Chapter 10
Energy Storage: Assessment of Selected Tools in Local and Global Scales

Over short periods of time, the amount of generated electricity is relatively fixed, but demand for electricity fluctuates throughout the day. Thus, technology for storing electrical energy is needed to manage the amount of power required to supply customers at times when need is greatest, during peak load. Also it can help to make renewable energy, whose power output cannot be controlled by grid operators, without interruptions of power supply and smooth. Suitable local energy storage can balance microgrids to achieve a good match between generation and load. Storage devices can achieve a more reliable power supply for industrial facilities, and hold considerable promise for transforming the electric power industry. Energy storage technology is applied to a wide range of areas that differ in power and energy requirements. It includes batteries, electrochemical capacitors, superconducting magnetic storage, pumped-storage hydroelectricity, and flywheels. Also new technology seeks to improve energy storage density in electrolytes and nano-structured electrodes.

10.1 Electricity Transmission, Distribution, and Storage Systems

Energy storage technologies can support energy security, as well as climate change goals by providing valuable services in energy systems. Their approach will lead to more integrated and optimized energy systems by improving energy resource use efficiency, helping to integrate higher levels of variable renewable resources, supporting higher production of energy where it is consumed, increasing energy access, and improving electricity grid stability and flexibility. While some energy storage technologies, such as pumped hydroelectric reservoirs, are well tried, most are still in the early stages of development and currently struggle to compete with other non-storage technologies due to high costs. But, governments can help accelerate the research and deployment of energy storage technologies by supporting targeted promising projects. The actual status of energy storage technologies

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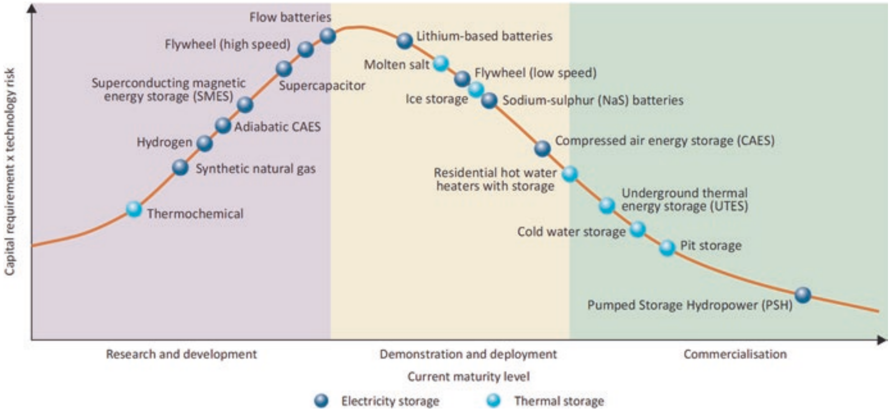

Fig. 10.1 The actual status of energy storage technologies. Source: IEA Technology Roadmap: Energy Storage, 2014

divided into research and development phase, demonstration and deployment level, and commercial utilization is illustrated in Fig. 10.1.

Generally, energy storage systems can absorb energy and store it for a period of time before releasing it to supply power devices. Through this process, storage systems can bridge temporal gaps between energy supply and demand. Energy storage devices can be utilized on large and small scales in distributed and centralized manners throughout the energy grid. Energy storage technologies are used to be categorized by output, which can be electricity or thermal. Energy storage deployment can be developed across the supply, transmission and distribution, and demand parts of the energy system. The best location for individual storage device depends on the services these technologies will supply to specific locations in the energy grid. The smart grid and other new energy infrastructure technologies may impact the structure for storage systems in the future. The basic schema for storage deployment is illustrated in Fig. 10.2, which contains utilization of storage systems across the supply, transmission and distribution, and demand parts of the grid.

10.2 Energy Storage Principles

The current global installed capacity for energy storage struggle from a lack of accessible datasets as well as conflicting definitions of various technologies. Some datasets exist in the United States, Japan, and some regions in Europe for a specific subset of energy storage technologies such as large-scale, grid-connected electricity storage systems. These datasets indicate that at least 140 GW of large-scale energy storage is currently installed in electricity grids over the world. The majority about 99% of this capacity comprises pumped-storage hydropower. The rest about 1% covers a mix of other storage systems, such as battery, compressed air energy

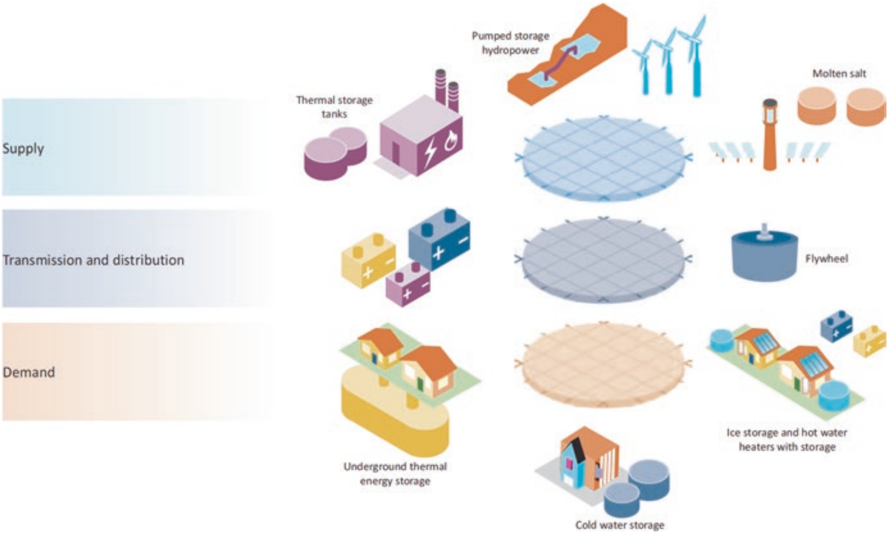

Fig. 10.2 The basic schema for storage deployment with utilization of storage systems across the supply, transmission and distribution, and demand parts of the grid. Source: IEA Technology Roadmap: Energy Storage, 2014

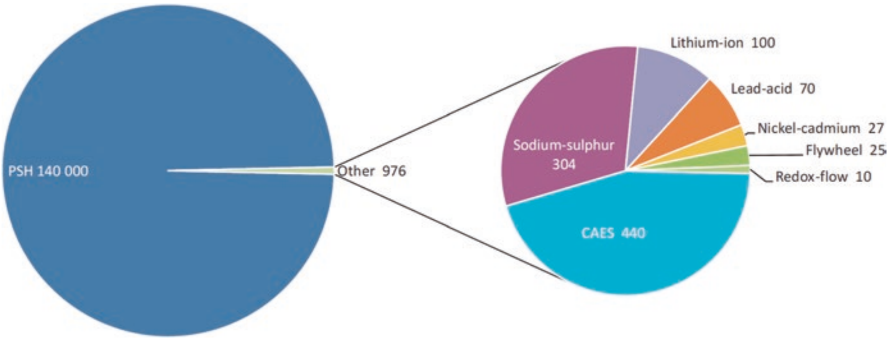

Fig. 10.3 Global installed grid-connected electricity storage capacity in MW (*PSH* pumped-storage hydropower, *CAES* compressed air energy storage). Source: IEA Technology Roadmap: Energy Storage, 2014

storage, and a wide range of various minor systems, Fig. 10.3. Energy storage systems are also utilized for thermal energy storage applications such as domestic hot water tanks, or ice and chilled water storage. Underground thermal energy storage systems are frequently used in Canada, Germany, and other European countries.

Electricity storage systems are used to be grouped into three main time categories: short-term, long-term, and distributed battery storage. The short-term storage systems have high cycle lives and power densities, but lower energy densities. Thus, they are best suited for supplying of short bursts of electricity in the energy grids.

These storage systems (supercapacitors and superconducting magnetic energy storage) are still great challenge for research and development. The long-term storage systems have been the most widespread method for long-term electricity storage for several decades. These technologies often require high upfront investment costs due to typically large project sizes and geographic requirements (pumped-storage hydropower or compressed air energy storage). There are a number of systems in commercial operation. The distributed battery storage can be used for both short- and long-term applications and benefits from being highly scalable and efficient. It has already achieved limited deployment in both distributed and centralized systems for mobile and stationary applications at varying scales. Widespread deployment is hampered by challenges in energy density, power performance, lifetime, charging capabilities, and costs. A specific technology is represented by hydrogen storage that can be used for long-term energy applications, where electricity is converted into hydrogen, stored, and then reconverted into the desired end-use form. These storage systems have significant potential due to their high energy density, quick response times, and potential for use in large-scale energy storage applications, but a lack of existing infrastructure for large-scale applications such as hydrogen storage for fuel-cell vehicles is available in the local and regional scales. A list of selected energy storage systems for electricity and thermal storage is presented in Table 10.1.

Thermal storage systems can store thermal energy for later use as heating or cooling capacity in applications such as seasonal storage. Some thermal energy storage technologies have already realized significant levels of utilization in electricity and heat networks. In dependence on an operational temperature, the thermal storage devices are utilized as low-temperature (<10 °C) applications, medium temperature (10–250 °C), and high-temperature (>250 °C) applications. Low-temperature applications represent cold-water storage tanks in commercial and industrial facilities that are already installed around the world to supply cooling capacity. Underground thermal energy storage systems have been successfully developed in order to provide both heating and cooling capacity in countries such as Canada, Germany, the Netherlands, and Sweden. Low-temperature applications also provide thermochemical storage based on reversible chemical reactions, where the cooling capacity is stored in the form of chemical compounds. It can achieve higher energy storage densities and is used for the transportation of temperature-sensitive products. The medium temperature applications have been utilized, for example, in New Zealand, Australia, and France that use storage capabilities in electric hot water storage heaters. The underground thermal energy storage systems have been successfully deployed on a commercial scale to provide heating capacity in the Netherlands, Norway, and Canada. Also thermochemical storage systems can discharge thermal energy at different temperatures, which make them an appealing option for medium temperature applications. The high-temperature applications are based on molten salts, which can be used, for example, to dispatch power from concentrating solar power facilities by storing several hours of thermal energy for use in electricity generation. But the high-temperature thermochemical energy storage and waste heat utilization systems offer many potential opportunities.

Table 10.1 Description of selected energy storage systems

Pumped-storage hydropower (PSH)	– Utilizes elevation changes to store energy for later use. Water is pumped from a reservoir at a lower elevation to a reservoir at a higher elevation during off-peak periods. Subsequently, water can flow back down to the lower reservoir, generating electricity like in a conventional hydropower plant
Compressed air energy storage (CAES)	– Utilizes pressure changes to store energy for later use. Systems use off-peak electricity to compress air, storing it in underground caverns or storage tanks. This air is later released to a combustor in a gas turbine to generate electricity during peak periods
Batteries	– Use chemical reactions with two or more electrochemical cells to enable the flow of electrons. Many types of batteries have been developed during a few decades. The current technologies are dealing often with lithium-based batteries
Chemical-hydrogen storage	– Uses hydrogen as an energy carrier to store electricity, for example, through electrolysis. Electricity is converted, stored, and then reconverted into the desired end-use form, which can be electricity, heat, or liquid fuel
Flywheels	– Store electricity as rotational energy. Flywheels are mechanical devices that spin at high speeds. This energy is later released by slowing down the flywheel's rotor, releasing quick bursts of energy
Supercapacitors	– Store energy in large electrostatic fields between two conductive plates separated by a small distance. Electricity can be quickly stored and released using this technology in order to produce short bursts of power
Superconducting magnetic energy storage (SMES)	– Stores energy in a magnetic field. This field is created by the flow of direct current (DC) electricity into a super-cooled coil. In low-temperature superconducting materials, electric currents encounter almost no resistance, so they can cycle through the coil of superconducting wire for a long time without losing energy
Hot/cold-water storage in tanks	– Meet heating or cooling demand. The devices are highly used in domestic hot water heaters, which frequently include storage in the form of insulated water tanks
Thermochemical storage	– Uses reversible chemical reactions to store thermal energy in the form of chemical compounds. Energy can be discharged at different temperatures, dependent on the properties of the thermochemical reaction
Ice storage	– Is a form of the latent heat storage based on a material phase change as it stores and releases energy. It refers to transition of a medium between solid, liquid, and gas states
Solid media storage	– Store energy in a solid material for later use in heating or cooling such as bricks or concrete. Some electric heaters also include solid media storage to assist in regulating heat demand
Underground thermal energy storage (UTES)	– Pump heated or cooled water underground for later use as a heating or cooling resource. Water is pumped into (and out of) either an existing aquifers or man-made boreholes

Source: IEA Technology Roadmap: Energy Storage, 2014.

Fig. 10.4 The Seneca pumped-storage generating station in northwest Pennsylvania takes advantage of the local topographical conditions by filling a reservoir at a higher elevation than the dam below. Source: Google Earth, 2016

The future utilizations of storage systems will depend on improving the technologies and costs drop, the implementation of new pricing and valuation schemes for the services storage, and the cost and efficiency of alternatives. The next description contains a few examples of pumped-storage hydropower (PSH) that represents a long-proven storage technology, but the facilities are very expensive to build, may cause environmental impacts, and extensive permitting procedures. Furthermore, it requires the site with specific topologic and geologic conditions. An example of operational pumped hydroelectric reservoirs in Pennsylvania is illustrated in Fig. 10.4. It takes advantage of the local topographical conditions. The device can be operated as a 435 MW hydroelectric power plant, generating power to supply demand for electricity during the daytime peak hours. Overnight, a reversible hydroelectric turbine is powered by low-cost electricity and provides pumping water from the lower reservoir up to the upper reservoir.

Another relatively proven storage technology is represented by compressed air energy storage (CAES), which provides an efficient solution to meeting peak requirements by taking advantage of lower cost, off-peak energy to generate energy during peak demand periods. An example of an operational device is shown in Fig. 10.5. A 110 MW plant with a capacity of 26 h was built in McIntosh, Alabama in 1991. The storage capacity is about a 19 million cubic foot solution mined salt cavern. The expansion phase requires combustion of natural gas at one-third the rate of a gas turbine producing the same amount of electricity.

A high-temperature application based on thermal energy storage to continue generating electricity is illustrated in Fig 10.6. The solar power station (150 MW) uses a thermal storage system, which absorbs a part of the heat produced in the solar field

Fig. 10.5 Compressed air energy storage at McIntosh power plant in Alabama. Source: PowerSouth Energy Cooperative, A Touchstone Energy Cooperative, 2016, http://wwwpowersouth.com

Fig. 10.6 The Andasol solar power station (150 MW), Europe's first commercial plant to use parabolic troughs, located near Guadix in Andalusia, Spain. Source: Google Earth, 2016

during the day. This heat is then stored in a molten salt mixture (60% sodium nitrate and 40% potassium nitrate) in order to produce electricity by a turbine when the sky is overcast. It almost doubles the number of operational hours at the solar thermal

Fig. 10.7 Tesla Gigafactory (planned annual battery production capacity of 35 GWh). Source: https://www.tesla.com/, 2016

power plant per year. A fully loaded storage system can hold around 1 GWh of heat, enough to run the turbine for about 7.5 h at full-load, in case it rains or after sunset.

Battery, which uses chemical reactions to enable electrical energy, is widely used in many mobile electronic applications. Rechargeable batteries can be charged, discharged into a load, and recharged many times, while a non-rechargeable batteries are supplied fully charged, and discarded once discharged. Batteries are produced in many shapes and sizes, ranging from button cells to megawatt systems that are used to stabilize an electrical distribution networks. A number of different combinations of electrode materials and electrolytes are used, such as lead–acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer). An example focused on automobile industry, Tesla Gigafactory, is illustrated in Fig. 10.7. The name Gigafactory comes from the factory's planned annual battery production capacity of 35 GWh. This mission is to accelerate the world's transition to sustainable energy in order to produce power for electric vehicles in sufficient volume to force change in the automobile industry. There is planned production rate of 500,000 cars per year.

Flywheels store electricity as rotational energy. They can be utilized in a continuously variable transmission. For example, trains can use energy, which is recovered from the drive train during braking and stored in a flywheel. This stored energy is then used during acceleration. In motor sports, this energy can be used to improve acceleration, but the same technology can be applied to road cars to improve fuel efficiency and reduce emissions, Fig. 10.8.

Advanced energy storage technologies are currently limited in use by higher production costs and represent great challenge to practical utilization. Besides pumped hydroelectric storage, majority of the storage technologies are in the early stages of development for widespread utilization. They can serve an array of functions around

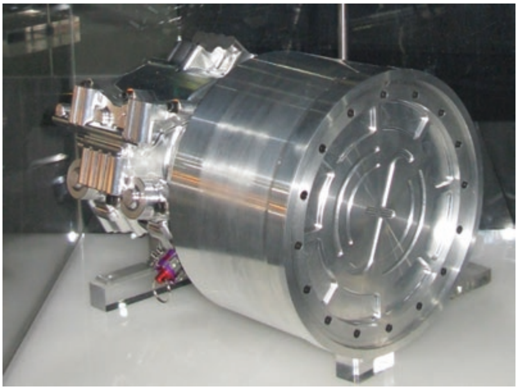

Fig. 10.8 A flybrid systems kinetic energy recovery system built for use in formula one. Source: Wikimedia, 2016

the electric power system, from assuring power quality to deferring electric power system infrastructure upgrades to integrating variable generation from wind and solar generators. Without stored electricity or heat, power system operators must increase or decrease generation to meet the changing demand in order to maintain acceptable levels of power quality and reliability. Currently, generating capacity is set aside as reserve capacity to provide a buffer against fluctuations in demand. In that way, if the reserve capacity is needed, it can be dispatched or sent to the grid without delay. There are extra costs, at times significant, to requiring the availability of generating capacity to provide reserves and regulation of power quality. But, the efficient way of utilization of energy storage systems could eliminate the need for extra generating capacity to fill that role.

Existing or potential storage technologies are adapted for different uses. Electricity storage technologies are designed to respond to changes in the demand for electricity, which can be provided on different timescales. Approximate comparison of described power energy storage principles to capacity and discharge time is shown in Fig. 10.9. The pumped hydroelectric storage or compressed air energy storage represent higher capacity technologies capable of outputting electricity for extended periods of time in order to moderate the extremes of demand over longer timescales. Demand fluctuations on shorter timescales of a few minutes down to fractions of a second can be supplied by rapidly responding technologies, such as flywheels, supercapacitors, or a variety of batteries, which are often of smaller capacity.

10.3 Environmental Effects of Using Selected Storage Systems

Utilization of storage systems brings indirect environmental benefits. The electricity storage systems can help to integrate more renewable energy into the electricity grid and to reduce use of less efficient generating units that would otherwise only

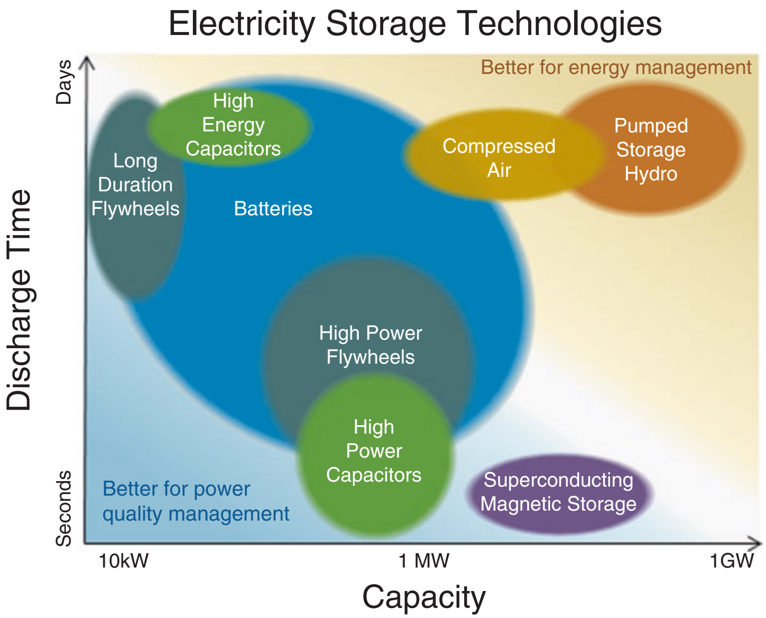

Fig. 10.9 Approximate comparison of described power energy storage principles to capacity and discharge time. Source: EIA, Today in Energy, December 2011, http://www.eia.gov/todayinenergy/detail.cfm?id=4310

run at peak times. Furthermore, the added capacity by electricity storage can decrease the need to build additional power plants or transmission lines. The negative impacts of storage systems depend on the type and efficiency of storage technology. For example, large pumped hydroelectric storages can influence local ecosystems like hydropower plants. In case of batteries, the use of raw materials, such as lithium and lead, can cause potential environmental hazards if they are not disposed of or recycled properly. In addition, some electricity is wasted during the storage process. An approximate comparison of environmental effects of using selected storage systems with conventional energy technologies is illustrated in Fig. 10.10. It aggregates values from individual projects and the final impacts in particular cases can be slightly different in dependence on local conditions. These issues are also discussed in the framework of the Energy Technology Perspectives (ETP) 2DS, which describes transformation of technologies across all energy sectors by 2050 to give an 80% chance of limiting average global temperature increase to 2 °C. The scenario sets the target of cutting energy-related carbon dioxide emissions by more than half by 2050 (compared with 2009). Energy storage will compete with other options in the energy grids to provide the flexibility needed to accommodate the energy resources, which sets the context for the vision for future storage technologies.

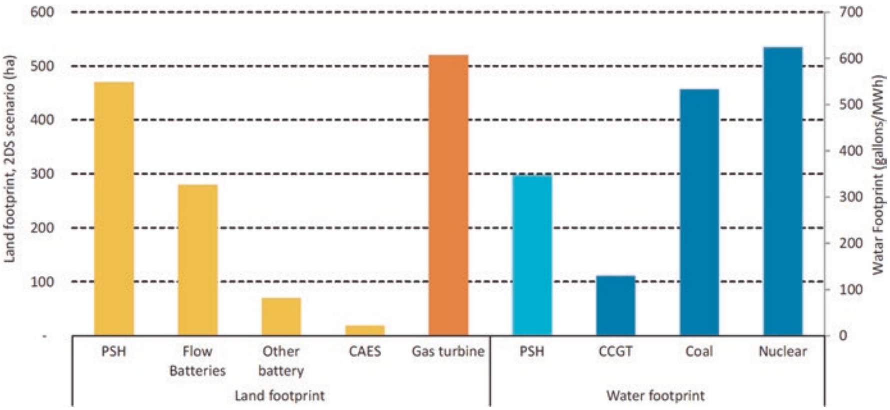

Fig. 10.10 An approximate comparison of environmental effects of using selected storage systems with conventional energy technologies (*PSH* pumped-storage hydropower, *CAES* compressed air energy storage, *CCGT* combined cycle gas turbine). Source: IEA Technology Roadmap: Energy storage, 2014

10.4 Case-Oriented Studies

Increased electricity generation from renewables, such as wind power and photovoltaic, requires development of energy storage systems, in order to integrate highly variable renewable energy into the grid. Only large-scale energy storage systems, such as pumped-storage hydropower and compressed air energy storage, can help to increase the penetration of renewables. Besides increased energy storage capacity, a number of other benefits include black start capabilities, grid stability, spinning and auxiliary reserve, peak shaving, and regulation control.

GIS can help to explore possibilities of using energy storage systems, such as pumped-storage hydropower or compressed air energy storage, which are geographically related to suitable places. The significant role of GIS is also in the risk assessment stages of project development. The resulting analysis can provide information about environmental perspective of storing electricity from renewables and consequent reduction in carbon dioxide production.

10.4.1 Environmental Evaluation of Selected Energy Storage Installations for Electricity Grids

The attached case study is focused on utilization of pumped-storage hydropower (PSH) and compressed air energy storage (CAES). Information about environmental impacts is derived from the report "Environmental performance of existing energy storage installations,", which has been produced in the framework of a project "Facilitating energy storage to allow high penetration of intermittent renewable energy" (www.store-project.eu). The magnitude of the environmental impacts for selected categories was classified to three levels such as high, medium, and low. The high level represents a significant impact by its character, magnitude, and duration or intensity, which alters a sensitive aspect of the environment. The medium level is related to a moderate impact, which alters the character of the environment in a manner that is consistent with existing and emerging trends. The low level is without noticeable consequences or represents a slight impact, which causes noticeable changes without affecting its sensitivity. The evaluation is presented for six selected installations of energy storage systems located in Europe: five different PHS in terms of age, technology, and environmental conditions, and only one CAES, Table 10.2.

The identified direct and indirect environmental impacts during operation are summarized in Fig. 10.11. The presented negative environmental impacts are dealing with human impacts, effects on ecology and natural systems, and links to physical environment. The list of selected environmental impacts can be complemented by other phenomena in dependence on a particular installation. Due to the life span of the presented energy storage systems, most impacts associated with their operation are proposed to be long term.

The benefits of described storage systems based on PSH and CAES from an environmental perspective are a partial elimination of the variability of electricity production (mainly from renewable sources), and an overall consequent reduction in carbon dioxide production. The Huntorf CAES facility indicates very few environmental impacts during operation, but it is a hybrid system, which is dependent on an external heat source (natural gas) to replace the heat lost during the compression stage. The remaining PSH systems can have high negative impacts on ecology and natural systems, as well as on physical environment related to the construction of a dam for hydro generation results in alteration of the natural flow regime of the river. The heavily modified environment by previously constructed dams results in a significantly lower environmental impact of the PSH.

10.4.2 Mapping of Environmental Impacts with GIS for the Energy Storage Installation Kopswerk II

The topography of the Alps is well suited for hydropower and pumped-storage hydropower (PSH). The PSH Kopswerk II can be integrated into the electricity grid with renewables not only in Austria but also in its neighboring regions in Germany. Kopswerk II is an open PSH with its upper reservoir, the Kops, at a height of 1800 m, which boasts a storage capacity of 127 GWh. The lower reservoir, the Rifa, is located approximately 800 m below, Fig. 10.12. Assessment of environmental impacts in ArcGIS Online is based on CORINE Land Cover shown in Fig. 10.13, the satellite image in Fig. 10.14, and changes of Normalized Difference Vegetation Index (NDVI) shown in Fig. 10.15.

Table 10.2 Selected installations of energy storage systems for environmental evaluation located in Europe

Type, location, and commissioning	Description of energy a storage system, installed capacity, and its potential environmental impacts
CAES, Huntorf (Northwest of Germany in Niedersachsen), commissioned in 1978	It is the first CAES facility installed worldwide. The installed capacity of 290 MW was upgraded to 321 MW in 2007. It has a storage capacity of 0.64 GWh and has the ability to operate at peak load for about 2 h per day. It uses two large underground salt caverns to store the compressed air. Each of the caverns is located at a depth between 650–800 m and is approximately 40 m in diameter. During decompression, the system requires natural gas, as its external heat source, to recover the stored compressed air. Due to extra energy for compression and heating during decompression, this type of CAES is therefore not considered to be a pure electricity storage technology, but rather a hybrid system
PSH, Thissavros (Greece, Nestos River Basin), basin is already regulated with dams in Bulgaria, commissioned in 1997	It has an installed capacity of 381 MW and provides electricity generation, peak power, and water for irrigation together with a further dam downstream of Thissavros called Platanovrisi (commissioned in 1999). Although habitat loss due to land inundation to create Thissavros reservoir is an impact of construction, the long-term effects on flora and fauna are attributed to the operational phase. Since Thissavros does not have a fish pass to facilitate fish migration, it causes ecosystem isolation in Platanovrisi and Thissavros reservoirs. The dam has also inhibited the river role in sediment transport. Thus, the beaches in the delta region have been found to have much higher erosion rates
PSH, Kopswerk II (Austria in the region of Vorarlberg), commissioned in 2008	An installed capacity is 450 MW. The facility utilizes the already-existing upper reservoir, Kops and the lower reservoir, Rifa. Thus, no extra impoundment was needed to operate Kopswerk II. The pre-developed environment was already changed to such a degree that the addition of Kopswerk II has brought very little environmental impact during operation. But the water level in the Kops has fluctuated more frequently since the addition of Kopswerk II as the storage system operates on a daily basis
PSH, Goldisthal (Germany, River Schwarza), commissioned in 2003	The facility has an installed capacity of 1060 MW. The lower dam also boasts a small hydropower facility that produces an additional 1.6 GWh annually from the water discharged to the downstream environment. The upper reservoir is situated approximately 300 m above the lower reservoir. Now, the system is deconstructed to allow for free fish passage along the river Schwarza and Saale
PSH, Bolarque II (Spain, Tagus River), commissioned in 1975	It utilizes the already existing Bolarque reservoir as the lower reservoir (commissioned in 1910). Upstream are two further dams Entrepenas and Buendia, and downstream of Bolarque dam is another dam Zorita. Bujeda reservoir was created as the upper reservoir almost 300 m above. Thus, the storage system was constructed into an already highly stressed and regulated environment. From this point of view, Bolarque II has almost no environmental impacts during operation
PSH, Turlough Hill (Ireland), commissioned in 1974	It utilizes the existing lake, Lough Nahanagan as the lower reservoir, and the man-made upper reservoir is located 300 m above. The installed capacity is 292 MW. The main environmental impact is daily lowering of the lower lake during pumping mode, which affects the shore line vegetation in terms of species cover

Source: "Facilitating energy storage to allow high penetration of intermittent renewable energy" (www.store-project.eu)

		CAES	Pump-back PHES	Semi-open PHES			Closed-loop PHES
Potential Issues/EIA terms of reference		Huntorf	Thissavros	Kopswerk2	Goldisthal	Bolarque2	Turlough Hill
Human Impact	Population	L	L	L	L	L	L
	Traffic	L	L	L	L	L	L
	Cultural Heritage	L	L	L	L	L	L
	Material Assets	L	L	L	L	L	L
Ecology and Natural Systems	Biodiversity	L	H	L	H	L	H
	Fisheries	L	H	L	M	L	M
	Air and Climate	L-H*	L-H*	L-H*	L-H*	L-H*	L-H*
	Landscape and Visuals	L	M	L	M	M	M
	Water Resources & Quality	L	H	L	M	L	M
Physical Environment	Noise & Vibration	L	L	L	L	L	L
	Soils, Geology & Sediment Transport	L	H	L	M	L	L
	Hydrology & Hydrogeology	L	H	M	H	L	H

- *Recommended to review each individual case study*
- *Inclusion of combined impacts with existing land uses and pressures*
- *Limited raw data*

Fig. 10.11 Summary of negative environmental impacts during operation highlighted by case studies (PHES—pumped hydro energy storage source marked in text as PSH—pumped-storage hydropower). Source: www.store-project.eu

Land use mapping is based on CORINE Land Cover (CLC), which is a geographic land cover/land use database encompassing most of the countries of Europe. An inventory of land cover in 44 classes is organized hierarchically in three levels at a scale of 1:100,000. The first level (five classes) corresponds to the main categories of the land cover/land use, such as artificial areas, agricultural land, forests and semi-natural areas, wetlands, and water surfaces. The second level (15 classes) covers physical and physiognomic entities at a higher level of detail. The third level composed of 44 classes, which are presented in this study for classes of the forest semi-natural areas, is shown in Fig. 10.13. Data layers on land cover are useful for the environment policy, regional development, and agriculture, as well as for impact assessment of the described pumped-storage hydropower. It can also provide information on other themes, such as soil erosion, and vegetation disturbance.

Vegetation analysis is provided by satellite image's band combination (5 4 3), which is helpful for vegetation studies. It complements CORINE Land Cover data and gives a view on living condition of vegetation. In Fig. 10.14, healthy vegetation is symbolized by bright green and soils are mauve. The used image was compiled from Global Land Survey (GLS) datasets, which were created by

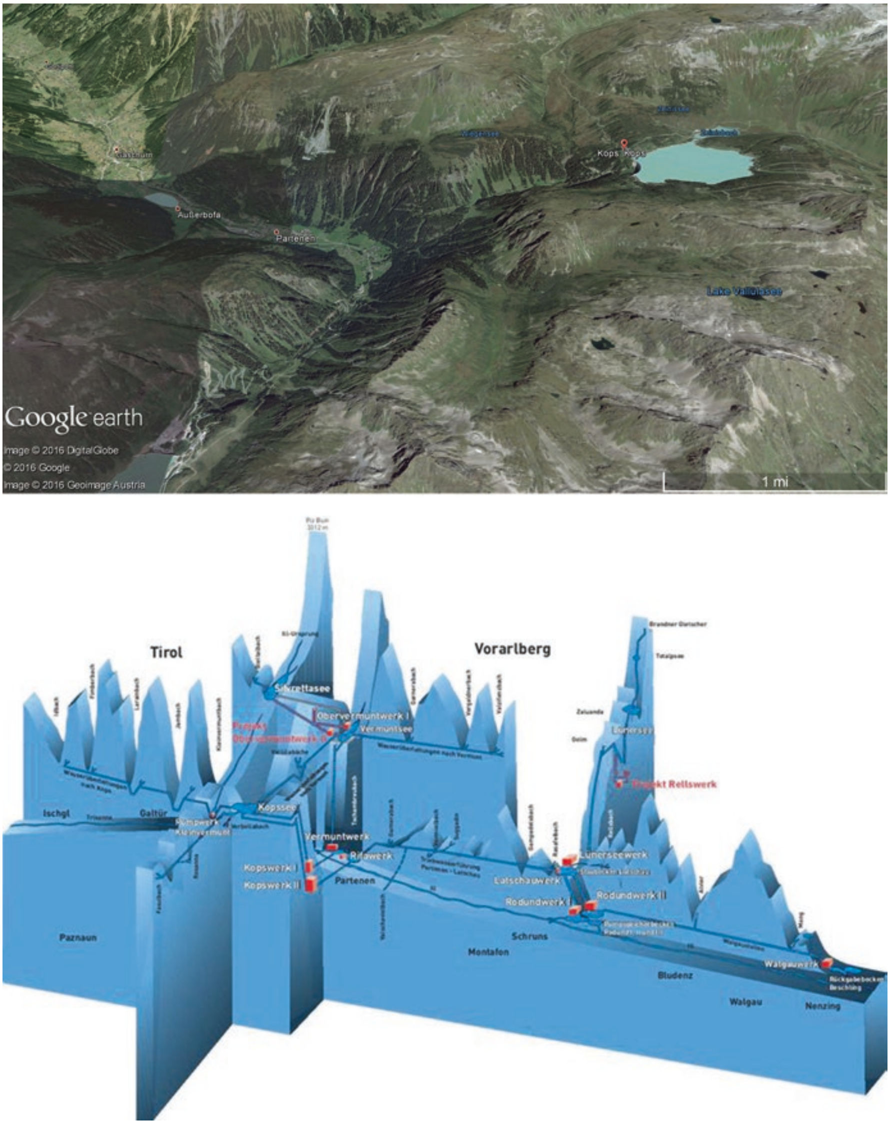

Fig. 10.12 Kopswerk II with its upper reservoir, the Kops (*right side* of an image), and its lower reservoir, the Rifa (*left side* of an image); complex run-off system Vorarlberg. Source: Google Earth, 2016; Illwerke vkw, 2008

the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) using Landsat images. The data layers can support global assessments of land cover, land cover-change, and ecosystem dynamics such as disturbance and vegetation health.

The vegetation changes in period 1990–2005 are highlighted by using the NDVI as shown in Fig. 10.15. In spite of that the described pumped-storage hydropower

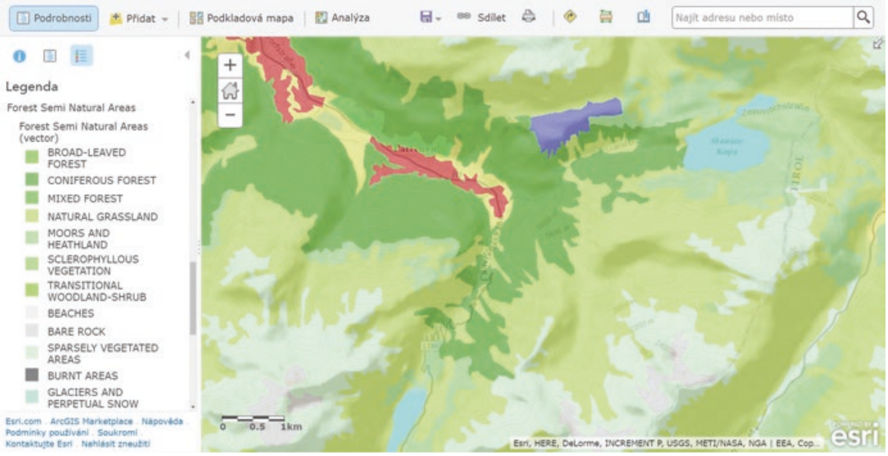

Fig. 10.13 Assessment of environmental impacts based on CORINE Land Cover in ArcGIS Online

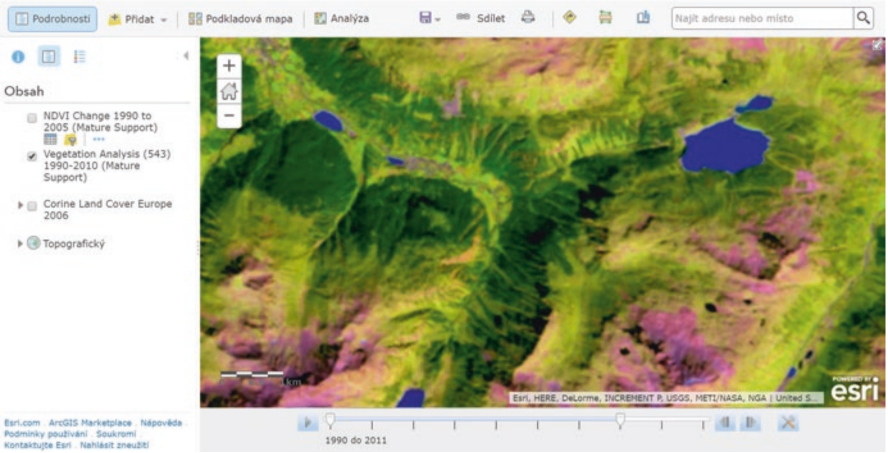

Fig. 10.14 Assessment of environmental impacts based on Landsat image bands (5 4 3) in ArcGIS Online

was commissioned in 2008, it can provide impact assessment of the hydropower systems operating before or in those years. The changes are generated by combining multi-temporal imagery of Global Land Survey (GLS) Landsat NDVI, where red, green, and blue color in the color composition is linked to NDVI in 2005, NDVI in 1990, and NDVI in 2005, respectively. Most areas in the image will be grey, indicating no change because each pixel has relatively the same value in each band. Areas that show up green were brighter in 2005, while areas that show up in magenta were brighter in 1990 than 2005.

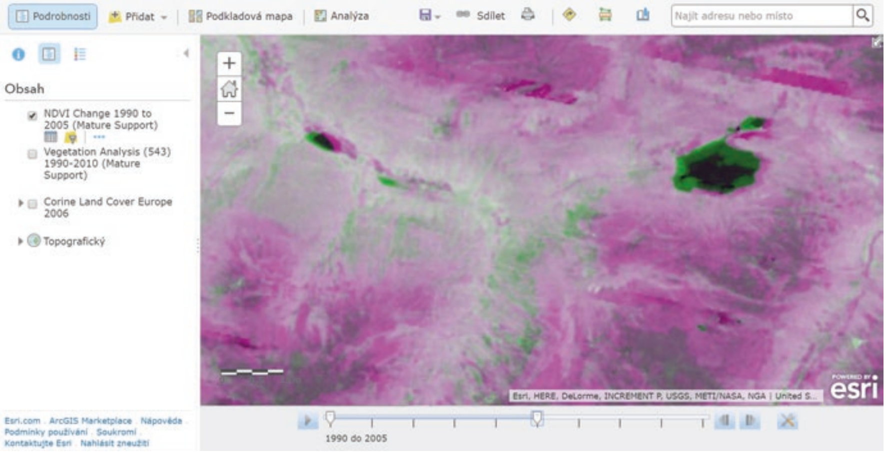

Fig. 10.15 Assessment of environmental impacts based on NDVI changes in the period 1990–2010 in ArcGIS Online

Kopswerk II is part of a more complex system of hydropower plants and reservoirs common in the alpine region. The Kops reservoir functions as an annual storage for the hydropower systems connected to it and as daily peaking storage for Kopswerk II. Kopswerk II consists of three sets of Pelton turbines, pumps, and generators with the installed capacity of 450 MW, but at Kopswerk II the turbines and pumps are separate in comparison to the most pumped-storage hydropower systems that have the turbine and pump integrated into one machine. This set up allows Kopswerk II to utilize the principle of hydraulic short circuit during pumping mode (Illwerke vkw, 2010).

The surrounding area of the reservoir Kops is sparsely populated by smaller towns. The most dominant features are hills, forests, and rivers. Thus, the human impacts are negligible.

The area around the Kops is designated as Natura 2000 site with a number of protected birds. The water has low levels of organic or inorganic nutrients with no significant oxygen deficit. Fish do not naturally occur, and do not reproduce as water temperature in the Kops reservoir is too low. Thus, rainbow trout is introduced into the reservoir for recreational fishing. Fish deaths have been observed in the upper reservoir due to high fluctuations in water levels where isolated areas can become dried out. Also, the impacts on ecology and natural systems are minimal.

Sediment transport has been an issue in the Kops reservoir about 10 years ago, due to weathering sediments flowing into the Kops during major and minor rainfall events, avalanches, and snowmelts. But sediment management has helped to prevent serious consequences of sediment accumulating in front of spillways.

Kopswerk II utilizes an already-existing upper and lower reservoir and its own operating environmental impacts of pumped-storage hydropower are low. It also confirms impact assessment based on remote sensing data, which is introduced in this case study.

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