TRANSFORMING COAL PITS INTO RENEWABLE ENERGY SOURCES: THE POTENTIAL OF PUMPED HYDRO ENERGY STORAGE IN THE BEŁCHATÓW LIGNITE MINE

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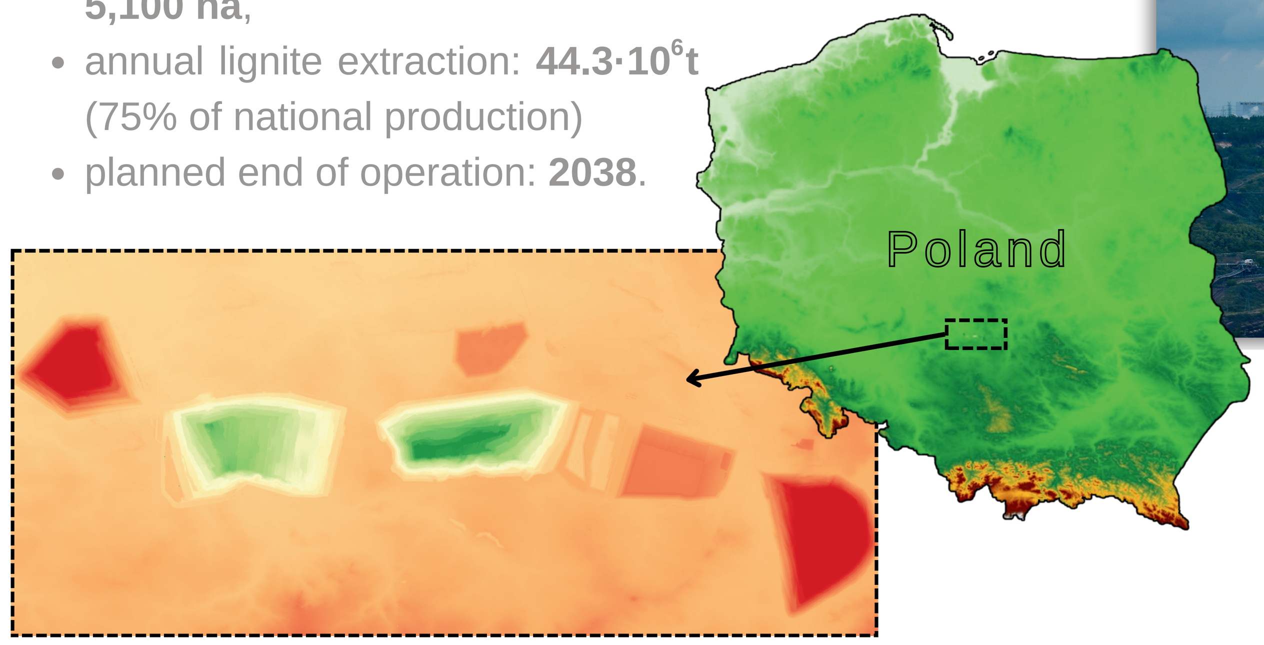
1. From coal mine to grid scale storage for renewables

The energy transition has several problems to solve, which include: increasing the potential for energy storage due to the non-dispatchability of renewable energy sources, in particular wind (WF) and photovoltaic (PV) sources, and developing abandoned coal mine sites. An approach that addresses both of these problems in a comprehensive manner is the concept of **utilisation of mine pits and dumps as sites for the location of Pumped Hydro Energy Storage (PHES)**. Poland, as one of the member states of the European Union and one of the most coal-dependent countries in its region, is also obliged to fulfil the demands related to the transformation of the electricity system. However, in terms of the potential for developing energy storage in the form of PHES, **Poland has limited potential**, mainly due to its topography and water resources. On the other hand, due to the significant number of open-pit mines, it is possible to restore them in the above-mentioned form, so that they can act as hybrid renewable energy sources with WF and PV. This work focuses on the utilisation of the **Bełchatów Lignite Mine** for the construction of the most mature and one of the largest technologies in terms of energy storage potential, which are undoubtedly PHES. In addition, factors that can affect the efficiency of the system were analysed, highlighting: **pressure losses in the derivation lines and evaporation of water from the upper reservoir.**

2. Bełchatów - current state

Open-pit lignite mine [1]:

- surface (mine pits and heaps): **5,100 ha**,
- annual lignite extraction: **$44.3 \cdot 10^6$t** (75% of national production)
- planned end of operation: **2038**.



Thermal power plant [2]:

- power capacity: **5 GW**,
- annual electricity production: **35 TWh** (22% of national production),
- planned phase out: **2036**.

3. Data and methods

PHES POTENTIAL

1 TOPOGRAPHICAL FACTORS

To determine the pumped hydro energy storage (PHES) potential based on potential energy of water equation, **QGIS software, digital elevation model, and open source maps** was used.

MINE PITS FILLING

2 VOLUME, DISTANCE AND ALTITUDE

In order to estimate the relationship between the volume of water in the lower reservoir and the height of the water table on the basis of **GIS tools**, **filling curves** were created for both pits. Also **distances to rivers** and their **multi-annual average flows** were determined.

PENSTOCK LENGTH AND PRESSURE LOSSES

3 COLEBROOK-WHITE FORMULA

To investigate how the distances between the pit and the heap will affect the efficiency of PHES, the **lengths of the penstocks** were determined, then the pressure losses were calculated using the **Colebrook-White formula** with the relevant assumptions.

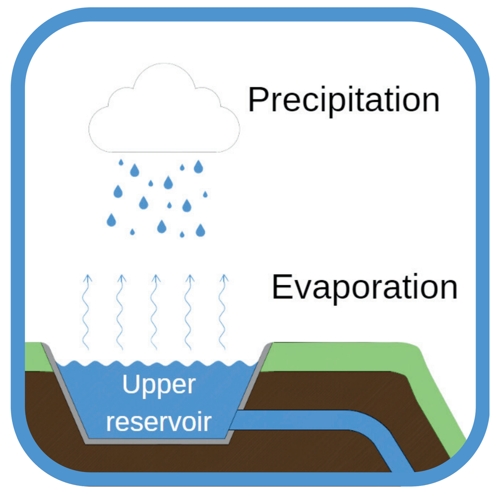
EVAPORATION AND PRECIPITATION BALANCE

4 PENMAN-MONEITH (P-M) EQUATION AND ERA5

Another potentially influential factor in energy loss is the balance between precipitation and evaporation from the upper reservoir. Therefore, using the **P-M equation [3] and data from the ERA5 reanalysis [4]**, annual evaporation was calculated for the period from 2001-2022, and monthly precipitation data from **in-situ measurements** were utilised.

If you would like to find out more

Abstract QR code



4. Results: PHES scenarios

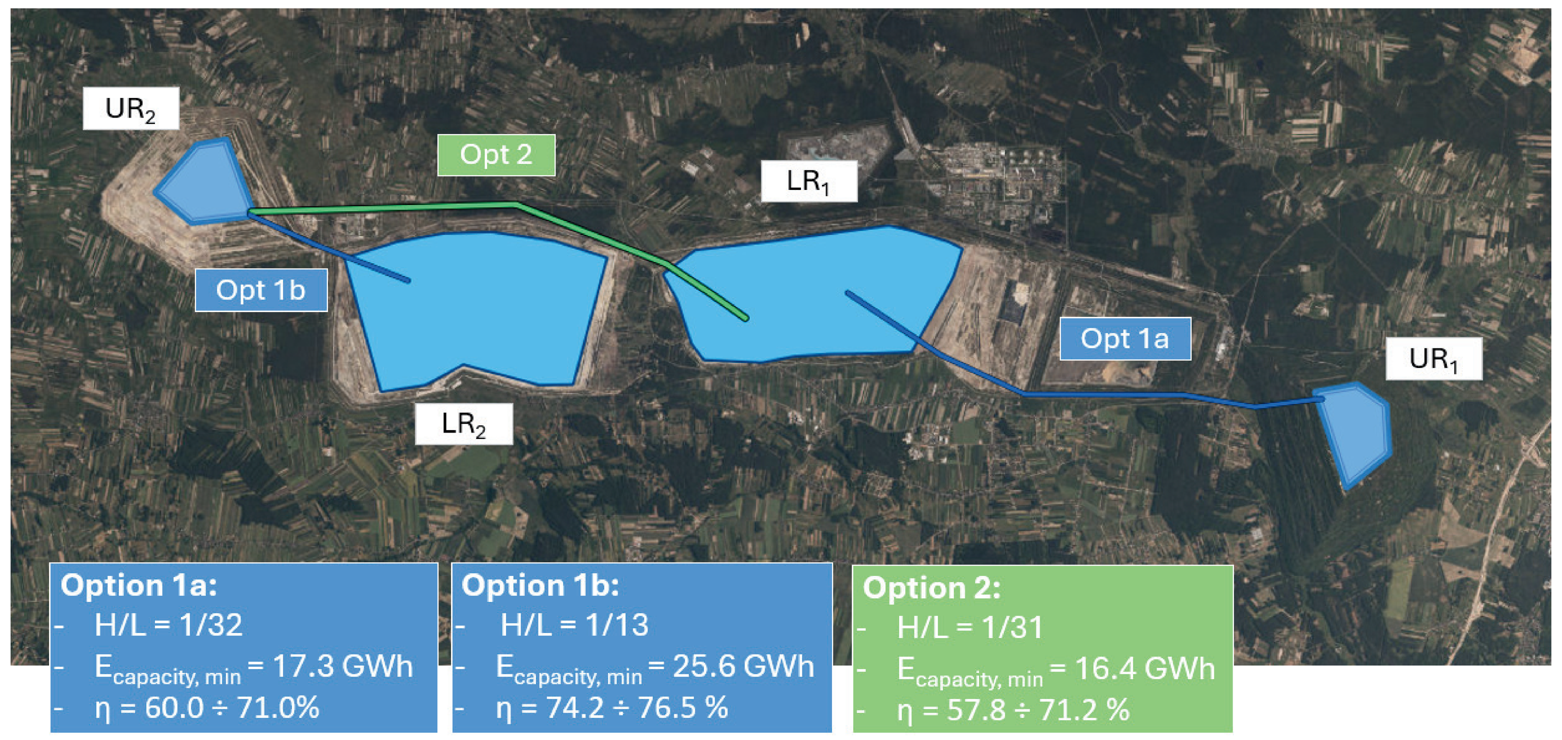


Fig. 1. Three scenarios analysis outcome, UR - upper resevoir, LR- lower reservoir

Fig. 2. Distances to nearest 2 rivers with multi-annual average flow (Q_{av}) over 4.0 m^3/s, measured for years 1991-2022

5. Results - evaporation

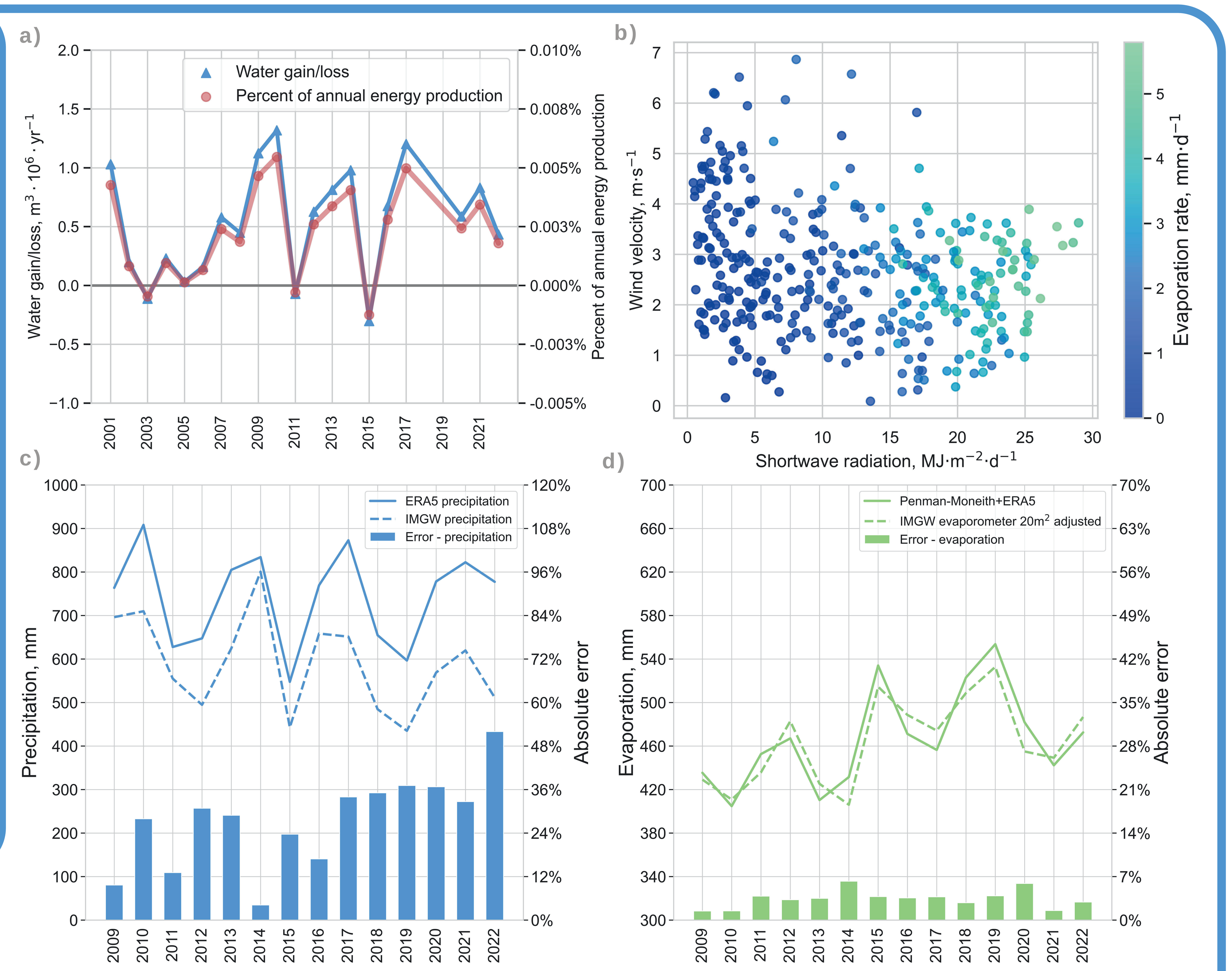


Fig. 3. Water precipitation-evaporation balance analysis graghs: a) Water balance and energy production, b) Influence of wind velocity and shortwave radiation on evaporation rate, c) ERA5 precipitation data validation, d) ERA5 evaporation calculations validation

Conclusions

1) After selecting 3 variants for connecting the pits to the heaps **Option 1b is the optimal variant** due to the highest energy storage efficiency per cycle, which is related to the most favourable altitude-distance ratio. The proposed concept enables **2,5-fold increase** of national closed loop PHES storage capacity. **2)** For assesed location **ERA5 provides accurate data to calculate annual evaporation rate** using Penman-Moneith equation, however **annual precipitation values show a high error rate combining with measured values. 3)** On an annual basis, the water balance between **precipitation and evaporation does not have a significant impact** on changes in pumped hydro storage efficiency for the case presented.

References

[1] PGE Górnictwo i Energetyka Konwencjonalna. (n.d.). Historia Kopalni. https://kwbbelchatow.pgegiek.pl/O-oddziale/Historia-Kopalni.
[2] PGE Górnictwo i Energetyka Konwencjonalna. (n.d.). Elektrownia Bełchatów. https://pgegiek.pl/Nasze-oddzialy/Elektrownia-Belchatow.
[3] Mousavi, N., Kothapalli, G., & Habibi, D. (2019). An improved mathematical model for a pumped hydro storage system considering electrical, mechanical, and hydraulic losses. Applied Energy, 247, 228–236. https://doi.org/10.1016/j.apenergy.2019.03.015.
[4] Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., Thépaut, J-N. (2023). ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). https://doi.org/10.24381/cds.adbb2d47. (Accessed on 10.04.2024).

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