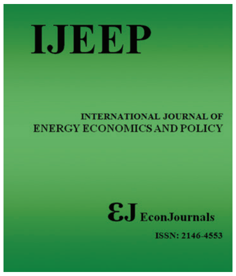

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Economic Aspects of Innovations in Energy Storage

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ABSTRACT

Energy storage is emerging as a potential method for addressing global energy system challenges across many different application areas. However, there are technical and non-technical barriers to the widespread deployment of energy storage devices. With regard to the above, it seems crucial to identify innovation processes, mechanisms and systems (in a broad sense) that can allow energy storage to help meet energy system challenges, and also deliver industrial growth from technology development companies. The pioneers in delivering these new technologies are few, among them for example Elon Musk with his ground-breaking projects such as Tesla Motors and SolarCity, Powerwall (the Tesla home battery), and some others. This paper is dealing with recent developments and trends in the field of innovations in the energy storage. Its main value-added is the comprehensive overview of the current state-of-the-art and identifying the pathways to follow.

Keywords: Energy Storage, Storage Device, Batteries, Energy Policy
JEL Classifications: C32, Q4

1. INTRODUCTION

From an economist's point of view, the value obtained from storing cheap or free energy obtained from renewable sources during off peak or low demand periods which could be sold during peak hours which are mostly in the afternoon can be calculated by simply taking the market price difference between the time periods. Thus, energy stored in batteries from the renewable sources such as wind turbines during off peak periods could be discharged during peak periods as opposed to running non-renewable sources such as natural gas turbines which are more expensive. For a complete view of the impact on using such technologies, it would be necessary to consider the negative impact of pollution towards the environment in obtaining a clear analysis. It may be that despite the environmental advantages brought about by energy storage, there may be simultaneous environmental disadvantages. For example, it may be unnecessary to curtail wind farms at night since the generated energy can be stored. However, coal fired power plants can also be left running at night since the energy can also be stored thereby resulting in an overall effect of a small increase in the total amount of pollution as a result of the mere existence of the grid (Jacobsen, 2016).

Electrical energy can undergo conversion into numerous varying forms for storage. Common practices include conversion and storage as: Gravitational potential energy with water reservoirs, compressed air, electromechanical energy in batteries and flow batteries, chemical energy in fuel cells, kinetic energy in flywheels, and magnetic energy in inductors and electric field in capacitors. The use of large scale energy storage systems such as pumped hydro storage (PHS), which involves storing electrical energy as gravitational potential energy of water, involves pumping water from a lower reservoir to an upper reservoir during off peak periods. The water is in turn released to flow to the lower reservoirs during peak hours and thus activates water turbines eventually generating electricity. There is a proportional relationship between the energy stored, the water volume in the upper reservoir and the height of the waterfall. PHS installations usually last for 30-50 years and have been determined as having an acceptable round trip efficiency of 65-75% with power capital costs of 50-150 £/kW and 10-20 £/kWh. It also has a fast response time of less than a minute in spite of its large power volumes and energy management which makes it suitable for controlling electrical network frequency and providing reserve generation (Díaz-González et al., 2012).

Compressed air energy storage (CAES) involve energy being stored as compressed air in as underground storage cavern. It is therefore based on the use of conventional gas turbines. During peak hours which usually require more energy to be injected into the grid, compressed air from the cavern mixed with natural gas is drawn, heated and expanded in high and low pressure gas turbines sets. This converts the compressed air energy into kinetic energy. The turbines in turn run the generators while the exhaust from the turbines is used to heat the compressed air from the cavern. However, this technology has not been widely applied around the globe. Examples include one in Germany with a capacity of 290 MW and another one in USA with a capacity of 110 MW. Improved technology has resulted in the creation of advanced adiabatic CAES which involves advanced air being adiabatically compressed and afterwards pumped to an underground cavern storage tank. This method includes the use of heat exchangers which have higher costs but greatly contribute to the efficiency, effectiveness and economics. They have proved highly successful as a result of their compressor and expander trains. CAES systems have been estimated to have a lifespan of at least 40 years with an energy efficiency of 71%. Due to very minimal self-discharge within the system, they have been regarded as the long-term competitors of PHS (Lu et al., 2004).

2. BATTERY ENERGY STORAGE SYSTEMS (BESS)

The most common technology applied in energy storage is the BESS. In this technique, a set or various sets of multiple cells are interconnected in series, parallel or in both sequences in a bid to acquire some value of voltage or capacity (Divya and Østergaard, 2009). This energy is stored in form of electrochemical energy. Electrodes which are usually made of conducting materials are put in an electrolyte contained in a special, sealed container thus supplying an external load (Winter and Brodd, 2004). Through the electrolyte, exchange of ions occurs between the electrodes while electrons flow through the external circuit. This method incorporates using power battery modules which produce lower voltages which after being connected in a series, parallel or both sequences, achieves the desired electrical output and behavior. Normally, a BESS is made up of power batteries, the control and power conditioning system and the protection plant for the whole system (Suberu et al., 2014). The various types of batteries used include lead-acid batteries, nickel-cadmium and lithium-ion (Li-ion) batteries. Lead-acid batteries have been used for the longest time of around 140 years. These batteries consist of two types, flooded batteries which are commonly used and valve regulated batteries currently being researched and developed.

They have a life cycle of 1200-1800 cycles which varies based on the depth of discharge, a round trip efficiency of 75-80% and a lifespan of 5-15 years often depending on the operating temperature (Dufo-López, 2015). They are best used for energy storage over long durations. However, they often display poor performance at high and low ambient temperatures and have quite a short life span. They also require water maintenance over time especially the flooded type. Effort has been directed into converting nickel-cadmium and Li-ion batteries into preferred options for higher power uses especially in terms of their costs. Nickel-cadmium batteries consist of alkaline rechargeable batteries often categorized according to its application (Hadjipaschalis et al., 2009). This involves its sealed form often used on portable electrical equipment and its flooded form used in industrial applications. This type of battery has quite a lengthy cycle life of more than 3500 cycles and requires low maintenance. They are however toxic due to the use of heavy metals which pose health and environmental hazards and often suffer from memory effect. Li-ion batteries on the other hand have common application in modern electronic gadgets such as portable phones and electronic devices requiring low power applications. Li-ion batteries have high energy density of around 170-300 W h/l and specific energy of between 75 and 125 Wh/kg. They also have fast charge and discharge capabilities as well as having high round trip capabilities of 78% within 3500 cycles. These batteries cannot be used for power backup systems due to their life cycle being dependent on the depth of discharge (Young et al., 2013).

Flow BESS is a new type of technology system based on the use of reversible electrochemical reactions to obtain a desired voltage output. This battery type utilizes two different aqueous solutions contained in two separate storage tanks. Commercially available types include vanadium redox battery, zinc bromine battery and polysulphide bromide battery. Flow batteries are capable of discharging without any damage occurring and have a relatively low self-discharge. They also have long life spans, are of low maintenance, have easily scalable capacities due to its dependency volume of the electrolyte stored and are also capable of storing energy for long durations (Chen et al., 2009).

3. OTHER ENERGY STORAGE SYSTEMS

Hydrogen-based energy storage system resulted from the extraction of hydrogen through different methods or means which can then be stored and used later on or used directly. Various means of obtaining hydrogen include water electrolysis, renewable energies and gasifying biomass, coal or fuel which is usually the most commonly practiced method. Storage of hydrogen usually involves the use of regenerative fuel cell technologies which normally involve electrochemical transformations in form of hydrogen later injected to the national or regional grids as electricity (Zhao et al., 2014). Reverse fuel cells (RFCs) require water electrolyzer systems for electrochemical decomposition of water into hydrogen and oxygen, a fuel cell system, hydrogen storage system, and a power conversion system. Electrolyzers are of different types namely alkaline electrolyzers, and polymer electrolyte membrane electrolyzers commonly in use today. RFCs usually incorporate fuel cells due to their good dynamic behavior, quick start-up and generally have no acoustic emissions while operating with discharge water being the only by product. Given that RFCs are based on flow battery technology, their power and energy capacity are nondependent on each other. Due to their modular design, they have high peak power of more than 10 MW for systems of high energy larger than 100 MW h. They also have no self-discharge allowing energy storage for long durations of close to 15 years. This system however has low efficiency of around 42% (Soloveichik, 2011).

Flywheel energy storage system (FESS) involves energy storage in kinetic form whereby a mass rotates on two magnetic bearings so as to decrease friction during high speeds coupled with an electric machine (Akagi and Sato, 2002). During machine operation with its motor rotating, a transfer of energy occurs to the flywheel resulting in its acceleration thus charging the energy storage device. As the machine regenerates through the drive thus causing the flywheel to decelerate, the FESS starts discharging. Machines that often use this type of technology include the axial-flux and the radial-flux permanent magnet machines or synchronous reluctance induction machines. FESS usually presents many advantages ranging from high efficiency of about 90% at the rated power, long cycling life, wide operating temperature range, freedom from depth of discharge effects, higher power and higher energy density. They however present challenges such as relatively high standing losses and 20% self-discharge of the stored capacity per hour for the whole flywheel system thus making them rather unsuitable for long term storage of power (Vazquez et al., 2010).

Another technology developed for energy storage is the superconducting magnetic energy storage which is a recent technology. It involves storing energy in a magnetic field resulting from passing DC current through a superconducting coil at cryogenic temperature. This system involves the use of superconducting coils which may be grouped as high temperature coils with an operating temperature of about 70 K and low temperature coils with operating temperatures of around 5 K. In deciding which technology is best suited for use, it is essential that both the cost and the system requirements are balanced. This system is capable of obtaining high energy densities similar to those obtained in flywheels and conventional batteries. They also have a high energy efficiency of up to 90% as well as having a very long cycle life of tens of thousands of cycles. It is also possible for this system to inject or absorb large amounts of energy within very short durations. However, due to their high costs, with a capital power cost of between 1000 and 10,000 $/kW, very few of these facilities have been established (Noe and Steurer, 2007).

4. ECONOMIC IMPLICATIONS OF ENERGY STORAGE

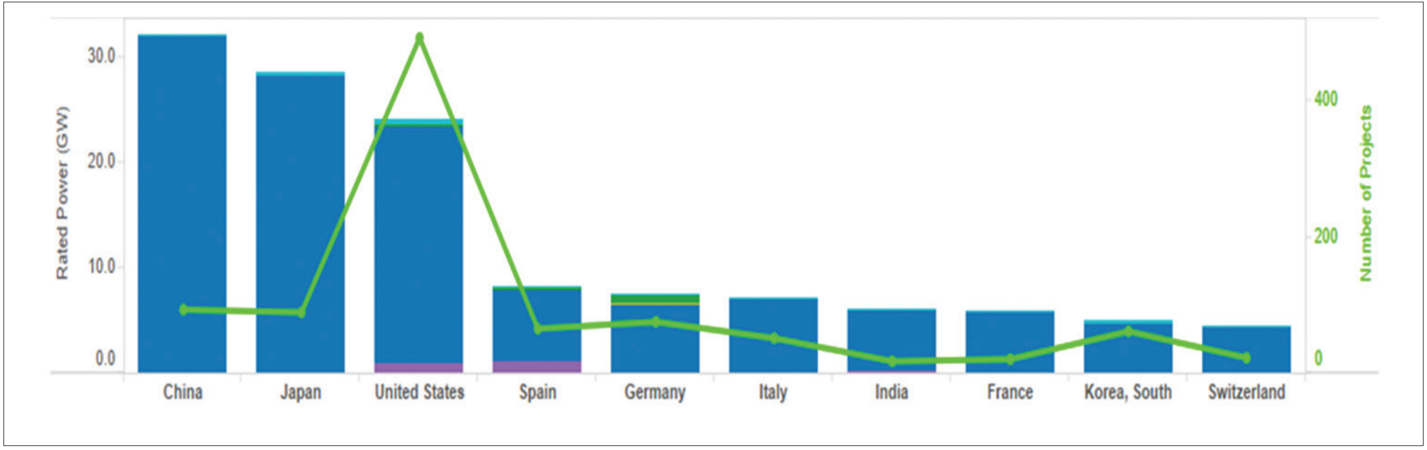
Energy storage is a favored applied science of the future for great purposes (Ciamician, 2012). Multiple individuals perceive affordable storage as the lacking connection between alternate renewable energy, such as the wind and solar and daily dependability. Businesses, both in Poland and worldwide, are interested in the possibility for storage to satisfy other demands such as reducing gridlock and ironing out the fluctuations in power that happen independently of renewable-energy production (Urbaniec, 2015). Significant mechanical businesses acknowledge storage an applied science that could change cars, turbines, and customer automatics.

Others, nonetheless, take a dimmer outlook, understanding that storage will not be reasonable any time soon. That uncertainty cannot be omitted. For some time now, the transformative prospect of power storage has been just around the corner, and presently, storage aggregates a small drop in a vast sea (Gallagher, 2009). A record 221 MW of storage capacity was installed in 2015 this was more than three times as much as in 2014 - 65 MW, which was itself a significant increase over the preceding year (Fertig and Apt, 2011). However, more than one hundred and megawatts of the year 2015 total was used by a private local transmission corporation, PJM interconnection. PJM serves all or section of Illinois; Delaware; Kentucky; Indiana; Maryland; New Jersey; Michigan; Ohio; North Carolina; Tennessee; Pennsylvania; Virginia; West Virginia and Washington, DC. Furthermore, 221 MW are not much in the setting of a full US production capacity of more than a million megawatts.

Chart 1 that follows shows the energy storage installations and project for the top 10 countries. It becomes apparent that although China has the most of the installed capacity, it tails the United States and Japan in the number or projects (DOE Global Energy Storage Database, 2016).

Research discloses a considerable near-term possibility for stationary power storage. One speculation for this is that prices are dropping and could be close to $200/kwh in the year 2020;

Chart 1: Energy storage installations and project (top 10 countries)



this is half today's rate, and $160/kwh or less in 2025 (Lundmark and Bäckström, 2015). Another is that identifying the most effective aspects and highest-potential consumers for storage has shifted to be a preference for a distinct set of organizations comprising power providers, grid engineers, battery producers, energy-storage integrators, and enterprises with built connections with prospective clients such as energy-service companies and solar developers. This is particularly important with regard to the growing share of renewables and RES targets set by the EU (Eurostat, 2016). Innovations in energy storage are crucial in helping to accommodate this growth (Chart 2).

Setting up plans and identifying clients are needed. It means seeing how power is utilized and how much it costs, as well as the cost of storage. Too frequently, though, businesses that have access to information on power use have an inadequate knowledge of how to assess the economics of storage; those that recognize this economics have inadequate access to actual-world data on energy usage. Furthermore, there has been an inclination to equate the data when executing analyses. Aggregating estimates, nonetheless, is not beneficial when evaluating possibilities for power storage since identical structures next door to each other could have completely divergent models of power use. Inferences formed based on averages, consequently, do not have the accuracy required to recognize which consumers would be helpful to serve.

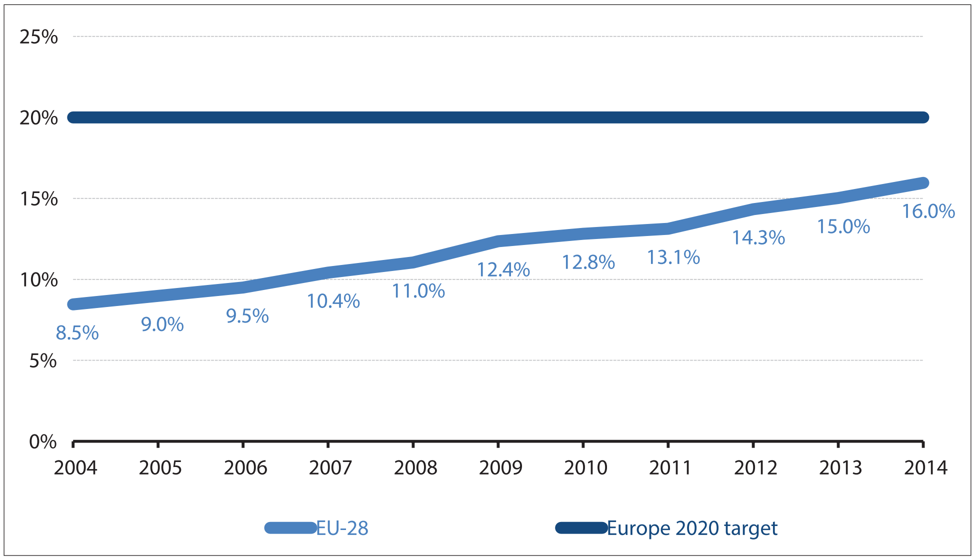
5. CONCLUSIONS AND DISCUSSIONS

In conclusion, it becomes apparent that there are several significant findings from the above discussion. First, power storage now makes an economic reason for specific utilization. This point is sometimes ignored given the importance on charges, payments for some storage designs, and noneconomic or tough-to-measure financial grounds for storage (such as elasticity and protection against power interruptions). Second, market shareholders need to obtain the complete data that could enable them to distinguish and prioritize those consumers for whom storage is helpful. Given the complexity of power storage, deployment is more reasonable to support a push versus a pull economics pattern, supporting entrepreneurial businesses that find inventive ways to obtain and utilize these data.

Third, storage providers need to be open-minded in their picture of energy-storage policies, determining if lead-acid, Li-ion, flow-cell, or some other technology will present the greatest value. An approach that uses various techniques may carry incremental expenses, but it may also guard against unexpected price increases. Fourth, healthy margins are expected to accumulate to firms that make use of battery and load profile data. The individual components of individual consumers will support tailored strategies, covering the progress of algorithms that find and obtain the highest value. Strong consumer associations are needed to achieve consistent data and to produce the most economical answer as laws and technologies evolve. Fifth, how to utilize storage to decrease system-wide expenses will need some knowledge. Models might incorporate price signals that are associated with notable differences in electricity generation and consumption, practices that reward the provision of storage to assist various sites in proximity, and charges that favor self-consumption (or load shifting) of renewable power.

The most significant relationship is this: The large-scale distribution of power storage could upset market as accustomed for several electricity businesses. In advanced nations, for instance, central or bulk production traditionally has been used to meet immediate demand, with ancillary assistance serving to smooth out inconsistencies between output and load. Energy storage is well adapted to give such additionally services. Ultimately, as prices drop, it could move past that role, producing more and more energy to the grid, replacing plants. That point is not imminent. But it is necessary to know that power storage has the possibility to upend the business structures, both economic and physical, that have established energy businesses for the last century or more. Moreover, it is even more vital to be equipped.

Chart 2: Share of renewable energy and RES targets in the EU-28



6. ACKNOWLEDGMENTS

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