a liquid, gel or solid substance. During discharge, this electrolyte enables movement of positively charged ions between the two electrodes, thereby generating a balancing flow of negatively charged electrons through an external circuit connected to the battery. Batteries for energy storage purposes are rechargeable batteries, i.e. the flow of ions and electrons occurs in the opposite direction, charging the battery when it is connected to an external electric source. The battery is charged when any excess power is available and discharged as needed. Several types of batteries exist, depending on the materials used in the electrochemical cells, e.g. lithium-ion, lead-acid, magnesium-ion, nickel-cadmium etc. For storage applications, lithium-ion is still the most common technology available.

Battery storage is highly versatile and scalable and can therefore be used for residential and utility-scale short-duration storage applications in distributed as well as centralised setups, and in both mobile and stationary systems. The fall in the cost of lithium-ion batteries is one of the key drivers of the increased demand for battery storage. According to Bloomberg New Energy Finance prices have dropped by 80% between 2010 and 2017[3], and costs are projected to fall another 52% between 2018 and 2030[4]. Moreover, the rise of electric vehicles has spurred innovation in battery technology. Nevertheless, several challenges remain, e.g. improving energy density, charging capabilities, lifetime and environmental and safety performance. .

Vehicle-to-grid

Fully charged and parked electric vehicles are actually large batteries sitting idle. Why not put this storage capacity to better use? This is where vehicle-to-grid (V2G) technology comes into play: when equipped with a bidirectional charger capable of charging and discharging their batteries on demand, these vehicles can act as mobile energy storage units to provide services to the grid by managing their charging patterns according to specific grid requirements.

At the November seminar a study was presented which analyses the conditions for profitability of an investment in a fleet of electric vehicles fitted with bidirectional chargers to provide frequency containment reserves (FCR) to the grid[5]. FCR or primary reserves are fast-acting reserves used for the short-term balancing of supply and demand, which requires the capability to increase or decrease power output at very short notice, typically within 0 to 30 seconds. The authors calculated the net present value (NPV) of the investment for 4 market design scenarios and different fleet sizes. The

[3] Source: Bloomberg New Energy Finance, Lithium-ion Battery Price Survey, 2018

[4] Source: Bloomberg New Energy Finance, Long-term Energy Storage Outlook, 2018

[5]Borne, O; Petit, M; Perez, Y. (2018) "Net-Present-Value Analysis for Bidirectional EV Chargers Providing Frequency Containment Reserve"

market design scenarios differed according to temporal granularity (i.e. 1 hour, 4 hours or 1 week; the latter corresponding to the actual temporal granularity of the FCR market) and volume granularity (i.e. 0.1 MW or 1 MW, which is the minimum bid imposed by the market design currently in place). Simulations showed that in order for a charging supplier to have a positive NPV, given the current market design, the fleet should total at least a few thousand vehicles, which would be a tall order for a starting business. A sensitivity analysis further demonstrated that market design parameters have a big impact on the profitability of the investment. It also highlighted that, given the current market design, the minimum fleet size is significantly affected by every other parameter considered (reserves price, recurring costs, lifetime, discount rate etc.). However, in the market design scenario with the highest granularity (i.e. 1 hour and 0.1 MW), the only influencing parameters are average reserves price and recurring costs.

The authors regard this analysis as a mere first step towards building a V2G business model. Indeed, they consider only one actor, i.e. the aggregator managing the fleet, who captures all the value, whereas in reality, there will be several actors fulfilling different roles and the value should be shared among these actors, including the users of the electric vehicles.

The study described here is only one of many in the emerging field of V2G, which is undeniably a hot topic in research. Expectations are running high, with enthusiasts going as far as predicting that V2G is the ultimate energy solution. However, the jury is still out as there are several uncertainties and issues yet to be resolved, which is perfectly normal for an emerging technology.

Power-to-gas

Power-to-gas (P2G) technology enables the storage of excess electricity from renewable resources by converting it to gas. There are different methods, all of which first use electric energy to produce hydrogen (H_2) by water electrolysis. Depending on the method, this H_2 is subsequently combined with CO_2 to convert it to methane (CH_4). H_2 and CH_4 are either injected in the existing gas grid or stored underground (see also **Error! Reference source not found.**) and then used for electric power generation in gas turbines or gas engine plants or, in the case of H_2, fuel cells.

There are currently few economical alternatives for grid-scale seasonal energy storage, given that pumped hydro suffers from geological restrictions. In countries with a gas network infrastructure, though, large-scale gas storage facilities and P2G technologies may provide alternatives to pumped hydro while complementing battery storage. Researchers from the university of Liège in collaboration with Fluxys, the Belgian gas infrastructure operator, developed a theoretical framework to tackle long-term centralised planning problems of integrated energy systems with bidirectional coupling of the electricity and gas infrastructure[6]. Which energy generation, conversion and storage technologies, and how much of each, should be deployed to supply electricity at minimum costs while satisfying technical constraints and specific policy targets, i.e. carbon emission and electricity import quota? The team modelled a simplified energy system comprising different technologies, i.e. (1) non-renewable generation including combined cycle gas turbines, H_2 fuel cells and other non-renewables (combined heat and power, biomass and waste), (2) renewable generation encompassing onshore and offshore wind turbines and solar PV panels, (3) pumped hydro storage and batteries and (4) the gas system made up of electrolysers, methanators and hydrogen and methane storage.

This framework was then applied to the Belgian energy system in order to identify the cost-optimal energy mix along with short and long-term (seasonal) storage requirements beyond 2025, when no nuclear power plants are assumed to be in operation. Two scenarios were analysed: the first put annual carbon emission quota at the estimated 2018 level and electricity import quota at 10% of

[6] Berger, M; Radu, D; Fonteneau, R; Ernst, D; Deschuyteneer, T; Detienne, G. (2018) “Centralised Planning of National Integrated Energy System with Power-to-Gas and Gas Storages”

annual electricity consumption, while the second used low carbon emission quota, i.e. 33% of 2018 levels, and the same import quota of 10%.

The simulations indicate that P2G, gas storage and batteries become relevant only when ambitious carbon dioxide reduction targets are pursued, in which case they are a necessity. This study also shows that economics alone will not be conducive to the emergence of large-scale P2G infrastructures, but that instead revised carbon pricing mechanisms or carbon quota should be considered.

Compressed air energy storage

Compressed air energy storage (CAES) systems use excess or off-peak electricity to compress ambient air, storing it in underground caverns or storage tanks. When electricity is needed, the pressurised air is recovered from its storage, heated and expanded in an expansion turbine driving a generator, which delivers the electricity back to the grid.

Unless the heat generated during air compression can be recovered and re-used, the efficiency of CAES systems is relatively low, i.e. 40-50%. Higher efficiencies up to 70% can be achieved if this heat is captured and used to reheat the compressed air in the electricity-generating turbine, in which case no extra gas is needed (third generation CAES technology).

Like pumped hydro and P2G, CAES is suited for seasonal energy storage. There are only two large-scale CAES plants in operation worldwide: a first-generation 290 MW plant in Huntorf, Germany, built in 1978, and a second-generation 110 MW plant in McIntosh, Alabama, US, which was commissioned in 1991, both designed to store inexpensive base load power produced by conventional sources during off-peak periods. Natural gas is burned in the compressed air to power an electricity-generating turbine when electricity is needed. The emergence of intermittent renewables, however, has revived interest in the technology. Current CAES developments focus on third generation CAES technology which aims to avoid the use of fossil fuel.

Not unlike pumped hydro, traditional CAES systems suffer from geological restrictions as they require suitable large underground caverns to store the compressed air. It is therefore all the more interesting that one of the demonstration case studies in the STORY project will experiment with a decentralised, small-sized CAES system, storing the compressed air in above-ground storage tanks. Like batteries, decentralised CAES systems could be installed anywhere (see Box 2).

Thermal energy storage

Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation (IRENA, 2013). Energy can be stored as heat for later use, or for conversion into electricity. The stored heat can be obtained in different ways: solar thermal heat, electricity conversion into heat, remaining heat from industrial processes, or heat produced by electricity generators.

There are three main kinds of thermal energy storage systems (IRENA, 2013):
1. Heat storage based on storing thermal energy by heating or cooling a liquid or solid storage medium (e.g. Water, sand, molten salts, rocks).
2. Heat storage using latent phase materials, e.g. Changing from a solid state into a liquid state.
3. Thermo-chemical storage using chemical reactions to store and release thermal energy.

Box 2: Distributed CAES provides local load on demand

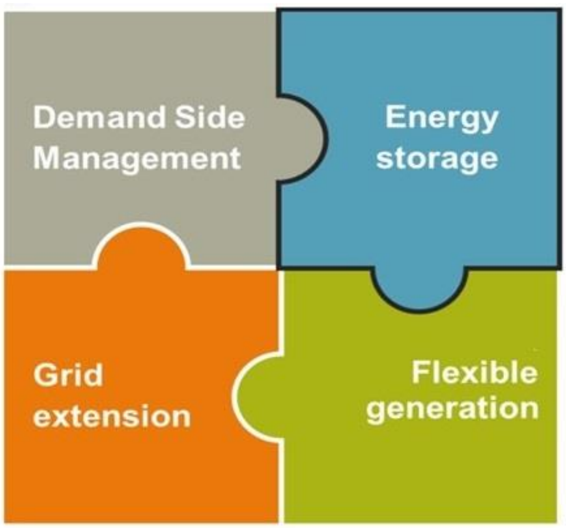
Lecale, a semi-rural area in the south-east of Northern Ireland, hosts a small-scale CAES demonstration project aimed at illustrating the benefits and opportunities of providing decentralised electrical storage through compressed air and stored heat to areas with relatively weak existing electrical infrastructure. The project should help to demonstrate the ability to store and regenerate electricity with standardised technology components and will validate models for operating the unit within a residential setting, both to maximise the penetration of local sources of renewable energy and to minimise transmission and distribution network reinforcement requirements. The project is one of six STORY demonstrators and is led by B9 Energy.

The demonstration unit is installed at the 33/11 kV Bishopscourt central substation, which is connected to a large solar PV installation. Two other distributed generators, a tidal turbine and a wind turbine, are connected to the 11-kV network, as are 300 houses and a fish factory. The CAES unit takes electricity from the grid to drive a compressor that stores the compressed air in above-the-ground air storage cylinders. The heat released during compression is recovered and stored in molten salt tanks. When electricity is needed for export, the compressed air is directed through an expander with heat injection from the heat store to drive a generator. The area occupied by the unit is rather compact, about 20 m by 20 m, including the control room, but excluding space for access and parking.

Source: horizon2020-story.eu and presentation by John Harrison (B9 Energy) at the November seminar

1.4 Alternatives to storage

The growing share of intermittent renewable energy sources in the energy mix increases the flexibility requirements of the grid. Energy storage, as we shall discuss further below, offers many opportunities, however, it is but one way to provide flexibility to the system, in addition to grid extension, flexible conventional generation and demand side management.



Source: adapted from EASE

Grid extension used to be a straightforward solution, but one requiring significant investments, for which there is little public support in the current social and economic climate. Flexible generation can be provided by both conventional and renewable energy sources. Today, however, flexible power generation still mainly comes from gas turbine plants, and while they are currently being used effectively to provide balancing services, there are concerns about their sustainability. Energy storage, grid extension and flexible conventional generation are all supply-side sources of flexibility, adjusting the amount of electricity provided to the grid to match demand. In contrast, demand-side management is a method of adjusting electricity usage according to availability by having users change their electricity consumption pattern in response to automated signals or incentives provided by the network operator. Demand-side management has been around for quite a while now and although it is designed to relieve and help balance the grid, it has yet to demonstrate its full potential.

Each having their pros and cons, these four solutions are to some extent complementary and the flexibility issue will need to be addressed by a combination of two or more of them. Only time will tell which of the four, if any, will prevail. A lot will depend on the evolution of the costs involved. It is also worth pointing out that different countries have different views on the issue (see section **Error! Reference source not found.**).

Takeaways

- The increasing share of intermittent renewables also increases the flexibility requirements of the electricity system.
- Energy storage is not limited to batteries. There are several storage technologies available, each with their pros and cons.
- Storage is one of four complementary solutions to increase flexibility in the electricity system.

1.5 Challenges and opportunities

The business case for energy storage obviously depends on its economic viability. Even so, this is not the only factor to consider. In assessing the potential of energy storage, we should look beyond the cost-benefit analysis. Public opinion, for example, is notoriously crude and unforgiving and can make or break an innovation. Moreover, social and geopolitical motives are equally important drivers for the development and adoption of energy storage solutions. And finally, we should not lose sight of any issues because, as always, there is a flip side to the coin. In this section we discuss Tesla's powerwall proposition for home and industry, possibilities of storage for developing countries, the option to leverage storage as a strategic reserve in developed countries, and the main challenges that storage faces such as raw materials and supply chain, end of life and safety issues.

1.5.1 Public opinion: The Musk factor

On 1 May 2015 Tesla CEO Elon Musk caused quite a stir. His Tesla Energy keynote had editors waxing lyrical, sending social media into overdrive. In what some have labelled a TED-style talk, while others likened it to a Steve Jobs performance, Musk launched the Powerwall and Powerpack batteries for residential and utility use[7]. Yet, rather than selling a product, he was painting a vision of a brave new battery-powered world, promising a fundamental transformation in how energy is delivered across the Earth. And because people do not buy products but solutions, he put his finger on the problem: batteries are riddled with issues. They are still rather expensive, inefficient, unscalable and, not least, unappealing – no one would dream of putting standard batteries in their living room. The Tesla Powerwall showed once and for all that batteries too can be attractive. But is a radical transition to

[7] https://www.youtube.com/watch?v=NvCIhn7_FXI

renewable energy feasible? With simple mathematics Musk argued it is: 160 million Powerpacks providing 16,000 GWh are enough to transition the entire electricity production in the US. With 900 million Powerpacks the entire world's electricity generation could be made renewable and primarily from solar PV panels. Transitioning not only electricity generation but also transport and heating to renewables would require 2 billion Powerpacks. Does this seem excessive? Considering there are almost as many cars and trucks on the road worldwide, Musk for one concluded that 2 billion is not the astronomical amount it sounds.

Feasible or not, one thing is certain: the great merit of inspiring and persuasive presentations like this one is that they manage to win the public support, even enthusiasm, for battery technology. Who knows, perhaps one day a Powerwall will be as desirable as the next iPhone.

Box 3: FlexGrid uses AI to accelerate universal energy access

FlexGrid is a social enterprise that brings electricity to isolated rural areas in Sub-Saharan Africa where connection to the medium- or high-voltage grid is not yet possible. The FlexGrid solution combines the simplicity of home solar systems with the power of traditional minigrids. Vlerick students helped develop the financial plan to attract investors, which resulted in financial support from the European Commission's Electrification Financing Initiative, ElectriFI.

As simple as home solar systems may be, they lack range and cannot be extended. Traditional minigrids with modules combined and controlled using a master-slave configuration require complex engineering and maintenance and are difficult to scale up. Moreover, if one of its components fails, the system fails. Because neither of these systems is a viable option, FlexGrid developed a radically new approach: a grid with a fully decentralised architecture, enabled by swarm intelligence.

Swarm intelligence is artificial intelligence inspired by a trait found in nature, e.g. in a school of fish, a flock of birds, a colony of ants or a beehive. Individuals in these communities can only perform a limited set of actions, but together they are capable of solving complex problems, efficiently, without there being a central control organism.

A FlexGrid is made up of interconnected power hubs that consist of one or more power units, i.e. portable solar panel powered batteries delivering 230 V AC, fitted with swarm technology developed by award-winning Swiss company Power-Blox. There is no central steering. Each power unit operates independently, while communicating with other power units. If one power unit fails, the others take over. Adding new power units is as easy as playing with Lego: the extra unit is plugged in and the system configures itself, without service interruption. In short: a FlexGrid is an autonomous, self-learning system that requires no engineering, configuration or maintenance and that can be extended endlessly.

The commercial business model is tailored to low-income households: there are no subscription or fixed usage fees and no minimum consumption constraints. Consumers buy credits via their mobile phones, providing them access to the full power of the FlexGrid. This pay-as-you-consume model is ideal as 70-80% of African households cannot afford regular electricity supply. Performance of the grid and consumer demand are monitored 24/7 via the cloud. The biggest advantage by far of a FlexGrid is that, as the name says, it is flexible. As a truly demand-driven system, it makes it possible to start small, with a substantially lower upfront investment, and grow organically, based on demand. This avoids the risks of both overinvestment and underinvestment.

The pilot project was set up in Zantiguila, 60 km south-east of Bamako, Mali, where a FlexGrid made up of 14 power units provides 70 households with a 3.5 kWp solar PV system and 16.8 kWh storage capacity. In the course of 2019 FlexGrids will be installed in 7 villages in Mali, Burkina Faso and Rwanda to supply 400 households with electricity.

Source: www.flex-grid.com

1.5.2 Developing countries

Autonomous minigrids play an important part in the electrification of rural areas where the electricity infrastructure is non-existent. Minigrids can be located closer to the demand, resulting in lower transmission and distribution costs. Those based on renewable energy sources, such as solar power and wind, have the added advantage of not being dependent on fossil fuel availability. However, for minigrids without a diesel generator as a backup, some form of energy storage is vital to ensure electricity supply security. While economically developed countries can choose from and combine different flexibility solutions (see Box 2), most developing countries do not have this luxury of choice. Their first priority is to increase mere access to electricity in order to enhance socio-economic development.

An inspiring case study illustrating the advantages of a flexible minigrid and the necessity of energy storage technology in developing countries is that of FlexGrid, providing electricity to low-income households and small businesses in Sub-Saharan Africa (see Box 3). This social enterprise has developed an innovative minigrid architecture based on artificial intelligence, combining solar PV panels and batteries. The result is a highly modular system ensuring electricity supply security at a lower upfront investment cost per connected user.

1.5.3 Strategic reserves

Despite their carbon footprint being smaller than that of coal plants, gas plants are frowned upon and considered a technology that should be phased out. Be that as it may, we should be wary of throwing the baby with the bathwater. Indeed, P2G technology has the potential to address the energy flexibility challenges (see **Error! Reference source not found.**) and could make good use of the existing gas infrastructure. The EU currently has more underground storage capacity in place than needed, which puts margins in the gas storage business under pressure. In the September 2018 issue of the OIES Quarterly Gas Review, senior research fellow Thierry Bros argues this underground gas storage should be treated as a strategic opportunity. Storage could significantly contribute to security of supply thus swaying public political opinion.

Considering the major natural gas consuming regions, the EU is frontrunner with underground gas storage facilities covering 26% of its gas demand[8], compared with 18% for the US and Russia and 5% for China. Having been a major net importer of gas for many years, mainly from Russia, Europe has developed a gas infrastructure with more underground storage capacity than the other net importers, the US and China. The combination of surplus EU and Ukrainian storage capacity and surplus Russian export potential could result in the EU becoming a global storage provider for gas, ensuring security of supply to the EU and other countries, especially China. As Bros points out, the main obstacle is the 2009 Council Directive 2009/119/EC, which imposes an obligation on Member States to maintain minimum stocks of crude oil and/or petroleum products – an obligation defined at a time when oil was more relevant than it is today. His advice is to rescind the strategic oil storage obligation and replace it with an energy storage obligation allowing all energy sources (oil, gas, water and electricity) and storage technologies to compete on an equal footing.

Although not a mainstream idea yet, it is one EU commissioners and other EU politicians are very inclined to entertain. With the EU having few natural resources, the political appeal of a strategic energy storage asset is obvious.

[8] This number refers to the EU and Ukraine

1.5.4 Raw materials and supply chain

Most commercial lithium-ion batteries contain cobalt, an increasingly scarce precious metal. Over the past two years, the price of cobalt has quadrupled. As the demand for lithium-ion batteries will continue to increase, battery manufacturers are looking for ways to reduce the cobalt content. Scarcity and price are, however, not the only reason to change tack. Cobalt is primarily mined in the Democratic Republic of Congo, a politically instable country. More importantly, it is mined by children working in dangerous conditions and battery manufacturers no longer want to be associated with child labour.

In May 2018, Panasonic, Tesla’s battery cell supplier, announced it is aiming to develop cobalt-free automotive batteries in the near future, having already cut down on cobalt usage. Reducing the cobalt content is first and foremost a technical challenge: lithium iron phosphate, lithium manganese oxide and lithium titanate batteries are cobalt-free, but their energy density is lower than that of lithium nickel manganese cobalt oxide or lithium nickel cobalt aluminium oxide cells. As the saying goes: every challenge comes with opportunities, and this one is no exception. Lithium iron phosphate batteries, for example, are said to be safer, having a cycle life similar to that of lithium nickel manganese cobalt oxide batteries and several manufacturers already offer them for storage applications. Researchers also continue to develop alternatives to lithium-ion battery technology altogether, such as flow batteries. Unlike conventional batteries, flow batteries keep electrodes and electrolytes separate, with energy being stored in electrolyte tanks that can be any size. As a result, flow batteries can store and discharge larger amounts of energy, in a safer and more durable way than their lithium-ion counterparts. Finally, organic flow batteries would even do away with the metal-containing electrolytes. Ongoing research is looking into quinones, organic compounds, as an alternative. The lifetime of these organic batteries is still an issue, though.

1.5.5 End-of-life

Despite considerable effort being put into increasing the longevity of batteries, they do have a finite lifespan. While recycling seems the obvious solution, there are technical and economic limitations that risk undermining its business case.

Recycling is considered beneficial for the environment, but the recycling process is not without problems as the chemicals used in batteries are hazardous, exposing those handling them to significant health and safety risks. Recycling also suffers from diminishing returns as the quality of the extracted materials degrades with every recycling cycle. Moreover, due to battery manufacturers investing in ways to reduce the use of certain raw materials (see above), there are increasingly fewer high-value materials worth extracting. In any case, sooner or later, we must deal with the end-of-life issue. Public opinion so far has turned a blind eye to the West using developing countries as its dumping ground for electronic waste, but for how much longer?

1.5.6 Safety

Increasingly more household and handheld devices are powered with batteries, which from time to time malfunction. And when they do, they tend to make it to the headlines. The Samsung Galaxy Note 7 is one of the most mediatised cases. Less than a month after its launch in 2016, production was discontinued following a worldwide recall due to several incidents with the phone’s battery catching fire. Exploding phone batteries are hardly ever completely out of the news, competing for attention with defective batteries in smart watches, laptops and e-cigarettes. Malfunctioning batteries are not limited to those in handheld devices either. Again in 2016, the US Consumer Product and Safety Commission issued recall notices against several manufacturers and retailers for more than half a million hoverboards after at least 99 incidents had been reported of injuries and material damage due to the battery packs overheating. And every Tesla car battery catching fire, spontaneously or after a car crash, continues to be big news, even if no one was injured.

If safety issues with small to medium-sized batteries are enough to provoke public anxiety, then what about large storage batteries? Incidents with small batteries reflect negatively on the entire battery industry. Moreover, it is not as if there have not been issues yet. In 2012 the 30 MW Kahuku wind farm in Hawaii suffered more than USD 30 million worth of damage when the 15 MW storage battery caught fire. It appears this event is the reason why insurers are still reluctant to cover battery storage assets.

Takeaways

- It is important to create public support for energy storage and storage technologies.
- In developing countries energy storage can mean the difference between electricity and no electricity.
- Gas storage should be treated as a strategic opportunity.
- Issues arousing public concern, even though they are mainly related to battery storage technology, may affect acceptance of storage technology in general.

1.6 The impact of regulation on the business case for storage

Technologies and business models do not exist in a vacuum. Regulation in particular is known to shape their development. Ranging from market design and tariffs to fiscal stimuli and subsidies, each form of regulation has a different impact on the business case for storage. Regulation affects the business case when it defines what market products storage has access to, what tariffs storage owners face, and what support incentives are available to investors.

1.6.1 Market design

Energy storage cannot be reduced to a single technology or application. Between pumped hydro storage, prototypical of long-duration storage and fast-acting batteries there is an entire range of technologies with different properties and characteristics rendering energy storage extremely versatile. Not only is it essential in the integration of intermittent renewables and conventional energy sources, it can play a role in any energy market – the wholesale and the balancing markets, as well as proving services to both the transmission and the distribution grid to ensure efficient, stable and reliable grid operation (e.g. transmission and distribution investment deferral, voltage control, congestion relief, black start capacity etc.). A case in point is the demonstration project undertaken by UK Power Networks near the town of Leighton Buzzard in South East England, where a multi-purpose grid-connected battery storage system performed peak-shaving services as and when required, while any remaining capacity could be used for other grid services (see Box 4).

While in principle energy storage devices can provide different services across all levels of the energy system, market design is such that there are several unintended barriers to their deployment. Technical access requirements for regulated markets are not yet adapted to the current context, but stem from a time when there were clearly distinguished roles, i.e. (1) generation, (2) transmission and distribution and (3) consumption. Energy storage devices do not fall into a single category, acting as both generators and consumers. Grid connection requirements, for example, also fail to take into account the presence of energy storage, with the exception of the long-standing pumped hydro installations. This is apparent in product definitions imposing minimum bid sizes and contracting periods that are out of reach for battery systems.

Researchers from TU Delft University and the Austrian Institute of Technology developed a detailed assessment framework mapping the barriers to entry of distributed energy sources, including storage, in the balancing market[9] while comparing the situations in Austria, Germany and the Netherlands. Based on their analysis they proposed a stepwise approach to adapting the balancing market design in order to enable storage technologies to compete on a level playing field against other flexibility providers. First of all, formal access requirements excluding distributed energy sources from participation should be removed. Flexible pooling conditions and separate capacity and energy markets need to be addressed next as they have an impact on most other variables. Extended pooling options, for example, help to reach the required minimum bid size and to comply with longer contracting periods, while splitting balancing capacity and balancing energy markets is necessary in order to be able to reduce bidding frequency – auction configuration variables which, once adapted, will increase competition between different service providers.

The extent to which energy storage can participate in the different markets and services depends on the regulatory framework, in which market design and tariffs (see **Error! Reference source not found.**) play an equally important part. For the business case to be robust, any regulatory framework should enable revenue stacking, i.e. energy storage providers should be allowed to tap into all possible sources of income, providing a combination of services in order to maximise the value of their storage facility. Such multiple service business models require a regulatory framework in which an entity can engage in both regulated and non-regulated activities.

Moreover, grid fees and tariffs should take into account the value provided by energy storage. Short-duration technologies, such as batteries, can respond to frequency imbalances in a matter of milliseconds, but have a limited service time compared to long-duration technologies, such as pumped hydro and P2G, which can be used to address weekly, monthly and seasonal imbalances. Each technology has its merits and strengths and their remuneration should reflect the value provided to the system. Unfortunately, at EU level, the value of some technologies' exceptionally fast reaction time is not yet recognised, and fast-acting energy storage devices are remunerated at the same rates as slower-reacting ones. This is not the case in the US, where already in 2011, the US Federal Energy Regulation Commission issued order 755 on frequency regulation compensation in the organized wholesale power markets, which requires system operators to add a performance payment with an accuracy adjustment to the capacity payment typically used in markets for ancillary services. In 2016 it issued order 825 on settlement intervals and shortage pricing, requiring that each regional transmission organisation and independent system operator align settlement and dispatch intervals[10] and trigger shortage pricing for any interval in which a shortage of energy or operating reserves is indicated during the pricing of resources for that interval. These pay-for-performance schemes are aimed at providing appropriate incentives for resource performance, encouraging fast responding units to participate in frequency regulation.

While this may all sound straightforward, the energy storage sector is well aware of the challenges: in a fast-changing technological context it has become increasingly difficult to develop policy and regulation. However, precisely because it is almost impossible to predict and anticipate technological

[9] Poplavskaya, K; de Vries, L. (2018) "Impact of balancing market design on business case for storage"

[10] Order 825 requires that each regional transmission organisation and independent system operator align settlement and dispatch intervals by: (1) settling energy transactions in its real-time markets at the same time interval it dispatches energy; (2) settling operating reserves transactions in its real-time markets at the same time interval it prices operating reserves; and (3) settling intertie transactions in the same time interval it schedules intertie transactions.

Box 4: The SNS project defers grid reinforcement while making the business case for revenue stacking

The Smarter Network Storage (SNS) project was a pioneering demonstration project to analyse how grid scale battery storage could be used as an alternative to distribution network reinforcement while also being used for a range of other services in different business models. Running from 2013 to 2016 it was largely funded by Ofgem’s Low Carbon Network Fund. Additional funding was provided by UK Power Networks and other project partners.

The primary substation near Leighton Buzzard, in South East England, was chosen as the site for this project. At times, peak demands at the substation exceeded the installed capacity. The conventional solution would be to install additional capacity. While solving the constraint, a reinforcement project would have a lead time of up to 4 years and the installed capacity would remain mainly underutilised until demand caught up with supply. A 6 MW/10 MWh battery storage system was designed to provide peak shaving for 1.5 hours to provide appropriate network support during the forecasted winter peaks. The system was built, operated and maintained by UK Power Networks, who also owned the facility. Construction was completed in 12 months, with the site being commissioned in December 2014, 2 years earlier than would have been the case for network reinforcement.

A storage scheduling and dispatch optimiser system was developed and tested to enable the use of the battery facility for other services during off-peak periods, which would help monetise the value of the facility over and above what peak shaving services could provide. Based on historic customer electricity demand, scheduled network outages etcetera, this system determines the optimised scheduling and dispatch of the storage facility, with priority given to network security, i.e. the schedule ensures that the storage system is available to support the local network by providing peak shaving when required, while for the remaining time it provides the most profitable services. Subsequently, UK Power Networks trialled various other services that could be provided, not only to evaluate their feasibility, but also to demonstrate how revenue from multiple services could be stacked to achieve the optimum business case. In addition to providing peak shaving services, the facility experimented with ancillary services, such as reactive power support, voltage control, frequency response, short-term operating reserve, TRIAD support and capacity market participation. They also simulated different business and ownership models.

The project delivered on all accounts, performing peak shaving services as intended while successfully deferring grid reinforcement. The trials showed that SNS could technically deliver all of the tested services individually and some simultaneously through the concurrent use of active and reactive power, e.g. reactive power support and frequency response services, which require active power. It also showed that revenues from peak shaving alone were insufficient and that a viable business case would rely on various ancillary services. At the time of the project, frequency response provided the highest revenue.

Source: UK Power Networks Smarter Network Storage Close-Down Report

developments, it is all the more important to ensure that the new EU network codes[11], for example, do not introduce any additional barriers to entry in any of the regulated markets, i.e. the wholesale, the balancing and the ancillary services markets. However legitimate and understandable this demand for investment certainty may be, it remains to be seen if and how it could be satisfied without compromising the level playing field.

[11] Rules governing grid connections, markets and system operation, designed to provide a sustainable, secure and competitive electricity market across the EU.

1.6.2 Tariffs

Consumer electricity bills in capital cities across the EU broadly consist of (1) energy costs, (2) network charges, (3) charges for renewable energy sources (RES charges) and (4) other taxes and charges and VAT. In 2017 energy costs represented on average 35% of the bill; this portion has been steadily decreasing since 2012, when it was 41%. By contrast, the share of RES charges has more than doubled from 6% in 2012 to 14% in 2017. The portion of network charges during the same period remained relatively stable at 27%, mostly distribution grid charges[12].

These grid charges or grid tariffs are designed to recover grid operating costs, i.e. running costs and investments. Historically, DSOs in many countries, including Belgium, apply volumetric tariffs or fees based on the amount of electricity drawn from the grid. Although big consumers do not necessarily cause more costs, volumetric distribution network tariffs were considered adequate enough and, equally important, perceived to be fair – the more affluent consumers who are likely to use more electricity, paying higher network contributions. With the uptake of solar PV panels this logic no longer held true. The use of volumetric distribution network charges with net metering resulted in solar PV panel owners paying significantly less than consumers who could not afford to invest in solar panels, all the while continuing to rely on the grid. All of a sudden, volumetric tariffs no longer seemed fair, which triggered the debate about how to change distribution network charges.

A temptingly simple approach is to charge for peak consumption. Solar panels generate most energy during the day, while their owners, like all other retail consumers, tend to use most of their electricity in the evenings, i.e. their peak consumption has not really changed. Moreover, this peak consumption is one of the most important drivers of network costs as the grid size is determined by system peak demand. This solution, as easy as it may seem, is not flawless: individual peak consumption does not necessarily coincide with system peak usage and tariffs therefore would need to send different signals at different locations and times.

In today's energy landscape with solar PV panels and batteries, it is crucial to bear in mind that grid tariffs can have unintended adverse effects on an individual consumer's investment decisions and, by extension, on the business case for home battery storage. Volumetric distribution network charges with net metering provide no incentive whatsoever for solar panel owners to invest in batteries as the grid acts as a free battery they can use at their own discretion. They can inject their excess power into the grid, free of charge, draw electricity when needed and pay only for their net consumption, if any. Conversely, grid tariffs based on peak consumption may over incentivise solar panel owners to invest in home batteries in order to avoid network charges. Moreover, in both scenarios the grid costs are being passed on to consumers without solar panels and/or batteries.

Obviously, grid tariffs not only have an impact on the business case for storage in a consumer context, they are also relevant on an industrial scale. As a study by EASE showed[13], grid tariffs imposed on utility-scale energy storage systems like pumped hydro vary significantly across EU Member States. As a result, investment in pumped hydro storage is most likely driven by tariff considerations rather than by geological or topographical suitability and local needs. A harmonisation of grid fees would ensure a fairer competition between storage providers.

[12] Source: ACER/CEER - Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2017 - Electricity and Gas Retail Markets Volume

[13] Source: EASE Position on Energy Storage Deployment Hampered by Grid Charges, 2017

1.6.3 Support Incentives

Most of the energy storage technologies discussed in this paper are still emerging or developing and therefore not yet economically viable, which means they could benefit from some form of regulatory support. Regulatory support being a highly political choice, it is expected to differ across the world.

If the EU's ambitious target of 32% renewables by 2030 is to be met, our energy system will have to tap into much-needed sources of flexibility. Determined to leave all the options open, the EU does not want to favour one source of flexibility over the other - energy storage, grid extension, flexible conventional generation and demand side management. Nevertheless, what is clear is that energy storage will be an indispensable part of the mix to ensure the effective integration of intermittent renewable energy sources while maintain grid stability. For energy storage to play any role at all, be it in the wholesale, the balancing, or the ancillary services market, it is therefore essential that barriers to entry should be removed. However, although market design changes may help to overcome certain obstacles, they are not enough to make the business case viable. Similarly, appropriate tariffs are *a sine qua non*, but not sufficient as such.

While the EU has subsidised renewables to achieve certain targets, it is not inclined to do the same for storage. Subsidies have enabled renewable technologies to grow and achieve economies of scale, resulting in solar and wind energy becoming cheaper. As far as energy storage is concerned, the EU seems to be banking on R&D support programmes, hoping innovation alone will help to further reduce the costs of storage technologies.

The US has taken a different stance. Rather than wait for the costs of storage to drop in order to achieve economies of scale, it has set targets for energy storage, granting subsidies to support those targets, similarly to its policy on renewables. Admittedly, there is no federal policy yet, but several states have already imposed energy storage deployment targets and in others target processes are underway. Moreover, the US Federal Energy Regulation Commission has a track record of issuing orders in favour of energy storage (see also **Error! Reference source not found.**), the most recent one being order 841, issued in February 2018, which commands to create participation models for energy storage across the country in order to remove barriers to participation of electric storage resources in the capacity, energy and ancillary services markets operated by regional transmission organisations and independent system operators.

Takeaways

- The extent to which energy storage can participate in the different markets and services depends on the regulatory framework in which market design and tariffs play an equally important part.
- While the EU has set ambitious targets for renewable energy it is also a strong proponent of the idea that grid flexibility can and should be achieved in various ways, considering energy storage to be but one of several possible solutions. Contrary to the US it has not yet set out a clear vision on energy storage with regards to market design and policy support.

1.7 My take

"Energy storage is increasingly recognised as one of the essential technologies that will enable the transition to a decarbonised energy system. We need to work hard now to get the regulatory framework for storage just right – otherwise we risk missing out on the enormous potential of energy storage."

- *Patrick Clerens, Secretary General, EASE*

"Individual residential batteries are seldom the way to go. Issues with safety, in-house emissions as well as safety aspects for firefighters, are to be taken serious: battery technology, but just as well the effective installation and coupling need more attention. Leveraging the storage capacity to a neighbourhood level has several advantages, overall smaller storage capacity compared to individual assets, potential for power quality improvements at a larger scale and the easier and less expensive inclusion for aggregation are just a few. Furthermore, tackling interoperability for 1 device is less effort compared to doing it for a number of individual and tailor-made set ups.

While safety and availability pose one challenge, an important aspect to be taken into account is information provision in a way that is understandable for the different stakeholders, e.g. permitting bodies are not used to terminology as power quality, energy markets, phase balancing and curtailment. We will only enable a roll out of storage at large if we manage to communicate in a multitude of languages."

- *Leen Peeters, STORY Technical Coordinator, Think- E*

"New regulatory framework is necessary for the effective roll-out of storages, but it needs to be carefully designed, to not lead to unintended effects on the market."

- *Mia Ala-Juusela, STORY Project Coordinator, VTT*

The STORY Project

STORY is a European project researching new energy storage technologies and their benefits in distribution systems and involves 18 Partner Institutions in 7 different European countries. Integrating large amounts of renewable energy into the grid poses a big challenge for the energy industry. This project answers a fundamental question to face the renewable energy challenge: what if a large amount of storage is integrated in the distribution grid?

To answer this question the STORY project aims to:

- Develop and demonstrate new ways to use storage in different sites.
- Analyse the impact of large-scale rollout of the demonstrated technologies.
- Develop various business model archetypes and determine the required policy and regulatory framework supporting them.

STORY presents 6 different demonstration cases with different local and small-scale storage concepts and technologies, covering industrial and residential environments. These 6 cases feed into a large-scale impact assessment. The assessment considers challenges to the grid infrastructure, and the impact on the integration of local decentralised and large-scale centralised renewable energy sources. STORY ensures critical opinions of the stakeholders – including business, policy, research communities and civil society – are integrated throughout the process, through a series of workshops, in order to maximise the project's long-term impact. [14]

Demonstration of a multi-energy grid in an industrial area
Olen, Belgium

Demonstration of medium-scale battery
Suha, Slovenia, Kranj

Demonstration of storage in residential district
Lecale, Northern Ireland

Demonstration Li-ion battery installed in industrial zone
Navarra, Spain

Demonstration at residential neighbourhood scale
Oud-Heverlee, Belgium

Demonstration at residential building scale
Oud-Heverlee, Belgium

[14] This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426.

1.8 Further Reading

The following papers were presented at the November seminar:

Berger, M; Radu, D; Fonteneau, R; Ernst, D; Deschuyteneer, T; Detienne, G. (2018) “Centralised Planning of National Integrated Energy System with Power-to-Gas and Gas Storages”

Borne, O; Petit, M; Perez, Y. (2018) “Net-Present-Value Analysis for Bidirectional EV Chargers Providing Frequency Containment Reserve”

Govaerts, N; Bruninx, K; Le Cadre, H; Meeus, L; Delarue, E.(2018) “Spillover Effects of Distribution Grid Tariffs in the Internal Electricity Market: an Argument for Harmonization?”

Poplavskaya, K; de Vries, L. (2018) “Impact of balancing market design on business case for storage”

Schillemans, A; De Vivero Serrano, G; Bruninx, K. (2018) “Strategic Participation of Merchant Energy Storage in Joint Energy-Reserve and Balancing Markets”

Schittekatte, T. (2018) ”On the interaction between distribution network tariff design and the business case for storage”

IRENA, IEA-ETSAP (2013) “Thermal Energy Storage, Technology Brief”.