Czech-Austrian Spring and Summer School

The relevance and costs of short vs long-term storage

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Content

Abstract

Extended penetration of renewables in electricity grids effects grid stability and demands storage technologies for allocating surplus or scarce energy generation. As low-carbon power generation increases, the increase of the energy storage capacity will be needed. This paper presents state- of-the-art of short and long- term energy storage technologies, as well as installed capacities in the Czech Republic and Austria. Method for comparing these technologies is presented, along with the cost calculation for pumped hydro, compressed air energy storage, flywheel, supercapacitor and Lithium-ion battery storage. Results are analysed in terms of economic feasibility and technical propositions for decision makers in both countries. Main contribution of the paper is cost comparison for different types of short and long-term storage technologies in Czech Republic and Austria and the importance of these storage technologies regarding grid stability and security of energy supply. Possible future installed capacities are being discussed.

1 Introduction

Climate change and greenhouse emissions have been main concerns of energy community for the past years. Global energy - related CO_2 emissions come dominantly from coal, industry and transport. Emission mitigation should be implemented through different policies and replacement of energy technologies. Paris Agreement as international treaty on climate change, aims at limiting global warming to below 2, but preferably to 1,5 degrees Celsius, compared to pre-industrial levels. Each country maps out National Energy and Climate plan (NECP) for achiving this goal. Europe strategy for emission mitigation is based on circular economy, energy efficiency and energy generation from renewable resources. In the past decade, total renewable generation increased by 47% (form 2010. to 2018., [1]) in EU-28. Technology costs for solar panels have decreased impacting growth of 361 GW installed capacities of solar in 2018.

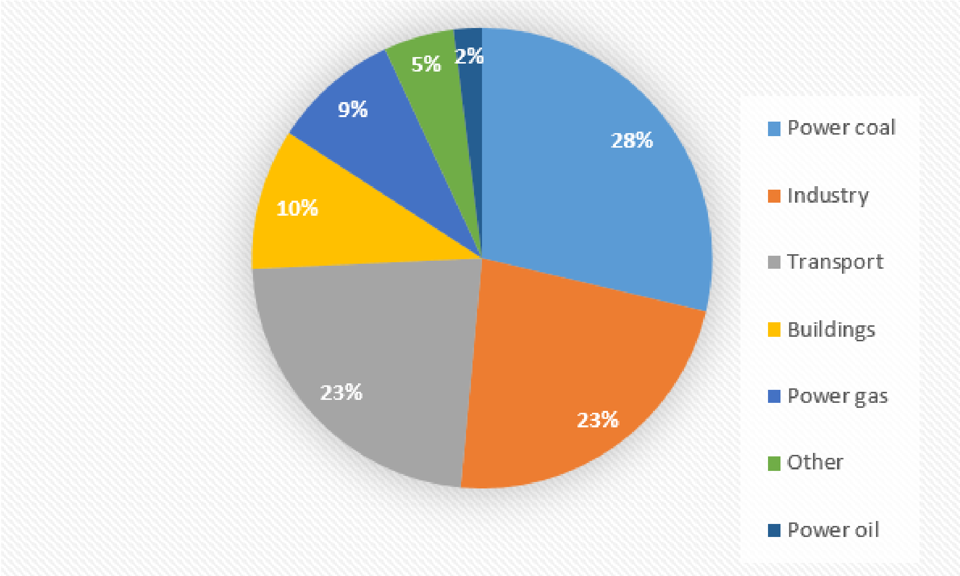

Figure 1 Global energy related CO2 emissions by sector [2]

Extended penetration of renewables in electricity grids effects grid stability and demands storage technologies for allocating surplus or scarce energy generation. As low-carbon power generation increases, the increase of the energy storage capacity will be needed. Comprehensive state- of- the-art of long- term energy storage technologies presented in [3], shows that existing models are inadequate to address future percentages of renewables. Energy storage higher integration is mainly conditioned by technology costs. Different types of storage technologies are used in the grid. Long- term storage (pumped hydro plants) provides seasonal changes and is used for dispatching power generation with renewables, while short-term storage, such as superconducting magnetic energy storage (SMES) and Flywheels, are devices for improving grid stability and power quality.

1.1 State of the Art of Czech Republic and Austria

Both Czech Republic and Austria have the most of their storage technology installed in pumped hydro storage (PHS) and smaller capacities in Li-ion batteries, in the latest years. Austria is in possession of much bigger capacities in PHS because of the geographical position of Alps mountain range. The oldest PHS is in Pfarrkirschen im Muhlkreis, Austria, with installed capacity 19 MW and commissioned in 1925. This illustrates that PHS can be used for a very long lifespan. Li-ion batteries have estimated lifespan around 15 to 20 years, depending on how many cycles is a battery built for and at what depth of discharge it operates the best. Lifespan of electricity storage affects the cost of the ability to store energy. PHS can be used for renewables integration shifting, load levelling, frequency regulation and voltage support. The response time is short – only minutes, and the storage can operate at full power for several hours. It is possible to use PHS both as short and long-term energy storage. Li-ion batteries can be used for renewables integration shifting, load levelling, frequency regulation, voltage support and black start. The response time is much shorter than for PHS – only milliseconds, and the storage can operate at full power from 10 minutes to 4 hours, depending on the size of the storage. It is also possible to use Li-ion batteries as short and long- term energy storage, however the response time of milliseconds and possibly short duration of discharge at full power implies Li-ion batteries have more of a character of short-term storage. [6]

1.2 Motivation

As the production of renewable energy resources (RES) increases, more storage capacities are needed because of the intermittent nature of the most RES. For example, wind power plants or photovoltaic power plants only produce energy when the weather conditions are suitable. Short and long-term energy storage capacities provide different ways of using the stored energy. Short-term storage is used for stabilization of the electrical grid. It ensures the power quality is remained. Long-term storage is used in times of peak demand, it can provide electricity for consumption for a few hours. Deployment and wide installation of both of these types of electricity storages will be needed if safe operation of the electrical grid is supposed to be ensured in the future.

1.3 Structure of the work

Firstly we provide an overview of energy storage technologies and their relevance as an important market players. Then we look into the energy storage technologies and capacities installed in Czech Republic and Austria. In chapter 4 paper gives detailed description of the storage cost calculation and method for comparison. Results in chapter 5 present comparison and economic feasibility between short and long-term energy storage costs. At the end, a discussion and a proposal of possible new energy storage capacities installations in Czech Republic and Austria is made.

2 Energy storage technologies

There are many different technologies used as energy storage. The qualities and characteristics of these technologies are variable and so is the way they are used to secure a safe operation of the electrical grid.

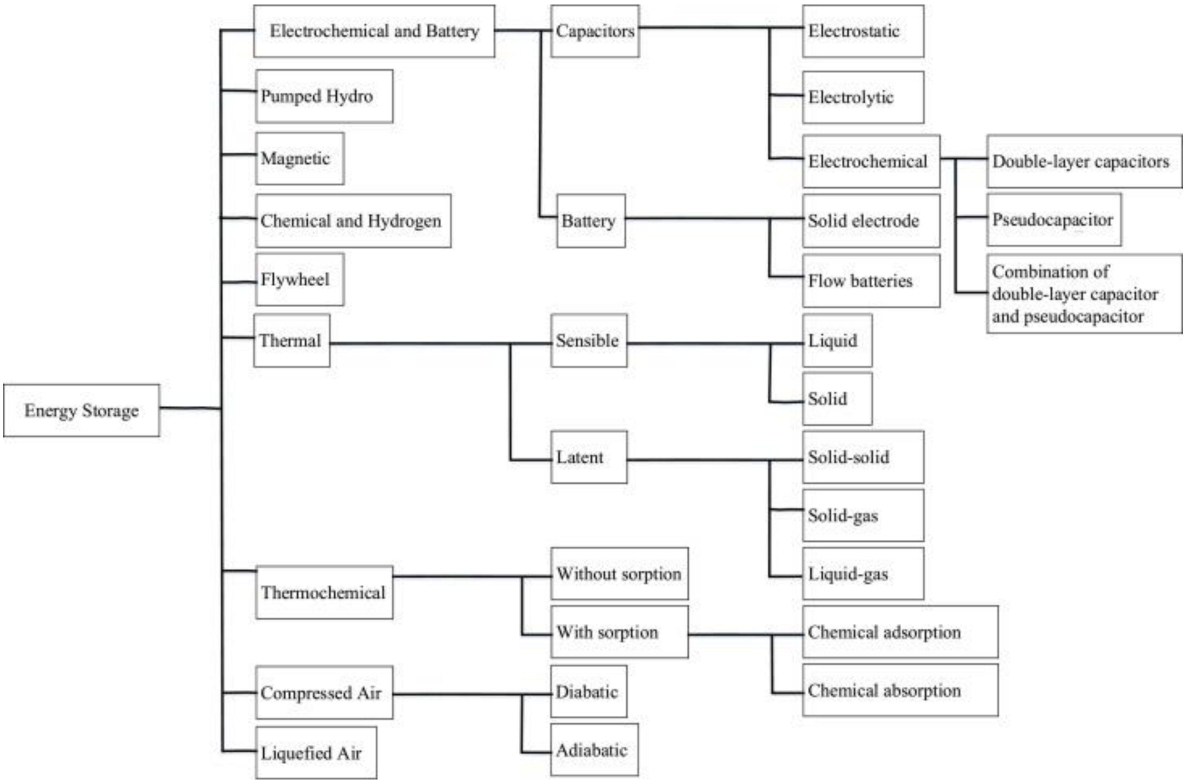

Figure 2 Classification of energy storage types [5]

Storage technologies can be divided into many categories as shown in the table. This chapter will focus on the main characteristics of electrochemical and battery energy storage, ultracapacitors, flywheel energy storage, compressed air energy storage, pumped energy storage, thermal energy storage, thermomechanical energy storage, magnetic energy storage and hydrogen energy storage.

2.1 Storage technologies examined in the paper

Different storage technologies are presented in detailed in [4] and [5]. Here, we are analyze short and long- term storage technologies, their differences and installations or future prospects in Czech Republic and Austria.

Batteries can store electrical energy electrochemically. There are many types of batteries with different electrode materials and electrolytes: lithium-ion (Li-ion), sodium-sulphur (NaS), nickel-cadmium (NiCd)…The material battery is made from defines its energy density, power density, cycle life, safety and of course cost. Li-ion batteries play an important role due to its high energy density and high efficiency. The lifetime (charge/discharge cycles) of Li-ion batteries is longest among the battery energy storages and they also possess short response time. Li-ion batteries have a disadvantage of high cost as energy storage.

Ultracapacitors or supercapacitors are capacitors capable of storing medium amounts of energy (can be a disadvantage when a large energy storage is needed) at high efficiency. The advantage of ultracapacitor compared to battery storage is that ultracapacitors poses longer life cycle and low environmental impact. The problem of ultracapacitor storage is its high cost. Utracapacitors are suitable for maintaining the power quality in the grid because of energy discharging speed and cycling ability. They are used together with battery storage to achieve better operational properties and large amounts of energy stored.

Flywheel energy storage transfers kinetic energy in and out with electric machine working as a motor when charging or as a generator when discharging. This type of storage has many advantages as a high energy density, high power density, high cycle life, long operational life, high round-trip efficiency and low environmental impact. The downside of this energy storage is its cost, noise and maintenance and its safety.

Compressed air energy storage (CAES) stores compressed air in an abandoned mine, a drilled cavern or a steel tank in the time of energy surplus and releases it through turbine when electricity generation is needed. Instead of compressed air liquefied air can used, stored at cryogenic temperatures in low-pressure insulated reservoirs. Liquid air has lower losses so it would be more suitable for long term storage. Liquid air can also be stored in smaller reservoirs cutting the space costs. Compressed air energy storage has the advantage of high energy capacity, however its efficiency is variable and there are safety issues (with leakage for example).

Pumped hydro storage (PHS) uses hydraulic potential energy of water. Upper and lower reservoir is needed. The water is pumped up the pipes to the upper reservoir and then run down the pipes to the lower reservoir through generator that produces electricity. PHS needs special conditions to be build: locations with difference in elevation and access to water. It is also difficult to make them sure they are commercially and socially acceptable. As for the electrical grid, PHS are very suitable. Their efficiency is up to 80%, they have a long life span (50-100 years), low operation costs and maintenance. The problems of PHS are large unit sizes (1000-1500MW), high capital cost and the impact a PHS facility has on the environment.

2.2 Other examples of storage technologies

Thermal energy storage uses different mediums (water, air…) to store energy for heating or cooling. It is used as hydro-accumulation, where energy is stored in water tanks or naturally occurring spaces (aquifer, borehole, cavern, ducts in soil, pit). The technology consist of a medium and heat exchanger. Further deployment of underground thermal energy storage is expected.

Thermochemical energy storage stores thermal energy from chemical reactions, it is possible to release this energy or the opposite. The advantage of this energy storage in its compactness compared to thermal energy storage, suitable for smaller or expensive spaces. Its small energy losses make it also potentially suitable for long-term energy storage.

Magnetic energy storage or superconducting magnetic energy storage uses the ability of superconductors to have almost no electrical resistance near absolute zero to store energy in its magnetic field. The magnetic field is generated by dc current flowing through the superconductor. The energy losses in the superconductor are almost zero. The superconducting magnetic energy storage can store large amounts of energy and immediately dispatch it. Number of charging and discharging is unlimited. Even though this type of storage is highly efficient, it comes at high cost and many requirements such as for large magnetic field and energy in general.

Hydrogen energy storage stores surplus energy in hydrogen that can be later used for generating electricity once again and injecting it into the grid or as a new fuel in the automobile industry. Hydrogen can be produces by photoconversion or electrolytic methods.

2.3 The relevance of energy storage

As already said, energy storage is needed in the electrical grid to ensure its smooth operation. It can be used for renewables integration shifting, load levelling, frequency regulation, voltage support and black start. Electrical energy system will be more and more in need of energy storage. This is caused by deployment of internment renewable resources. To stabilize the grid and ensure its safe operation (and to ensure uninterrupted electricity supply), many types of energy storage with different services will have to be implemented into the system. The energy storage technologies can be divided into short and long term according to the services they are able to provide for the grid. Short term energy storage is used mainly for support of stability of electrical grid. Flywheels, batteries and ultracapacitors are considered to be short term storage. Long term storage technologies have a support role as well as electricity supply in times of high demand. Pumped hydro storage, compressed air storage, hydrogen storage and other are considered as long term storage.

A model of storing renewable wind energy at its production in PHS and generating electrical energy at peak demand is presented. This can solve the issue of internment energy production by wind and other RES. A synergy with RES and energy storages could make the decarbonized energy systems possible.

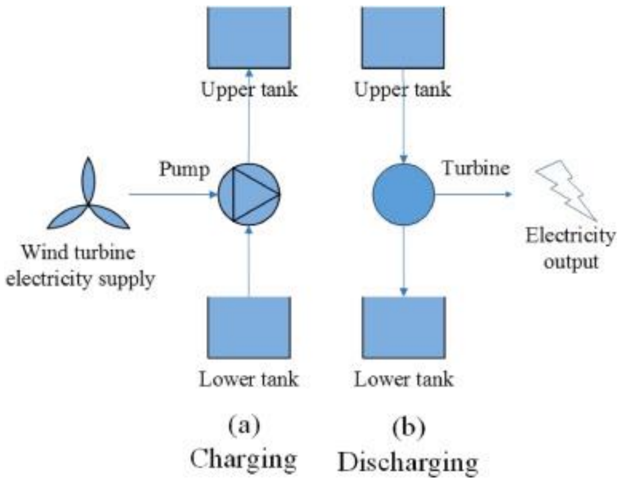

Figure 3 Pumped hydro storage with pumping energy supplied by wind turbines [5]

3 Short and long-term energy storage capacities overview

In this chapter we present capacities overview of storage technologies installed in Czech Republic and Austria.

3.1 Czech Republic

There are three pumped hydro storage facilities in Czech Republic with the total amount of 1175 MW power installed capacity. The biggest one, Dlouhé stráně, has two reverse Francis turbines, each with installed capacity 325 MW. The energy capacity of Dlouhé stráně is 3,5 GWh. There are also few projects with Li-ion battery storage technologies.

Table 1 Energy storage installed in Czech Republic [4]

Czech Republic			
City	**Facility Status**	**Technology**	**Power installed capacity (MW)**
Dalesice	Operational	PHS	120
Dalesice	Operational	PHS	120
Dalesice	Operational	PHS	120
Dalesice	Operational	PHS	120
Jesenik	Operational	PHS	325
Jesenik	Operational	PHS	325
Stechovice	Operational	PHS	45
Mydlovary	Operational	Li-ion	1
Obořiště	Operational	Li-ion	1
Ochoz	Announced	Li-ion	
Prakšice	Operational	Li-ion	1

3.2 Austria

The Alps mountain range gives Austria the perfect opportunity to build PHS. There are many with the total capacity of 6455,8 MW installed. There is one Li-ion battery of 2,5 MW installed now in operation (data from the year 2020).

Table 2 Energy storage installed in Austria [6]

Austria			
City	**Facility Status**	**Technology**	**Power installed capacity (MW)**
Mallnitz	Operational	PHS	70
Mallnitz	Operational	PHS	70
Fragant	Operational	PHS	334
Häusling	Operational	PHS	360
Berg	Operational	PHS	104
Kaprun	Operational	PHS	112,8
Kaunertal	Announced	PHS	400
Partenen	Operational	PHS	247
Partenen	Operational	PHS	175
Partenen	Operational	PHS	175
Partenen	Operational	PHS	175
Kühtai	Announced	PHS	130
Kaprun	Operational	PHS	480
Kaprun	Authorized	PHS	480
Lünersee	Operational	PHS	232
Klagenfurt	Operational	PHS	730
Brandstatt	Operational	PHS	120
Vermunt	Operational	PHS	360

Austria			
City	**Facility Status**	**Technology**	**Power installed capacity (MW)**
Rastenfeld	Operational	PHS	48
Molln	Under Construction	PHS	300
Pfarrkirschen im muhlkreis	Operational	PHS	19
Kollnitz	Operational	PHS	430
Vandans	Operational	PHS	198
Vandans	Operational	PHS	295
Ginzling	Operational	PHS	231
Stubachtal	Bidding process	PHS	130
Prottes	Operational	Li-ion	2,5

4 Approach

For better understanding the difference between short- term and long-term storage, we compare the costs of implementing these technologies. Total costs or investment costs cover the purchase, installation and delivery of energy storage unit, which includes: $Cpcs$ power conversion system costs (€/kW), $Cbop$ balance of power costs (€/kW) and $Csto$ energy storage related costs (€/kWh), t represents storage discharge time in hours (h) [7].

$$Ctotal = Cpcs + Cbop + Csto \times t \quad (1)$$

Power conversion system costs are related to power rate and those represent costs for turbine, pump or converter. Balance of power costs consider costs for project engineering, grid connection and installation. Costs for battery banks, reservoirs or electrolyte are related to energy capacity and are representation of construction costs. Storage costs represent costs for available capacity in kWh as a function of discharge time.

Since we need to evaluate the state of each long-term and short-term storage technology, in orded to properly compare it, results of the costs should be annualized. Framework for the comparison of technologies with finanacial parameters is presented as life cycle costs. Results are obtainted calculating the sum of annualized capital costs for storage system $Ccap, a$, expressed in (€/kW-annual), fixed and variable operation and maintenance costs $CO\&M, a$, (€/kW-annual), replacement costs of energy storage systems Cr, a (€/kW-annual), and costs for disposal and recycling Cdr, a (€/kW-annual).

$$Clcc = Ccap, a + CO\&M, a + Cr, a + Cdr, a \quad (2)$$

Annualized capital costs of storage system are total capital costs $Ctotal$ calculated with capital recovery factor α, which considers interest rate (i) during the lifetime (T) of the storage system:

$$Ccap, a = Ctotal * \alpha \quad (3)$$

, where capital recovery factor is :

$$\alpha = \frac{i(1+i)^T}{(1+i)^T - 1} \quad (4)$$

Operation and maintanance variable costs consider both fixed annual costs for energy storage system Cf,a in (€/kW) and variable annual costs Cv,a (€/ kWh) which depend on hours of charging/ discharging energy storage systems t.

$$CO\&M,a = Cf,a + Cv,a * t \quad (5)$$

Most of the literature gives overview of investment costs of energy storage systems regarding to eq. (1). Future replacement costs of battery storage systems Cr, in €/kWh and replacement period *p* in years, calculated as in eq (6), results in annualized replacement costs Cr,a in (€/kW) during battery calendar life, where t is discharged battery time (hours), *k* is number of replacements, and ηs overall battery efficiency which takes in consideration losses of charging/ discharging battery during the life cycle.

$$Cr,a = \alpha * \sum_{k=1}^{r}(1+i)^{-kp} * \frac{Cr*t}{\eta s} \quad (6)$$

Disposal and replacement costs Cdr in €/kW are annualized with interest rate i for battery lifetime period *T* . These costs are rather omitted in storage costs calculation as well as in this paper.

$$Cdr,a = Cdr * \frac{i}{(1+i)^{T}-1} \quad (7)$$

Constant or levelized cost of energy storage considers the full amount of energy a storage system can hold and discharge over lifespan, unlike levelized cost of electricity which only considers discharged energy. Levelized cost of storage considers all technical and economic parameters for utilizing storage system, including costs for charging system, which makes it market dependent. It is used for costs comparison between different storage systems. In literature [8], [9] there are different cost parameters included in calculation of levelized cost of storage, since some studies exclude replacements or disposal costs, due to lack of data from technology producers. Some methods take into consideration performance characteristics as self- discharge and capacity degradation [10]. In the equation (8), levelized cost of storage is given:

$$Cs = \frac{\frac{Ctotal*\alpha+CO\&M}{T}+Ce}{\eta s} = \frac{\frac{Ccap,a+CO\&M,a}{T}+Ce}{\eta s} = \frac{Clcc}{T\eta s} + \frac{Ce}{\eta s} = Clcoe + \frac{Ce}{\eta s} = Clcos \quad (8)$$

Cs = storage costs
Ce=energy costs, electricity price
Clcoe=levelized cost of electricity
Clcos= levelized cost of storage
T*= full load hours*
ηs*= efficiency of storage*

5 Results

Following asumptions were made for estimation of the costs in the analysis:

- Depth of discharge is 80% for all technologies,
- Constuction and Commissioning for Flywheel and Ultacapacitor are 20% of capital costs,
- Interest rate i=10%,
- Everyday minimum one cycle,
- Dollar/ euro conversion of 0.83 (since the input parameters given in the Table 3, are obtained from the literature [11] which was provided in USD (dollar currency).

Table 3 Input parameteres for different short and long- term storage technologies [11]

	PHS	CAES	Flywheel	Ultracapcitor	Lithium- ion battery
Capital costs €/kWh	2,190	1,385	1,992	332	225
Power conversion system PCS €/kW			included in Capital Costs	290.5	239.04
Balance of Plant BOP €/kW	included in Capital Costs			83	83
Construct and Commissionig €/kWh			398.4	66.4	83.83
Total Costs €/kW	2,190	1,385	2,390	772	1,557
Total Costs €/kWh	137	87	9,562	61,818	389
O&M Fixed €/kW-year	13.20	13.86	4.65	0.83	0.0249
O&M Variable (cents/kWh)	0.0002075	0.1743	0.0249	0.0249	0.0249
Round- Trip efficiency %	0.8	0.52	0.86	0.92	0.86
Cycles at 80% DoD	15,000	10,000	200,000	1,000,000	3,500
Calendar Life	50	25	>20	16	10
Energy/power ration	16	16	0.25	0.0125	4

Table 4 Results of the economic analysis for different short and long- term storage technologies

	PHS	CAES	Flywheel	Ultracapcitor	Lithium- ion battery
Capital recovery factor	0.1009	0.1102	0.1175	0.1278	0.1627
Capital costs €/kW	220.84	152.61	280.78	98.66	253.41
Capital costs €/kWh	13.81	9.60	1123.10	7901.42	63.35
Life cycle costs €/kW	234.03	166.50	285.42	99.49	253.43
FULL load hours	5,840	5,840	91	5	1,460
Levelized cost of electricity €/MWh	40.07	28.51	3127.93	21806.39	173.58
Electricity market price €/MWh Hudex 2019.			50.36		
Electricity market price €/MWh Epex 2019.			40.06		
Levelized cost of storage for Czech Republic market	113.04	151.67	3695.69	23757.34	260.40
Levelized cost of storage for Austria market	100.17	131.87	3683.71	23746.14	248.42

Table 4 shows levelized costs of energy storage systems that are calculated with life cycle costs and in regard to given assumptions. Electricity market plays important role in evaluating energy storage costs. Calculating levelized costs of discharged electricity without price of charging power neglects electricity market influence, which is inevitable for energy storage system implementation. For adequate comparison of storage costs in Austria and Czech Republic, analysis was conducted taking into the consideration market specific factors. Since, electricity price in previous year was historically low, due to the global pandemic of COVID-19, for this analysis electricity prices in EPEX and Hudex electricity markets from 2019. are used (Figure 4 and Figure 5).

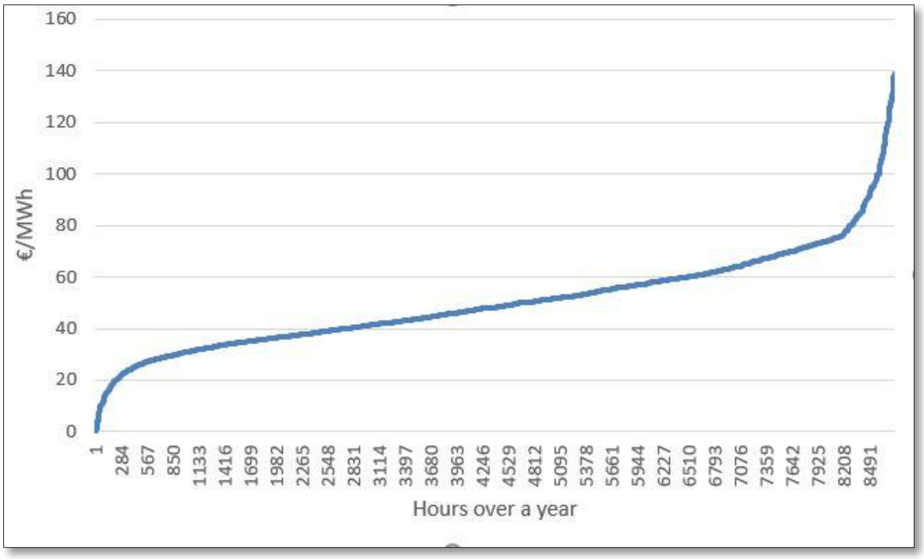

Figure 4 Electricity market Hudex hourly prices (data source : Hudex DAM 2019)

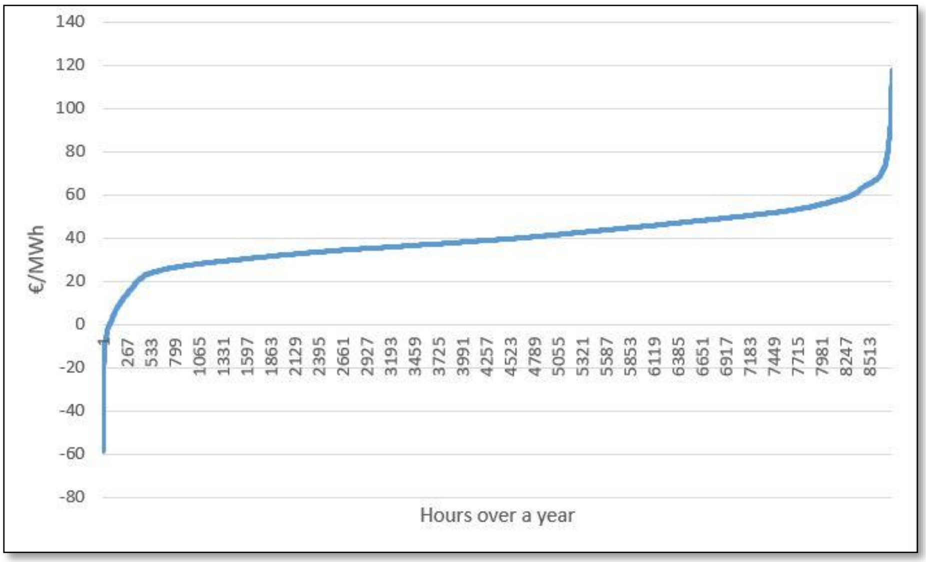

Figure 5 Electricity market Epex hourly prices (data source: EPEX 2019.)

Given the equation (8), levelized costs of energy storage are calculated with life cycle costs, taking into the calculation number of cycles per year. Depending on energy/power ratio and yearly number of cycles, annual hours of operating storage present full load hours. Figure 6 and Figure 7 illustrate levelized cost of discharged electricity from operating storage system in one year. Pumped hydro as long-term storage has the lowest levelized cost of electricity and is still most cost efficient storage technology. Lithium- ion battery, as short- term storage has the lowest costs, hence these technlogies are mostly used in Czech Republic and Austria.

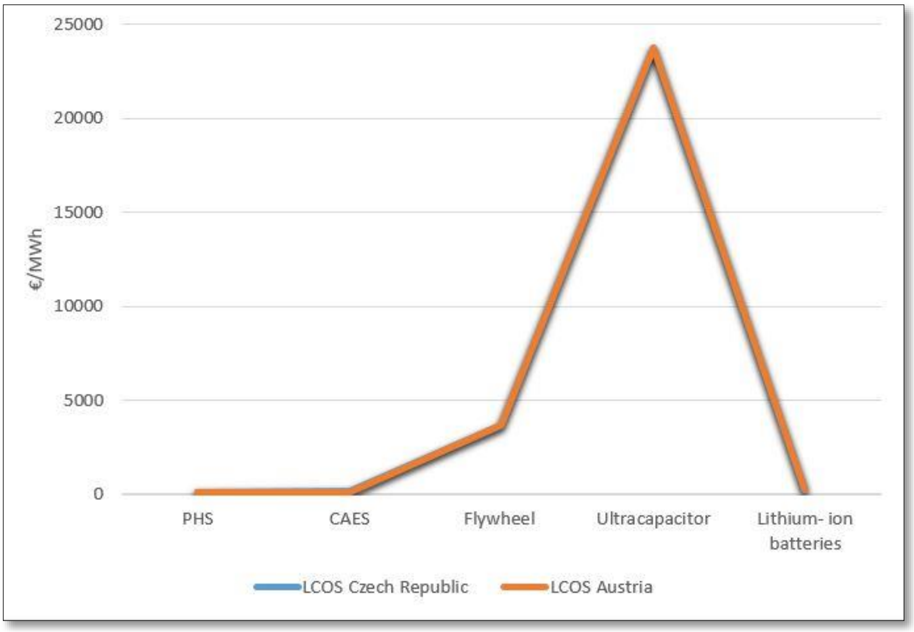

Figure 6 Levelized costs of storage for Hudex and EPEX market price

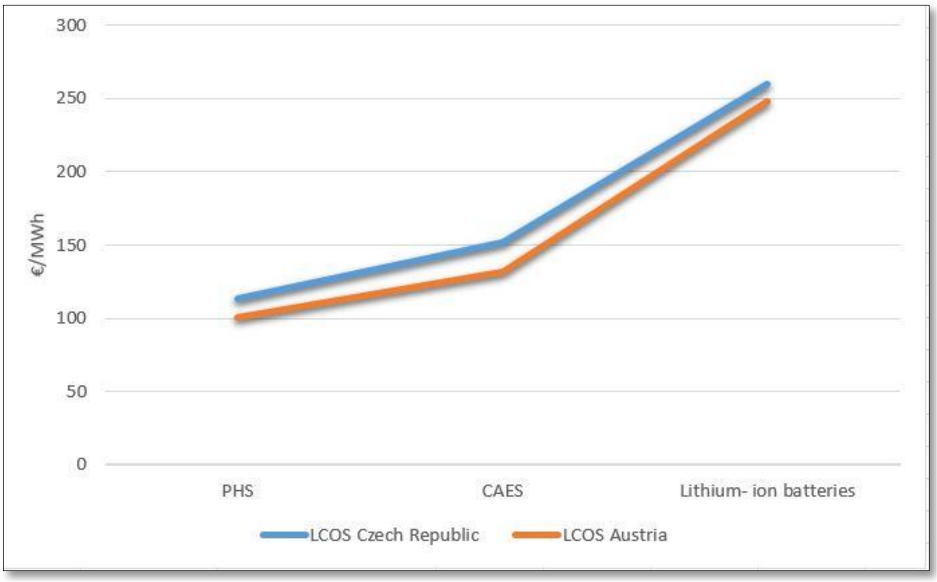

Figure 7 Levelized cost of storage for most cost- effective short and long-term technologies

Comparing costs of short and long-term technologies with levelized costs of storage, that includes capital, fixed and variable operation and maintenance, replacement and disposal and recycling costs is suitable for analysing economic liability of the storage future projects. Electricity market prices are subject to different variations and fluctuations caused by global changes, renewable generation in the grids and oil prices. Recent events in the market, shows price increase of more than 20%, hence sensitivity analysis is done in this percentage of electricity rise. Figure 8 levelized storage costs increase in regard to increase of 20% electricity price in market. Considering effects of global pandemic or some other factor which indicates electricity market price, nevertheless the cheaper renewable generation technology, implementing storage systems is also expensive. Should prices in EPEX market go higher for 20 %, average price would be 48, 07 €/MWh or 60,43 €/MWh for Hudex market. These price changes would increase energy storage costs, hence they are important when analysing implementation of storage systems.

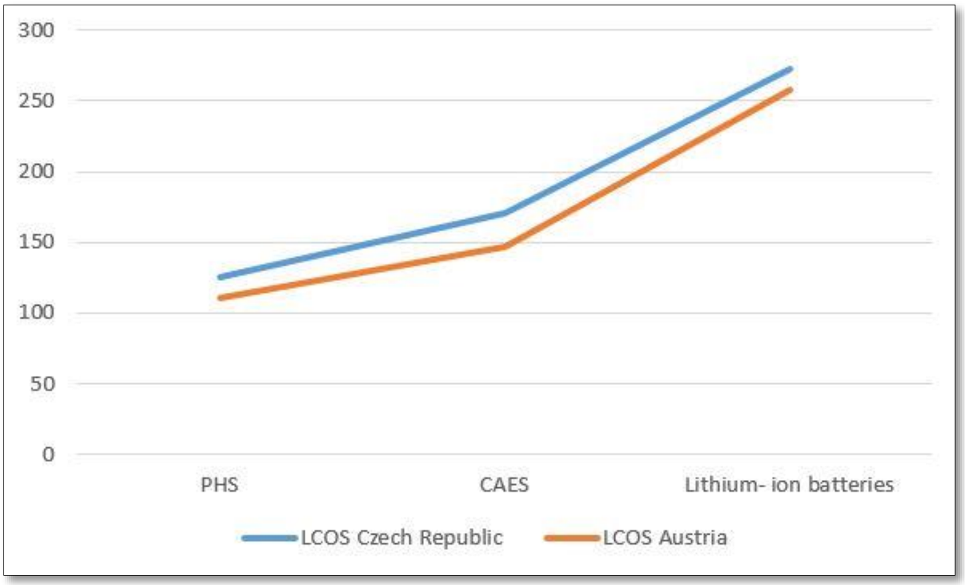

Figure 8 Sensitivity analysis of levelized cost of storage for different short and long-term technologies

6 Conclusion

Investments in renewable generation systems are going to increase in the following years, hence we out to expect more investments in energy storage systems as well. The energy storage systems become more and more relevant with higher penetration of intermittent energy resources. It is important to ensure the stability and safe operation of the interconnected electricity grids. Energy storage systems have the ability to enhance integration of renewable resources and they can be used as a tool for load levelling, frequency regulation, voltage support and black start. Not only the energy storage can help with grid operation, it is also possible to optimize the transmission and distribution of electricity and lower the losses in the grid. Many challenges arise with the development of RES resources, one of them is to ensure there is enough energy according to demand. Energy storage systems, long-term storage systems to be exact, should be able to supply electrical energy in the time of peak demand or when demand overcomes supply. As already stated, energy storage systems enable the development and further installations of intermittent renewable resource. Without energy storage the application and use of RES would be very problematic. To achieve carbon-neutral EU and other goal for the years 2030 and 2050, further deployment of energy storage systems and technologies is necessary.

In this paper we provide an overview of short and long- term storage technologies and installed capacities in Czech Republic and Austria. For adequate comparison of energy storage systems, we present methods for costs calculation, followed by cost analysis for pumped hydro storage, compressed air storage, flywheel, supercapacitor and Lithium- ion battery storage. Results show that for long- term storage, pumped hydro storage is still the most cost- effective technology with 113 €/MWh levelized cost of storage, followed by compressed air storage with 152 €/MWh. Short- term energy storage are stil quite expensive, but Lithium- ion batteries are leading with costs of 260 €/MWh, with possible future even higher decrease in costs, since the technology is rapidly improving. Since the market price is important parameter in cost analysis, we conclude that with market prices increase, levelized cost of energy storage would increase as well. Nevertheless, policy makers should plan energy storage technologies, not just based on the costs, but more in terms of usability. When comparing two countries, it is evident that Austria having the desirable geographical position, has pumped hydro storage installed, but should invest more in short-term storage technologies. Czech Republic, on contrary should invest more in long-term energy storage, possibly in compressed air storage technologies, since it doesn't have the same potential for pumped hydro storage as Austria. Renewable energy sources are key factor for sustainable development and zero- emission European plans by 2050, but their intermitent nature is limiting factor. Energy storage systems are flexibility and balancing soulution and they are going to be assisting in reaching these goals. Firstly, investments will be in the most cost-efficient short and long-term energy storage technologies, but others will follow as well. Future work would likely cover other calculation for other energy storage technologies.

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