



## INTEGRATED ENERGY PRODUCTION AND STORAGE USING CAES IN ENGINEERED CONCRETE CAVERNS WITHIN SURFACE LIGNITE QUARRIES

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**Abstract:** *This work presents an integrated energy production and storage system based on Compressed Air Energy Storage (CAES), implemented within a surface lignite quarry. The proposed approach enables the reintegration of closed, degraded, or closed mining areas into the economic circuit while supporting environmental restoration, including the conservation of local flora and fauna. The concept capitalizes unused quarry surfaces and tailings dumps by installing photovoltaic panels on these deposits. In addition, artificial underground caverns are created at the quarry face using ecological concrete and segmented linings made of prefabricated reinforced concrete rings, designed for compressed air storage. In Romania, existing CAES initiatives are limited, mainly consisting of small-scale projects of up to 1 MWh, alongside a larger proposed project of approximately 300 MWh using external vessels, often associated with long investment payback periods. This study proposes a scalable alternative by integrating renewable energy generation with large-scale storage directly within lignite quarry perimeters. The system aims to achieve an estimated annual energy production of approximately 100 GWh per cavern, offering both economic and environmental benefits.*

**Keywords:** *lignite surface quarries, CAES, ecological concrete caverns, energy production, energy storage, environmental benefits*

### 1. Introduction

The proposed energy production and storage framework utilizes Compressed Air Energy Storage (CAES) technology implemented within decommissioned or preserved lignite open-pit mines. This approach aims to reintegrate degraded post-mining landscapes into the regional economic circuit or dedicate them to ecological conservation, specifically for local flora and fauna. To achieve this, the system capitalizes on the unexploited spatial potential of the remaining quarry faces and associated internal waste tailings dumps. Specifically, large-scale photovoltaic (PV) arrays are deployed across the stabilized tailings deposits, while artificial storage caverns are engineered directly within the unexploited quarry faces. These caverns are constructed using ecological concrete [1] and feature a segmented lining system composed of prefabricated reinforced concrete rings [2]. Conventional Compressed Air Energy Storage (CAES) systems are inherently limited by geographical constraints, as they traditionally rely on naturally occurring salt caverns or depleted gas fields. To overcome these spatial limitations, this paper proposes an innovative approach: the integration of CAES within engineered reinforced concrete caverns constructed inside depleted surface lignite quarries. The novelty of this configuration lies in its dual-benefit paradigm; it eliminates geographical dependency while simultaneously repurpose abandoned mining infrastructures, thereby mitigating post-mining environmental impacts. By utilizing excavated surface mine profiles, the proposed method offers a scalable, modular solution

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for large-scale energy storage, facilitating the seamless integration of intermittent renewable energy sources into the grid.

A representative candidate site for this post-mining transformation is the Tismana Quarry, along with its internal waste dumps. Located within the administrative jurisdiction of Călnic commune, Gorj County, Romania, this facility belongs to the Roșia Rovinari Open-Pit Mining Operation (E.M.C. Roșia Rovinari). Currently, the development of two major photovoltaic parks with planned installed capacities of approximately 115 MW and 118 MW, respectively, is envisioned for this perimeter [3]. As illustrated in Fig. 1, the designated development areas are categorized into Zone A (comprising the active quarry exploitation front and stabilized waste dumps), which is allocated for both the segmented-lined cavern configuration and the PV installations, and Zone B (representing the sector that has not yet been fully exploited). Generally, Compressed Air Energy Storage (CAES), where high-pressure air is contained in underground geological or engineered structures, represents a well-established and environmentally benign storage pathway. To date, it remains the only technically mature option for large-scale, long-duration bulk energy storage, alongside pumped hydro storage utilized in conventional hydroelectric plants [4].



Fig. 1. The exploitation zones A and B within the administrative territory of Călnic commune, Gorj, Romania

At present, numerous CAES-based storage methods are known, especially in the form of small-scale projects in Romania. One example is the system developed within the Popeci Heavy Equipment Plant in Craiova [5], [6], with a capacity of 0.1 MWp (MegaWatt peak), using a 50 m<sup>3</sup> storage vessel at a storage pressure of 25 bar (abs) and with a maximum operating time of 20 minutes. Additional energy storage and production initiatives are also known through Siemens, which offers solutions of up to 300 MWh using external storage vessels [7]. However, such equipment is extremely costly and involves long payback periods.

Globally, only three large-scale utility-operated CAES plants are currently functional: the McIntosh plant in Alabama, USA (110 MW, 2,860 MWh), the Huntorf plant in Germany (290 MW, 580 MWh) [8], and a recently commissioned advanced non-supplemental CAES system in China featuring an external storage capacity of 1,500 MWh [9]. Furthermore, large-scale storage projects under development include a 1,200 MWh salt cavern project in Utah, USA (with a physical volume of 1,161,000 m<sup>3</sup>), and the Corre Energy–Eneco joint venture in Ahaus, Germany, designed to provide 320 MWh of storage capacity [10]. Both international pipeline projects rely strictly on deep salt formations, underscoring the innovative nature of the engineered surface-cavern approach proposed in this study.

## 2. Description of work

The primary advantage of the proposed configuration lies in its ability to return decommissioned lignite quarry perimeters to the economic cycle through industrial-scale electrical energy production and grid-balancing services. By applying advanced geomechanical stabilization techniques, the waste tailings dumps can be safely utilized as structural foundations for solar arrays without the risk of landslide or structural collapse. Additionally, the available open-pit spaces and exploitation fronts are capitalized on (see Fig. 2) for

the construction of engineered, concrete-lined caverns. These caverns enable the safe containment of compressed air at pressures up to 50 bar (abs), which is sufficient to balance peak grid loads and smooth out the intermittent generation profiles of the co-located photovoltaic parks during non-operational periods (e.g., nighttime or overcast weather).

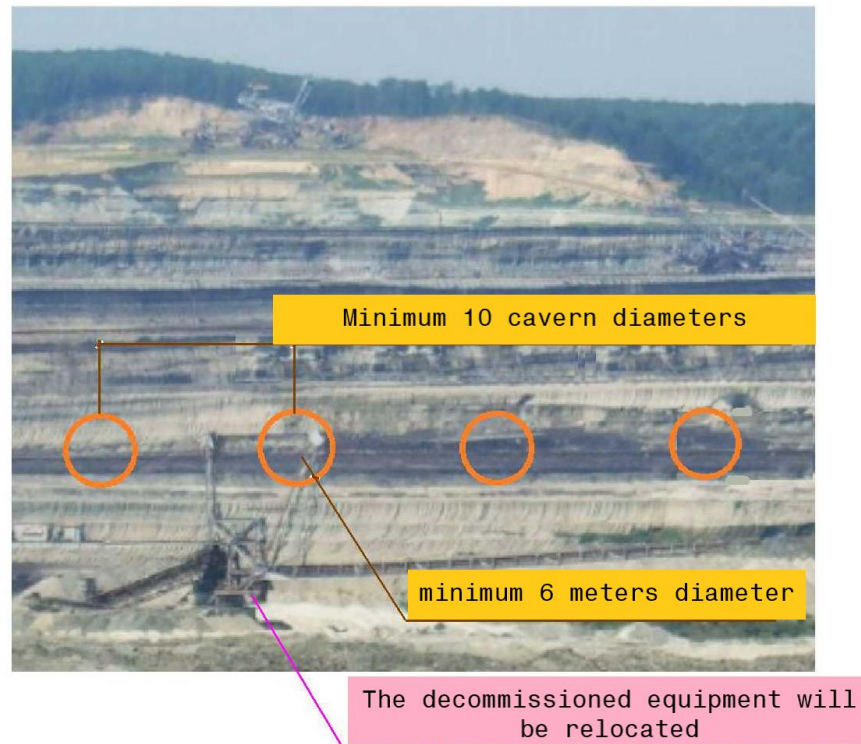


Fig. 2. The exploitation front and the ipotetical caverns

To ensure the technical, thermodynamic, and structural feasibility of this system, the following main assumptions and design paradigms are established:

- **Geomechanical and Structural Assumption:** Unlike conventional CAES systems developed in stable, self-supporting salt formations [11, 12], the surrounding strata in surface lignite quarries consist of highly fragmentable sedimentary rock formations. Therefore, the rock mass alone cannot withstand high internal tensile stresses. It is assumed that an engineered multi-layer lining system is mandatory to transfer internal pressure loads uniformly to the surrounding backfilled and compacted soil, which provides stabilizing passive lateral pressure.
- **Pressure Containment and Impermeability:** It is assumed that cyclic pressure fatigue over a 30-year operational lifespan can be mitigated by utilizing a multi-barrier lining system. This system includes a structural layer of reinforced ecological concrete combined with prefabricated high-strength concrete segments, supplemented by inner polymer or steel membranes to completely prevent air leakage through micro-cracks.
- **Thermodynamic Modeling:** The compression and expansion processes are assumed to follow real-gas polytropic behavior. Advanced thermal energy storage (TES) integration is assumed to limit the maximum air injection temperature into the cavern to 35°C, thereby safeguarding the structural integrity of the concrete linings against thermal stress.

As illustrated in Fig. 3a, the construction of the segmented-lined cavern (C) utilizes a combination of ecological concrete and reinforced concrete segmental lining techniques. A dedicated layer of reinforced ecological concrete (3) is cast to provide the necessary structural resistance against the internal tensile forces exerted by the compressed air. This backing layer is completed prior to assembling the high-strength reinforced concrete segments (5). The segments are joined using a staggered zig-zag configuration (see Fig. 3b) [13, 14], with high-durability elastomeric insulating filler elements (7) applied at both the horizontal and vertical joints (6). To prevent structural degradation and fluid migration, the design incorporates external and internal impermeable insulation layers (2 and 8), alongside an intermediate impermeable membrane (4) positioned between the ecological concrete layer (3) and the structural segments (5). Groundwater or seepage accumulation is actively managed via an integrated drainage system (9).

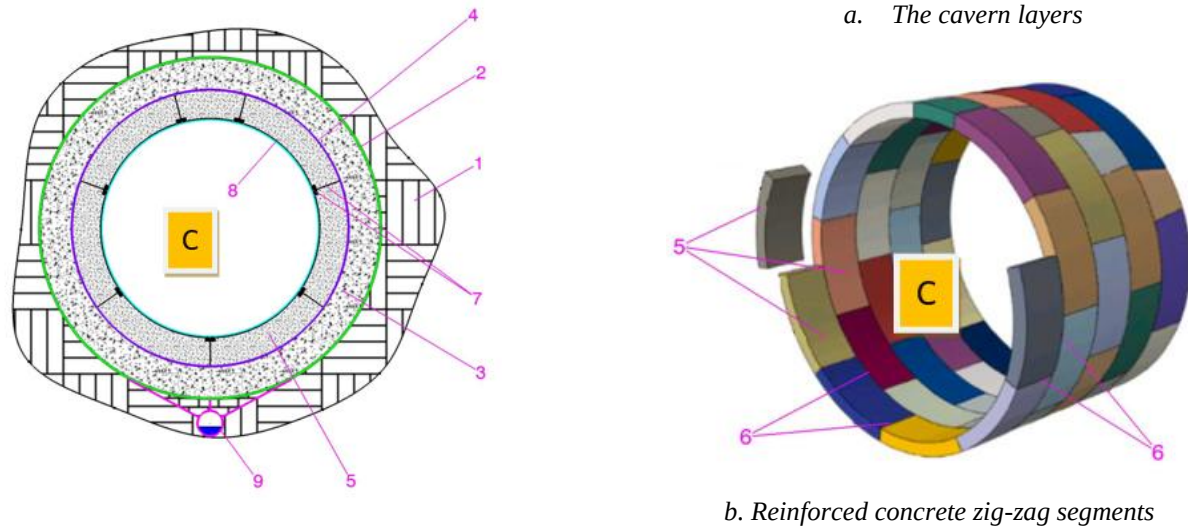


Fig. 3. The concrete lining cavern construction

A further example of the paper is presented below, in connection with Figure 4, which schematically illustrates the electrical energy production and storage system based on CAES technology using closed (preserved) lignite quarries.

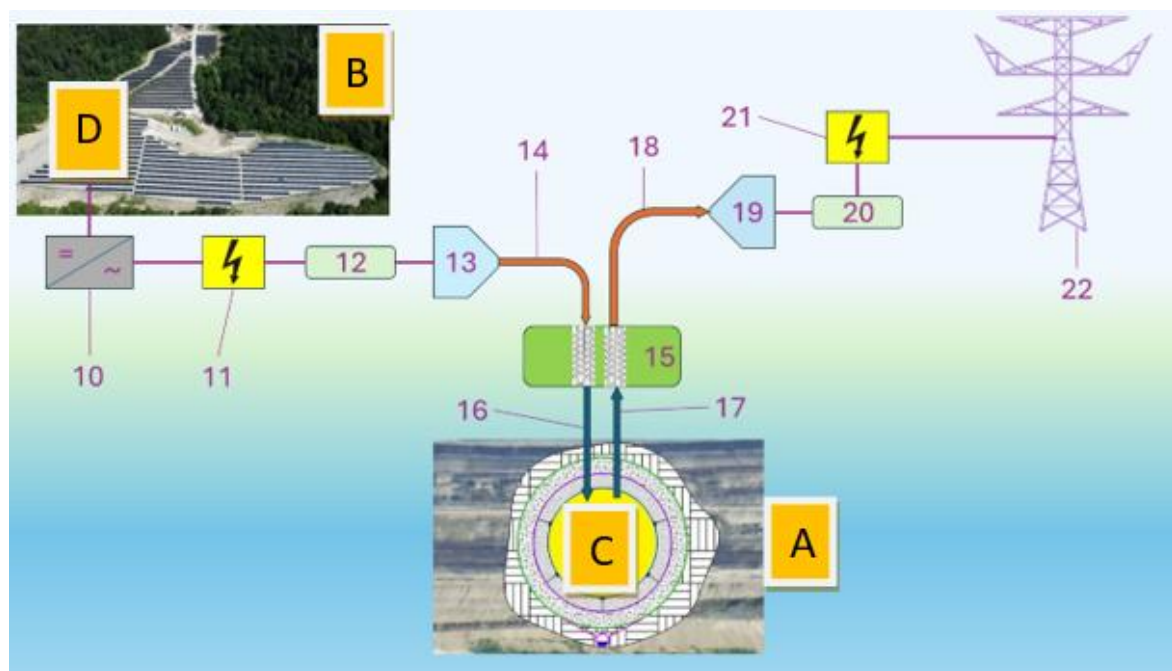


Fig. 4. The concrete lining cavern. a. b.

Within the engineered, segmented-lined concrete cavern (C), constructed along the exploitation front (A) of the preserved open-pit mine, compressed air is injected at high volumetric flow rates utilizing a multi-stage compression system (13). This compressor (13) is driven by an electric motor (12), which draws its electrical energy from the co-located photovoltaic (PV) array (D) deployed on the stabilized tailings dumps across Zones A and B. The direct current (DC) power generated by the PV arrays in Zone B is converted to alternating current (AC) via an inverter (10) and subsequently stepped up or adapted by a transformer (11) before being transmitted to the electric motor (12). During the charging phase, the compressed air is routed through a primary pipeline (14) into an intermediate thermal energy storage heat exchanger (15). This subsystem captures and stores the heat of compression, allowing it to be recovered for air reheating prior to the expansion phase. From the heat exchanger (15), the cooled compressed air is channeled into cavern C at a maximum controlled temperature of 35°C. Through convective thermal exchange with the engineered cavern walls, the internal air temperature stabilizes at a ground-ambient average of approximately 10–15°C under peak full-charge conditions, corresponding to a maximum operational pressure of 50 bar (abs).

The discharge and power generation process is initiated by releasing the compressed air from cavern C through an extraction pipeline (17) back into the heat exchanger (15). Here, the high-pressure air recovers the stored thermal energy previously extracted during the compression phase. Once appropriately reheated to maximize thermodynamic efficiency, the air enters the power turbine (19) via pipeline (18), where it expands down to atmospheric pressure. This expansion process drives an electrical generator (20) to produce electrical energy, which is then adapted by a step-up transformer (21) to meet the voltage requirements for seamless transmission into the regional electrical grid (22).

The compression unit (13) generally consists of a multi-stage centrifugal configuration designed to elevate the air pressure from ambient atmospheric levels up to the maximum cavern storage pressure. The system operates at a nominal volumetric flow rate of approximately 15,000 Nm<sup>3</sup>/h, which corresponds to an air mass flow rate of 5.0 kg/s [15]. For an engineered cavern volume (*V*) of approximately 30,000 m<sup>3</sup>, the total mass of the contained air at 50 bar and 15°C is approximately 1,800 tons. Neglecting the compressibility factor at moderate pressures, this storage capacity is quantified using the ideal gas equation of state:

$$M_s = \frac{P_s \cdot V_s}{R \cdot T_s} \quad (1)$$

where:  $P_s = 50 \cdot 10^5$  Pa is the storage pressure,  $R = 287$  J/(kg·K) is the specific gas constant for air [16],  $T_s = 288$  K is the storage temperature.

For a preliminary estimation of the stored energy capacity, the power turbine expansion subsystem (19) is modeled with a nominal capacity of 4 MW. In practice, this configuration may comprise a cluster of modular, smaller turbines arranged in a series-parallel network; to ensure high operational flexibility and partial-load economic efficiency, each individual turbine unit is assumed to have a minimum power rating of 1 MW. Under nominal design conditions, the turbine inlet pressure is set to a baseline threshold of 16 bar (abs), acknowledging that higher operational inlet pressures remain technically feasible depending on the optimization strategy. The expansion subsystem operates at a design air mass flow rate of 10.0 kg/s, which corresponds to a volumetric circulation rate of approximately 30,000 Nm<sup>3</sup>/h based on specialized manufacturer design parameters for high-pressure air expanders [17]. Consequently, during the generation cycle, a constant air mass of 10.0 kg is extracted each second, systematically depleting the total inventory contained within cavern C.

As the cumulative air mass inside the storage volume drops, the instantaneous cavern pressure undergoes a corresponding transient decrease. This thermodynamic depletion process is governed by the following relation:

$$P_{s\_intermediar} = \frac{(M_s - 10.0) \cdot R \cdot T_s}{V_s} \quad (2)$$

Until the final pressure of 16 bar (abs), at which turbine 19 can still operate, the total operating time is 34.0 hours, determined by:

$$H_f = \frac{P_s - 16 \cdot 10^5}{P_s - P_{s\_intermediar}} / 3600 \quad (3)$$

Thus, the total possible stored energy is:

$$E_{tpi} = P_t \cdot H_f = 136 \text{ MWh} \quad (4)$$

or 99.3 GWh/year, where  $P_t = 4$  MW represents turbine power.

To achieve higher fidelity, a more precise transient thermodynamic calculation must be performed iteratively, explicitly accounting for the temperature drop inside cavern C induced by rapid air expansion during the extraction phase. Consequently, thermal integration via the heat exchanger (15) is critical to reheat the high-pressure air before it enters the power turbine (19). This thermal management strategy ensures that the turbine inlet and exhaust temperatures remain strictly above the pressure dew point, which is generally established at a maximum threshold of 3°C [18]. Maintaining temperatures above this baseline prevents condensed water droplet formation inside the turbine (19), thereby avoiding severe blade erosion and preserving its operational lifespan.

From a spatial and economic perspective, the southern face of a typical waste tailings dump features an average available surface area of approximately 50,000 m<sup>2</sup>. For a medium-sized tailings deposit constructed using standardized dumping techniques [19, 20]—with representative dimensions of 420 m in length, 210 m in width, and 120 m in height—the electrical energy production potential is estimated at approximately 7.7 GWh/year via integrated photovoltaic (PV) arrays. When accounting for both the inclined southern face and the flat upper surface of the dump, the feasible installed capacity reaches approximately 5.4 MW.

To validate these generation estimates against empirical regional data, Table 1 outlines the technical capacities and historical energy outputs of several prominent operational photovoltaic power plants (PVPP) in Romania relative to their land footprint. Commissioned primarily in 2013 during the foundational phase of Romania's solar energy sector, these legacy facilities demonstrate the long-term operational viability and strategic necessity of commercial-scale renewable infrastructure. Additionally, a comprehensive baseline reference and structural ranking of the top 21 largest domestic photovoltaic installations can be found in [21]. To facilitate scalable design metrics for post-mining reclamation, the average power density (MW/ha) and specific annual energy yield (GWh/y/ha) per unit of installed surface area have been derived from these operational datasets (see Table 1).

Table 1. Table name / description, TNR italic 10p

| Location                                     | Installed power | Energy produced | Installed surface | No. of photovoltaic panels |
|----------------------------------------------|-----------------|-----------------|-------------------|----------------------------|
| CEF Ciuperceni, jud. Satu Mare               | 56 MW           | 67 GWh/y        | 135 ha            | 230,000                    |
| CEF Izvoarele, jud. Giurgiu                  | 42.5 MW         | 70 GWh/y        | 125 ha            | 215,000                    |
| CEF Slobozia, jud. Giurgiu                   | 38 MW           | 60 GWh/y        | 113 ha            | 180,000                    |
| CEF Ucea de Sus Solar Park, jud. Braşov [22] | 55 MW           | 77 GWh/y        | 112 ha            | 222,000                    |
| CEF XPV Miercurea Sibiului, jud. Sibiu [23]  | 23 MW           | 30 GWh/y        | 59 ha             | 105,000                    |
| T1 [MW/ha]                                   |                 | 0.34...0.49     |                   |                            |
| T2 [GWh/y]                                   |                 | 0.61...0.83     |                   |                            |
| T3 [no. of photovoltaic panels/ha]           |                 | 1600...2000     |                   |                            |

Taking as reference the Tismana Quarry in Călnic commune, Gorj County, the associated land surface area of the quarry is  $S = 3,304,998.00 \text{ m}^2$  ( $S_1 = 1,682,878.00 \text{ m}^2 + S_2 = 1,622,120.00 \text{ m}^2$ ), according to the Zonal Urban Plan (PUZ) registered with the Gorj Environmental Protection Agency [24]. Assuming that two such waste dumps are formed through dumping operations according to the data above, the resulting total available surface area is:

$$S_{tta} = (S_1 + S_2) \cdot \zeta \cdot \varepsilon = 506.5 \text{ ha} \quad (5)$$

on which photovoltaic panels can still be installed, where  $\zeta = 95.78$  represents the utilization factor accounting for roads, buildings, auxiliary structures, etc., and  $\varepsilon = 1.6$  represents the surface multiplication factor relative to the ground area  $S$ . The total theoretical available energy is:

$$E_{tta} = S_{tta} \cdot \frac{T_1}{T_2} = 207.5 \dots 406.9 \text{ GWh/year} \quad (6)$$

or an installed capacity of approximately 172...248 MW, which demonstrates that the requirement of 115 (132) + 118 (128) = 233 (280) MW installed capacity is feasible for the two photovoltaic parks planned by E.M.C. Roşia Rovinari [25].

It should be noted that the empirical data compiled in Table 1 reflects the technological baseline of 2013; however, commercial photovoltaic panel efficiency has continuously improved since that period. Consequently, the contemporary required total surface area and the corresponding number of PV modules can be estimated more conservatively by applying the specific baseline density parameter  $T_3$  derived from Table 1. From a techno-economic scaling perspective, an engineered cavern featuring an internal diameter of 6 m and a total length of 1,000 m (1 km) yields a physical storage volume of approximately 30,000 m<sup>3</sup>. Operating at a peak compressed air storage pressure of 50 bar (abs), this single-cavern configuration provides a nominal single-cycle capacity of approximately 140 MWh of electrical energy. Assuming a standard peak-shaving operational regime with an average discharge period of 2 hours per day, the annual energy throughput reaches approximately 100 GWh/year per cavern. Extending this modular configuration to a cluster of four identical engineered caverns scales the total storage capacity to approximately 560 MWh, equivalent to an annual grid-injection potential of roughly 400 GWh/year. This bulk energy volume can be systematically dispatched back into the electrical grid via multi-stage expander turbines coupled with appropriately rated synchronous generators, dynamically adapting to high-demand peak intervals within the power system.

### 3. Conclusions

This paper successfully demonstrates the technical and economic feasibility of an innovative, integrated renewable generation and bulk energy storage framework. By utilizing advanced geomechanical stabilization, cleaning, and leveling techniques, decommissioned surface lignite quarries and internal waste tailings dumps

can be safely transformed into structural foundations for large-scale photovoltaic power plants (PVPPs). Financially, the deployment of these solar arrays is highly viable, aligning directly with strategic international mechanisms such as the European Union's Modernisation Fund, which accelerates the transition toward climate neutrality and supports energy sector modernization under the European Green Deal guidelines, targeting commissioning targets as early as 2026 [26].

The integration of a single engineered, segmented-lined concrete cavern (C) delivers a storage capacity capable of returning at least 25% of the total co-located PV park energy back to the grid during peak intervals. This integrated setup effectively mitigates the inherent intermittency of solar energy, enhances grid stability through peak-load regulation, and drastically reduces regional reliance on carbon-intensive fossil fuels [27].

To address critical comparative metrics within contemporary energy storage literature, the proposed engineered concrete cavern configuration offers distinct paradigms over conventional Compressed Air Energy Storage (CAES) implementations:

- **Elimination of Geographical Constraints:** Unlike legacy utility-scale installations - such as the Huntorf plant in Germany or the McIntosh plant in the USA, which are strictly dependent on naturally occurring, deep salt dome formations [8] - the proposed solution can be dynamically replicated across any post-mining landscape regardless of local deep geological traits.
- **Cost-Effective Scaling vs. Surface Vessels:** Compared to modular commercial alternatives utilizing high-pressure external steel vessels (e.g., configurations proposed by Siemens or deployed in recent Chinese pilots [7, 9]), which suffer from prohibitive capital expenditures (CAPEX) and prolonged investment payback periods, this design exploits pre-existing open-pit mine profiles and cost-efficient ecological concrete linings to deliver a structurally sound, economically superior bulk volume of 30,000 m<sup>3</sup>.
- **Circular Economy and Environmental Synergies:** Beyond pure energy dispatch, the proposed system introduces a dual-benefit environmental paradigm by directly accelerating the ecological reclamation of degraded landscapes, ensuring biodiversity conservation, and establishing a scalable blueprint applicable to all closed or preserved surface mining perimeters globally.

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## References

- [1] \* \* \*, 2026  
*Ce este betonul ecologic. Berdia*. Available online: <https://berdia.ro/utilizarea-betonului-ecologic-in-constructia-de-locuinte-noi/#ce-este-betonul-ecologic>. Accessed 01.05.2026
- [2] \* \* \*, 2025  
*Normativ pentru proiectarea și execuția căptușelilor prefabricate la tuneluri executate cu scutul (Normative for the design, execution of prefabricated linings for tunnels executed with shield)-indicativ NP 105-04. Monitorul Oficial al României, nr. 446 bis, 26 mai 2005* Available online: <https://www.mdpla.ro/uploads/articole/attachments/651132cd6d9d7694053274.pdf#:~:text=446%20bis/26.V.2005.%20NORMATIV.%20Cap.1%20pentru%20proiectarea%20%C5%9Fi,tuneluri%20executate%20cu%20scutul%2C%20indicativ%20NP%20105%2D04>, Accessed 02.05.2026
- [3] \* \* \*, 2024  
*Raport anual de evaluare a activității Directoratului Societății Complexul Energetic Oltenia S.A.* Available online: <https://energie.gov.ro/wp-content/uploads/>, 2024
- [4] \* \* \*, 2026  
*Compressed Air Energy Storage (CAES)*. UN Climate Technology Centre, Network (CTCN). Available online: <https://www.ctc-n.org/technologies/compressed-air-energy-storage-caes>. Accessed 01.05.2026
- [5] \* \* \*, 2014  
*Tehnologie inovativă de stocare a energiei prin utilizarea de compresoare și expandere cu șurub*, COMOTI. Available online: <https://comoti.ro/proiecte/3-participarea-la-programe-nationale/poc--2020/rocaes/>. Accessed 02.05.2026
- [6] Vlăduță I., Tomescu S., Ionescu M.D., Nedelcu R., Popescu S., Ilie I., 2020  
*Research Activity in Air, Other Gases Compression, Energy Storage*, WEC Central, Eastern Europe Regional Energy Forum – F.O.R.E.N., 2020 7, 1, pp. 40-50 (2021), ISSN 2668-7003, ISSN-L 2457-5011, DOI: 10.37410/EMERG.2021.1.03

- [7] \* \* \*, 2024  
*Sisteme A-CAES, A-CAESS, D-CAES. Siemens Energy*. Available online: [https://p3.aprimocdn.net/siemensenergy/c5b3433e-d9f4-47f1-8229-b1ea00d7f8bc/CAES-one-pager\\_09-, 2024-pdf\\_Original%20file.pdf](https://p3.aprimocdn.net/siemensenergy/c5b3433e-d9f4-47f1-8229-b1ea00d7f8bc/CAES-one-pager_09-, 2024-pdf_Original%20file.pdf), Accessed 01.05.2026
- [8] \* \* \*, 2026  
*Electricitate și stocare a energiei*. DS New Energy. Available online: <https://ro.dsisolar.com/info/electricity-and-energy-storage-80681847.html>. Accessed 01.05.2026
- [9] \* \* \*, 2024  
Redacția PiataAuto.md, *China a inaugurat cea mai mare centrală de stocare a energiei pe bază de aer comprimat*. Available online: <https://piataauto.md/Stiri/2024/04/China-construit-cea-mai-mare-centrala-din-lume-stocare-electricitate-aer-comprinat-mai-ieftin-decat-hidrocentrala-pompare-dar-randament-mai-mic/>, Accessed 02.05.2026
- [10] **Martijn I., de Kuijer C.**, 2026  
*Welcome to a new kind of energy storage (CAES)*. Newsletter: The Future of Transportation. Linkedin. Available online: <https://www.linkedin.com/pulse/welcome-new-kind-energy-storage-caes-martyn-de-kuyer-hvryc/>. Accessed 01.05.2026
- [11] **Popescu S., Radu S.M., Vilceanu F., Dinescu S.**, 2022  
*Research on the Setting of Maximum Pressure in Salt Caverns Intended for CO2 Storage*, MATEC Web Conf. 373, Available online: <https://doi.org/10.1051/mateconf/202237300066>, Accessed 01.05.2026
- [12] **Popescu S., Radu S.M., Dinescu S., Vlăduță I., Obreja A.M.**, 2024  
*A New Research Approach Regarding the Storage of Different Gaseous Products Under Pressure in The Eligible Romanian Salt Caverns*, MATEC Web Conf. 389, Available online: <https://doi.org/10.1051/mateconf/202438900073>, Accessed 01.05.2026
- [13] **Guan Z., Deng T., Wang G., Jiang Y.**, 2015  
*Studies on the key parameters in segmental lining design*, Journal of Rock Mechanics, Geotechnical Engineering 7, pp. 674-683, <https://doi.org/10.1016/j.jrmge.2015.08.008>, Accessed 02.05.2026, <https://doi.org/10.1016/j.jrmge.2015.08.008>
- [14] **Liu M.-b., Liao S.-m., Xu J., Men Y.-q.**, 2021  
*Analytical solutions, in-situ measurements on the internal forces of segmental lining produced in the assembling process*, Transportation Geotechnics 27, 100478, <https://doi.org/10.1016/j.trgeo.2020.100478>, Accessed 02.05.2026
- [15] \* \* \*, 2026  
*Compresoare centrifugale de aer*. Available online: <https://comoti.ro/proiecte/directii-principale-de-cercetare/compresoare-centrifugale-de-aer-2/>. Accessed 01.05.2026
- [16] **Radcenco Vs., Alexandrescu N., Ionescu E., Ionescu M.**, 1985  
*Calculul și proiectarea elementelor și schemelor pneumatice de automatizare (Calculation, design of pneumatic automation elements, schemes)*, Editura Tehnică, București
- [17] \* \* \*, 2026  
*Expanders MAN Energy Solutions*. Available online: <https://www.man-es.com/process-industry/products/expanders>. Accessed 01.05.2026
- [18] \* \* \*, 2026  
*What is a pressure dew point?* Atlas Copco Compressors Canada. Available online: <https://www.atlascopco.com/en-ca/compressors/air-compressor-blog/what-is-a-pressure-dew-point>. Accessed 01.05.2026
- [19] **Smeu A.C.**, 2012  
*Soluii eficiente de construire și gestionare a haldelor de steril din Bazinele Miniere Rovinari și Motru pentru redarea în circuitul economic (Efficient solutions for the construction, management of tailings dumps in the Rovinari, Motru Mining Basins for reintroduction into the economic circuit)*, Ph. D. Thesis, University of Petrosani
- [20] **Lazar M.**, 2016  
*Cercetări privind stabilitatea și reconstrucția ecologică a terenurilor afectate de minerit (Research on the stability, ecological reconstruction of lands affected by mining)*, Habilitation Thesis, University of Petrosani
- [21] \* \* \*, 2026  
*Cele mai mari parcuri de energie solară din România. TOP 21 centrale*. Newsletter Cursdeguvernare. Available online: <https://cursdeguvernare.ro/cele-mai-mari-parcuri-de-energie-solara-din-romania-top-21-centrale.html>. Accessed 01.05.2026

[22] \* \* \*, 2026

*Power plant profile: Ucea Solar PV Project, Romania.* Power Technology. Available online: <https://www.power-technology.com/data-insights/power-plant-profile-ucea-solar-pv-project-romania/?cf-view>. Accessed 01.05.2026

[23] \* \* \*, 2026

*Power plant profile: Miercurea – XPV EnergySolar PV Park, Romania.* Power Technology. Available online: <https://www.power-technology.com/data-insights/power-plant-profile-miercurea-xpv-energysolar-pv-park-romania/>. Accessed 01.05.2026

[24] \* \* \*, 2022

*PUZ (Planul Urbanistic Zonal) înregistrat la ANM Gorj (Agenția pentru Protecția Mediului Gorj) cu nr. 6217/21.06.2022* Available online: <https://djmgj.anmap.gov.ro/category/3-2-4-drafturi-acte-reglementare/>, Accessed 01.05.2026

[25] **Măruță E.**, 2023

*Cele mai mari parcuri fotovoltaice din Oltenia se construiesc la Călnic*, Gazeta de Sud, 30 martie 2023, Available online: <https://www.gds.ro/Local/Gorj/2023-03-30/cele-mai-mari-parcuri-fotovoltaice-din-oltenia-se-construiesc-la-calnic/>, Accessed 02.05.2026

[26] \* \* \*, 2026

*Denumire proiect: Construirea unui Parc Fotovoltaic pe Halda interioara Tismana 2 - unitatea minieră de carieră Roșia -Rovinari. Parc Fotovoltaic.* <https://parc-verde.ro/parc-fotovoltaic-tismana-2/>. Accessed 02.05.2026

[27] \* \* \*, 2026

**What is solar energy storage?** Available online: <https://www.shieldenchannel.com/blogs/portable-power-station/what-is-solar-energy-storage>. Accessed 02.05.2026



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