Centre international de formation européenne

Energy Storage Policies and its Transformational Role in EU's Energy Paradigm Shift

Master Thesis

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Abstract

Sustainable development in the realm of energy is becoming lesser of a choice and more of a need and one cannot address sustainability without the notion of renewable energy sources. However, due to intermittency of renewable energies, EU's energy paradigm shift cannot be fulfilled without the implementation of energy storage. Energy storage technologies will be the hardware that allows the integration of renewables whilst at the same time, be the pillar of strength in stabilising EU's energy system. Therefore, energy storage is the key component needed to thrust EU's transformation into a low carbon economy. Nevertheless, the lack or almost non-existent policies pose as a barrier in preventing the deployment of energy storage. This paper aims to understand the role of energy storage technologies and then to critically analyse how the lack of policies hamper the practicability of energy storage in EU's energy paradigm shift. There is one caveat however, energy storage is still at its birthing stage of deployment in the EU and therefore there is a limitation on the data available. Moreover the available data will be based on a short time-scale which may not be entirely precise in providing an analysis. However so, this paper aims to analyse the extent to which energy storage policies are needed and could be implemented.

Keywords

Energy Storage, European Union, renewable energy sources (RES), greenhouse gas emissions (GHG), climate change, energy transition, technologies,

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Introduction

Energy storage will be the future's essence of life. This is because, the quality of life more often than none depends on energy. The way most people live their lives today, their standard of living is based on an incessant supply of energy. Humans are unconscious for the need of energy as it has, for many eras been an intrinsic component for survival. The importance of energy has only grown through every civilisation, however, the dependence and decisions of energy made by humans have impacted the earth. Natural disasters, extinction of living organisms and health implications have opened the eyes of many to understand that it is now more than ever important to take actions to help preserve what we have left of our environment. Therefore, there is a paradigm shift taking place globally acknowledging the need to shift to more sustainable standards of living and this includes being environmentally conscious of the energy that we produce and consume. Renewable energy sources are starting to gain importance however the unpredictability of this resource has made it unaccountable. This is why, the future will depend on energy storage as the fundamental core of allowing sustainable development.

Background of Thesis

The phenomenon of climate change has plagued the earth and over the past decades, the ecological impacts have been increasing. This has caused the earth's temperature to warm up by 0.6℃ over the past 100 years (Walther, et al., 2002). However the rate of warming has doubled only in the recent years and this has caused for a revolution with global efforts pushing for environmental protection. Although some may claim climate change to be a mere myth, there is still a majority of consensus embracing the necessity to combat climate change and this is mainly because global warming in general owes its increase in temperature to anthropogenic emissions. Carbon Dioxide (CO_2), Nitrous Oxide (NO_2) and Methane (CH_4) are the most common greenhouse gasses contributing to climate change and all of which have been directly linked to human activities. COP (Conference of Parties) summits are shifting its focus onto significantly reducing greenhouse gas emissions (GHG) and stabilising temperature change. One of the main ways that have been identified to reduce emissions and stabilise temperature is by enhancing the efficiency of energy.

Climate change and energy are undisputedly intertwined. According to Goodman and Marshall (2018), climate change is induced by the patterns of production, politics and even the technology of energy. In fact, as noted by Mgbemene, et al. (2016), global warming is a by-product of the industrial revolution. Prior to the industrial revolution, climate change was caused by natural occurrences but as Lavelle (2017) highlights, a substantial amount of evidence has indicated that fossil fuels especially coal that was used to develop industries have contributed to the climate in very negative ways. Being that Europe was at the heart of the industrial revolution, many argue that the countries within this continent have contributed greatly to the greenhouse gas emissions.

The industrial revolution that occurred in Europe marked the emergence of a modern capitalist economy. As underlined by Fernihough and O'Rourke (2014), this economic transition was above all else dependent on coal. Coal was the single most important resource but due to the world wars, there was a dire insufficiency of it. The fear of competition leading to another world war led to the "supranationalisation" and creation of the European Union (EU). Unrefuted of its past, the EU today has taken responsibility to significantly reduce emissions. Having said that, there is a deeper threat that is forcing this supranational to be proactive in combating climate change.

According to a study conducted, the European and northern hemisphere are irrefutably warming at a faster rate as compared the rest of the world (Neslen, 2017). In Europe for example, temperature increase have soared the levels of glacier-melting whilst the areas of the Mediterranean are facing extreme heat waves causing droughts and disrupting Europe's food production (Berwyn, 2017). This is fundamental, as according to European Commission (2016), Europe is an important supplier that contributes greatly to the global food security and therefore even though it is essentially a worldwide phenomenon, the effects of global warming in some nations could have a higher detrimental domino effect globally. Due to this detrimental impacts, the paper will sought to focus on the European Union.

The EU's principle of "leading by example" has thrusted them to become one of the prominent global leaders of climate change. In order to do so, the EU has set binding targets to ensure GHG emission reduction and one of the main ways to achieve this target is by introducing and integrating renewable energy sources (RES). As acknowledged by Nitsch, et al. (2004), the EU has taken into account the need to foster renewable energies in Europe to reduce its emission pollutants at both a local and global scale. Renewable energies are a clean source of energy but is intermittent and highly unpredictable. As such the desire of incorporating renewable energies are ultimately coupled with the development of sustainable energy systems that is able to support its growth.

Sustainable energy systems may be a central component of integrating renewable energy sources however, it is the technologies that form the core which allows functional efficiency. Moreover, these components are the building blocks of EU's energy paradigm shift into a low carbon economy. However, the high unpredictability and intermittency of RES and the instability of current conventional grids to incorporate multiple generation have delayed EU's transformation. As such, energy storage is definitely the key to support the integration of renewable energies and provide stability in the sustainable development of energy systems in EU's transition into a low carbon economy. As highlighted by Krajacic (2012), only renewable energies supported by energy storage can fulfil requirements of long term demand and supply. Thusly, there is no doubt that energy storage especially its technologies are the vital basis of implementing a sustainable energy system. However as pointed out by Creitaru (2008), the performance of energy storage technologies cannot be implemented nor evaluated without the novelty of concrete policies.

According to Nilsson and Wene (2001), the essence of deploying energy technologies for the use of economic and sustainable development depend on policies. The authors add on that policies help shape, execute concerted efforts that ensure deployment. Therefore, the need for energy storage in EU's energy paradigm shift may be hindered by the lack of policies. This begs for a deeper understanding and as a result, this thesis aims to answer the question of "**To what extent can energy storage policies contribute to EU's energy paradigm shift?"**

Research Questions, Motivations and Objectives

Research Questions

Before answering specifically to the thesis question of "**To what extent can energy storage policies contribute to EU's energy paradigm shift?"** there are some basic questions that needs to be answered. One of the basic question that needs to be fundamentally answered is how important is energy storage? To answer this, it is essential to understand the historical importance of energy storage. Furthermore, as aforementioned, this paper will focus on the EU, therefore, it is also important to highlight to what extent is energy storage a necessity for the EU?

The Historical Importance of Energy Storage

Since the birth of mankind, the notion of providing energy has been intrinsically insinuated. The discovery of fire by cavemen in the Palaeolithic era underlined that energy was in fact a fundamental aspect of life. As civilisations transitioned from hunting and nomadism to settlements and agriculture, the need for energy grew exponentially. However one of the biggest hurdles was the fact that these energies could not be stored and that one had to constantly replenish and seek energy resources.

The idea of energy storage is thought to be revolutionary. An idea that symbolises the evolution of the modern world. However, contrary to popular belief, the fascination of storage came about very early when ancient civilisation came up with the idea of preserving food. Ancient Egyptians would dry and compact grains in sealed pots in order to store them for long periods. This was a radical moment in history that carried significant importance as storing allowed many items to have a long life and this was essential during war. Nonetheless, the idea of retaining energy and reusing it for future use was only further developed as the civilisation grew. The most notifiable case of modern energy storage was a clay pot discovered 2,200 years ago in Iran with functioning fuel cells (Danila and Lucache, 2010). When discovered, the pot had a ramrod of iron in the middle which passed through a copper foiled tube. The use of acids such as vinegar allowed the flow of electrons from the copper tube to generate a flow a current. The alchemy of such was in fact the very first noted creation of an energy storage.

Since this discovery, it took man years to replicate such a mechanism. It was not until the 18th century that Alessandro Volta created a similar mechanism. The creation as we know today, the "photovoltaic cell" was only used in the mid-19th century to store energy. However, the most prominent usage of storage came when Camille Alphonse Faure innovated the lead acid battery which was used to light up the city of Paris electrically, for the first time ever, giving birth its name of "city of lights" (Guarnieri, 2011). This incident was critical in human history as it emphasised the importance of energy storage that exist in today's world.

The Role of Energy Storage within the EU

In the last decade, the EU has been engaged in serious discussions on how to archetypically shift its consumption to include less polluting forms of energy. EU's manifestation to environmentally correct its behaviour has analogously reemphasised the need for energy storage. This was also propelled due to EU's growing ambition to increase energy output from clean sources such as renewable energy sources. The intermittency of such resource posed a hump in its development but the ability of energy storage to store RES allows the EU to ripen its ambition. Not only that, energy storage is also necessary in stabilising grid infrastructures that are not fully equipped to comprehend the influx of RES. Additionally, pressure from social and geopolitical changes have also influenced the role of energy storage in EU's energy transition.

Energy has always been the ignition of many geopolitical debates. The more conventional energy like fossil fuels have long-standing parameters with the economic prosperity, military power and resource scarcity (Lehmann, 2017). The speculation of oil peaks coupled with the turmoil of global warming has increased the energy security concerns within the EU. This has also subsequently pushed the EU to shift its focus onto RES whereby the dependence is locally widespread and flows as opposed to being imported and limited by an exhausted stock (Johansson, 2013). For that matter, the European Commission has been pursuing efficient ways to "paradigm shift" EU's energy into a low carbon economy.

Digitalisation, decarbonisation and decentralisation are the lenses that symbolise efficiency in EU's future low carbon economy. For example, decentralisation is a concept that has sprouted the possibility energy systems to cogenerate power from both conventional and RES. This is an essential breakthrough as even though the role of fossil fuels in today's world is seemingly decreasing, it is important to remember that fossil fuels are still very much necessary in this energy transition. What differs is the extent to which fossil fuels needs to be dependent on. Therefore, energy storage will be an essential component that allows the amalgamation of conventional and renewable sources to cogenerate.

The European Commission has pressed upon the notion that in order to transition into a low carbon economy, clean technologies must be present. This is where energy storage will play a critical role, revolutionising and modifying the EU's transmission and distribution to allow better reliability of intermittent resources that are locally and abundantly available.

Research Motivations

60.3 percent of gas and 82.6 percent of oil is imported by the EU in order meet their energy needs. The dependence on imported fossil fuels are directly relative to the never ending issues of security of supply. As Maltby (2013) highlights, any enlargement may it be in demography or economy will cause a rise of more fossil fuel import dependent member states. According to the statistics released by the World Energy Outlook, with the growing demography, the EU may become more and more dependent on energy imports (See Figure 1). As such, energy storage will be an important asset in diversifying EU's energy mix as well as thrusting the supranational's paradigm shift into a low carbon economy by aiding to overcome the ongoing energy trilemma.

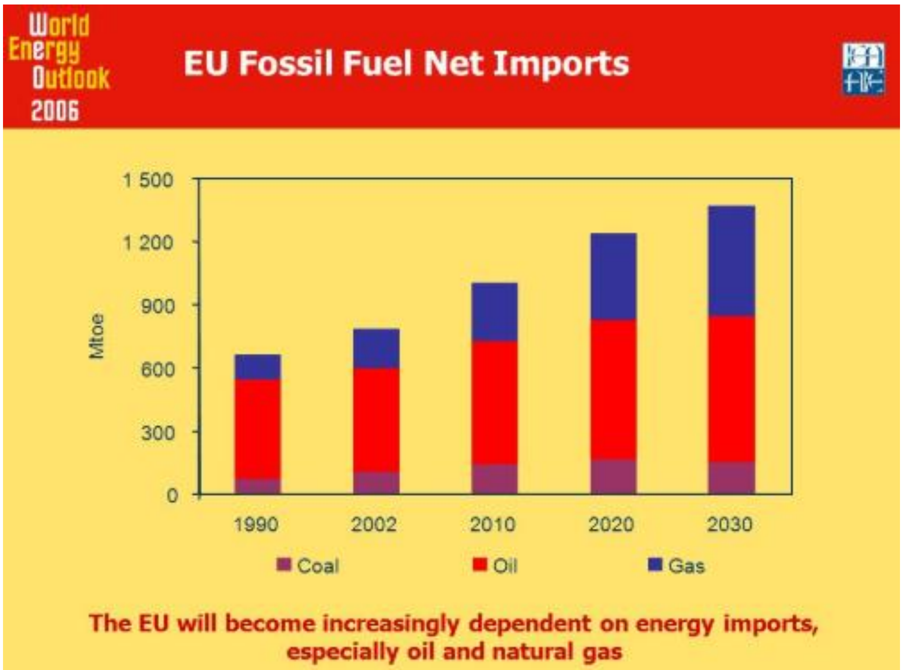

Figure 1: The Trend of Fossil Fuel Imports within the EU
Source: World Energy Outlook (Source Link)

The energy trilemma is a global cataclysm that needs urgent attention (World Energy Council, 2016). As illustrated in figure 2 below, it is the paradoxical complexity of meeting the competing demands of climate change mitigation (energy sustainability), prevention of energy poverty (energy affordability) and solidification of the security of supply (energy security). Gunningham (2013) underlines that in order to achieve a balance in the trilemma, efficient energy governance must take place.

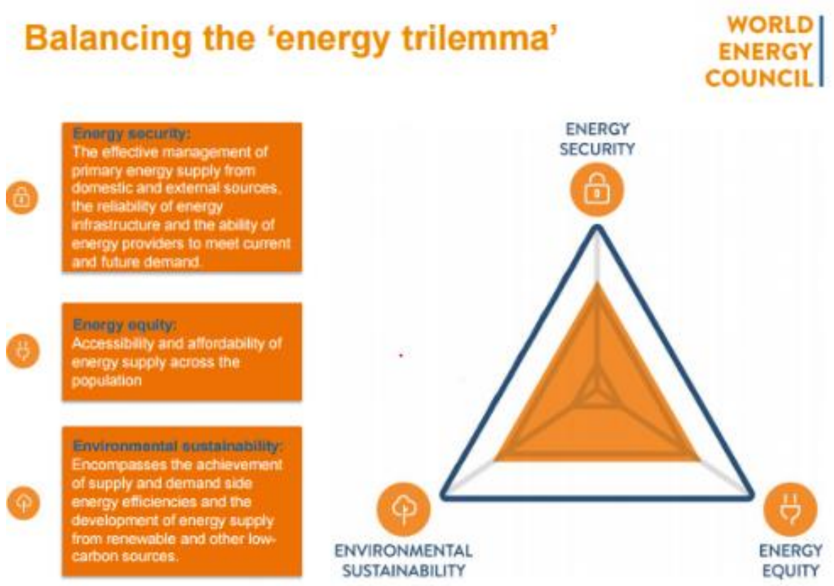

Figure 2: The Energy Trilemma
Source: World Energy Council (Source Link)

As highlighted above, the EU has set binding targets to ensure GHG emission reduction and this includes reducing emissions by 20 percent, 40 percent and up to 95 percent by 2020, 2030 and 2050 respectively. According to Rueter and Russell (2017), in order to achieve its binding targets, the EU needs to substantially reduce its energy consumption that comes from fossil fuels and replace it with alternative sources like renewable energy. As such, the EU is focussed on policies and measurements that will aid to increase the share of RES. Moreover the aim of these policies is to diversify the energy portfolio to benefit from economies of scale (energy affordability), increase the security of supply (energy security), and reduce GHG emissions (energy sustainability).

The European energy strategy is enabled through its various energy policies and directives. The *EU Directive 2001/77/EC* follows up on the 1997's *White Paper* that promotes the use of renewable energy to support the electricity sector. This directive placed a target of incorporating at least 12 percent of RES in the electricity production. This directive was repealed and *Directive 2009/28/EC* was introduced. This new directive emphasised on increasing efficiency which further promoted the use of RES. Moreover, the directive also touched upon the notion of increasing technological improvements to reduce GHG emissions and to reduce dependence on energy imports (European Parliament, 2009). This directive then became a large part of EU's *2020 Climate and Energy package* which included an Energy Strategy that emphasised the reduction of GHG emissions by 20 percent and increasing energy efficiency by 20 percent by increasing the share of RES also by 20 percent. In 2016, a *Clean Energy Package* was proposed that provisioned the need of increasing the share of renewables to 27 percent by 2030 (Cruciani, 2017). Despite all the initiatives taken, the EU is seemingly far from reducing their emissions.

Based on the statistics released by the climate action tracker below, it seems that the EU has yet to significantly reduce their emissions (See Figure 3). This is because, as underlined Apak and Atay (2013), major changes in infrastructure is needed in order to support the integration of renewable energy sources (RES). Energy storage is the "enabling" technology that allows a greater penetration of renewable energy in EU's energy sector especially in the electricity market (Denholm, et al., 2010). However in the EU, none of the policies thus far have underlined nor introduced the significant importance of energy storage. Therefore, the lack of policies act as a barrier to energy storage making it a big question mark in EU's low carbon future.

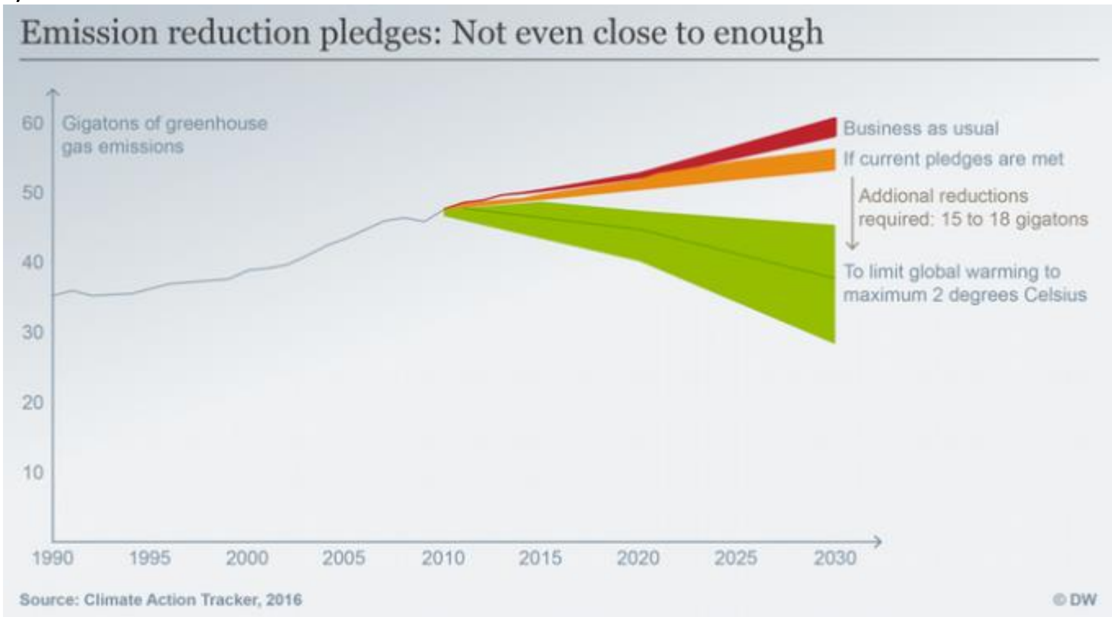

Figure 3: Emission Reduction Pledges in the EU
Source: Climate Action Tracker (Source Link)

The credibility gap that exists with the EU policies lay a conundrum that crucially intersects the deployment of energy storage. The repercussion of the lack or almost non existing energy storage policies inhibit the EU to design its market to fully capture the value of energy storage. Hong and Radcliffe (2016) reiterates this by indicating that the lack of market design have hindered the deployment of energy storage as a potential solution to EU's transition into a low carbon economy. Correspondingly, Castellano and Pollitt (2016) further emphasises that inadequate market and regulatory framework for energy storage systems in Europe are the main barriers preventing the advancements for a new energy system. Decentralisation is an essential denominator for EU's future low carbon economy and this new energy system is a mosaic consisting of a collection of interdependent technologies like energy storage. As such, the need for energy storage policies is also necessary for creating an even stronger framework of decentralised energy system policies.

An underlining objective of this thesis is to understand the extent to which the lack of energy storage policies can be detrimental for EU's energy paradigm shift. The research of this thesis will strive to prove the hypothesis that energy storage policies can make storage technologies feasible and applicable for EU's future of a low carbon economy.

Hypothesis and Significance of Research

It is definitely feasible to find energy storage technologies that is able to integrate and transform various energy sources at every given level of the power sector (generation, transmission and distribution) in order to meet demands in an environmentally, socially and economically acceptable way. The defining feasibility factor is of course the policies that govern it. This is because policies and regulatory frameworks are the pillars to which define the introduction of energy storage in the market. Thusly, it is irrefutably necessary for energy storage policies to be in place in order to make storage technologies viable.

There is no novelty to energy storage. As highlighted in the discussions above, energy storage technologies have long been in existence. However, the novelty of this thesis will highlight how energy storage technologies can foster the development of EU's energy paradigm shift into a more decentralised and decarbonised future. As a result, the significance of this thesis and research would be to highlight the importance of energy storage policies as a key enabling factor for the deployment of these technologies as well as to recommend appropriate policies that could be implemented.

Data and Constraints

There is no doubt that energy storage could help not just the EU but its member states to achieve their pledged climate change targets. Not only does energy storage provide the convenience of storing intermittent RES of energy, it also provides an array of ancillary services that will be crucial in providing stability for EU's electrification needs. The caveat at the moment however is that, for the EU, energy storage is still in its birthing stage (See Figure 4). As such, there is a limitation of data that can be provided and at the same time, these data will be based relatively on a short-time scale.

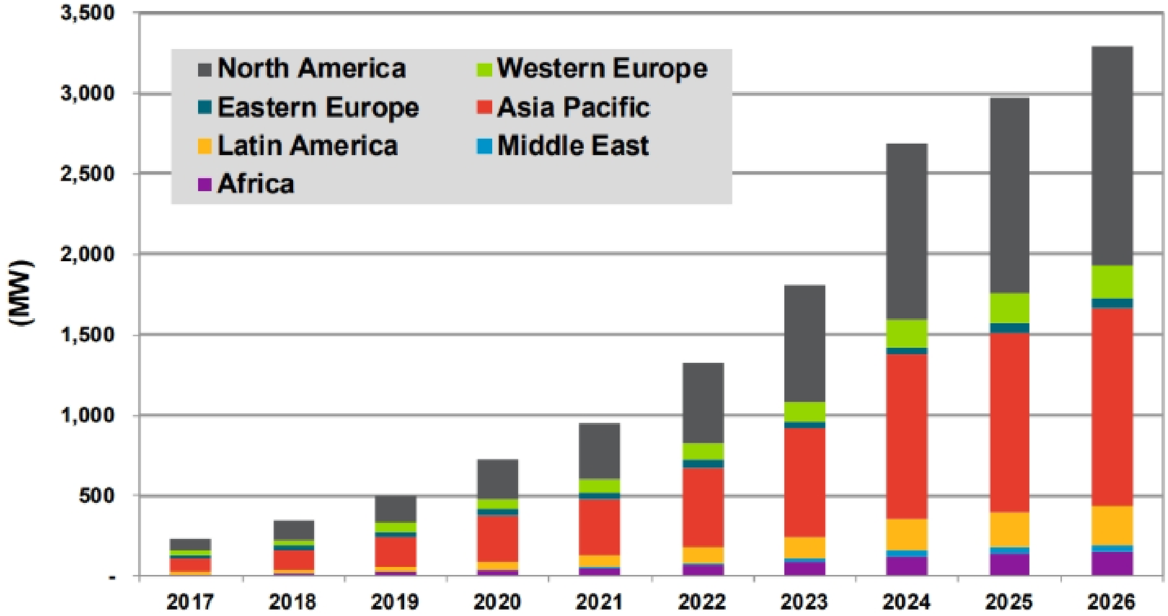

Figure 4: The Growth of Energy Storage
Source: CleanTechnica (Source Link)

Thesis Framework

The main purpose of this thesis is to enrich to the current energy and climate policies that govern the EU to include energy storage as a component and also allow for the EU to optimise the use of energy storage technologies in aiding to transform EU energy system. To do so, the paper will be structured in the following manner. Firstly, in the following chapter, the context of energy storage will underline the specific techniques to which renewable energy may be stored conveniently for a later use. In order to better comprehend this, the chapter will analytically dissect the added value of energy storage emphasising the role of its technologies in within EU's energy sector. In addition to that, this paper will also indicate the ancillary services offered by energy storage and how it could be an important tool for Europe's energy transition into a low carbon economy. Subsequently, in chapter 2, the paper will seek to evaluate the extent to which energy storage can practically penetrate the EU energy market. Correspondingly, chapter 3 will analyse the data gathered and based on the observations, proposals will made to recommend appropriate policies. Upon these, a conclusion will be drawn to answer the research question.

Chapter 1: The Added Value of Energy Storage

Over the decade, the domain of energy storage has grown continuously. This is due to the fact that there has been progressive growth with regards to the technologies surrounding energy storage. According to EASE (European Association for Storage of Energy), there have been significant developments since 2013 for energy storage technologies within the EU (EASE, 2017). These technologies allow energy storage to add value to the whole energy system (Barton and Infield, 2002). It is a crucial tool that will enable the incorporation of renewable energy by ensuring grid stability and above all else ensuring a secure and sustainable supply. Hence why, energy storage plays an immense important role in aiding the EU's goals of renewable expansion and on decarbonisation. On the contrary though, the overall deployment of energy storage has been hindered due to the lack of policies that do not allow an appropriate market design to be shaped. For that matter, the aim of this chapter is to highlight the benefit of energy storage technologies and services in adding value to the EU's energy paradigm shift.

This chapter will be organised in the following manner. The first section will provide an overview of the advancing role of energy storage technologies. Then, the following section of this chapter will acknowledge the various type of energy storage technologies that could be feasibly used in the EU.

1.1 The Advancing Role of Energy Storage Technologies

Addressing climate change has become a supranational effort. As mentioned, under the climate and energy package, the EU parliament has agreed on a target of incorporating at least 20 percent of renewable energy in its total energy consumption by 2020 (Aune, et al., 2010). Based on the statistics released by the European Commission in 2016, more than half of the EU member states have yet to reach its 2020 target (See Figure 5). Despite so, the EU is optimistic that the target will be achieved and some countries like Sweden, Denmark and Hungary have already reached the set target. The efforts by member states are continuing though there is less ambition in the new targets set by the EU and therefore, Visser (2016), refutes that acknowledging this target on its own does not give a fair analysis. This is because the author notes that despite the incorporation of renewable energies by these member states, the EU is still highly dependent on fossil fuels. Therefore, calculations of energy consumption should not just be based on the levels of renewable energy incorporated but should also include the level to which these energies can be efficiently used to help EU's paradigm shift into a low carbon economy.

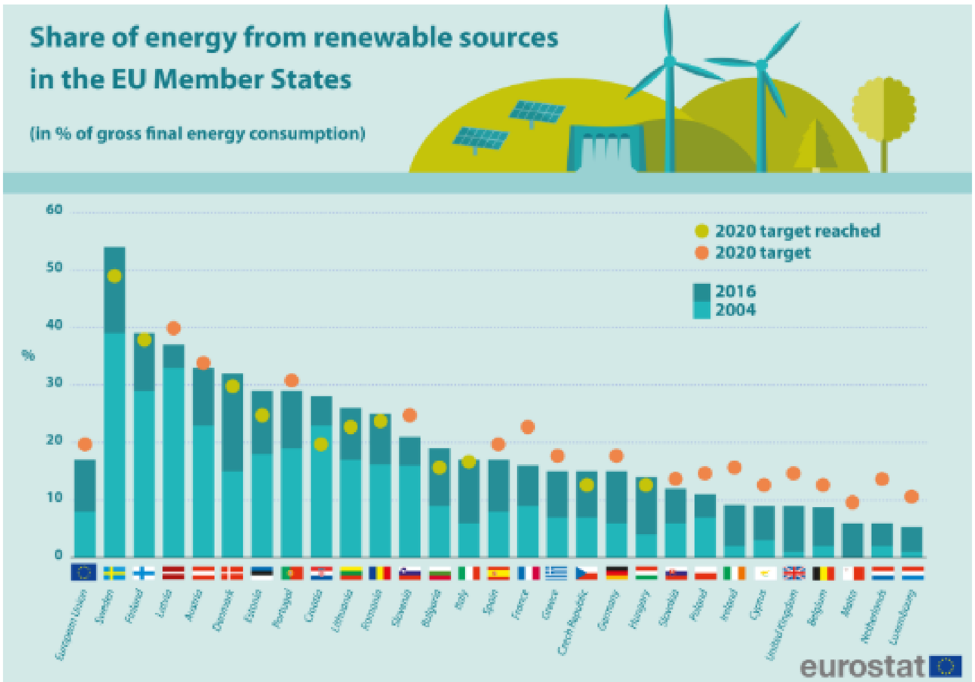

Figure 5: The Share of Renewable Energy Sources by EU Member States
Source: European Commission (Source Link)

Even if the EU has 100 percent renewables in its total consumption, there would still be a severe need for fossil fuels (Swinkels, et al., 2015). The issue is not the lack of renewables but the intermittency of it. Renewable energies such as wind and solar are so sporadic that it makes it difficult to dispatch in order to meet demand. In addition to this, the majority of the population in the EU have grown accustomed to on-demand sources of energy that is reliable in providing a constant flow of energy therefore it will not be surprising that people may refute the irregularity of renewables. This irregularity and non-flexibility has also compelled the continuous dependence on fossil fuels. This dependence does not aid in reducing the EU's set target of greenhouse gas emission reduction of 20 percent by 2020. However as mentioned above, the role of energy storage could aid in both enhancing the security of supply of renewables by providing a reliable and stable flow of RES and at the same time, promote the reduction of greenhouse gas emissions for a more sustainable future.

The increment of renewables for electrification requires an increased flexibility to the energy system. Energy storage is the contrivance that provides support in enhancing the entire energy system. The reasoning is that the capacity of energy storage may allow the production of power to be directly mapped to its supply. Energy can be stored when there is an excess and subsequently released when production levels are not able to meet demand. It is a solution that addresses the intermittency problem but at the same time, does not produce a significant level of carbon footprint as compared to the burning of fossil fuels (Rugolo and Aziz, 2012). This solution depends on the availability and advancement of energy storage technologies. This is why energy storage technologies are undeniably an integral part of allowing new sources of energy to be integrated. It is important to also bear in mind that these technologies is only a part of the synergy that makes up the entire energy system and that the economic factors such as cost and benefits are equally as integral and this will be dealt with later in the next chapter. Nevertheless, energy storage technologies acts as the hardware that help run an energy system.

Technologies could contribute in increasing the efficiency of energy management. For example, energy storage technologies have the ability of effectively managing the surplus of energy generation by storing the excess which would otherwise be wasted. This allows energy storage technologies to maximize the value and contribution of renewable energies (Chatzivasileiadi, et al., 2013). Taking the electricity market as an example, energy storage technologies can be used to stabilise the grid and regulating the grid for peak and intermediate generation (See Figure 6).

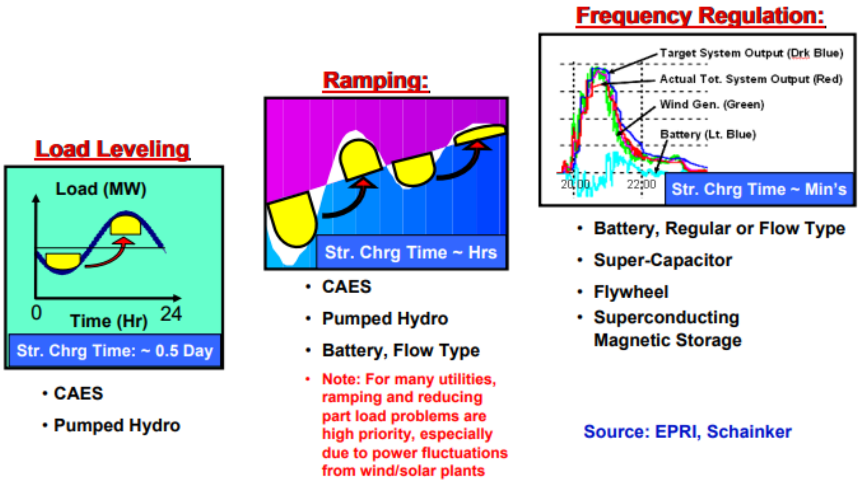

Figure 6: The role of Energy Storage in Efficient Renewable Energy Management
Source: EPRI, Schainker (Source Link)

1.1.1 The role of Energy Storage Technology in Load Levelling

A regular energy system in the past would be centralised to harvest energy remotely then transported in order to be utilised. However, with the integration of renewable energy sources, a decentralised system has been developed to accommodate various sources of energy. This new system tends to be less vulnerable as diversification allows efficient resource allocation. Conversely though, this is the enigma as diversification causes the grid to be instable. Continuing the example of the electricity market, a power grid usually functions at 50 Hertz. When energy is consumed, this frequency drops to a certain extent just before energy is refed to levelise back to the original frequency (Julich Research Centre, 2018). Integrating renewable energy however causes volatile fluctuations in the frequency. This is because wind energy for example does not blow at a constant speed. The fluctuation of frequencies from intermittent energy may become overwhelming for the grid to function properly. At the same time, these fluctuations may be damaging to electrical devices which are highly sensitive to a change in frequency. Energy storage technologies have the ability to level the load. As shown in figure 7, when generation is greater than the load, an excess occurs. Storing this excess will be important in avoiding wastage but at the same time, this excess can be used to supply the grid at peak hours when the load is higher than the generation (Dunn, et al., 2011). Additionally, energy storage technologies have the ability to promote energy efficiency as unused generation of energy is reserved thus significantly reducing the need of partially loaded fossil fuel based thermal generators.

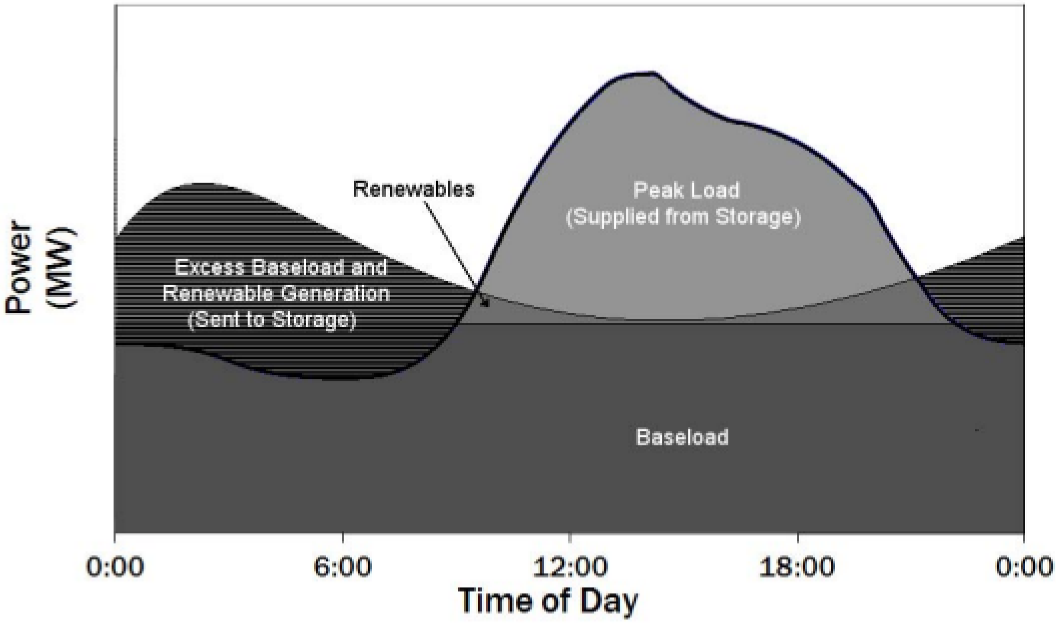

Figure 7: The effect of renewables in load levelling
Source: Dunn et al., 2011 (Source Link)

1.1.2 The role of Energy Storage Technology in Ramping

EU's energy paradigm shift involves the need to transition into a decentralised energy system to accommodate the integration of RES. This in return, has a caused a shift in the role of thermal generators in conventional power plants. Due to the irregular dispatch ability of renewables, the operation of conventional power plants is now focussed on the cycling of thermal generation of units. Van den Bergh and Delarue (2014) define cycling as the process whereby energy output of a thermal generator is ramped up and as accordingly ramped down. For example, for conventional power plants like gas power plants, this includes the shutting off and restarting of plants in accordance to the generation capacity of renewables. The reasoning is that the aggregate of a power load may vary greatly over the course of a day. Since the generation of renewables are not consistent, these sources of energy are not able to coincide with peak loads. Therefore, conventional plants like a gas power plants are treated as a mid-merit plant typically generating units to succumb to the load shape. The notion of cycling does support the integration of renewables by filling in the gaps to generate capacity. However so, the process of cycling does bear a cost.

The process of cycling does have a degenerating effect. There is a huge strain and cost to bear when shutting down and starting up a plant. These strains may accelerate component failures thus forcing outages to occur (Van den Bergh and Delarue, 2015). A constant maintenance is required to prevent such wear and tear and this carries significant cost. This is where the role of energy storage technologies could come in. The operational flexibility of energy storage technologies could fill in the gaps of both intermediate and peak load generation (See Figure 8). The only forewarning in this case is the capacity of storage. However, in an instance whereby there is sufficient energy storage, hydroelectric units from pumped hydro storage could be used. According to Ausfelder, et al. (2017), strategic stockpiling of energy resources can compensate for the bottlenecks associated with conventional power plant cycling. Here, the importance of energy storage is not just associated with renewable sources but also includes fossil fuels. This underlines the vital role of energy storage as an ancillary component in a decentralised energy system, supporting the development of renewables but also supporting the efficient management of conventional energies.

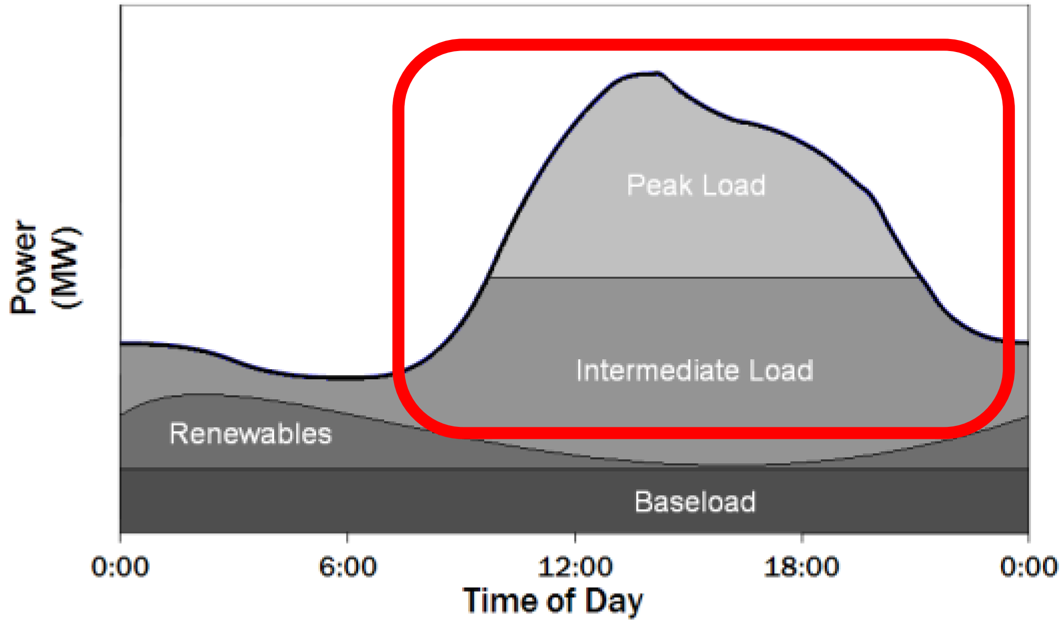

Figure 8: The Ramping of Intermediary Load using Energy Storage
Source: Dunn et al., 2011 (Source Link)

1.1.3 The role of Energy Storage Technology in Frequency Regulation

The functioning consistency of a decentralised energy system depends on the synergy of all its ancillary components. In addition to that, a decentralised energy system operation depends on the balance between generation and load. As identified above, the integration of various energy sources such as renewables could cause high irregularity of frequency that imbalances load and generation. Similar to ramping, thermal generators current take on the responsibility of regulating frequency. Frequency regulation in essence is a service that regulates changes in energy output delivered for a balanced provision. The role of thermal generators however is not efficient as it was primarily designed to deliver bulk energy (Leitermann, 2012). This is because a frequency regulation causes small but multiple increases and decreases in output in order to restore the equilibrium in the system which is not adapted to be handle by thermal generators. On the other hand though, energy storage technologies have characteristics well suited for handling frequency regulation.

The technologies surrounding energy storage allows it to be more competent in dealing with changes in energy output that is required in short bursts of time. Moreover, frequency regulation would need as mentioned a small amount of energy to be delivered frequently at different intervals of the hours or days. The ability of energy storage technologies in storing energy throughout the day and slowly releasing it when needed directly comprehends to the requirements for frequency regulation. Prospectively, energy storage technologies allow the dynamicity of energy security to be coherent in the future of a low carbon economy. As there is not just one energy storage technology, a decentralised energy system could comprise of a combination of various technologies. The next part of this chapter will provide an overview of the various energy storage technologies that could add value in EU's energy paradigm shift in accelerating the progress of EU's ambition to decarbonise and decentralise its energy system in attaining a low carbon economy.

1.2 The Types of Energy Storage Technologies

The adaptability of energy storage has made it possible to exist in different forms. Forms of mechanical, thermal and even chemical energy storage technologies have been explored thus leading to the existence of systems that will be described herein. Some technologies for example are better used in smoothing out fluctuations whilst others may be more competent in providing power requirements for short peaks. Furthermore, even though there are many technologies, the levels to which these are developed vary greatly in terms of its technological readiness (See Figure 9). Additionally, the application of these technologies varies as well.

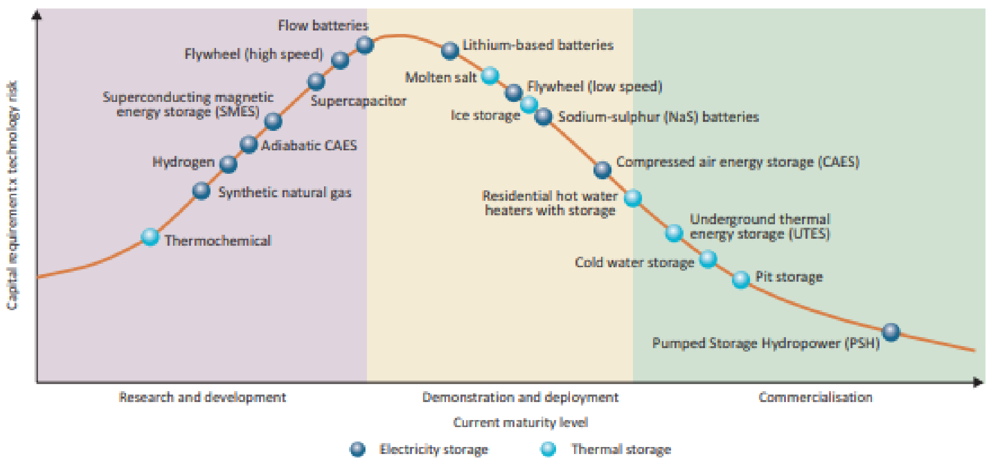

Figure 9: Maturity Levels of Energy Storage Technologies
Source: International Energy Agency (Source Link)

The subsequent part of this chapter will analyse the application of energy storage technologies using a SWOT analysis to provide an in depth analysis of the challenges of applying these technologies in the energy sector. The breakdown of technologies will be clustered into 2 categories. The first category will focus on small scale energy storage technologies. For example, the paper will highlight how these technologies may be applied in isolated areas. Subsequently, the second category will address the large scale energy storage technologies such as thermal energy and compressed air to name a few. These technologies however could be used for stabilising high powered energy systems. The application of these various technologies will be acknowledged and along with that, a comparative study will be rendered to better understand the applied optimisation of each of these technologies.

The swot analysis will provide a preliminary study of the pros and cons of the different energy storage technologies developed and available within the EU. Figure 10 below shows the advantages (strengths and opportunities) and disadvantages (weakness and threats) of deploying such energy storage technologies. To further analyse, a breakdown of technologies is specified according to the mention parameters.

STRENGHTS	WEAKNESS
Low Operating Cost (PHS) Long Storage Time (CAES) Load Levelling (BES) Fast Response Time [Ideal for ramping] (PHS) (FES) Cost Effective (BES) Grid Stability (H Fuel-Cell)	Limited Lifespan (BES) High Investment Cost due to Geological Constraints (PHS) (CAES) (CCS) Highly Sensitive (BES) Ecological Constraints (PHS) (BES)
OPPORTUNITIES	**THREATS**
Continuous Technological Advancement (BES) Dynamic Functionality (PHS) Technological Mobility [Ideal for rural or isolated areas] (H Fuel-Cell) Bridging Technology (CCS)	Social Acceptance (PHS) (CCS) (H-Fuel Cell) Technological Discontinuation (CAES) Health & Safety (FES) (BES) (CCS) (H-Fuel Cell)

(H-Fuel Cell): Fuel-Cell Hydrogen Energy Storage	(BES): Battery Energy Storage
(PHS): Pumped Hydro Storage	(FES): Flywheel Energy Storage
(CAES): Compressed Air Energy Storage	(CCS): Carbon Capture Storage

Figure 10: Swot Analysis of Energy Storage Technologies
Source: The Author

1.2.1 Small Scale: Fuel-Cell Hydrogen Energy Storage (H-Fuel Cell)

The technology behind fuel-cell hydrogen storage is the conversion of electrochemical energy. The fuel used in such a technology is hydrogen whilst oxygen acts as a catalytic oxidant. Pellow, et al. (2015) simplifies by illustrating that with this technology, there are 3 main components. This includes an electrolyser, a compressed hydrogen storage tank and a fuel cell (See Figure 11). This technology uses spent energy to produce hydrogen from water electrolysis. This regeneration allows for energy from other sources to be stored as hydrogen gas which can subsequently be dispatched to reproduce energy when needed. This small scale technology is suitable for providing energy to isolated areas simply because of the mobility of its parts.

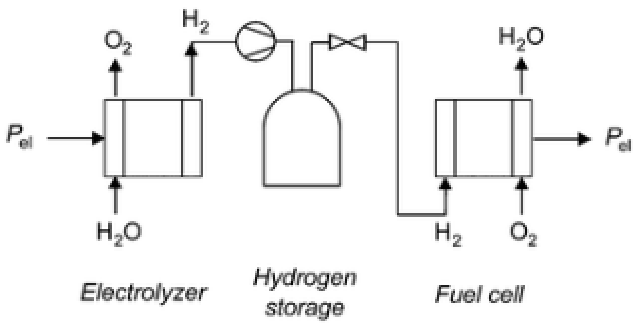

Figure 11: Illustration of a Hydrogen- Fuel Cell Energy Storage
Source: Royal Society of Chemistry (Source Link)

The use of fuel-cell hydrogen storage can represent an ideal solution for isolated or rural areas where for example power lines are unable to exist or may be too costly (Ibrahim, et al., 2008). This makes it suitable to have fuel-celled hydrogen storage on remote islands. In addition to that, even though this technology can be used with both conventional and renewable sources, the major component which is hydrogen is abundantly available and when used, the only by product of this technology is water. This makes the technology a viable option allowing the storage optimisation of 100% clean energy from sources like wind and solar thus avoiding any renewable curtailment (Gonzalez, 2017). The technology may also independently allow the push for electrification. For example, fuel-cell hydrogen storage allows the electrification of the transport sector to be more penetrable.

Transport represents almost a quarter of Europe's greenhouse gas emissions. Despite the efforts taken, emissions have not been able to have a significant decline compared to the 1990 levels. According to a report released by the European Environmental Agency (EEA), in spite of a decline in emissions from 2008 to 2013, greenhouse gas emissions have in fact increased by 23.1 percent from 1990 to 2015 (EEA, 2017). With the transport sector exempted from EU emissions trading scheme and the cost of vehicles decreasing, there is a little to no impact induced by fuel costs (Santos, 2017). As a result, the EU commission introduced a "low emission mobility strategy" which was adopted in 2016. The aim of this strategy is to introduce new CO_2 standards for road transportation and enable conditions to incentivise the use of electric vehicles. Fuel-cell vehicles are a good alternative as unlike other electric vehicles, their range and refuelling process are very similar to that of conventional cars. The vehicle runs on hydrogen that is stored in a tank. The light weight of such this technology allows vehicles to be very energy efficient in consuming the stored energy. However, the high flammability of hydrogen is a downfall of this technology.

The Hinderburg disaster in 1937 epitomised the risk of using Hydrogen when a German airship was destroyed in flames after an electric spark ignited the hydrogen that was present. For that matter, this technology poses a grave threat on safety and thus a greater threat of being socially acceptable. Having said that, there are well known advancements in technology that are used control the influences of ignition and the use of these applications are already underway (Ricci, et al., 2006). In fact, the European Commission has funded the CHIC (The Clean Hydrogen in European Cities) project that aims on powering public busses using hydrogen fuel-cells (New Energy World, 2011). The project has been carried out in 5 locations across Europe and in Hamburg, 6 busses have already been commercialised. As such, when compared to other energy storage technologies like battery, fuel-cells still out way in reliability.

As highlighted by SOPAC (South Pacific Applied Geoscience Commission), the principle of fuels cells are similar to battery when it comes to the way it operates. However, what gives fuel-cell hydrogen storage its competitive advantage is the fact that it does not require recharging. Energy can be continually produced for as long as the fuel is supplied (SOPAC, 2001). This can be great solution for the EU as it can be used to overcome the issues of security of supply. Aside from that, there some ancillary services that can be provided by fuel-cell hydrogen storage. Stationary fuel-cell hydrogen storage is an energy storage technology that can be connected to an electric grid as an application to provide continuous and uninterrupted balance in the grid. This application will be necessary in ensuring the stability of a decentralised energy system.

1.2.2 Small Scale: Flywheel Energy Storage (FES)

Despite the plentiful options in energy storage technologies, one technology that is seemingly grabbing interest is the flywheel energy storage. FES have a long life cycle making them durable and economically efficient. In addition to the high operational life, FES have a low environmental impact with its round-trip efficiency and with the fact that it is able to store mega joule (MJ) levels of energy (Amiryar and Pullen, 2017). Its low environmental impact makes it an ideal storage option in aiding the EU's environmental sustainability. The technology behind flywheel has been existent for decades in big objects like a steam engine to small objects like potter's wheel. However the notion of using this technology as energy storage only came about in the early 20th century. In the EU, major developments in the flywheel technology were deterred due to the existence and development of electricity grids. However with the historical growth of energy demand in the EU coupled with the current pressure to adhere to climate change targets, FES technologies have resurfaced.

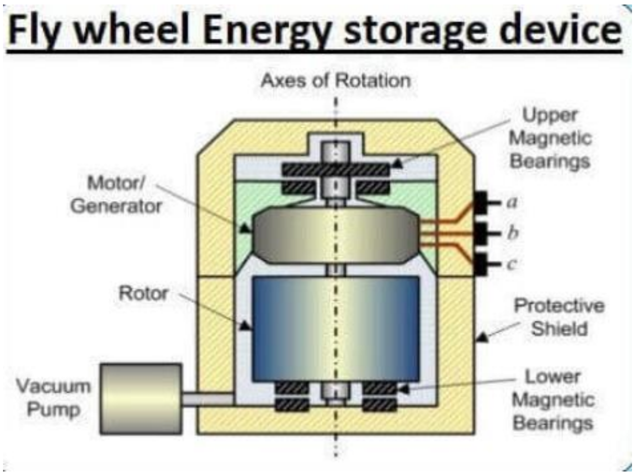

Figure 12: Flywheel Energy Storage Diagram
Source: Electricalfundablog.com (Source Link)

This technology works by rotational energy. A rotor or flywheel is accelerated at high speeds to form energy that is stored in the form of kinetic energy (See Figure 12). The technology works in such a way that the flywheel increases in speed as it stores energy and correspondingly decreases in speed as energy is dispatched. The fast response time in FES makes it a notable solution for ensuring voltage support and frequency regulation (Khan, et al., 2009). This technology is a matured technology that is readily available in the EU market. However so, there are some safety barriers that threaten the potential of this technology.

Flywheels operate at high speed. The flywheels need to spin to produce energy and the danger is associated with the fact that, in an adverse situation of a failure, the flywheel could cause damage to its surrounding. However, the way to overcome any potential threat is to control the speed of the flywheel. Coupling the flywheel with a battery storage could also be an ideal solution. As part of EU's horizon 2020 scheme, a project has been undertaken to build the largest flywheel battery storage that will be connected to the Irish and UK electricity grid. This system uses the durability of flywheel combined with battery to allow for a more efficient usage of energy that is fast in responding to energy demand (Pratt, 2017). This will be Europe's pioneering storage system, storing up to 10MW of energy. The project is still in its pilot stage and has yet to be commercialised.

1.2.3 Large Scale: Pumped Hydro Storage (PHS)

The principle of pumped hydro storage stores surplus electrical energy as potential energy of water. For example, during periods whereby demand is low and availability is high, water is pumped into the upper reservoirs. The water from the upper reservoir is then subsequently released when the demand gets high. The water released during high demand is flowed through a turbine, activating it to generate high powered electricity needed at peak hours (See Figure 13). PHS is the ideal technology used to ramping. With its quick response time, PHS is able to ramp up full production within a few minutes allowing it to react accordingly to supply energy for peak loads (Gutierrez and Arantegui, 2015). The EU has one of the largest capacity of PHS.

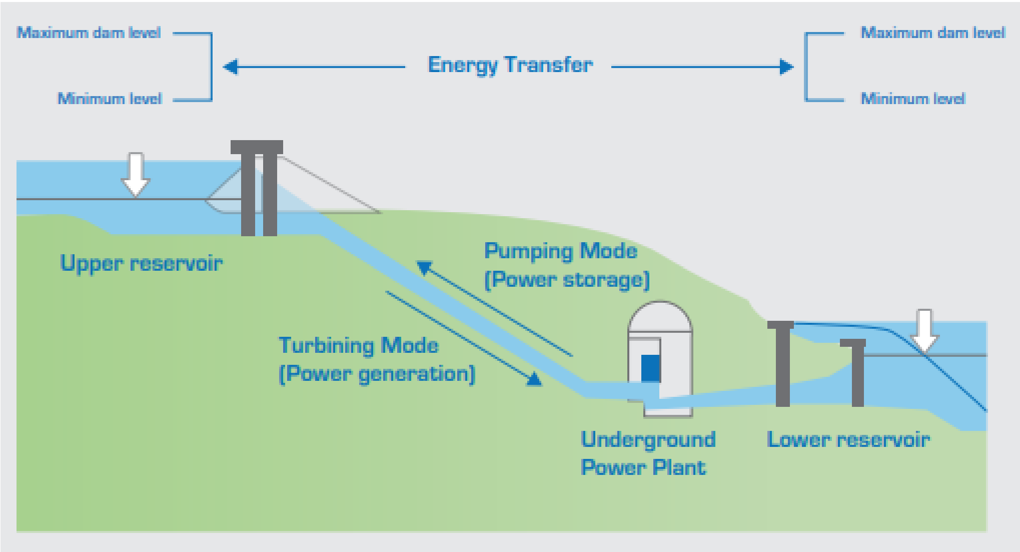

Figure 13: The Mechanics of a Pumped Hydro Storage
Source: European Association for Storage of Energy (Source Link)

The European Union has about 421 Gigawatt hours (GWh) of pumped hydro storage. According to Tisheva (2016), the mountains of Pyrenees in Spain has readily developed land space for PHS which upon commercialisation will produce 118GWh of installed capacity. Most of PHS technologies can be found in mountain regions of Austria, Switzerland, Portugal and Spain. Due to this very fact, people are not in favour of pumped hydro storage claiming it to be detrimental to the ecosystem. For example, the construction of a pumped hydro storage brings about concerns surround the vibration of drilling which is said to inflict geological instability such as landslides. However with this being such a mature technology, most infrastructures already exist therefore eliminating the need for further construction. Moreover, PHS accounts for about 97 percent of energy storage worldwide and because of the already existing systems, this form of energy storage is relatively the cheapest to implement (Blakers, et al., 2017). Similarly, Fickling (2018) elaborates that PHS is not just cheap to implement but will undoubtedly increase the affordability of energy prices by reserving energy during off peak hours whereby electricity prices are relatively cheaper and using this to compensate energy during peak hours for which prices of electricity hikes high. As a result to this, the EU is taking sustainable initiatives to implement PHS technologies using the existing reservoirs to avoid further ecological constrains (Smudde, 2016).

With the common target for climate change, many EU member states have structured an economic support programme to promote the expansion of PHS technologies (EASE, 2016). The focus of EU on PHS technology is mainly because the large scale technology is highly flexible allowing it to be good tool in ensuring the balance of the European electricity grid. PHS technologies are already commercialised within Europe however so, their economic feasibility is hardly justifiable due to non-technical gaps that exist in the regulatory framework (EASE, 2017). These gaps will be discussed later in detail in the coming chapter.

1.2.4 Large Scale: Compressed Air Energy Storage (CAES)

A standard gas turbine power plant uses power to compress the combustion of air. Compressed air energy storage works as a modified version of a gas turbine power plant. In the CAES technology, surplus of energy for example is stored in an underground cavern. In situations whereby there is a lack of energy supply, the energy stored as air is then heated and expanded in order to generate power (See Figure 14). The properties of this technology are desirable simply because, the technology has the potential for a power capacity rating of hundreds of megawatt (Kerestes, 2010). Although the current CAES systems in place functions using natural gas, the adjustability of this technology has allowed the system to replicate the process by storing surplus of renewable energy as compressed air and heating it to produce power when the demand is high. Due to this potential, the technology has successfully caught the attention at the European Union level. While this may be true, the generation of CAES technologies capable of accommodating clean energy is yet to be commercialised in the EU.

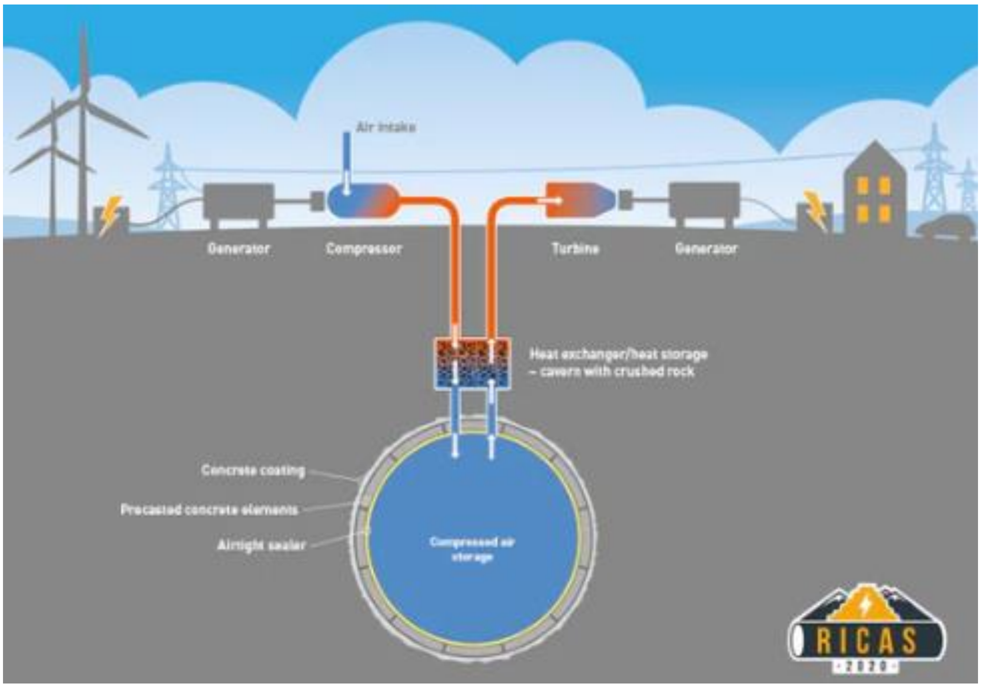

Figure 14: Illustration of a Compressed Air Energy Storage
Source: RICAS (Source Link)

CAES has the potential of providing a large part of the storage capacity needed for Europe's decentralised future (EASE, 2016). Scientist working on the EU funded RICAS2020 project believe that CAES is in theory the cheapest way to store massive amounts of energy (Lee, 2017). Moreover, the scientist believe that this technology could be more feasible then pumped hydro storage as the latter requires certain auxiliary facilities. On the contrary, CAES systems may still need to be improved as technological constraints hamper the feasibility of this technology. For example, a prominent issue with this technology is the lack of drainage system which is essential for securing of steel linings under high pressure. According to Perazzelli and Anagnostou (2016), this issue could affect the feasibility of CAES technologies in a decentralised system. Finkenrath et al (2009) identify that uncertainties in the energy market could potentially delay the commercialisation and deployment of such technologies.

1.2.5 Large Scale: Battery Energy Storage (BES)

The technologies behind batteries have been around for some time and the maturity of this technology has made it to be one of the most promising applications in EU's energy paradigm shift into a low carbon economy. On a broad perspective, BES technology consists of electrochemical cells that are wired in sequence (See Figure 15). The chemical reactions between these cells generates energy (Akinyele et al., 2017). The variety of BES technologies also highlights the flexibility and diversity of its potential application in the EU.

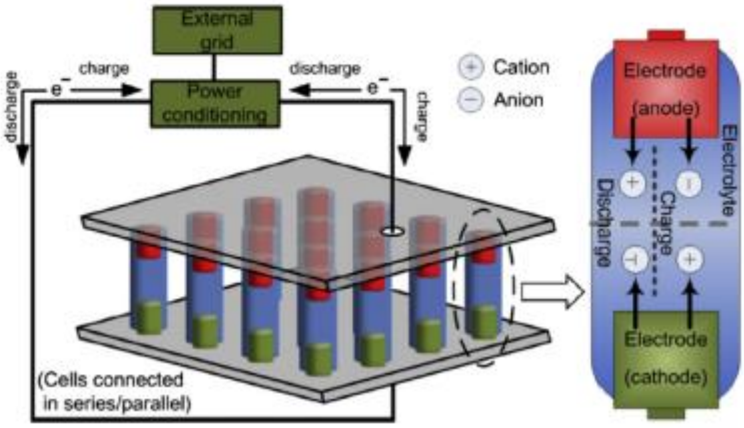

Figure 15: Diagram Demonstrating the Schematics of a Battery Energy Storage
Source: MDPI (Source Link)

According to EUROBAT (European Automotive and Industrial Battery Manufacturers), batteries have the ability to bolster Europe's energy efficiency, security and overall independence (EUROBAT, 2016). Moreover, the penetration levels of a BES in an energy system are vast and as such this technology could offer an abundance of services (Fitzgerald, et al., 2015). For example, continuous improvements in BES technologies have allowed it to enhance the ability of an off-grid system. Additionally, for example, in the EU, the energy transition is now becoming a multi-governed effort with regional and local levels taking sustainable energy initiatives. As such, more and more communities are striving for sustainable self-sufficiency leading to an increase in off-grid systems. Community based energy storage technologies play a key role in localising distributional power. Feldheim is an example of a pioneering large scale community based battery storage. It comprises of a battery storage with 10MWh installed capacity that is used primarily to stabilise the grid and balance out any discrepancy between demand and production. Feldheim is still connected to the national grid due to regulations but the village is indirectly "energy independent" having its own distributed power lines and living off its local energy system (ENERCON, 2015). Success stories such as Feldheim have pushed the EU to make battery storage a core element in its future energy systems.

In the recent years, the EU commission has advocated the production of battery cells, stating that this technology is essential for Europe (Williams, 2017). As such the EU has taken initiative to launch a battery alliance to develop a battery manufacturing base that could compete globally. At present, the price of battery energy storage is gradually decreasing worldwide (Malhotra, 2016). This has allowed the once outsourced manufacturing of battery storage to be localised within the EU. However, the manufacturing of batteries requires the need of high purity metals and unfortunately, in Europe, there are limited primary reserves for lithium. This imposes a new dilemma for the EU as the supply of the metals would have to be imported. Nevertheless, researchers at Lappeenranta University of Technology (LUT) have made a pioneering breakthrough in being able to recover metals such as cobalt, lithium and nickel from battery wastes (LUT, 2016). With the increasing manufacturing of batteries in the EU especially for the need of electric vehicles, this breakthrough would help secure the viability of this technology. Despite the alliance and discoveries, there are legislative barriers that exist at both the member state and EU level (Robson and Bonomi, 2018). This significantly disincentives the potential growth and application of battery energy storage.

1.2.6 Large Scale: Carbon Capture Storage (CCS)

The paper has thus far spoken about energy storage technologies that mainly enable the integration of renewable energy sources. The puerility of renewable energy developments however has caused the continuation of fossil fuel dependence. As such, EU's energy paradigm shift into a low carbon economy will still need to largely depend on fossil fuels for the moment. Nevertheless, as Bassi, et al. (2017) emphasises, the focal aim of the EU climate commitments is not to decrease the amount of fossil fuels but to decarbonise the energy sector to significantly reduce greenhouse gas emissions. Therefore, it is critical to understand that decarbonisation can occur in both a decentralised and centralised energy system (McLellan et al., 2015). What is needed however is the technology behind carbon capture storage.

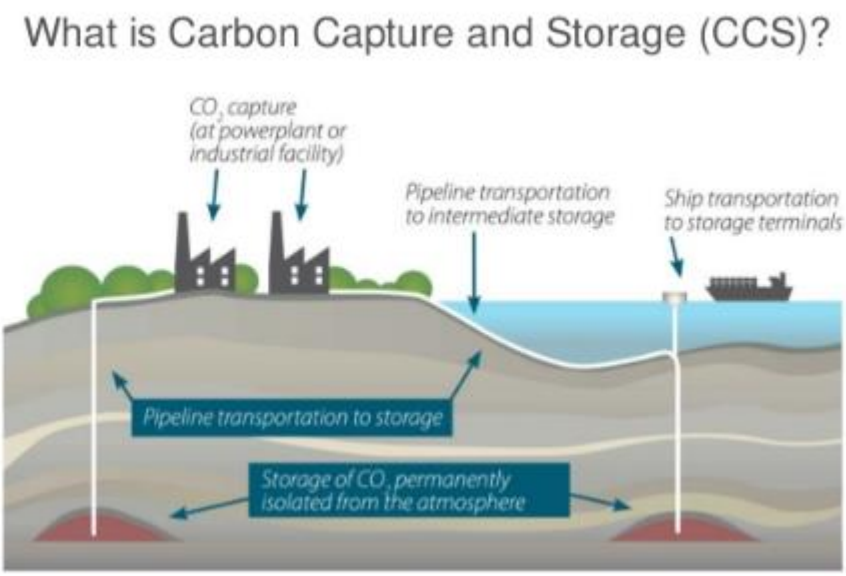

Figure 16: Schematics of Carbon Capture Storage
Source: IEA (Source Link)

The technology behind carbon capture storage allows it to concentrate CO_2 and strip out this emission from fossil fuels. As figure 16 illustrates, the CO_2 captured is pressurized to 70 bar, liquefying it to be injected into the rock's pores located at least 800 meters below the earth's surface (Haszeldine, 2009). This technology supresses CO_2 emissions released by fossil fuel and as a result acts as a "bridging technology", providing a solution that makes the continuous dependence on fossil fuel more comprehensible. A good CCS site will be able in theory to retain CO_2 for thousands of years. This can definitely help the EU increase its environmental sustainability trilemma factor whilst still being able to use fossil fuel to assist in meeting demands. Nonetheless, there still might be technical barriers that might cause CO_2 seepages. These seepages under the earth's crust could be detrimental geologically but also harmful to live forms. Cuellar-Franca and Azapagic (2014) hypothesise that there are more disadvantages in having CCS. According to the authors, the levels of human toxicity and environmental impacts induced by CCS makes this technology non beneficial. Even though so, there is keen interest by EU member states to deploy such a technology.

In 2009, the EU enforced a CCS directive aimed at establishing a legal framework to ensure the installation of environmentally and geologically safe CCS. However so, within the EU, deployment of such technology was hindered due to the lack of social acceptance. In addition to that, even with safe geological conditions, the extensive high cost of this technology may prohibit its deployment (Kim and Choi, 2015). Moreover, there is still rampant uncertainty with the deployment of such technology as apart from the directive, there is still an imminent policy framework in allowing the integration CCS into the current market design. As such, the EU at present acts as an unfriendly environment for the integration energy storage.

Based on the analysis of energy storage technologies, it is evident that these technologies and application is continuously evolving and competing. Despite this fact, most of these technologies are yet to be deployed. As Daim et al. (2012) infers the growth and improvements in innovation does not really transcend the feasibility of these technologies. Majority of energy storage technologies emphasised above is yet to be implemented in the real market. As such there is an uncertain feasibility of these technologies with regards to social, economic, technical and even legal factors. However, one of the main deterrents is the lack of policies. This leads to the next part of the paper that questions the actual practicability of energy storage. Since energy storage is just one component of a low carbon economy, a fair evaluation would require evaluating the role of energy storage as a whole. To do so, the aim of this next chapter is to critically evaluate the extent to which energy storage could be feasible in EU's energy paradigm shift.

Chapter 2: The Practicability of Energy Storage in an Energy System

One of the scope towards aiding climate change has called out for the EU to shift and transform its energy system to reflect EU's future of a low carbon economy. As such the energy system in the EU is currently undergoing a facelift to decentralise. According to a report released by the European Commission (2013), decentralised generation combined with local storage will enhance the EU's energy efficiency. The locality of energy storage systems is what gives a decentralised energy system its competitive edge. The ability of the system to be structured close to where the energy is needed allows for a greater penetration of supply. As such, energy storage could be a key concept that needs to be regarded as it could be the glue that enhances the functionality of a decentralised energy system. However, in order to better quantify the technological, economical and overall feasibility of storage, this chapter will evaluate the practicability of energy storage in EU's low carbon future. As such, the analysis will be based closely on EU's pillar for decentralisation. In order to do so, a PESTLE analysis will be carried out to extensively evaluate the extent to which energy storage can penetrate the energy market, solve the technical constraints of a decentralised future as well as be accepted as a potential tool in the overall energy paradigm shift of the EU. As a result, the aim of the next section is to inference the feasibility on energy storage in a decentralised energy system.

Political	The E.U. Framework Energy Trilemma –Security of Supply Lack of Regulation & Insufficient Policies Multilevel Governance Energy Union
Economic	Lack of Market Integration Energy Trilemma-Affordability Investments Value for Money Economic Vulnerability Protest from Energy Companies Market Competitiveness
Social	Social acceptance and awareness Energy poverty Energy Independence
Technology	Diversity of technologies Hampered deployment Lack of synergies of Technologies Smart Grids (Multilateral Flow)
Legal	Outdated Regulations Incoherent Market Design

Environmental	Low Carbon Economy Energy Trilemma- Environmental Sustainability Decarbonisation Environmental Hindrance

Figure 17: PESTLE Analysis of a Decentralised Energy System
Source: The Author

2.1 Political Factors

The EU's Framework

Post 1945, the tenets of the EU have been influenced highly by the notion of "integration". Therefore, the political aspects of the EU have very much been driven by its geopolitical building blocks. The geopolitics of energy has always been one of the main drivers of prosperity within the EU. The creation of the energy union was enforced to overcome the fragmented and isolated regulations that were hovering across Europe (Andoura, et al., 2015). As a result, the climate and energy framework was further strengthened to drive the EU's progress towards a low carbon economy. The revised target as highlighted, emphasised on incorporating at least 27 percent renewable energy whilst attaining the same percentage of energy efficiency. This "shift away" from EU's high carbon energy system acknowledged the anthropogenic threats of climate change but addressed a new concern in terms of energy security.

The Insecurities with the Security of Supply

The position of the EU with regards to energy has always been fragile. For example, being one of the largest importer of energy, the EU is faced with insecurities when it comes to the security of supply. To intensify its fragile position, wake of events like the Russian and Ukraine dispute in 2014 emphasised the vitality of energy security (Leal-Arcas, et al., 2015). In the present day however, the concept of energy security in the EU refers to the security of supply that has been reconceptualised to include sustainability (Puntaru, 2015). Having said that, the EU also faces internal fragility as energy is a shared competence between the EU and its member states but this creates competing interest that hamper the capacity of action at the EU level (J. Zeitoun, personal communication, 2018). For example, member states were very much rebuttal with the European Commission's plan of having a new government system to supervise its target of incorporating 27 percent of renewables (Renssen, 2014). This plan proposed member states to draw up NAPs (National Action Plan) that would cover the integration of renewables to emission reductions and to the security of supply that will be approved by the European Commission. Even though, this was a bottom up approach, member states were unpleased with the European Commission's overextending role on its energy mix as that was seen as a very nation competency. As such, there are difficulties in getting agreements to be both accepted and pledged by both the EU institutions and member states. It is necessary for the EU to find a common ground to which member states feel secure and willing to comprehend, otherwise, this insecurity will creep in to threaten the whole integrity of the European Union.

Brexit: A Challenge for EU's Integrated Market

On the 29th of March 2017, the UK triggered *Article 50* of the European Union which acknowledge their formal application to leave the EU. The notion of "Brexit" as it has been labelled does leave a detrimental impact on the EU's energy and climate policy. The UK was the first country in the EU to implement a wholesale market for electricity and this subsequently led as a model for other EU Directives (Pollitt and Chyong, 2017). Similarly, the UK has been pioneering with its "Smart Power Revolution" that improves the storage of power. In fact, according to a press released by The Guardian (2016), the UK could save up to 8 billion Pounds yearly and significantly reduce its carbon footprint. It is not hearsay that energy storage could undisputedly increase the security of supply of a nation causing an abundance of savings and at the same time improve the environmental sustainability by reducing the carbon footprint. Therefore, UK's know-how of electrical energy storage could have been a weighty asset for the EU's decentralised and decarbonised future. This may pose the loss of Britain's influence on EU's energy security. A matter a fact as well, the UK electricity system is interconnected to the Republic of Ireland so the notion of Brexit will also disaggregate the interconnection that lies between the EU (Bosch, 2017). Additionally the UK has been ensuring policies are in place to address a more decentralised future. According to Allen (2014), the UK government has introduced policies to ensure that by the year 2020, all homes in the UK will be equipped with smart meter technologies to ensure a better efficiency of energy. The EU on the other hand have yet to identify standardised policies to enforce a more decentralised future.

The Insufficiency of Policies

Despite the synergistic push for a European energy transition, the EU is yet to have any policy on decentralised generation. A fundamental concern is with regards to the association of responsibility of actors. This is also transcended in the domain of energy storage. The concomitant policies surrounding energy storage today are link through the climate policies of renewable energy integration. The *Renewable Energy Directive* recognised the need for energy storage but only bounded target to promote the integration of renewable energy sources. As such energy storage is seen as a mean to achieve the climate change target and not necessarily a domain on its own. However, having said that, it is transparent that the lack of energy storage policies has delayed the overall progress of a decentralised energy system .In addition to that, the lack of a common EU definition for energy storage has left it uncertain when it comes to the ownership.

As of yet, there is not a standardised framework on how energy storage is perceived in the EU. The question of ownership and who bears the benefits and cost of energy storage is still a puzzle for member states, not just the EU level. Member states lack consistency to the way storage is treated. This is largely due to the fact that, member states still perform sovereignty and as a respect for national diversity, the policy competency has been left to the national level (Smismans, 2004). This is a good way to empower nations to incorporate energy storage but leaves no room for a centralised EU common policy. On the bright side however, local energy solutions are increasingly driving the fight against climate change. As Ringel (2018) underlines, EU's initiatives like the "Covenant of Mayors" are helping to bring together the different stakeholders from different levels of governance to push for policies in a systematic manner.

Old vs New: The Threat of Emerging Actors

Lammers and Diestelmeier (2016) highlights, the transition of a decentralised energy system will pose potential conflict, arguably between current and emerging actors. For example, there will be a new profound emergence of prosumers, consumers who will also produce their own energy. As such, there will be competing interest and potential conflict in the generation of power in EU's future low carbon economy. The transition for a decentralised energy system as mentioned created new emerging actors. The independence of decentralised energy systems in allowing an increase of actors to take responsibility to curb emissions has resulted in conflicts and opposition between the current centralised actors and the emergence of decentralised actors. These conflicts has contributed to the hierarchical shift in EU's energy governance.

A Hierarchical Shift towards Multilevel Governance

There is a growing nature of "multilevel" governance. According to Kern and Bulkeley (2009), the concept of "multilevel" governance in essence shifts competences amongst the supranational (EU), national (member states) and local levels. This is of immense importance as the interaction between the different levels of governance is said to be the key that links the concept of acceptance amongst all actors (Lepesant, 2016). Being that energy independence is a by-product of a decentralised energy system, the role of local actors play a critical role. Due to this, there will be an absolute relationship between the growth of decentralised energy systems and prosumers. However, this could cause a paradox increasing local and national sovereignty thus weakening EU's mission for policy harmonisation (Jordan, et al., 2012). Therefore, policy developments for decentralised energy systems and the components therein should take place within EU's framework which will foster multilevel cooperation between member states and its local authorities. Nevertheless, at present, the regulatory uncertainty and insufficient policies in both a decentralised energy system and energy storage could economically stifle investments in the respective domains.

2.2 Economical Factors

The Lack of Market Integration

In the recent years, the EU has taken an ambitious stride to foster the transition into a low carbon economy (European Commission, 2014). As denoted above, the regulation of a decentralised energy system still lacks competence and compliance across the EU and this led to a lack of market integration. Even though there is an opportunity of benefiting from an array of technologies, the lack of market integration may weaken the economy. This is mainly because the technological components such as energy storage have yet to be economically valued (Liu, et al., 2011). For example, the cost of energy storage differ greatly in accordance to the type of technology that's being applied as well. However so, with the growing advancements in technologies, energy storage costs has been predicted to globally decrease (See Figure 18).

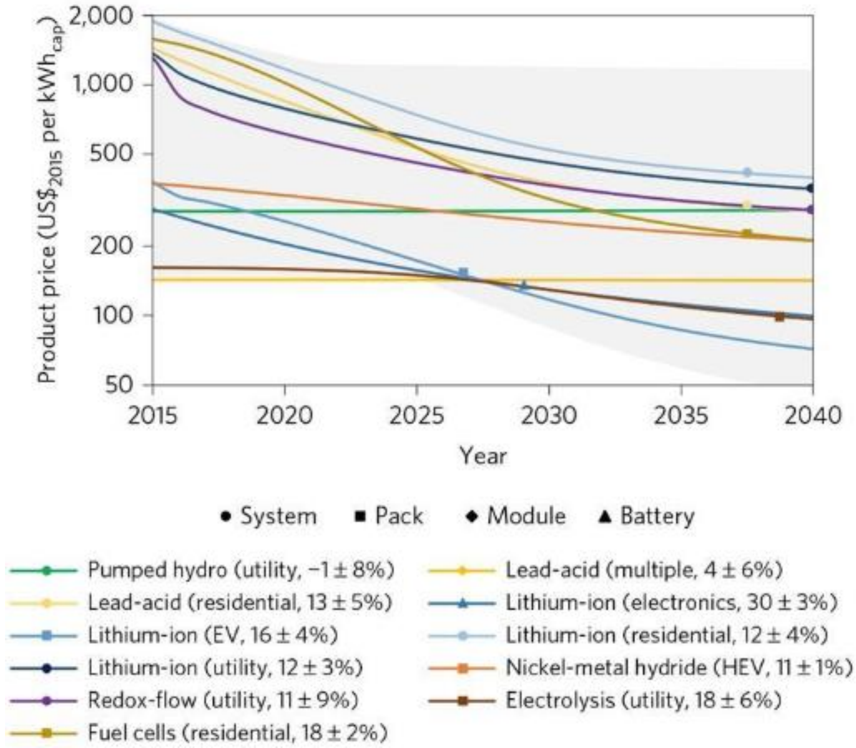

Figure 18: Decreasing Cost of Energy Storage Technologies
Source: Spring Nature (Source Link)

The Investment Revolution

The decreasing trend in energy storage costs has made it a more viable solution. For that matter, the EU has launched the "Strategic Energy Technology" (SET) plan which is a capacity mapping intended to enhance the research and development in investments for low carbon technologies like Energy Storage (Lepsa, 2015). As noted by Williams, et al. (2018), the EU has invested up to 1 billion Euros under its European Energy Program in order to fund research, development and construction of CCS technologies. Moreover, more and more companies are starting to invest in energy storage technologies. For example, according to Morris (2017), German manufacturer AKASOL has invested up to 10 million Euros for the production of commercial sized vehicle batteries. In addition to that, Orsted and Statoil are looking into investing in batteries for offshore wind plants in Denmark which will allow the reservation of more offshore based wind energy (Deign, 2017). These investment have directly driven down the cost of batteries. Even though, there isn't much data for cost on energy storage systems in the EU, according to the GTM research shown in figure 19, there will be a 9 percent annual cost reduction for energy storage systems globally. Therefore, energy storage will become more and more economically viable for the EU to implement across its member states. Nevertheless, reduction in energy storage cost will still challenge its deployment in the EU's future decentralised energy system simply because of the risks that are more so associated with the energy infrastructure itself (Strachinescu, 2017).

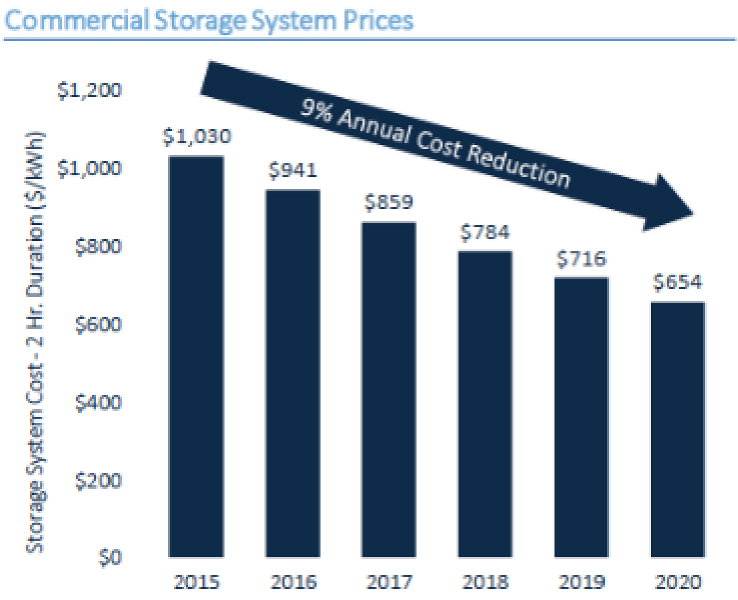

Figure 19: Prices of Commercial Energy Storage Systems
Source: GTM Research (Source Link)

Value for Money

Despite decreasing cost of energy storage systems, the value of energy storage within an energy system still remains uncertain. For example, the cost of a decentralised energy system is predicted to increase with energy storage. Sisternes, et al. (2016) elaborates on this by saying that energy storage's marginal value diminishes as capacity is deployed. According to a report conducted by the FCH JU (Fuel Cells and Hydrogen Joint Undertaking), the value of energy storage depends on multiple parameters such as composition on energy generated, CO_2 prices and also the regulations that govern it (FCH, 2015). However, if policies are established to eliminate these parameters, then energy storage will economically be value for money.

Energy storage has the flexibility in having multiple operations within a decentralised energy system. It could be used to trade energy in order to make a gain from arbitrage and at the same time in ancillary markets, through the offering of reserves (Staffell and Rustomji, 2016). For example, energy storage has the ability to flatten electricity prices of renewables. To elaborate, prices of renewables tend to hike up when there is a decline in generation and at the same time, prices have plummeted below zero like in the case of Germany when there was an excess of generation. Stabilising electricity can make prices more affordable for end consumers.

The Increasing Affordability of Energy

Energy storage enhances the flexibility of an energy system allowing for greater efficiency and consumption thus increasing the affordability of prices. The affordability of prices will reduce significantly with the increasing role of consumers becoming producers (prosumers). The surge of prosumers in a decentralised energy system will drive electricity prices down because more and more households will become self-sufficient thus eliminating the need for external energy supply. This self-sufficiency underlines the "cost parity" principle that economically justifies the use of storage in allowing self-consumed electricity to be equal to that conveyed from the grid (Faure-Schuyer, 2016). For that matter, having energy storage policies could in fact solve the energy affordability trilemma factor. Unfortunately due to the lack of energy storage policies, the clarity of economic feasibility of energy storage is very much blurred. This poses the question of who will bear the cost. According to Wesoff (2011), energy storage comes in an array of applications, acting not just as a load but as a generator, therefore, the cost is spread. According to the author, this makes it difficult to pinpoint which actor should bear the cost. Nevertheless, under fulfilling conditions, energy storage could enhance local autonomy which in return could reduce vulnerabilities that may exist in the economy.

Economic Vulnerabilities

A centralised energy system does not promote local autonomy however the opposite is true under a decentralised energy system (Akizuki, 2001). The result of this is that, there will be less sovereignty asserted thus leaving actors more independently responsible for their energy production and consumption. Energy storage substantially increases local autonomy by reducing the need for external demand which could potentially be beneficially in overcoming vulnerabilities like an economic crisis. Instead of having to bear cost, local actors like households can now benefit from such vulnerability by selling their excess energy. This increase in autonomy will spark protest from energy companies that will indisputably face an exponential growth of market competition. However, setting guidelines and policies could provide a platform to which all actors benefit from using energy storage technologies whilst at the same time enhance the security, affordability and environmental sustainability thus thrusting EU's energy paradigm shift. Moreover, policies could be a way to represent and justify the interest of different actors thus encouraging the level acceptance of technologies in EU's energy paradigm shift.

2.3 Social Factors

The Need for Social Acceptance

The venture into the millennium has influenced and increased the "socio" factors. May it be in politics or technology, social acceptance is becoming inevitable. According to Wustenhagen, et al. (2007), a barrier to a successful implement could be a manifestation of a lack of social acceptance. There are complexities challenging social acceptance in this energy transition and one of the barriers of social acceptance in the EU is the lock-in effect. Bao, et al. (2008) elaborates that lock-in effect is the paradox that exist between the environment and a transition into a low carbon economy. As such, lock-in effect within the EU energy context is used to conceptualise the persistent dependence of fossil fuels based systems despite understanding its environmental consequences (Klitkou, et al., 2015).This lock-in effect is posing a challenge for the social acceptance as well as for EU's energy paradigm shift as most people in the EU are used to uninterrupted flows of electricity which may differ significantly with the integration of renewable energy. Energy storage would indefinitely aid with this but there will be caveats that may not be foreseen. Hence forth, energy security could play a key role in encouraging social acceptance.

Energy Security the "Incumbent" of Aiding Energy Poverty

Energy security is also an internal issue faced by EU nations. Although most member states in the EU disregard energy poverty as a by-product of the lack of security of supply and clump it as a component of income poverty, the issue is becoming more and more a concern. According to EPEE (European Fuel Poverty and Energy Efficiency), 1 out of 7 households in the EU live in energy poverty today or is marginalising on it (EPEE, 2009). Energy poverty is apparent due to the lack of affordable electricity prices. However so, the role of storage along with the implementation of a decentralised energy system is said to be resilient in overcoming such inadequacies. According to Nathwani (2018), decentralised energy technologies have the ability to create income and forevermore disrupt the relational hierarchy of an energy user and a producer. The author adds that technologies coupled with a decentralised energy system provides the households the power to negotiate and the ability to access electricity on a "pay as you go" basis. The amalgamation of energy storage with decentralised energy system will allow for back up generation ensuring that demand is met thus overcoming the hikes in electricity prices reflected to households. Energy storage also has the technical capability of regulating the flow of electricity on the grid, levelling the volatility of high price fluctuations. There is no doubt that this will make electricity prices more affordable thus reducing the levels of energy poverty in the EU. The figure 20 below is an example case study that shows the annual savings of energy cost that is brought by energy storage such as battery. Even though, there isn't data to support such analysis in the EU, this figure can be analysed theoretically to acknowledge that energy storage does in fact promote savings in energy cost and increases the efficiency of energy thus allowing cost cuts to be attained in the monthly electricity bills. Not only will energy storage potentially lower the rate of energy poverty but it will help less affluent households to efficiently manage their consumption and thus forth, their cost of supply. Energy storage coupled with digitalisation allows for an advanced metering infrastructure (AMI) which in return, allows households to adjust consumption in response to the changes in the cost of supply (Poudineh and Jamasb, 2012). A fundamental factor contributing to this of course is the diversity of technologies.

Battery Type	Installed Cost ($/kW)	Est. Annual O&M Cost ($/kW)	Avg. Round-Trip Efficiency	Est. Annual Fuel Savings (L/kW)	Est. Annual Fuel Savings ($/kW)
Flow Battery: Utility-Scale	2,300.2	31.1	70%	1,680	1,831.2
Flow Battery: Distributed	2,874.4	34.5	70%	1,680	1,831.2
Advanced Lead-Acid: Utility-Scale	2,903.5	66.2	80%	1,920	2,092.8
Advanced Lead-Acid: Distributed	3,284.5	66.8	80%	1,920	2,092.8
Lithium Ion: Utility-Scale	2,062.0	47.3	90%	2,040	2,223.6
Lithium Ion: Distributed	2,150.3	50.8	90%	2,040	2,223.6

(Source: Navigant Research)

Figure 20: Energy Saving and Energy Efficiency Promoted by Battery Energy Storage
Source: Navigant Research (Source Link)

2.4 Technological Factors

The Diversity in Technologies

Technologies are the assets of continuous improvement. As highlighted previously, the levels to which energy storage technologies are developed differ greatly and as such this has an impact on the availability of energy storage technologies. Therefore, the differing technological designs and operational parameters such as cost place constraint in highlighting which storage technology is more suitable (Gustavsson, 2016). However Copeland (1983) refutes by saying, it is not possible to identify which storage technologies would be more successful. However so, the author adds on by saying that even though the risks may be significant, the benefits that may be reaped will be worthwhile. Moreover, the technologies are the frontier to EU's decentralised energy system.

A decentralised energy system has the ability to deliver a multi-directional energy supply measure due to the vast array of technologies it incorporates (Baker and Woodman, 2008). The amalgamation of different technologies will allow for better integration of clean energy thus addressing environmental concerns and undoubtedly promoting sustainable energy generation. For that matter, in the coming future, the electricity market in the EU will be marvelled by smart grids. The concept revolves around self-sufficient systems that are able to manipulate information to provide an optimised level of energy generation and consumption. In fact, information is revolutionising the way these diverse technologies work symbiotically.

The Issues of Digitalisation

Data and information are the backbone on ensuring energy efficiency. As such, digitalisation will be a prerequisite of a decentralised energy system. The world of ICT (Information, Communication and Technology) will augment the efficiency of decentralised energy systems like smart grids as it permits a multilateral flow energy (Ristori, 2017). The use of information could be used to forecast demand by meritoriously monitoring and controlling the system and coupling this with energy storage could foster a better usage of energy. For example, behind the meter (BTM) storage allows for a "on demand" generation. BTM storage operates by weighing the information it receives and optimally responding in way that will be most beneficial to the consumer. This use of such technology would also be economically favourable as it could be designed to operate and respond in accordance to financial signals thus resulting in ways that produce efficiency but also optimises the highest financial return (Hart, 2017). As such, there is no doubt that technologies are crucial in aiding EU's energy paradigm shift. Nevertheless, the deployment of technologies and systems still depend on regulations that are currently outdated or almost nonexistence.

2.5 Legal Factors

Outdated Regulations

The push for a low carbon economy is causing the EU and its member states to contemplate a bilateral movement of centralised and decentralised set of regulations. The oxymoron to this is that, member states are indirectly required to reduce their sovereignty for a standardised EU common policy but at the same time the EU is engaging a decentralised principle to drive the transition. However, with insecurities of supply and the demand for electricity in Europe growing yearly by 1.8 percent, the prospect of having an energy union with a unified set of regulation is very tantalising (L'Abbate, et al., 2007).

The current EU policies surrounding a decentralised energy system are principally sectioned around the publication of 2016's *Clean Energy for All Europeans* package. However till today, this package does not necessarily emphasise the need for energy storage within the system but more so the efficiency of energy measured by savings. To understand this better, Korteweg (2017) asserts that enclosed in Article 7 of this package is the "Energy Efficiency Directive" but even with the current negotiations, the article narrowly acknowledges energy efficiency by requiring energy companies to achieve an annual saving of 1.5 per cent out of its sales to final consumers. This may nudge electricity bills to me more affordable but the directive fails to recognise other forms of efficiency such that of a decentralised energy system coupled with energy storage. Energy storage as highlighted can plateau the volatility of prices thus making it more affordable. Recognising this gap will be crucial to encourage EU's energy paradigm shift whilst at the same time, working towards overcoming the EU trilemma factors that could potentially halter the paradigm shift. There is no doubt that the lack of EU policies have made energy storage a big question mark in EU's ongoing energy transition.

Energy storage acts as pacemaker in a decentralised energy system. According to a report released by EURELECTRIC (2012), energy storage has the ability of increasing the energy security in a decentralised energy system as it decouples production and consumption. In the future, energy storage could also be an important element bridging neighbouring EU countries' with the sharing of renewable resources (European Commission, 2017). The significance of storage has caused the European Commission to recognise its value. Once again, in its *Clean Energy for All Europeans* package, the European Commission highlighted the need of energy storage as a means of levelling the field between the various generations. Regardless so, the deployment of energy storage is hampered by the lack of regulation.

Uncertainty

It is not surprising that there are energy storage projects that are already used in practice. What's surprising is that despite the fact that the EU has identified the importance of energy storage, there is still a huge uncertainty surrounding its role in a decentralised energy system. One of the principal hindrance of energy storage in the EU is the lack of regulation. Due to this fact, at present, energy storage is yet to be categorically classified as an asset nor a decentralised activity. The EU does have a directive on technologies that are capable of generating electricity but this does not reciprocate the role of energy storage nor does it recognise it as a potential mechanism that's integral to a decentralised energy system (Gissey, et al., 2016). This is simply because there is an unresolved primary uncertainty of whether energy storage will serve as a transmission, generation or distribution asset. Correspondingly, the ambiguity surrounding decentralised generation has also snowballed the uncertainty of energy storage. As a result, this has also snowballed in preventing investments in storage technologies from being incentivised thus hampering the technological growth and ultimately impeding an appropriate market design for deployment. (Giglioli, et al., 2010).

The Incoherence of Market Design

Market design are usually a supplementary development in the regulatory process (Cramton, 2017). This is because electricity markets for the matter are seen as an essential service and therefore regulation is needed to ensure it is available to all. The existing EU market design includes policies that support national instruments of integrating renewable sources of energy. This is where the problem lies as the current market design is fragmented and segregated nationally thus making it incapable to accommodate the exponential growth of renewables deployed across Europe. The core that needs to be addressed is how to uniformly objectivise the EU energy policy so that all is member states benefit a brighter future of energy security, energy affordability and environmental sustainability. Addressing this trilemma factors in the policy will allow for great synergy amongst member states whilst thus accelerating EU's energy paradigm shift. In the recent "trilogue negotiations", member states voiced their concerns regarding the impact the new decentralised energy system will have on their security of supply (Beckman, 2018). Therefore there is grave importance in first addressing the energy trilemma factors as it plays a key role in EU's energy transformation. Nevertheless, having said that, it is undisputedly a difficult task as trade-offs that exist between the EU's energy goals (energy trilemma) differ greatly from one member state to another, therefore making it almost unmanageable to have a coordinated policy. For example, the desire to decarbonise is undoubtedly the primary goal but some member states are more concerned with security of supply whilst others may be more concerned about the affordability aspect. As highlight by Peng and Poudineh (2017), this misalignment may continually enforce isolated policies and incoherent market design. This will then barricade the deployment of energy storage and also delay EU's transition into a low carbon economy which would deter EU's trilemma goal of increasing environmental sustainability.

2.6 Environmental Factors

The Transitional Consensus for a Low Carbon Economy

The need for a low carbon economy comes hand in hand with EU's need to solve its energy trilemma of environmental sustainability in order to evade the worsening of climate change. Therefore, the need to reduce GHG emissions should not be questioned for. It has been denoted that 80 percent of the pollution around the globe has been contributed by the burning of fossil fuels (Qian, et al., 2008). In the EU, air pollution has caused more than 500 thousand premature deaths (Diehn, 2017). To add further, according to a research done by White (2018), the impact of climate change analysed over hundreds of European cities showed that the outcome is gradually worsening. As such, there is a dire need of decarbonisation to occur.

Therefore, the EU has made it clear that it intends to decarbonise its economy. The EU's GHG emissions have reduced significantly, and that is all except the transport sector which has seen a 20 percent increase in emissions (Tagliapietra, 2018). Moreover, transport is the one of the key contributors to air pollution. According to World Health Organisation (WHO), shifting to cleaner types of power generation such as low emission vehicles could significantly reduce the sulphur content in the air that causes many adverse health effect (WHO, 2018). However, in report released by the European Climate Foundation (2018), the transition towards clean forms of mobility cannot be achieved without the profound technologies needed to power the vehicles. This can only be quintessentially made possible through energy storage.

The Sustainability of the Environment

It is clear that a sustainable low carbon future will require the integration of renewable energy sources and the intermittency of such a resource can only be overridden with energy storage. As Parnell (2016) highlights storage is the missing puzzle piece to solving the energy trilemma. The role of energy storage as a core component is indisputable. The ability of storage to aid in generation, transmission and distribution of energy makes it an all-round service that is incomparable. Moreover, it is the bridge that allows renewable energies to be more reliable. There is no doubt that energy storage is an asset enabling technology in enhancing EU's environmental sustainability. However for that the EU needs to acknowledge the role of energy storage as a solution and establish appropriate and relative policies that can influence the use of such technologies.

The overall analysis above justified the practicability of energy storage technologies. It identified how the geopolitical interlinkages of EU at present integrates an energy market driven mainly by the security of supply but fuelled based on sovereign economic prosperity. However, the underlining factor comprehended that the severity of overcoming the security of supply requires intervention from technologies like energy storage. Nonetheless, as expressed in the analysis above, this requires multilevel governance of political uniformity amongst the EU in the form of policies in order to align the new technologies with processes that could enhance not only the security of supply but also increase the affordability of prices and encourage environmental sustainability. The lack of energy storage policies was the key theme of the analysis. It clarified how the lack of these policies do not provide a level of clarity of economically valuing energy storage. Because energy storage is seen as a supplementary asset, there are no specific policies to address its different functionalities and as such, its economic value as mentioned is interpreted based on the energy system. However, there is no contest against the flexible operations of energy storage and how it can be a prolific asset used to increase the affordability of energy prices. Since cost is an influencing factor, the analysis carried out showed how increasing the energy affordability could contribute to the social acceptance of integrating renewable energy and its required technologies. The debacle of energy poverty facing the EU places great emphasis for the need of more solutions to allow energy to be equally affordable. The analysis identified how energy storage allows for equity to take place. The ability of energy storage to reduce price volatility and promote autonomy to households (prosumers) enables a level of authority for households to efficiently manage their own consumption at a desired price. Of course, the engine behind these services is the technology and therefore, implementing the technology will ignite the transformational change needed for this transition. Nevertheless, the pattern of the non-existent energy storage policies has been climaxed throughout the analysis as the defining factor towards the delay in technological implementation. Indirectly, the analysis acknowledged that the design of EU's regulatory framework did not take into account energy storage. The policies did touch upon the supplementary services of energy storage but not one policy as of yet has thoroughly detailed the necessity of energy storage as a solution. It is apparent nonetheless that energy storage policies can thrust EU's energy paradigm shift and solve EU's energy trilemma to a great extent. To ensure this, current EU energy transition policies need to be reformed to take into account the credibility of energy storage. Therefore, the following chapter will analyse the conditions under which energy storage policies can be more widely implemented in EU's regulatory framework for energy.

Chapter 3: Energy Storage Policy Recommendations

Without energy storage, there will be an overall imbalance of generation and consumption of energy within the energy system. As such, the competency of energy storage technologies does not depend solely on research and development. Deployment is a good indicator for analysing the feasibility of energy storage. However as identified throughout this paper, the lack of policies have been identified as the ultimate barrier to the deployment of energy storage.

Therefore, there needs to be importance placed upon enabling a regulatory framework that levels the field for energy storage be integrated into the market. This is essential to optimise the services provided by energy storage and to enhance its compliance with the EU's energy targets. To address policy bottlenecks, the following recommendations have been developed.

3.1 Instituting a Definition of Energy Storage in EU's Regulatory Framework

EU's regulatory framework has always been prided for being a strong strategic pillar of EU's integrated energy market. Westgeest (2017), highlights that the primal precondition of a fully functioning integral market requires the abolishment of unnecessary national differences to create more wielded and efficient market. Hence why, with the evident need of energy storage responsibilities in the EU, it is necessary to have a "common" European definition of energy storage. The absence as underlined has created a myriad of definitions within the member states' regulatory paradigm preventing a level of playing field for energy storage in the EU. Therefore, it may be necessary for the EU to amend its current directives like the EU's Electricity Directive under its Clean Energy Package.

A recast draft was actually made on EU's *Electricity Directive 2009/28/EC* which included a proposed definition of energy storage. However so, this definition limits the application of energy storage technologies and its applications. As cited in *Article 2.47* of the Electricity Directive,

"***Energy storage in the electricity system means the deferring of an amount of the energy that was generated to the moment of use, either as final energy or converted into another energy carrier.***" (European Commission, 2017)

This definition however, does not justify the other applications of energy storage that makes it viable as essential components in transmission, distribution, and consumption as well as an energy infrastructure (for the use of ancillary services). For example, this will pose barriers for transmission system operators to invest in energy storage as it is not necessarily involved with generating energy (Colthorpe, 2016). Therefore, a robust yet extensive definition is required to reflect the current and potential applications of energy storage. Not only will this allow further development of new technologies but it will be the "stepping stone" for investment and deployment security. Thusly, this paper would like to suggest a reformation on EU's proposed definition of energy storage.

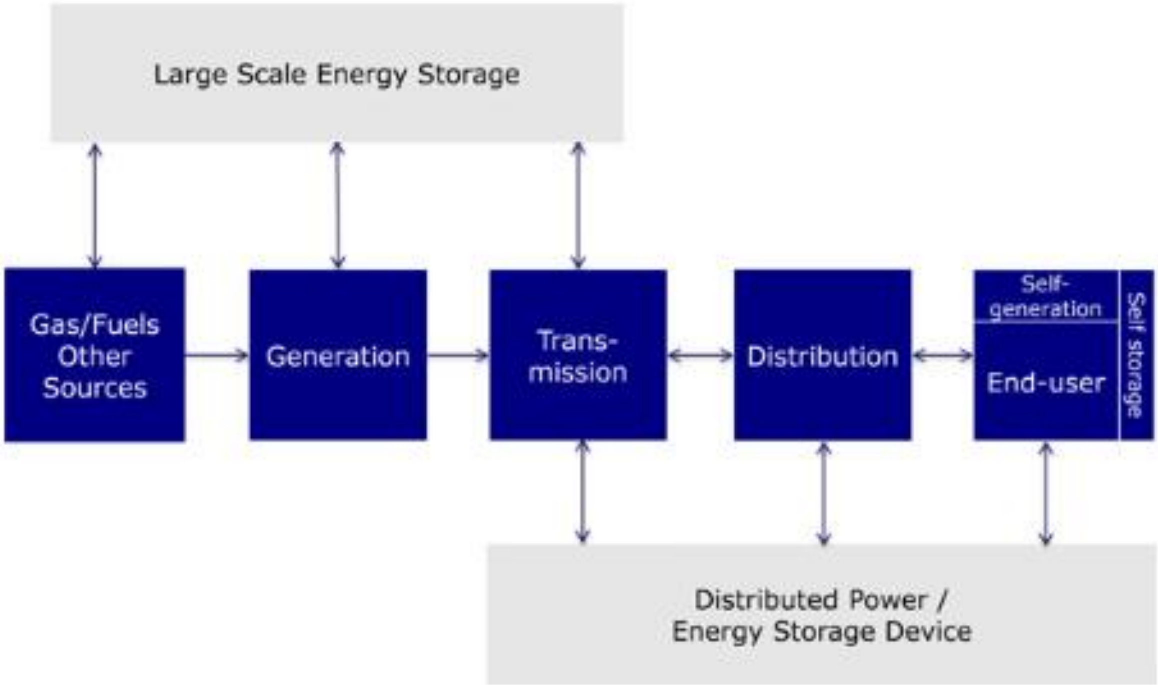

Figure 21: Energy Storage at all levels of an Energy System
Source: Energypost.eu (Source Link)

The definition highlighted does support the integration of energy storage however the key word limiting the deployment is the word "generated". The word "generated" implies an unjust and direct ownership of storage to those who partake in using storage for generation. However, as figure 21 above illustrates, energy storage has a broader application in the energy system and therefore, a broader definition is needed to parallelise the definition to its application. The European Association for Storage of Energy (EASE, 2017) suggests that the term "generated" should be replaced with the term "produced". However this paper would like to refute this definition as well. The reasoning is that, "produced" indicates the presence of energy production which inevitably is the same as the term "generated" which strictly limits to the generation aspect of energy. Instead, this paper would like to suggest the replacement of the word "generated" with the word "yielded". The word "yielded" or "yield" acknowledges a more extensive definition that succumbs the overall availability of energy within an energy storage which could be used for generation, transmission, distribution, consumption and even infrastructural applications. Economically, having a broader yet thorough definition of energy storage will avoid the possibility of double cost of fees.

Fees and taxes need to be fairly applied in order to avoid the double payments for the charging and discharging of energy (Blackman, 2016). Classifying and defining storage to include all of its respective applications will allow an appropriate financial framework to be designed to address the rationale of electricity pricing. Moreover, this definition will support the classification of storage as a separate asset of investment which subsequently will lead to the clarity for the ownership of energy storage devices.

3.2 Energy Storage Ownership

The lack of definition as seen above has stirred vagueness when it comes to the ownership of storage. The vagueness is by-product curtailment of the current energy system. In the current energy system, energy storage would fit in either one of the energy system domains (generation, transmission and distribution). However so, in EU's energy paradigm shift, the role of energy storage stretches across to all these domains and further due its ancillary services. As a consequence, there will be shift from a single "vertical" ownership to a multiple "holacratic" ownership. Holacracy implies evolvement through the principal of working together (Robertson, 2007). A holacratic ownership for energy storage initiates the idea of multilevel ownership for the various levels of storage applications providing clarity of rules under which energy storage can access markets.

First and foremost, as highlighted in the analysis above, energy storage disrupts the traditional hierarchy of electricity supply chain that exist between the producer and its end user. For example, as illustrated in Figure 22 below and aforementioned, energy storage increases autonomy whereby more and more end-users will be able to produce and consume their own energy (prosumers). The whole economical structure of the energy system changes as prosumers go against the conventional unilateral flow of energy. The rise of prosumers will introduce more and more owners in the form electricity suppliers. This is mainly because the excess of energy from prosumers will now be used to supply the grid and meet demands if and when necessary. Therefore, it is necessary for the EU to take into account that utilities are no longer the singular owner of the power grid services. However a key deterrent in establishing ownership is the blurred roles of actors in the power grid.

Utilities and end-users now both share the responsibility of generating, transmitting and distributing electricity. Albeit prosumers may yield a smaller amount of electricity, the synergistic effect of energy produced of multiple energy storage units could be beneficial for the grid. At present, the EU does not have any specific policy on prosumers. In 2015, the European Commission issued a working document "*Best Practices on Renewable Energy Self Consumption"* that promoted different models of market integration involving the notion of self-consumption of electricity (Energy Community, 2018). However this does not in any way recognise the energy that is yielded by a prosumer. As such this paper recommends that the EU redefines the role of prosumers that include the energy storage services provided by households and electric vehicle owners. Roberts (2016) declares that in the context of its 2030 climate and energy targets, the EU must ensure that legislation of the *National Energy and Climate Plans (NECP)* of member states includes guidelines to permit the participation of prosumers. Nevertheless, this participation should recognise prosumers as energy storage owners. This will inevitably aid in overcoming the energy trilemma on affordability and security. The European Parliament acknowledged that the rise in the number of prosumers has facilitated the fall in the cost of electricity prices (Sajn, 2016). Moreover, Leal-Arcas, et al. (2017) emphasises that the decentralised nexus of prosumers will be improve EU's security of supply. For that matter it is important recognise the prosumer ownership of energy storage which is an essential component in allowing them to provide electricity into the power grid.

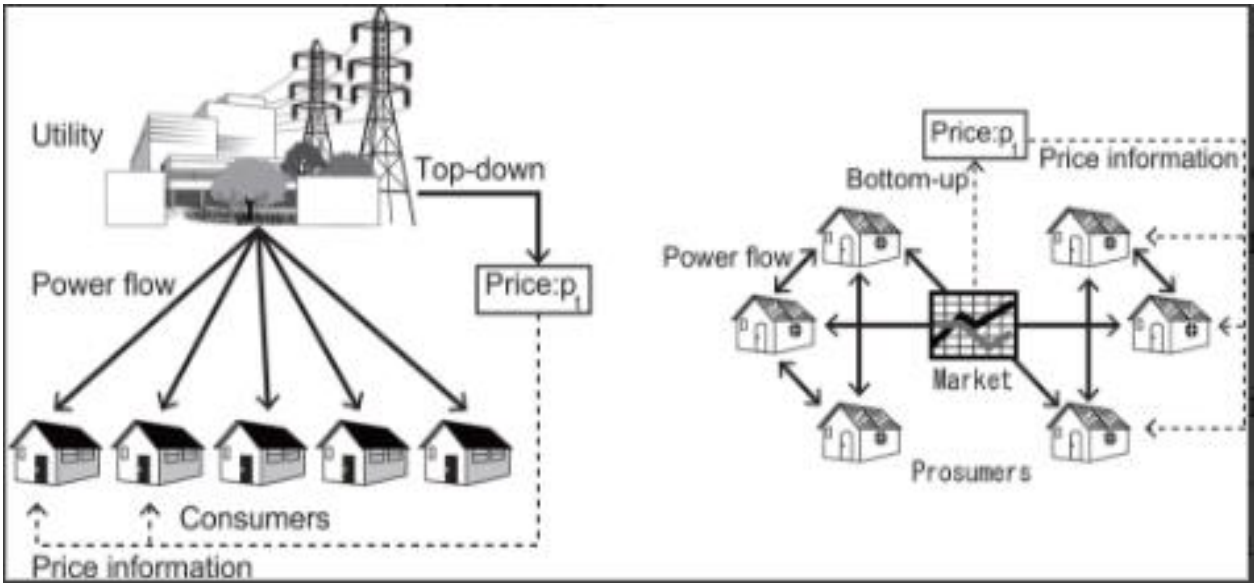

Figure 22: Unilateral (left) and Multilateral (right) Power Grid
Source MDPI (Source Link)

Ideally everyone who should be able to own and operate an energy storage. However, like all services there is a cost to bear. The question however is will it be possible to have multiple energy storage ownerships? At present, power exchanges from prosumers impose a cost for the grid operator as it requires additional investment to support and stabilise the grid with the extra load (Gautier, et al., 2016). Therefore, grid operators will also have to depend on energy storage to provide stability. In addition to that, generation companies will also need to depend on energy storage as a means of storing surplus energy to avoid wastages. As mention before, there will be a multilevel ownership of storage based of its various levels of application (See Figure 23). The conundrum this poses is how the energy system will react to multilevel ownership. What happens if everyone starts to invest in energy storage? This will increase the level of energy storage competitors making coordination an issue. Moreover, an increase in the amount of energy storage ownership in relation to the power grid may cause negative power prices. Negative power prices can have an impact for grid operators. The loss of profit from electricity prices may become a little overbearing for these grid operators to continue running their plants. This may also be a burden to consumers as Amelang and Appunn (2018) highlights that, producers more often than none receive a guaranteed feed-in of payments therefore when electricity prices drop to negative, the imbalance in the feed-in payments will be levied onto consumers. As such, this paper would like to propose recommendations on how the EU can set clearer rules of energy storage ownership.

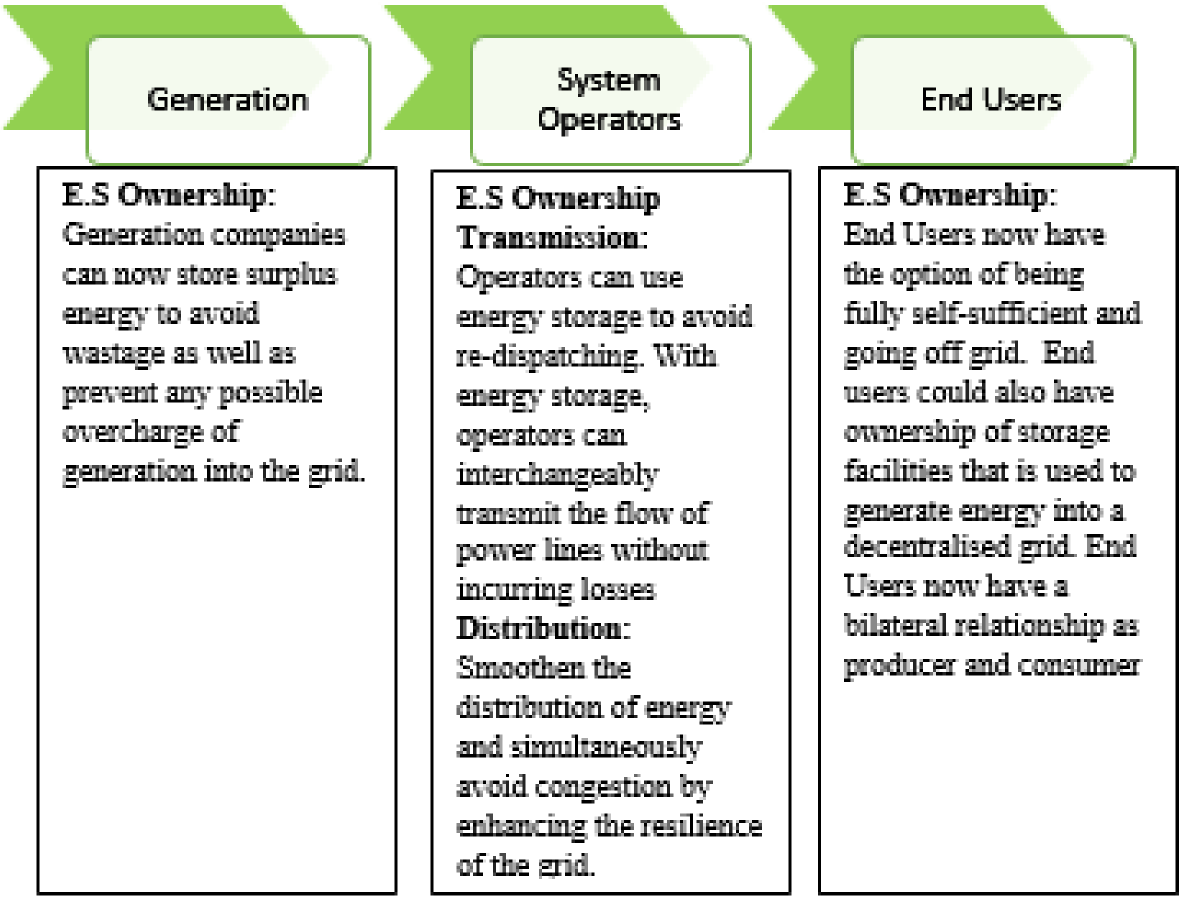

Figure 23: Types of Energy Storage Ownerships
Source: The Author

To ensure the use of energy storage is optimised, it is necessary to control how energy storage is operated and how its services is being sold. According to Revesz and Unel (2018), system operators are at the best place to operate energy storage in an energy system simply because they understand the electricity demands of the market. As such, this paper would recommend that the EU make provisions to allow system operators such as transmission and distribution operators to have ownership of energy storage system in an energy system. Generators and End-Users (prosumers) are allowed to own energy storage but only for the use of their own operation. Generators and end-users should not be able to have ownership of energy storage used in a power grid. This provides a better level of clarity and avoids the unnecessary risk of conflict amongst the different actors. Nevertheless, generators and end-users who own energy storage should be able to trade their energy on a peer to peer platform. This means that these actors get an indirect reward in the form of feed-in tariff for storing and providing yielded energy and ancillary services to the grid but at the same time need to contribute to the cost of being connected to the energy system. Having said that, the EU needs to make significant changes in its policy to accommodate the above recommendations.

The EU has an unbundling obligation set in its Electricity *Directive 2009/72/EC* which acknowledges the need to separate entities in its “vertical” energy system. However so, according to a report released by European Distribution System Operators (EDSO), *Article 36* of the EU Directive proposed that,

Distribution system operators shall not be allowed to own, develop, manage or operate energy storage facilities (EDSO, 2017)

This inhibits the growth and implementation of energy storage technologies. For that matter, the EU needs to take into account the valuable services that could be offered to system operators such as distribution operators. This paper would like to propose amendments for the *Article 26* by stating that,

Distribution system operators should not be allowed to privately own energy storage facilities but should be allowed to own, develop, operate and manage energy storage facilities including ancillary services under the approval and regulation of national regulatory authorities.

This implies that distribution operators have the ability to own and operate energy storage for the purpose to delivering service to the energy system if and only if national authorities take the responsibility of regulating the activity. The same should be applied to a transmission system operator.

By recommending ownership of energy storage, it allows the deployment of storage technologies to take effect. The reliability of energy storage services is crucial for maintaining a constant flow of energy from more sustainable sources and therefore, the recommendations for energy storage policies are not set in biasness of any utility or energy actor but as a platform to thrust the EU's energy paradigm shift whilst ensuring secure, affordable and sustainable measures of energy.

3.3 Economically Valuing Energy Storage

First and foremost, energy storage will need to be seen as an infrastructure. At present, regulation may find it difficult to assign the value of energy storage and this, as mentioned before is because as opposed to the traditional method, energy storage falls into generation, transmission, distribution and ancillary services. According to Berg, et al. (2017), if energy storage is only valued under one of the domains (generation, transmission, distribution), it can be significantly undervalued thus not providing the required economics benefits. For that, this paper would like to suggest that the EU ensure mandates are in place for member states to structure their utility regulations to include energy storage as this would allow participation of energy storage in wholesale and capacity markets. This will also take into account the value of ancillary services provided to power grid. In addition to that, a certain amount of influence is first needed to reap the full economic benefit of energy storage.

As highlight throughout this paper, it is transparent that energy storage is valuable in many different ways. However as this will relatively be a new component of EU's energy system, the EU should provide incentives to utility, commercial and residential energy storage. The EU should mandate that a certain amount of energy storage capacity is needed to be deployed by each member state whilst providing an adequate amount of incentives to nudge the initial deployment. On the other hand, the EU could also obligate member states to ensure incentives are in place to promote investment and deployment of energy storage. This could be done by offering energy efficiency incentives which includes rebates or loans given on the basis of energy efficiency improvements. Another way to which the EU could economically place a value for energy storage is by providing tax incentives. As an example, the EU ETS is a carbon pricing scheme aimed to reduce emissions, however this is not applied across all the economic sectors such as transport. As a solution, the EU could recommend policies whereby member states could impose a direct income tax reduction for individuals and businesses (utilities) who make use of energy storage for the purpose of increasing energy efficiency. By doing so the EU will establish a common ground of how individuals can integrate energy storage. Moreover, with incentives in place, there will be a market for energy storage thus making it more relative to value energy storage.

The need to value energy storage is necessary to ensure that energy storage is not just feasibly applied to an energy system but to ensure energy storage provides its full array of benefits. Valuing energy storage will allow pricing to be adjusted to the market and over time this value will provide a leverage to which electricity prices will benefit from economies of scale with an increase of renewable energy production. As such, energy storage can be a major stimulus in ensuring the affordability of prices whilst also progressing the development of a sustainable environment.

Chapter 4: Conclusion

In the truth of it all, despite all the political upheavals like national sovereignty of member states and insecurities of security of supply, the implementation of energy storage policies and its deployment in the energy system has a more devoted reasoning associated to it. The European Union has been a vigorous figure for tackling climate change issues and the manifolds of benefits from deploying energy storage in overcoming climate change issues are innumerable and undeniable. Based on the analysis, it is evident that the need for energy storage policies will not only aid EU's increasing need for renewable energy but will ensure that the EU meets its climate change targets whilst enforcing the transformation into a low carbon economy. Nevertheless, despite the apparent benefits, bottlenecks of the lack or almost non-existent energy storage policies are evidently persistent.

There is no doubt that the purpose of energy storage policies are clear. It acts as a stepping stone in ensuring support of applying energy storage technologies. Energy storage technologies from fuel-cell hydrogen to carbon capture storage all have a multipurpose application of ancillary services in addition to the primary feature of storing energy. As such, these applications are not just dependent on renewable energies and therefore a policy response acknowledging the multipurpose of energy storage is necessary. This is necessary to address the value of energy storage which in return is a necessary parameter to influence its deployment. Economically, implementing energy storage policies can induce the increase of autonomy. As highlighted in the analysis, the self-sufficiency of prosumers could very well indeed drive electricity prices down making it more affordable thus solving the energy affordability issue within the EU. According to Platt (2014), in the UK, the price of renewables generated electricity is already the same price as conventional energy bought from the grid so with the aid from energy storage, the prices of renewable electricity will further decrease. Due to this fact, Casey (2018), affirms that policies provide certainty in the market which could further promote the investments made on energy storage technologies, resulting in the desirable outcome of making the EU a low carbon economy with a resilient network of reliable renewable sources.

It is clear that energy storage technologies enhance the reliability of renewable energy. The role of technologies like fuel-cells improve the irregularity of renewables by improving the balance of the power grid to avoid disruptive flows of electricity. On the other hand, technologies like battery allow for off-grid applications with can be used to provide electricity to in areas that do not obtain enough energy from the grid. This could very well be used to enhance the power supply on the south of Germany that consumes more energy but produces less energy from the north. In the EU, there are already many existing energy storage technologies that are also matured to a certain extent. Nevertheless, Bhatnagar, et al. (2013) indicates that there is slow modification in the participation level in the market due to the aforementioned insecurities of supply and the value of product (energy storage). This slow modification has also increased the suppression of social acceptance for energy storage.

As above-mentioned, even if all factors are aligned for the deployment of energy storage, the success of deployment will inevitably depend on social acceptance. According to Devine-Wright and Batel (2017) and as highlight in the analysis above, social acceptance is needed to foster the polycentric perspective of actors in understanding the need for energy storage. This is the problematic as based on the analysis, one can conclude that lack energy storage policies provides an insufficient base of information needed to educate the society about energy storage thus causing an increase be path dependent. It has been evident that the deployment of energy storage depends on an amalgamation of factors, from political to economical to technological to social and et cetera. This is why relevant policies will be the epicentre of deploying energy storage (Jacobs, 2018).

There is no doubt that energy storage policies can contribute significantly to EU's energy paradigm shift. However, it would not be fair to conclude that energy storage policies will be the "silver bullet" in thrusting this paradigm shift. It is greatly evident that the deployment of energy storage could significantly aid in transforming the EU into a low carbon economy. Nevertheless, one of the greatest barriers of deployment as highlighted throughout this paper is the lack of policies that are almost non-existent in helping to govern and lead to the deployment of energy storage within EU's regulatory framework for energy. The implementation energy storage policies will allow the deployment of energy storage to be applicable across all spectrum, enhancing the security of supply through the storing of surplus energy, increasing the affordability of energy by making use of the “yielded” energy to compensate the high peaks of demand and also improving the environmental sustainability of the EU by allowing the integration of renewable energy thus unquestionably driving the shift into a low carbon future. Therefore, energy storage policies as the ones recommended above will contribute to EU’s energy paradigm shift to a great extent by allowing the deployment of technologies that are necessary in the transformation into a low carbon economy. However, the wiser conclusion would be to acknowledge that these energy storage policies are needed but should be implemented and integrated alongside EU’s framework of existing energy policies in order to fully optimise the extent to which energy storage can contribute in EU’s energy paradigm shift.

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