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Decentralised Electricity Storage Possibilities – From a Geographical Viewpoint

Béla Munkácsy
PhD, Lecturer, Eötvös Loránd University, Faculty of Science, Institute of Geography and Earth Sciences, Department of Environmental and Landscape Geography
e-mail: munkacsy@elte.hu

Ádám Harmat
MSc, Geographer, WWF Hungary
PhD Student, ELTE University, Faculty of Sciences, Doctoral School of Earth Science
e-mail: harmatadam@caesar.elte.hu

Tamás Soha
BSc, Geographer, MSc Student
Eötvös Loránd University, Faculty of Sciences
e-mail: tamas.soha@gmail.com

Márton Havas
BSc Student, Eötvös Loránd University, Faculty of Sciences
e-mail: renewable.energy.havas@gmail.com

Nándor Zaja
MSc Student, Eötvös Loránd University, Faculty of Sciences
e-mail: zaja.nandez@gmail.com

Henriett Daróczi
MSc, Environmental Scientist
e-mail: daroczi.henriett@gmail.com

Tamás Budimácz
MSc Student, Eötvös Loránd University, Faculty of Sciences
e-mail: bud6783@gmail.com

Mária Szabó
Full Professor, Eötvös Loránd University, Faculty of Sciences, Institute of Geography and Earth Sciences, Department of Environmental and Landscape Geography
e-mail: szmarcsi@caesar.elte.hu

Gergely Horváth
College Professor, Eötvös Loránd University, Faculty of Sciences Institute of Geography and Earth Sciences, Department of Environmental and Landscape Geography
e-mail: horvger@caesar.elte.hu

Gábor Csüllög
PhD, Lecturer at Eötvös Loránd University, Faculty of Sciences Institute of Geography and Earth Sciences, Department of Environmental and Landscape Geography
e-mail: g.csullog@gmail.com

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Abstract

The development of energy systems has a quite conspicuous direction which can be described as renewable energy based decentralisation. This way of the energy evolution demands an extensive presence of storage applications, in regional and local level, as well. The battery storage is the simplest solution but the financial part of these applications (pumped hydro, power-to-gas, liquid air, and compressed air energy storage) can be demanding. This is why this research is focused on some alternative technologies and their spatial dimension. This latter is considered as a limitation in some of the researches. In our approach, the spatial aspect is considered as possibility for the less-developed rural regions, as the research area of this paper, the operation area of the 'Bükk LEADER rural development region' in North East Hungary. According to the GIS analysis, all the four storage technologies seem to be applicable: 78–160 pumped storages; 29 power-to-gas storages; 7 liquid air storages; and a significant number of small-scale compressed air energy storage would be applicable in the research area. However, it is important to underline, that the above mentioned values are not comparable from the quantity of the stored energy point of view, because it is mostly affected by the technology.

Key words

Decentralised energy system; electricity storage; seasonal storage; GIS; environmental burden; rural development

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1. Introduction

The current increase in the deployment of new renewable electricity generation systems is making the energy storage and other methods (demand side management; energy mix optimisation; energy system optimisation with involvement of heat and transportation solutions; import and export) more and more important in order to secure the supply of electricity. The decentralisation in the field of the energy production especially highlights the importance of small scale storage solutions, as batteries. On the other hand, the popular and simple battery storage seems an expensive technology so far. This paper focuses on its main alternatives.

According to ANTONELLI, M. *et al.* (2016) "an ideal energy storage technology would have a high power rating, a large storage capacity, high efficiency, low costs and no geographic constraints". This paper argues this statement, that in some regions geographical abilities cannot be seen as constraints, but much more as possibilities.

Figure 1 – Research area
Edited by HARMAT, Á (2016)

This paper considers that energy storage technologies offer advantages of balancing the demand and supply of the electricity grid throughout the day or even through seasons of the year, moreover they can help to solve some electricity system management tasks, as frequency regulation.

As for the research methods, the main ways are desktop research, field research (plant visits in existing energy storage facilities) and GIS analysis. The latter focuses on special geographical areas in *Hungary*, namely the *Bükk LEADER rural development region (Figure 1)*—as a part of a more general research on sustainable energy solutions in these regions.

2. Current state of the energy storage technologies

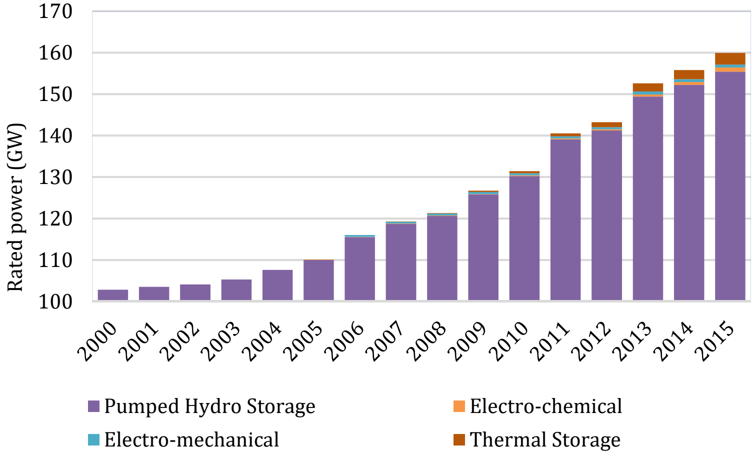

Figure 2 – Global energy storage capacities by technologies
Source: DOE (2016); Edited by HARMAT, Á. (2016)

2.1. Power-to-Gas

Power-to-Gas (P2G) is one of the most promising methods in which the surplus electricity can be transformed into gases, in order to store energy *(Figure 3)*. The stored gas can be:

a) *hydrogen* via water electrolysis;
b) *synthetic methane* or 'synthetic natural gas' (SNG) or 'renewable methane' via subsequent methanation;
c) a *mixture* of hydrogen and methane.

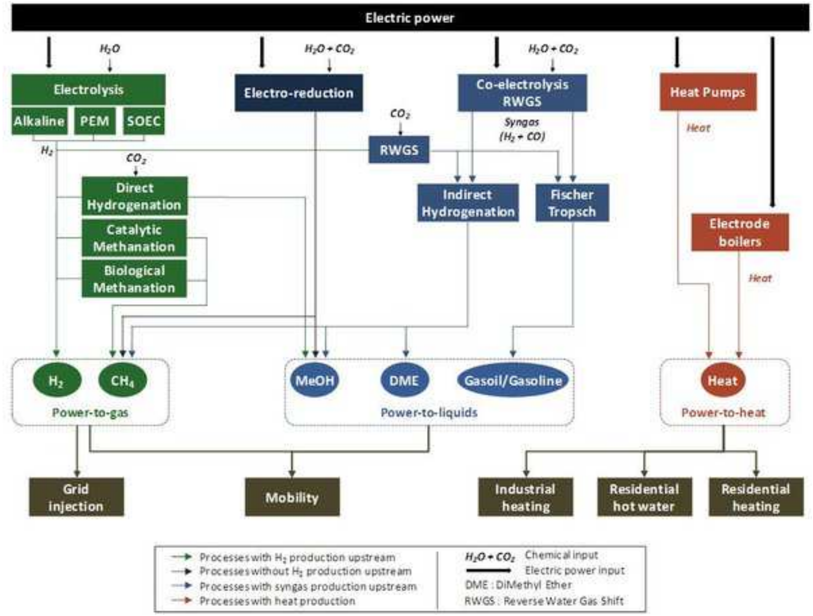

Figure 3 – Power-to-gas, power-to-liquids and power-to-heat routes and their energy markets
Source: ENEA (2016)

There is a similar method *(Figure 3)*, in which the energy storage happens in the form of liquid methanol (Power-to-Liquid) (RÄUCHLE, K. *et al.* 2016).

The main advantage of the method is the huge storage capacity of the *existing gas grid*, including the caverns and other storage facilities. According to HAFENBRADL, D. (2016), it means 300 TWh storage possibility only in *Germany* against the 0.04 TWh existing pumped hydro and battery storage capacities.

The Power-to-Gas procedure has two or three steps:

1) the *electrolysis* in order to create hydrogen;
2) chemical conversion, like *methanation*—an optional step;
3) the *storage*.

The first step is the water electrolysis which is a mature and well understood technology (PAIDAR, M. *et al.* 2016). The main goal is to create hydrogen in such periods when the electricity demand is low and the wind or/and photovoltaics (PV) solar power production is high.

The second, optional step is the conversion. Its main goal is to create more stable chemical forms in order to find simpler storage solutions. The most relevant stable forms are the liquid organic hydrogen carriers (LOHC) and the synthesised hydrocarbons. One of the simplest methodology is the methanation which can be done both in catalytic and biological methanation reactors. In a *catalytic methanation* reactor the methane is synthesised under high pressure and temperature (Sabatier process) and in the *biological method* special microbes (for instance *Archaea*) create the methane *(Table 1)*.

Table 1 – Comparison of methanation processes

Source: HAFENBRADL, D. (2016)

	Sabatier process	**Biomethanation using Archaea**
Operation temperature	300–400°C	60–65°C
Ramp up time (0–90%)	~1 hr	Sec/Min
Tolerance against contamination (H_2S, O_2, KOH)	low	high
Product gas	CH_4 + side products	CH_4
Product purity (%CH_4)	~92%	98–99%
Energy efficiency	~50%	58%
System complexity	high	low
Scalability	low	high

In the last decades, several reactor concepts were developed for large scale coal-to-gas plants, mainly in Japan. However, the smart grid system requires smaller and more flexible methods (GÖTZ, M. *et al.* 2016). The biological method, using *Archaea* seems proper for the future applications as its scalability and overall efficiency are higher.

In a sustainable energy system, in these conversion processes CO_2 emissions of biogas plants or industrial facilities must be used (SCHNEIDER, L. – KÖTTER, E. 2015). Another requirement due to the excess heat produced during methanation is to have heat demand—preferably a district heating system—nearby. Both of these factors make the P2G facility more efficient; thus, less costly to run (VARONE A. – FERRARI M. 2015).

In the *third step* the hydrogen or the methane (or their mixture) or another product of the chemical conversion need to be stored. It can be both a short time and a seasonal period of time. The storage unit for the *hydrogen* can be

- surface or subsurface tanks
  - compressed gas tank;
  - cryogenic compressed liquid hydrogen tank;
  - metal hydride storage;
- geological underground storage *(Figure 4)*.

As for the *methane*, the most important type of gas storage is in underground reservoirs (depleted gas reservoirs, aquifer reservoirs and salt cavern reservoirs).

The large scale geological storage can be one of the cheapest ways, however in the case of hydrogen there is no direct option to store it in high amount for long period (SCHIEBAHN, S. *et al.* 2015). In the case of methane, the long-term storage from weekly to seasonal time periods may require huge underground gas reservoirs, however their availability is regionally limited.

Another feasible option can be the injection into the existing natural gas grid. In general, 4–5% of biogas (synthetic natural gas [SNG] or hydrogen is allowed to be injected into the system (QADRDAN, M. *et al.* 2015; SCHNEIDER, L. – KÖTTER, E. 2015).

Figure 4 – A geological underground storage site for methane (90%) and hydrogen (10%) mixture at a depleted natural gas reservoir near Pilsbach, Austria

Photographed by MUNKÁCSY, B. (2016)

2.1.1. Projects

There are many different parameters (location, intersectoral co-operation) which influence the efficiency of Power-to-Gas systems. According to the *European Power to Gas Platform*, 41 projects are existing today, most of them are in pilot phase. The biggest project is in *Wertle* (*Lower Saxony, Germany*—launched in 2013) which produces 1300 Nm^3/h of methane and hydrogen while its installed capacity is 6.3 MW.

In the field of biological methanation (based on *Archaea microbes*) have been some significant steps ahead: a demonstration plant in a biogas plant of *Allendorf (Hesse, Germany)*, a pre-commercial scale facility in a biogas research centre in *Foulum, Denmark* and a 1 MW commercial-scale field trial at a wastewater treatment plant outside *Copenhagen, Denmark* have been launched lately.

Table 2 – Operational and planned P2G projects in Europe

Source: EPGP (European Power to Gas Platform)

	Operational projects (number of units)	Planned (number of units)	Installed power (kW)	Planned power (kW)
United Kingdom	4	0	1,436	1,436
France	3	1	0	1,150
Spain	2	0	4,270	4,270
Germany	20	8	15,996	26,661
Norway	1	0	48	480
Denmark	4	1	1,270	2,470
Netherland	2	1	15	12,327
Belgium	1	0	150	150
Switzerland	1	1	315	1,015
Italy	1	0	1,000	1,000
Austria	2	0	700	700
Total:	**41**	**12**	**25,200**	**51,659**

2.1.2. Geographical aspects

As it was mentioned above, in these conversion processes CO_2 emissions of biogas plants or industrial facilities must be utilised. In order to identify the suitable areas of P2G storages in the *Bükk LEADER rural development region*, GIS analysis were used. In case of the study area, block industrial and chemicals production facilities were identified as significant CO_2 sources. Also, livestock facilities and existing or planned wastewater treatment plants—where biogas utilisation is viable—were selected according to the amount of livestock units. In terms of the storage, the location of the existing gas grid was in the scope of the study. According to SCHNEIDER, L. – KÖTTER, E. (2015), it was assumed that the maximum distance to the gas grid is 5 km. This buffer distance was used in this research, as well.

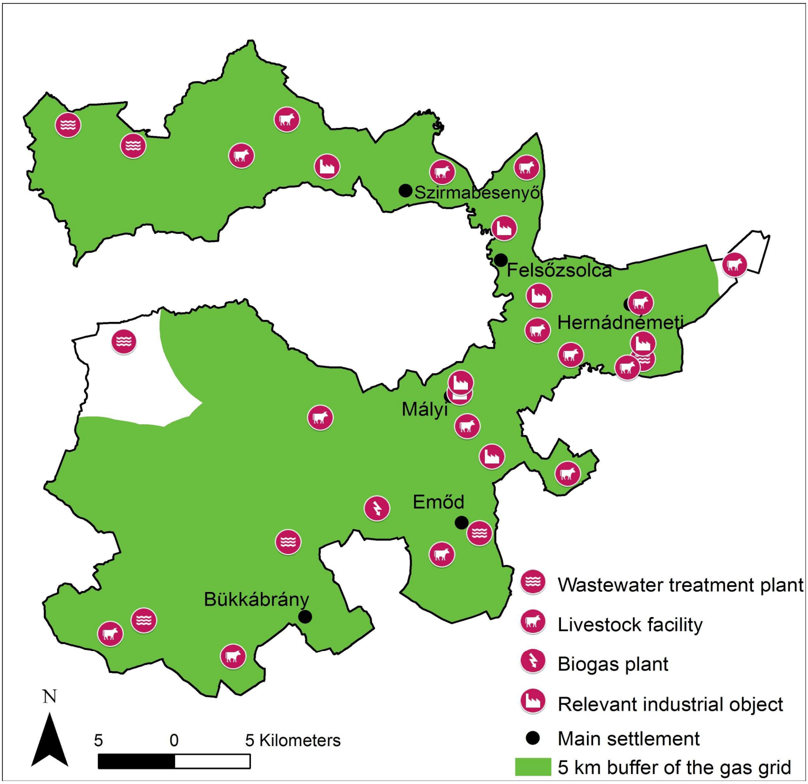

Figure 5 – Potential CO_2 sources for P2G facilities in the Bükk LEADER rural development region

Edited by HARMAT, Á. (2016)

As for the results, in the research area there are *26 potential sites (Figure 5)* within the 5 km buffer of the natural gas grid system (namely 1 biogas plant and 7 industrial objects where surplus CO_2 could be captured; 3 wastewater treatment plants and 15 significant livestock facilities where surplus CO_2 capture is possible) and *3 planned units* (wastewater treatment plants) seem appropriate as possible sites for P2G storage facilities, most of them is situated in the eastern part of the area.

2.2. Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) is a promising technology for future electric grids that may help to compensate the unbalanced generation of renewables and consumption of power. A CAES facility can be effective with a coal and nuclear energy based electricity system, however the most impressive is cooperated with wind or solar farms which production depends on the weather circumstances (LUND, H. – SALGI, G. 2009). The importance of this is meaningful considering the energy and climate strategy of *European Union* for 2020 where renewable energy sources have higher (20%) participation in final energy consumption, while renewable electricity already contributed to 27.5% of total electricity consumption in 2014 (DA GRAÇA CARVALHO, M. 2012). Among all forms of energy storage some are still under development or are on pilot project level. When considering each technology, there is no absolute best one, implementation depends on location, purpose and costs. In consequence, there will be a chance to find the most appropriate technology after analysing each location or business case individually.

On the one hand, a CAES plant fits well in a more sustainable electricity system that minimises losses and fuel usage. Current pilot projects of CAES plants on some occasions suggests more than 80% round trip efficiency (JOHNSON, P. M. 2014). On the other hand, a CAES system should be suitable in international electric grids and make advantage of price arbitrage (LUND, H. – SALGI, G. 2009). The latter authors made an analysis about some energy storage systems like CAES, EB (electric boiler), HP (heat pumps), ELC (electrolysers), an H_2 electrolysers for comparison. They determined that CAES plants may can be parts of the future electric grids. CAES is not the only solution, however because other options—like batteries or P2G—might be more attractive in the long run.

2.2.1. Brief History

Currently there are two working CAES plants worldwide with an installed capacity of 431 MW. The timeline on *Figure 6* shows the evolution of CAES technology.

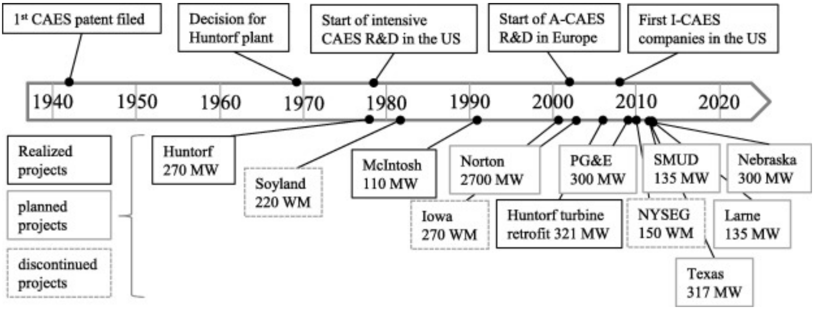

Figure 6 – Timeline of CAES R&D and industrial efforts; projects are not exhaustive and limited to the largest installations

Source: BUDT, M. et al. (2016)

The first finished plan and patent appeared in the *USA* in the 1940s but the first CAES plant had been planned and constructed in *Huntorf, North Germany* only in 1978. The idea of energy storage occurred partly due to the first oil crisis in 1973 and was even more attractive after the second crisis in 1979. Reliable operation of the German facility spread interests in the *USA* and the CAES got into the sight of R&D. New technologies were developed to reduce the fossil fuel dependency. There were plans to construct a CAES facility in the *USA* and in 1991 the first one came into operation in *McIntosh*, *Alabama*, which draw attention to the technology again. For example, in the states of Tennessee and Hawaii the technology got in sight, but it remained only on the level of plans. In *Norton*, *Ohio* state, another one was planned through delays and proprietor changes so far it was not constructed. *Seneca project* had a similar way until its cancellation in 2012. There are plants which are under planning process both in the *USA* and *Europe*, the details of these running and planned CAES constructions are summarised later in this paper. So, besides some very small (1–2 MW range) plants, no utility sized CAES facility was built since 1991 (BUDT, M. *et al*. 2016).

2.2.2. Technologies

Figure 7 shows a simple, fundamental diabatic CAES (D-CAES) process.

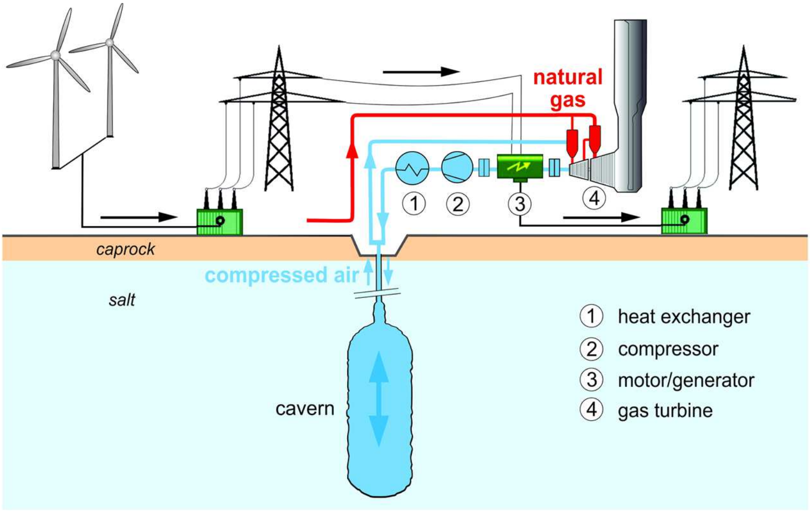

Figure 7 – Schematic illustration of a D-CAES plant
Source: KBB UNDERGROUND TECHNOLOGIES (2014)

Diabatic in this situation means that excess heat during air pressurisation (energy storage mode) is released without thermal storage and during expanding process, the air has to be heated up by external energy (for example natural gas). The basic idea is similar to most of the other energy storage alternatives. The process starts in the off-peak periods (typically at nights) or when generation is high, but consumption is low. The latter often occurs as a consequence of high solar and wind energy penetration connected to the grid. In this situation, a compressor pumps air into a reservoir/air storage where the gas is pressurised, thus stored in the form mechanical energy. In peak demand periods the stored air is released, and while expanding it goes through a turbine that is connected to an electric generator. According to the laws of thermodynamics, as air loses pressure and expands (its volume grows), its temperature decreases rapidly and to avoid freezing in the case of D-CAES air is usually heated up using combustion of fossil fuels, thus making it inefficient and environmentally damaging. *In spite of using natural gas as a means of heating air up, a typical CAES facility releases 80% less* CO_2*/MWh than a coal fired* and about 45% less than a natural gas fired *power plant* (AzRISE, 2010)**.** The next step of the exhausted air (natural gas mixture) is to spin up a turbine and finally to leave to the environment. The turbine drives a generator that produces electricity for the national or local grid. This is a simple description of a diabatic-CAES plant. However, in the last approximately 70 years of development and research of compressed-air energy-storage more and more developments were created, variances for higher efficiency, lower emissions and cost effectiveness.

When developing higher efficiency CAES systems the main direction is to create a plant that is more sustainable in both environmental and economic terms. The most crucial problem is reheating expanding air that would otherwise cool down. Solutions had been found by R&D programs which may be able to solve this issue.

Adiabatic-CAES (A-CAES) focuses on storing thermal energy that accumulates during the compression phase *(Figure 8)*. Correspondingly to D-CAES the process start with usage of the off-peak (or intermittent renewable) electricity that drives the motor of compressors. Air pressurisation happens in two steps by low and high pressure compressors. The arising heat energy can be captured in two ways: with or without thermal energy storage (TES). Firstly, without TES process the heat is stored in the air itself with a combined thermal energy and compressed air storage system. In consequence, the air becomes hot and it narrows the storage possibilities and steepen the prices. Understandably, there are no plans to construct one like this.

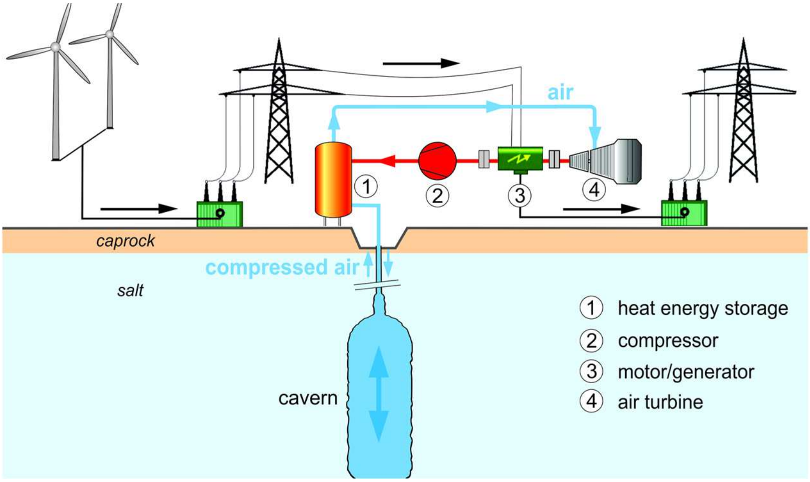

Figure 8 – Schematic illustration of the main elements of an A-CAES plant
Source: KBB Underground Technologies (2014)

The other option (with TES) is to keep the heat in a separated tank. It is possible in three levels of pressure:

- High-temperature processes (above 400°C)
- Medium-temperature processes (between 400°C and 200°C)
- Low-temperature processes (below 200°C)

The heat storage media and the system can be different depending on the temperature. Solid storage media can contain more heat energy but liquid media is more mobile that gives the possibility of pumping it. Consequently, when it is on-peak period, the expanding air is heated up by the stored thermal energy. The advantage of the whole A-CAES process, therefore, is that it does not need external intake energy, this leads to higher efficiency and lower CO_2 emissions. At the end of this process the air escapes through a turbine and the generator generates electricity (Budt, M. *et al.* 2016).

Isothermal compressed air energy storage, however, (I-CAES) pays attention to reduce heat energy by a specific compression process. It is supported by additional water which absorb and store heat energy.

During the expansion, the warm, heat container water is injected in cooling down air. The electricity production is like above mentioned ones (BUDT, M. *et al.* 2016).

2.2.3. Storage

Storage reservoir is a crucial part of a CAES plants, because the construction opportunity usually depends on the spot. There are three types of CAES plant by storage reservoir, the one which is least depending on the location is the one using an *aboveground tank*. This is a favourable technology on the view of mobility because it is almost always possible to settle close to a solar or wind farm to shorten the electricity transport distances. The disadvantages of this storage are mainly the size and volume limits comparing to a natural geological reservoir. In short, it gives opportunity to create a mobile, but expensive and relatively small CAES plant. The most spread out technology is underground air storage. It has two types depending on underground storage formations. The two working plants are implemented into *salt caverns,* that is the most known type of underground air storage. However, salt caverns are very infrequent geological formations (salt domes especially), so there is not so much spot where it coincides with (intermittent) renewable generation. Another type could be *porous rock aquifers*. There are no working plants implemented into this, but research shows possibility of further development (HAVAS, M. – HRENKÓ, I. 2015). In short, the underground storage largely depends on location, but it usually has a nature created, large store capacity that can be used with relatively low costs. Some of these geological formations are used as natural gas storages, which might be transformable to a CAES plant. Finally, there is a yet relatively unknown storage idea: underwater compressed air energy storage. This "emphasizes a solution for storing the compressed air that employs bags under waterbodies using the hydrostatic pressure to keep the air stored" (GALLO, A. *et al.* 2016). The technology still requires to be researched, but it may become a relevant future possibility (GALLO, A. *et al.* 2016).

2.2.4. Operating plants

There are two working CAES plants worldwide as mentioned earlier. *Huntorf plant*—with its 321 MW installed capacity—was the first constructed compressed air energy storage plant in the world. It works by the process of the diabatic CAES technology. Due to this there is energy loss at the compressing phase which demands additional heat source at the expansion phase. However, the two-staged compression used in *Huntorf* technology reduces this deficit. The compressed air is stored in two solution mined salt caverns with 310,000 m^3 total capacity. These two caverns allow the plant to be maintained and run at the same time. In 2006, the expansion turbine was retrofitted for a more efficient one, so installed capacity reached 321 MW from the previous 290 MW.

13 years after the first CAES plant, another D-CAES facility with 110 MW of installed capacity was implemented in *McIntosh*, *Alabama*, *USA*. Storage capacity is higher than in the *Huntorf* one (26 hours of nameplate capacity with ~2,800 MWh storage capacity, while only 3 hours of nameplate capacity in *Huntorf* with ~1,000 MWh of storage capacity), but it has only one large cavern in an abandoned salt mine. It works with diabatic process, so there is no heat storage device. Like previously mentioned, the energy loss is reduced by a multiple stage compression system. In this system, the usage of an exhaust-heat recuperator poses the main difference and advancement compared to *Huntorf*. The recuperator is applied as a simple form of exhaust heat recovery to limit the exergy losses which would come from the hot exhaust gas (GALLO, A. *et al.* 2016).

In recent years, no utility sized CAES facilities were built, however, there are good examples of decentralised CAES plants like the one in *Gaines*, *Texas*, *USA* that uses no external energy source and has a rated power of 2 MW. The *Huntorf plant* went into reserve as there is no business case for it in *Germany*, because renewable generation and imports tend to be a cheaper option (GALLO, A. *et al.* 2016).

2.2.5. Opportunities in Hungary

The installed intermittent renewable energy capacity is still in a low level in *Hungary*. However, some energy storage plants can be effective with the current energy mix, too. Especially if we check the European trends and the aims of *EU* then the research of energy storage possibilities will be indispensable in the following decades. In the case of underground CAES the main restrictive point is the underground geological formation itself. In *Hungary*, there is no countrywide research about rock formations focusing especially on compressed air storage. The salt dome storage is not possible, because that is not exists in *Hungary* (SUCCAR, S. – WILLIAMS, R. H. 2008). On the one hand, the porous rock formations usually occur. On the other hand, most of them also not measured for compressed air storage. For northwest *Hungary* however, there is a research about the underground storage conditions and possibilities of creating a CAES plant. This survey was created by HAVAS, M. – HRENKÓ, I. (2015) They worked with water drillings, and they appointed 7 eligible rock strata were suitable out of the 16 examined ones. These are in *Győr–Moson–Sopron County* (2), *Vas County* (3) and *Zala County* (2). They mentioned that a more comprehensive location based research would be a necessity. This survey also compared the available locations of CAES plants and wind turbines and the 7 suitable locations are close to the competent wind energy production spots. This article can be a base to plan CAES plants in *Hungary*, but the examination cover only a part of the country. There is no another survey, but underground gas reservoirs may be able to store compressed air, too. This is confirmed by ZSCHOCKE, A. (E.ON Innovation Center Energy Storage), who saw CAES as a possible energy storage system, and he also mentioned their four gas storage in *Hungary* (ZSCHOCKE, A. 2012). The problem can be the size of the previous and other reservoirs in the country, because these are much larger than the ever constructed or planned compressed air storages.

With decentralised CAES facilities—like the one in *Texas*—implementation in the *Bükk LEADER rural development region* could be possible. Such a small (~2 MW) facility would not need an underground reservoir or a large area, so taking it into consideration is essential.

2.3. Liquid air energy storage

The use of liquid air as energy carrier has been studied since 1900 with the first liquid air car application in the *USA*. *Liquid air energy storage* (LAES) is a much younger methodology which dates to 1995, as "liquid air storage energy system" (KISHIMOTO, K. *et al.* 1998). It uses the air as an energy storage medium and applies the natural law that air can be turned into a liquid by cooling it to a very low temperature, around –196°C. Therefore, it sometimes is referred to as *Cryogenic Energy Storage* (CES). The liquid air can then be stored in a relatively small unpressurised insulated vessel—as 700 litres of ambient air becomes about 1 litre liquid. When heat is reintroduced to liquid air, it boils and turns back into gas, expanding 700 times in volume. This expansion can be converted into electricity or mechanical energy by a reciprocating engine or a turbine (STRAHAN, D. [Ed.] 2013) or *Organic Rankine Cycle technology* (MORGAN, R. *et al.* 2015). The expansion process can be boosted by the addition of low grade waste heat (cooling water of power stations, factory process heat up to 100–150°C), which significantly improves the energy return (KANTHARAJ, B. *et al.* 2015). It is also possible to use waste cold (mainly from regasification of *Liquid Natural Gas*) during the cooling process.

In practice, there are two main ways of LAES research, the first one deals with *ambient air*, the other focuses only on *nitrogen*, the main component (78%) of the Earth-normal air. The industry has a significant surplus of gaseous nitrogen that could be made available for liquefaction.

LAES can be a competitive storage alternative in applications above 50 MW and for storage durations from 2–20 hours. According to the calculations of an industrial player *(Linde)*, a 1600 m^3 liquid air tank can store about 220 MWh of electricity.

There is also an interesting future development possibility to create a hybrid thermodynamic system of CAES and LAES in order to convert compressed air to liquid air and back with heat pump and heat engine with a relatively high efficiency (KANTHARAJ, B. *et al.* 2015).

2.3.1. Existing projects

The LAES technology is in a pre-commercial, demonstration phase *(Figure 9)*. A first significant *pilot project*, called *Highview Power Storage*, was located in *Greater London*. This small unit could provide to the electricity grid 350 kW power with 2.5 MWh storage capacity between 2011 and 2014. In order to increase the system efficiency, waste heat was used from the neighbouring biomass power station. The plant was relocated to the *University of Birmingham (Centre for Cryogenic Energy Storage)* in 2015.

A much bigger *pre-commercial project* is under construction in *Greater Manchester*. Its capacity will be 5 MW/15 MWh. The waste heat supply will be provided by the gas engines of the nearby landfill site.

Figure 9 – Pre-commercial demonstration plant

Source: HIGHVIEW POWER STORAGE

In a next phase, a *full commercial* design could be built up to 200 MW capacity, presumably within 3 years.

The benefits of the LAES are:

- theoretically it can be located almost anywhere *without geological constraints* and risk—*Figure 10* (STRAHAN, D. [Ed.] 2013a; KANTHARAJ, B. *et al*. 2015);
- it uses existing mature components;
- it does not need a special pressurised storage vessel;
- it has a relatively large volumetric exergy density at ambient pressure.

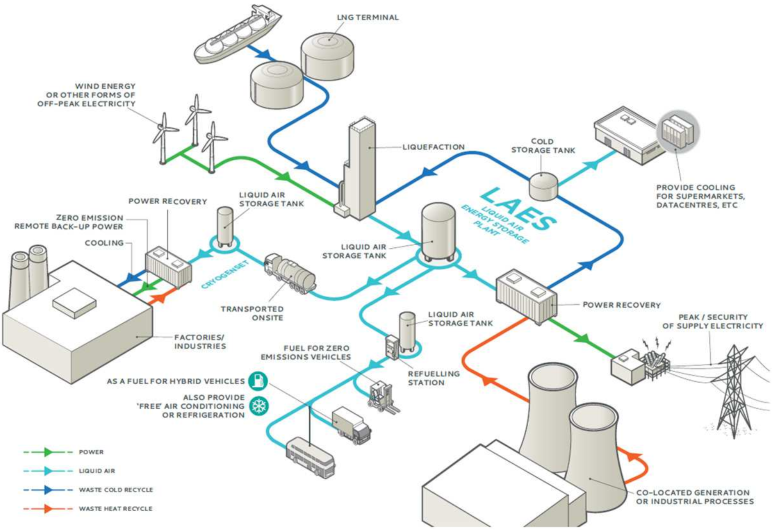

Figure 10 – Optimal location of a LAES facility showing the significant geographical constraints of a system

Source: STRAHAN, D. (2013b)

Its drawbacks are:

- it works in very low temperature, which requires insulated storage tank;
- cryogenic liquids present significant hazards because of their intense cold and substantial gas production when warmed;

- in a simple design, the system has lower roundtrip efficiency (~50–60%) than other energy storage technologies;
- to improve the efficiency with waste heat or/and waste cold utilisation, it is important to locate to nearby proper industrial sites (STRAHAN, D. 2013a)—which means a strict *geographical constraint (Figure 10)*.

On the whole, a geographical site optimisation needs to consider several factors. Most importantly the LAES plants need to be located near to *weather-dependent renewable* (wind and solar) energy applications, in order to provide storage possibility for them without significant energy loss. The distance from the *electricity grid* is also substantial factor in order to limit the electricity loss. To improve the storage system efficiency the most relevant need to build LAES projects in the vicinity of significant *waste heat* producers.

2.3.2. Geographic Aspects

To assume the geographic potential sites of LAES facilities in the study area, industrial objects with surplus heat production were identified. With the lack of such a database, the scale of the industrial production in the municipalities were concluded from the amount of paid business tax. Municipalities where the annual income from business tax was higher than 65,000 Euro were examined, and the potential industrial objects were identified according to their profiles. In the next step, the location of relevant facilities was registered in the GIS software. It was assumed, that the surplus heat can be transformed within 3 km. From the 3-km-radius buffer area restricted areas were extracted, such as forests, conservation areas and landscape protection areas.

As for the results, in the research area 7 potential sites (such as a brewery; a pharmaceutical company; chemical and brick factories) and a geothermal pipeline (with two geothermal wells) were identified as significant heat sources, therefore potential sites for LAES applications in the future *(Figure 11)*.

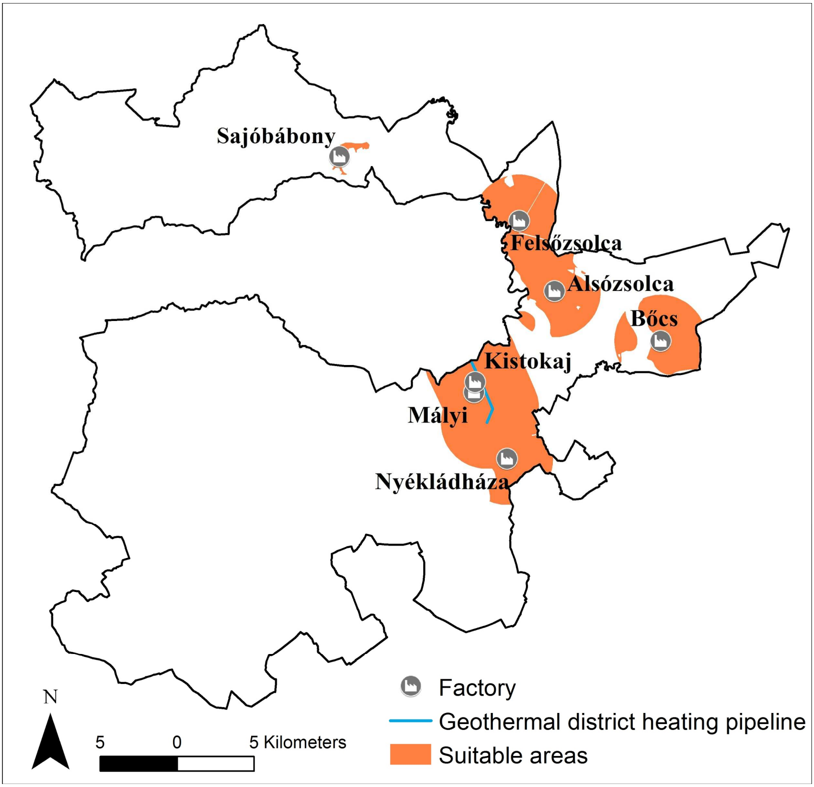

Figure 11 – Suitable area for LAES facilities in the Bükk LEADER rural development region
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2.4. Pumped-hydro Energy Storage

Pumped Hydro Energy Storage (PHES) is currently the most widely used large scale energy storage technology, providing *99% of the world's ES capacity* (SAUHATS, A. *et al.* 2016), with 164,630 MW of total installed capacity and around 320 projects worldwide (energystorageexchange.org). The advantages of this system are:

- mature technology (over 120 years of experience);
- long lifetime (40–80 years);

- limited quantity of pollutant emissions (methane—from biodegradation; CO_2—considering the whole lifecycle);
- provide ancillary grid services.

As for the disadvantages, large capacity usually demands large flooded areas which can be a major environmental problem. Solutions with small size applications can reduce the environmental impacts and it also can provide the possibility of decentralised utilisations in microgrids.

PHES requires two water reservoirs in different elevations, connected with a pressure tunnel *(Figure 12)*. Operational projects have 100–500 m water level difference in average, with maximum 2–3 km horizontal distance. Ratio of these two parameters cannot exceed 1:10 to keep up the optimal water flowing speed to run the turbines. Reservoirs can be natural (lakes or rivers) or artificial water bodies, even existing ones. Just like other storage technologies, PHES uses electricity to pump water to the upper reservoir in off-peak periods, or when the renewable energy sources generate more electricity than the consumption of the demand side. This can be converted back (so-called 'discharging') when it is needed, for example peak-periods or when grid regulation is required (CAVAZZINI, G. – PÉREZ-DÍAZ, J. I. 2014). Their efficiency is from 65% up to 85% at recent projects (AENKE, M. – WANG, M. 2016). The newest pumped storage stations use reversible pump-turbine/motor-generator assemblies, in which case water can flow in both directions according to charging or recharging phases. In general, the running projects have a generating capacity between 100 MW and 1,000 MW, however it could be 3,000 MW (KÁDÁR, P. – VAJDA, I. 2010). The amount of stored energy is mainly based on the volume of the water reservoirs. Other factors are

- the head difference of the reservoirs;
- turbine efficiency;
- the ratio of total length of the pressure tunnel and the height difference between the water levels of the reservoirs (LEVINE, J. 2011; ARÁNTEGUI, R. L. *et al*. 2012a).

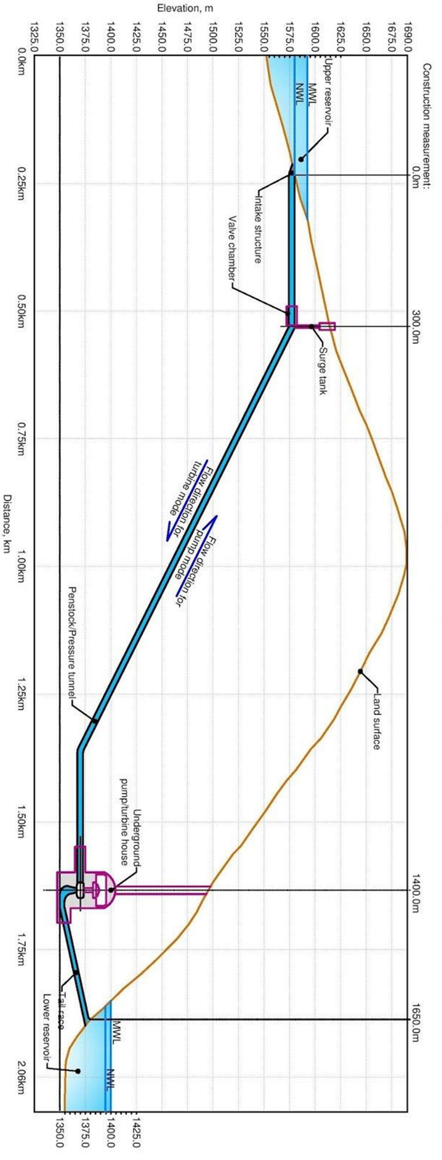

Figure 12 – Basic scheme of a PHES plant

Source: BADARCH, A. (2015)

2.4.1. Recent situation in Hungary

Despite many PHES construction plans from the 1970s to recent days, *Hungary* still does not have any operating plant. In the background, there are mainly financial shortages and the negative environmental effects of the planned projects. The suitable construction sites are situated mainly in the mountainous regions of *Hungary*, among others in the *Danube-band* and in the *Zemplén Mountains (Table 3)* (SZEREDI, I. 2011). Due to the significant planned capacity, the water reservoirs would take large flooded areas as well (38–169 hectares), which also means *higher environmental impact* on natural areas, some of them are protected.

Table 3 – Some of the potential construction sites for large scale PHES in Hungary. *The area data means only the upper reservoir, considering only technical aspects*

Source: SZEREDI, I. (2011)

Region	Site	Area	Planned capacity
Danube-band	Keserűs Hill (Prédikálószék)	38 ha	600+600 MW
Danube-band	Urak asztala (Dunabogdány)	137 ha	600+600 MW
Danube-band	Naszály quarry (Vác)	108 ha	600 MW
Zemplén Mts.	Aranyos Valley (Sima)	85 ha	600+600 MW
Zemplén Mts.	Nagykopasz Hill (Tokaj)	129 ha	500 MW
Zempléni Mts.	Hideg Valley (Szerencs)	92 ha	600+600 MW

2.4.2. Geographical aspects in site location

Using GIS applications, it is possible to effectively investigate ideal sites, due to raster-based remote sensing and other vectorised data. Using the above mentioned information, GIS methods can be used to specify the suitable sites for the water reservoirs.

In European level calculations have already been made for *Croatia* and *Turkey* by the *European Commission*'s *Joint Research Centre* (JRC). The JRC has developed a GIS tool to find the *existing water reservoirs* which can be transformed as potential parts of PHES (ARÁNTEGUI, R. L. 2012b). In this research, the GIS model used to investigate pumped storage potentials was similar to the methodology of the JRC. However, it was not limited to the existing water bodies, but more focused on *smaller storage reservoir sites* in order to redound the integration into the future microgrids, preferring the decentralised aspect. The data used were:

- Digital terrain model;
- Land use–Corine Land Cover (CLC 50) database;
- Settlements;
- Infrastructure components (roads, railway lines, transmission lines);
- Surface hydrography;
- protected natural areas at regional, national, and *EU* level.

The study was made by using *ArcGIS software*, contains 32 major steps. The main steps, in a shortened way, were the following:

- creation of the digital terrain model and slope maps of the study area;
- erasing the area of settlements, infrastructure, and other land use categories, except agriculture and natural habitats;
- selecting of the polygons close enough to water and transmission lines access (2 km and 10 km respectively), and creating pairs by filtering their head/length ratio (min. 1:10) and energy capacity (min. 60 MWh, calculating by 6 hours of operation with a 10 MW turbine capacity);
- reconsidering the results with all the protected natural areas (national parks, NATURA 2000, etc.) in order to promote the energy related developments without the loss of ecological values, moreover, creating higher ecological diversity within the existing ecosystems with new water bodies (PATOCKA, F. 2014).

According to the results, the study area contains significant number of suitable sites as a potential to construct *small scale* PHES water reservoirs. The exact quantity correlates with the slope category, therefore two different calculations were made considering *0–5° and 0–7.5°*

slope categories, respectively. It was also important to consider an *appropriate elevation* (at least 100 metres) as well as a maximum *distance* (2,500 metres) between the potential reservoirs *(Table 4)*.

Table 4 – Small scale PHES reservoir potentials at the study areas (with 10 km buffer zone of the study area), and different assumptions on slope

	Bükk <5°	Bükk <7.5°
Total (number of sites)	78	160
Total area (hectares)	5,852	7,584
Protected (number of sites)	53	109
Not protected (number of sites)	**25**	**51**

The '<5° sites' represent 1.6%, the '<7.5° sites' represent 2.5% of the whole study area (92,563 hectares). Despite the high amount of protected natural areas, there are enough sites remaining for construct in both cases. Based on the <5° model version, suitable sites mainly occur near valleys and ridges, such as vicinity of *Sajókápolna*, *Tardona* and *Tibolddaróc*. Average capacities are 10–15 MW with 100–180 m head between the PHES reservoir pairs. To the south of *Tibolddaróc*, the large suitable area presented by the model means that it is possible to choose the best site for construction within *(Figure 13)*.

The presented model can be developed in many ways:

- more versions can be made by modifying the calculation criteria;
- with the data of the existing water reservoirs (location, volume) the model can more focus on existing water storage basins (JRC method) in order to reduce the construction costs;
- using *ArcMap Model Builder* function, the methodology could be applied to any areas to investigate PHES water reservoir potentials.

2.4.3. Conclusion of the GIS research

In comparison to large-scale solutions, the methodology provides much more results in case of small size reservoirs. It also means that the site selection proved to be much easier in case of smaller projects. The small scale PHES seems to be a proper solution for the integration of intermittent renewable energy sources, such as wind and PV. Furthermore, thanks to the limited area demand, negative environmental effects can be minimised.

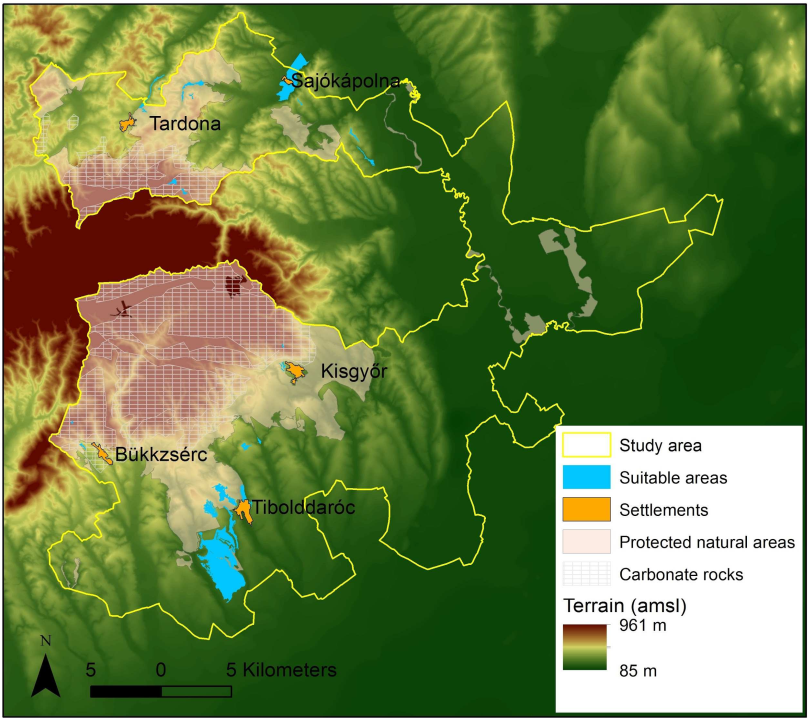

Figure 13 – Map of potential reservoir sites (<5°) for PHES in the Bükk LEADER rural development region
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3. Summary & conclusion

The whole energy system needs to be rethought and rebuilt at national, regional and local levels. In a *sustainable energy transition*, the different kind of decentralised energy production and storage applications seem to be significant parts of this profound development. According to this research, in the *Bükk LEADER rural development region* all the four of the examined technologies would be applicable; thus, contributing to the rural development, as well as energy autonomy of the area *(Figure 14)*.

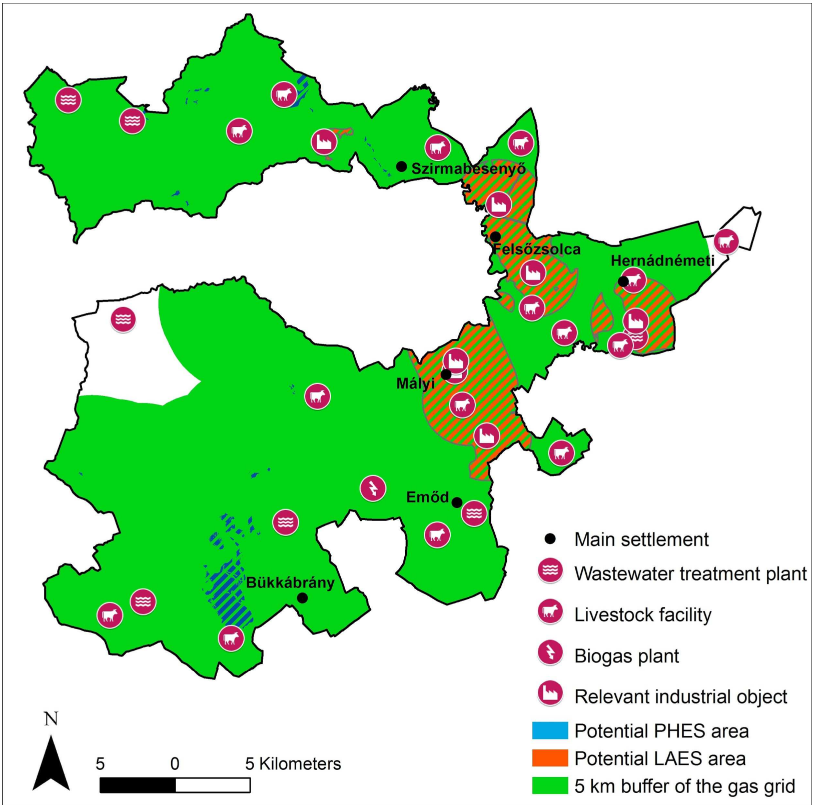

Figure 14 – Potential PHES, LAES and P2G facilities in the Bükk LEADER rural development region

Edited by HARMAT, *Á. (2016)*

As far as *underground geological formations* concerned P2G and CAES facilities have very similar technical parameters regarding strata, as storage media. However, implementing a P2G facility into a given geological formation could be more beneficial, due to higher energy density when storing hydrogen or methane comparing to storing compressed air. In such a situation, another reason to prefer P2G is the multifunctionality of its stored product (hydrogen, or synthetic natural gas), that can be used as fuel for turbines generating electricity, as fuel for transportation or it could straight be injected into the national gas grid.

Another possibility could be the conversion of *existing natural gas storage facilities* into CAES or P2G technology. As the composition of the stored gas is basically the same in the case of P2G (methane), this kind of conversion would be technically feasible. In the case of CAES systems, however, the storage media cannot contain any hydrocarbons so implementation of a CAES system into an existing natural gas storage system is both technically and financially challenging.

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