From irreversibility to sustainability linking energy storage, geo-ecology recovery and renewables

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Abstract:
Trying to find a way to make a turn from the current one-way irreversibility to sustainability, in addition to the uninterrupted R&D aimed to advance RES (Renewable Energy Sources) technologies it is necessary to find innovative ways of universal schemes, quantities, indicators and criteria relevant for the sustainable Earth resources utilization, environment protection and/or already damaged environment recovery. Interruptible availability and variable quality of most types of the RES requests energy storage. Large-scale RES utilization needs large-scale storage systems and large storage volumes. Worldwide, many abandoned mines (of coal or minerals) offer large storage volumes almost ready-made to be used directly for energy storage. Related technologies and a few case studies are reviewed.

Key words: renewable energy sources, sustanaible Earth

1. Introduction

As, fossil energy resources are closer to their exhaustion, global warming in raise, and more catastrophic weather extremes are occurring worldwide, there are more and more warnings that the risks to the Earth humanity survival are also in growth and the Earth/humanity as a whole is becoming more complex system than ever /1/. Trying to find a way to make a turn from the current oneway irreversibility to sustainability, in addition to the uninterrupted R&D aimed to advance RES (Renewable Energy Sources) technologies it is necessary to find innovative ways of universal schemes, quantities, indicators and criteria relevant for the sustainable Earth resources utilization, environment protection and/or already damaged environment recovery to reach humanity's resilience and sustainability.

Renewable energy sources (RES), particularly solar and wind, have significant potential for replacing fossil fuels and reduction of CO2 and other GHG emissions in all economies and societies areas of electrical and thermal energy demands in Serbia and Romania as well as in other countries worldwide. However, as both solar and wind energy availability and power intensity are strongly variable and intermittent, broader spreading larger amounts of their integration and dispatchable utilization in corresponding countries energy systems is still pretty far away from the earlier predictions and expectations. Consequently, there is crucial need to find reliable ways to increase reliability of these systems. In NREL (Oak Ridge) study /2/ did explore impact of energy storage on the large scale implementation of solar and wind energy in the electricity grid. Renewable energy sources, such as wind and solar, have vast potential to reduce dependence on fossil fuels and greenhouse gas emissions in the electric sector. Because their intermittency and variability there is increased challenge for the deployment of energy storage as an essential component of energy systems that should use at large scale these RR (Renewable Resources). An approach is to be found that can confirm maintenance of the required system reliability, including necessary technologies and changes in operational routines, as well as the cost-competitiveness benefits of the selected technology/ies. Report /2/ presents results of conducted evaluation of the potential role of several forms of enabling technologies for energy management, including energy storage in the electricity grid addressing especially effects of large-scale deployment of wind and solar energy. Beside high-energy batteries, study did encompass Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES) and Thermal Energy Storage.

2. Pumped Hydro, Compressed Air and Thermal Energy Storage

PHS Pumped hydro storage is the only energy storage technology deployed on a GW scale worldwide /2/. PHS is using conventional pumps and turbines and needs significant amount of land and water for necessary two reservoirs (the upper and lower).

PHS systems can achieve overall efficiencies abode 75%.

Environmental regulations may limit large-scale above- ground PHS systems. However, study /4/ includes also great alternative environmentally even friendly lower-impact configurations: natural or mined underground formations for the lower reservoir.

Underground pumped-storage hydro power plants with mine water in abandoned coal mines is topic addressed in /21/. The Asturian Central Coal Basin in northern Spain has been an exploited coal mining area for many decades and its network of tunnels extends among more than 30 mines according to /21/. Its infrastructure parts will soon become available for alternative uses since most of the underground coal mining facilities in Spain will fade out in 2018 (EU 2010/787/UE). The network of tunnels in closed-down mines has been suggested as a possible lower storage for the development of an underground pumped-storage project whose infrastructure can hold approximately 200,000 m^3 at depths that range between 300-600 m.

CAES technology is based on conventional gas turbine technology and uses the expansion potential energy of compressed air. Energy is stored by compressing air in an airtight space -underground storage cavern. As described in /2/ for extraction of the stored energy, compressed air is to be drawn from the storage vessel, heated, then expanded via high-pressure turbine that captures some of the compressed air energy and then mixed with fuel and combusted, with the exhaust expanded through a lowpressure gas turbine connected to an electrical generator. Main disadvantages of CAES are its reliance on fossil fuels and the need for an underground cavern (could be overcome if there is available closed mine. Some alternative configurations for CAES have been proposed: use of certain above-ground vessels, new turbine designs to reduce fossil fuel use, or heat recovery - use of the of compression heat and exclude need for fuel use.

Thermal energy storage (TES) stocks thermal energy by heating or cooling a storage medium and when necessary the stored energy can be used for heating and cooling applications and power generation (comprehensive review is given in /3/). TES is TES systems particularly those linked to heat pumps and their use of the Underground Thermal Energy (UTE) are used on large scale in buildings, neighborhoods, in industrial processes and district heating and cooling of cities. Technical schemes and principles of TES methods, design and construction as well as calculation of relevant TES capacities and dynamics are well known for both Sensible and Latent (associated with PCM (Phase-Change Materials) heat storage technologies and systems. These systems are in use in solar thermal and PV powered heat pump heating/cooling of buildings and sanitary water heating, diverse types of other heat-pump systems, concentrating solar power plants as well as thermo-chemical storage.

This short review of PHS, CAES and TES energy storage systems technologies, and by specific configurations outlined special needs, can help us to illuminate and recognize potential advantages of a energy/ecology/technologies/mix combining use of available underground spaces of closed old mines in the frame of prospective environmental rehabilitation in synergy with large scale RES utilization development and growth.

Naturally this conclusion is valid for regions reach on fossil and mineral resources and history of extensive and intensive mining and taken as an introductory conclusion it deserves our special attention and could be one of the crucial R&D and commercialization topics to achieve task – entitling this paper not only in Serbia and Romania but globally at-large.

3. Resources Exhaustion, Closing Mines and Ecological Rehabilitation Needs

Closing mines in Romania where mining is dating back to 100 years B.C.E (/5/,/6/) is focusing mainly mines of ores which over time became exhausted, and therefore become non-profitable to operate. As the best option for the State was determined to be their ecological rehabilitation and closure in accordance with responsibilities established by Romanian laws, and providing an assurance with the reference to the project sustainability to all stakeholders concerned. Based on this program more than 450 mines was planned to be closed in Romania over 10 years, with a financial provision of approximately US $400 million.

Study /7/ task was mapping and forming GIS databases of the mineral deposits and mining districts of Serbia. It was carried out within the joint project of a French Gov. aid and Republic of Serbia's Ministry of Mining and Energy. Study result are mineral deposits and mining districts databases constructed under Microsoft Access. Its "Ore deposit" database /7/ contains 199 records that include among other: geological data (typology, morphology, age and type of mineralization and host rock, mineralogical composition of the ore, gangue and hydrothermal alteration); economic data (mine status, type of development, former production, status of resources and reserves); data concerning environmental hazards likely to be generated by the deposit; a list of the deposits located within the district; the main primary and secondary ore minerals (commodities or substances) present, each annotated with an assessment of the contained metal weight so as to enable an evaluation of the district's economic importance, the age of the mineralization and host rocks; a comment on the potential environmental releases and damage associated with the relevant mining and mineral-processing industry; mineral deposits and mining districts of Serbia with the compilation map and GIS databases including Serbia's Kosovo-Metohija Pliocene Basin containing the largest exploitable reserves of lignite in Europe and also Serbian copper mining in the Timoc District and lead-zinc mines in the Kopaonik District. Moreover, in Serbia, this province appears to have been underexplored for gold, particularly with the availability of modern exploration tools and procedures suited to the country's geology and morphology.

Study /8/ done as joint Romanian and Serbian investigation addresses important topics and is to be shortly reviewed also. It analyzes the impacts of mining activities on sustainable land management in Serbian and Romanian mining areas focusing main challenges for the management related to legislation issues, particular their relevance to land disturbance, mine waste management and land reclamation, as well as access to land for purpose of mining, transfer of mining royalties and broader partnerships (mining industry, governments, communities, civil societies for sustainable mining, etc.). Although, both governments are willing to provide the adequate role to mining in strengthening the national economies, they face numerous constraints. Study final concluding statement in /8/ “Sustainable mining practices and consistent implementation of the mining for the closure planning approach, within an improved legislative framework and in cooperation with stakeholders at all levels, create conditions for the development of creative, profitable, environmentally-sound, socially-responsible management and reuse of mine lands”.

These documents (Romanian and Serbian) and plenty other, can provide a basis for founding, investigating, developing, promoting and aiding in the restructuring and development of a NEW Program RES integrated energy/mining/ecology sector to provide multidimensionally enhanced sustainable development approach.

4. Potential of Abandoned Mines for Energy Storage and Land Re-cultivation

Mining-energy-industrial system in Kosovo Basin (/9/, /13/) can serve as one case example of large lignite basin’s most important aspects of the structural changes caused by the mining exploitation: consumption of large areas of land, degradation of eco-systems; people migration and changes in the pattern of settlements/villages; potential high level of environment pollution (air, water, land and living species) from the industrial complex (/9/, /13/). Development of the Mining-energy-industrial system in Kosovo basin have accelerated the socio-economic transformations (urbanisation, deagrarisation) and caused the changes in the location and functions of town centers /13/. Finally, the surface mining exploitation and the building and functioning of thermal energy and other systems for coal processing represent a major structural change which requires unique and specific approaches to planning in large lignite basins.

Sustainable mining and consistent implementation of the mine closure planning approach require a developed mutual partnership of mining companies, spatial planners, investors, institutions and local communities to identify creative, profitable, environmentallysound and socially-responsible management and reuse of mine lands /8/.

Transnational and cross-border cooperation between countries in the Danube River Basin is extremely important /8/, bearing in mind the transnational risks of large mining environmental hotspots in both countries which need ecological rehabilitation (accident of the cyanide spill into the river Tisa from the gold mines in northern Romania in 2000) left behind long-term consequences for the ecosystems in Romania, Hungary and Serbia /8/.

On fig's is given map of Serbia with legend of main mines for energy, metallic and non-metallic mineral resources (Prof. Dr. S.Vujić, Mines Institute Belgrade).

Abandoned mines (where mining activities occurred, but acceptable mine closure/reclamation did not take place or was incomplete) contribute to the legacy of environmental degradation left by historic mining which occurred before mine closure regulations were founded. In Canada regulators have initiated various programs to assess and remediate the abandoned mines within their jurisdictions.

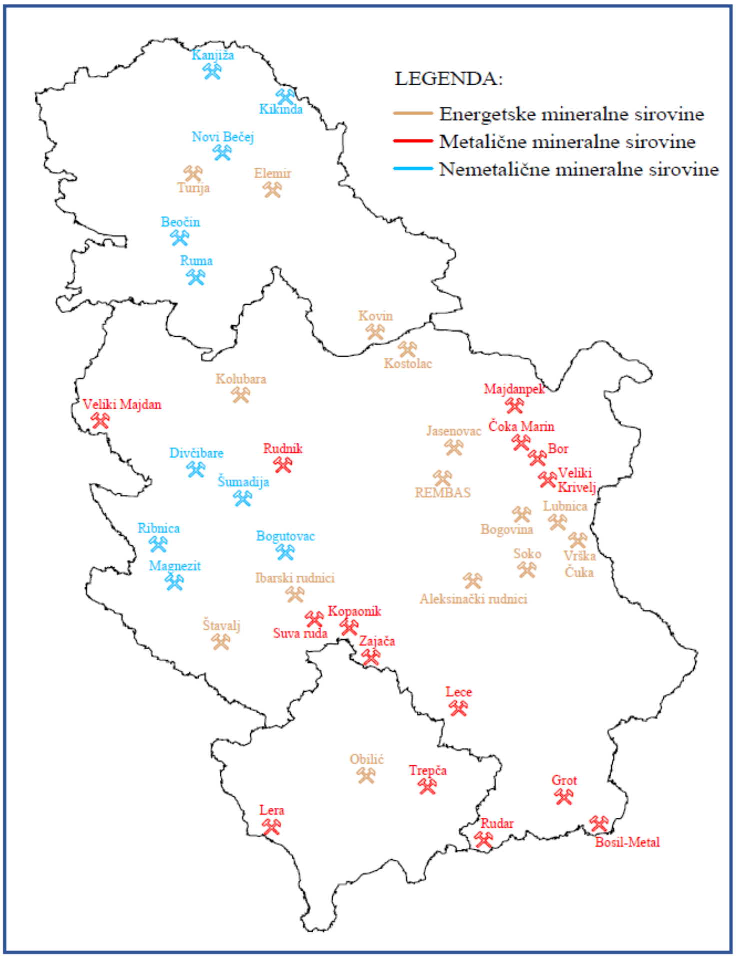


Fig.1. Energy, non-metallic and metallic mineral mines

Study /12/ presents the development of a WebGIS application aimed at providing safe and reliable data needed for recultivation of abandoned mines in national parks and other protected areas in Vojvodina in compliance with existing legal regulations. The WebGIS application was developed and is publicly available, based on an appropriate central database, which for the first time encompasses all available data on abandoned mines in Vojvodina, and as such may serve as a model for similar databases on the territory of the Republic of Serbia. The Cadastre of Abandoned Mines in the territory of AP Vojvodina which was presented in 2015, provides information about the state of 217 abandoned mines.

It is the first such project implemented in Serbia Paper entitled "Heat-Storage in Deep Hard Coal Mining Infrastructures" /19/ presents German project aimed to develop heat storing technologies in the subsurface infrastructure of hard coal mines. By end of 2018 the last productive deep hard coal mine in Germany - Prosper Haniel – in the Ruhr-Area will be closed down as the last one of more than hundred already closed coal mines in the industrial heart of Germany with more than 6 Mio inhabitants in area of 50 cities.

Due to the large mine area dimensions of tens of km^2 per mine, depths of max. 1.500m at rock temperatures up to 50°C the mines have the potential to become an enormous geothermal reservoir for seasonal heat storage. Paper presents fine review of project details: investigation of the technologies of thermal reuse of underground mines (open and closed loop geothermal extraction systems in coal mines), types of underground TES (UTES), technical criteria for the realization of seasonal heat storage in mine, identification and accessibility of adequate mining infrastructure, geometry and orientation of the storage, open- and closed-loop systems, adequate storage media, safety of the cross-section stability, tightness of the storage system, technical examination of the heat storage & exchanger systems materials, etc. Due to the large mine area dimensions of tens of km^2 per mine, depths of max. 1.500m at rock temperatures up to 50°C the mines have the potential to become an enormous geothermal reservoir for seasonal heat storage.

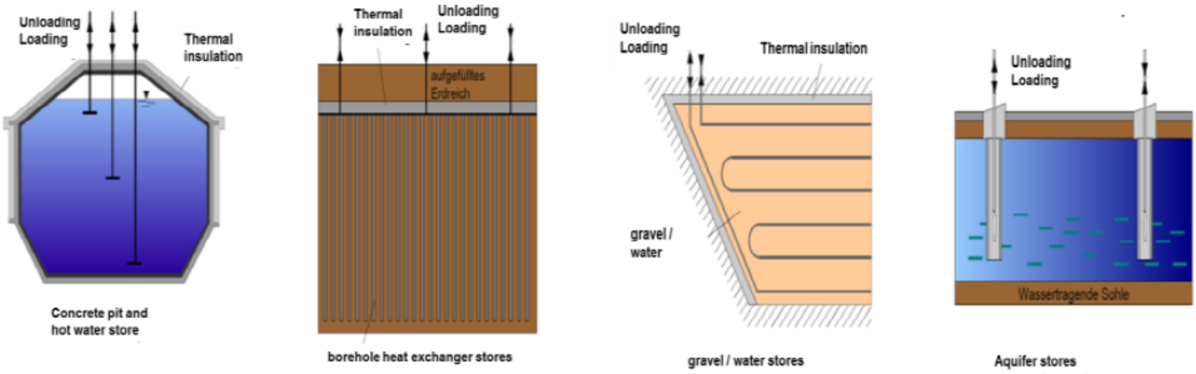


Fig.2. Underground thermal energy storage concepts

Paper presents further fine review of project details: investigation of the technologies of thermal reuse of underground mines (open and closed loop geothermal extraction systems in coal mines), types of underground TES (UTES), technical criteria for the realization of seasonal heat storage in mine, identification and accessibility of adequate mining infrastructure, geometry and orientation of the storage, open- and closed-loop systems, adequate storage media, safety of the cross-section stability, tightness of the storage system, technical examination of the heat storage & exchanger systems materials, etc.

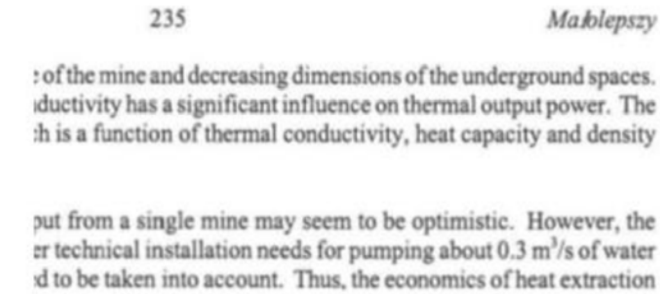
Canadian challenging experience in utilization of abandoned mine workings for TES started in 1989 /18/ when the Town of Springhill created an industrial park and offered to companies to tap into the geothermal energy supply from the local abandoned coal mines. The mines are estimated to have an energy potential in excess of 67,000 MWh/yr, and a study of former gold mines in Timmins found that the mines had a potential energy resource of at least 28,000 MWh/yr /18/. A simple methodology for the Geothermal Energy Potential of Abandoned Underground Coal Mines is given in /20/.

Zbigniew Malolepszy and group of authors in papers (/11/, /14/, /22/) presented reach Polish experience in: geothermal resources of former coal mine Nowa Ruda, low temperature man made geothermal reservoirs in abandoned workings of unuderground mines and modelling of geothermal resources within abandoned coal mines.

Study /10/ reviews factors affecting the feasibility of geothermal systems on mining projects and has identified the possible configurations of geothermal systems suitable for the exploration, operational and closure phases of mine development. The geothermal opportunities associated with abandoned or legacy mines are also discussed, as well as the potential categories of heat reservoirs associated with mine sites: natural ground; backfilled workings; mine waste; dewatering pumping; and flooded workings/pit lakes.

Flooded coal mine in the Upper Silesian coal basin constitutes a reservoir of low enthalpy geothermal water at a temperature of 20·S0°C, depending on depth. In order to extract and utilize the heat stored in the reservoir, the water must be drawn from the mine.

After the heat has been extracted the water must then be reinjected into the reservoir because of its high mineral content. Another method is to extract the heat energy by a system of loop heat exchangers installed within the mine itself /14/.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: of the mine and decreasing dimensions of the underground spaces.
ıductivity has a significant influence on thermal output power. The
:h is a function of thermal conductivity, heat capacity and density

put from a single mine may seem to be optimistic. However, the
er technical installation needs for pumping about 0.3 m³/s of water
d to be taken into account. Thus, the economics of heat extraction

Fig. 3. Three simplified schemes for the extraction of geothermal energy from abandoned coal mine /14/

5. Cavern Storage And More Construction Details On The Abandoned Mines Utilization

Till now, very little use has been made of the energy store that relies on large caverns in the rock which are suitable for storing water at high temperature (40 to 90°C). Construction of such caverns is relatively expensive if it is not possible to convert already existing caverns (e.g. used for oil storage). Main problems are heat losses caused by circulation of the warm water in fissures located outside the storage cavern.

As a rule, abandoned mines fill up with water which can also be used for thermal energy storage. In contrast to the cavern stores the geometry is not optimized towards achieving a small surface area, as mines are characterized mostly as widely branching systems of tunnels/galleries. Consequently, mines are suited best for TES close to the natural ambient temperature of the subsurface (examples are from Canada). Higher-temperature TES can be constructed in deeper mines with related higher rock temperatures. Attention deserve also near-natural underground thermal energy storage systems that constitute a hybrid form between a natural UTES system and an artificially constructed store.

Fundamental structural principle is important in these types of thermal stores, as the subsurface is not directly used to store heat; instead, the storage medium consists of a mixture of gravel or earth and water. The storage systems can consist of a pit that has been sealed by suitable means and that is filled with the storage medium.

It is advantageous that, compared with a pure water storage system, no load-bearing roof-structure is required, and this keeps the construction costs down. As a rule the stores are thermally insulated laterally and at the top, sometimes also at the bottom, depending on the volume and depth of the store. The insulation material must possess adequate compressive strength for this application.

Thermal energy is generally charged into the store and withdrawn from it again indirectly via embedded plastic pipe loops.

Therefore, it is also possible to use as the heat transfer medium mixtures of anti-freeze which permit operation below 0 ° C. In addition to storing heat at a high temperature level, it is thus also possible to operate the system in combined heat and cold storage mode, using a heat pump.

6. Instead Of Conclusions – Old Cole Mines Can Be Part of Green Energy Future

German government's ambitious goal is to transform their energy landscape over the next few decades: by 2025 to have 35-40% of electricity to come from RES; by 2035 55-60%, and by 2050 to hit at least 80% RES, coupled with an overall reduction in energy consumption of 25% (compared to 2008). To realize these goals a huge investment in wind and solar energy generation is necessary, as well as a step up in their use of hydropower, as well as improvement of overall efficiency of natural gas power plants.

Early signs are encouraging, particularly in terms of their energy mix (in 2015, RES reached 32.5% of Germany's total electricity demand. It was reported in Quartz at the time, that there was too much electricity available, "Power prices actually went negative for several hours, meaning commercial customers were being paid to consume electricity". As China now is taking a leading role in the fight against climate change, the prices of renewables are likely to drop further.

The main argument laid against renewable energy generation is that it is often intermittent and this doesn't really match with way the traditional electricity grid operates. To have balance between the supply and demand, and keep distribution system stable, when RES technologies enter into the grid, the only real option is to store the energy when it's produced, and then send it back to the grid when it's needed. And it is energy storage that old coal and mines could play a major role.

As final comments can be outlined: as fossil energy resources are closer to their exhaustion, global warming in raise, and more catastrophic weather extremes are occurring worldwide, there are more and more warnings that the risks to the Earth humanity survival are also in growth. The Earth/humanity as a whole is becoming more complex system than ever. Trying to find a way to make a turn from the current one-way irreversibility to sustainability, in addition to the uninterrupted R&D aimed to advance RES (Renewable Energy Sources) technologies it is necessary to find innovative ways of universal schemes, quantities, indicators and criteria relevant for the sustainable Earth resources utilization, environment protection and/or already damaged environment recovery) to reach humanity's resilience and sustainability. Availability of most types of RES is interruptible and of variable intensity. Therefore, energy storage is important for the large-scale utilization of RES, and large-scale storage systems require large storage volumes. Worldwide, many abandoned mines (of coal or minerals) offer large storage volumes almost readymade to be used directly for energy storage.

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