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LETTER TO THE EDITOR

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China: legacy collieries versus renewable energy

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Abstract

The findings of the major strategic consulting project of Chinese Academy of Engineering 'Research on the strategy of coal mine safety and abandoned mine resources development and utilization in China' suggest that almost 13,000 discarded collieries in China will provide abundant surface lands and massive underground heritages to not only develop but also store renewable energy within the Earth's Critical Zone, thus helping attain its net-zero energy goal.

A major strategic consulting project of Chinese Academy of Engineering 'Research on the strategy of coal mine safety and abandoned mine resources development and utilization in China' has been successfully implemented in China during 2017–2019. Its achievements press conference held in May 2021 suggests that almost 13,000 discarded collieries in China will provide abundant surface lands and massive underground heritages to not only develop, but also store renewable energy, particularly of renewable geo-energy within the Earth's Critical Zone. This may bolster support for decarbonization of China's energy sector, finally helping attain its net-zero energy ambition (O'Meara and Ye 2022) and double carbon' goal (Shi et al. 2021).

Firstly, obsolete collieries' land resources in China—approximately 23,000 km^2 of subsidence area and abandoned land according to the data—can be repurposed to construct wind and solar power stations and thereby develop electricity (O'Meara and Ye 2022). Such projects have been initiated in the abandoned metallic mines in Mexico and Germany (Lin et al. 2023). A consensus is emerging that it is also achievable in China's now-defunct collieries—both open pit and subsurface coal mines.

Secondly, abandoned underground coal mines are the best candidates for low-enthalpy geothermal exploitation due to their lower capital cost without extra drilling expenditures and enhanced strata permeability characteristic deduced by previous mining activities (Loredo et al. 2016). Until now, dozens of documented demonstration projects of mine-oriented geothermal systems have been successfully operated worldwide, mainly distributing in Canada, USA, UK, Germany, Nederland and China (Chu et al. 2021). Apart from shallow geothermal resources, underground mine is more accessible to deep geothermal reservoir. This advantage makes the innovative transformation—from mining minerals to mining heat: excavation based enhanced geothermal system (EGS-E)—possible. Such a new concept is also initiatively proposed by Chinese mining industry (Zhao et al. 2020).

Thirdly, China's discarded collieries since 1949 create as much as 1.56×10^{10} m^3 of valuable underground space (Xie et al. 2020). After renovation, these legacies are optimal for earth-contact heat and energy storage, including but not limited to mine water pseudokarstic aquifer interseasonal heat storage, pumped hydroelectric energy storage (PHES) and compressed air energy storage (CAES) (Menéndeza et al. 2019). Therefore, abandoned collieries

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can be defined as available energy storage facilities for addressing an urgent issue hindering renewable energy penetration in China, i.e., the spatio-temporal intermittency and imbalance of renewable energy generation (Yang and Xia 2022).

Most importantly, legacy mines' renewable energy development and storage involve various substance migration (solid—soil/rock, liquid—water, and gas—wind and compressed air) and energy conversion (wind–solar–electricity–heat–geopotential, etc.) within the Earth's Critical Zone (Fig. 1). This is caused by mines' inherent attributes and special topology. Accordingly, the key scientific issue on the law of Earth's fluid matter migration that accompanying energy conversion is a critical challenge that must be faced head-on (Chu and Wang 2023). This topic is also a general challenge for multitudinous earth-contact energy and environment issues. Therefore, open-related researches are urgent and necessary.

Given its significance, we suggest and expect reusing legacy mines' geoassets, both surface resources and underground heritages, to develop, store renewable energy, and finally fight energy crisis and climate change. It can help to pivot China to carbon neutrality by 2060. To achieve it, various geological investigations and renovation technologies, e.g., well logging, pumping test, strata grouting and artificial rock lined caverns should be carefully conducted to ensure long-term sealing, stability and safety, prior to agreeing above developments. Besides, economic and environmental assessments are also essential to the feasibility of these projects. For instance, various mine-oriented renewable energy production and storage must not irritate threats to biodiversity. Typically, mine water-based hydrothermal systems have thermal impacts on water temperature, which can affect aquatic ecology in the receiving water body (Preene and Younger 2014). Moreover, renewable energy development and storage need special infrastructure; this will drive an increase in the exploitation of rare metals, creating new mining threats for biodiversity (Sonter et al. 2020). Targeted strategic planning should be considered. If not, renewable energy production and storage deduced extra mining threats for biodiversity may surpass those averted by energy crisis and climate change mitigation.

In a word, technically reliable, environmentally friendly and economically feasible to extract and store

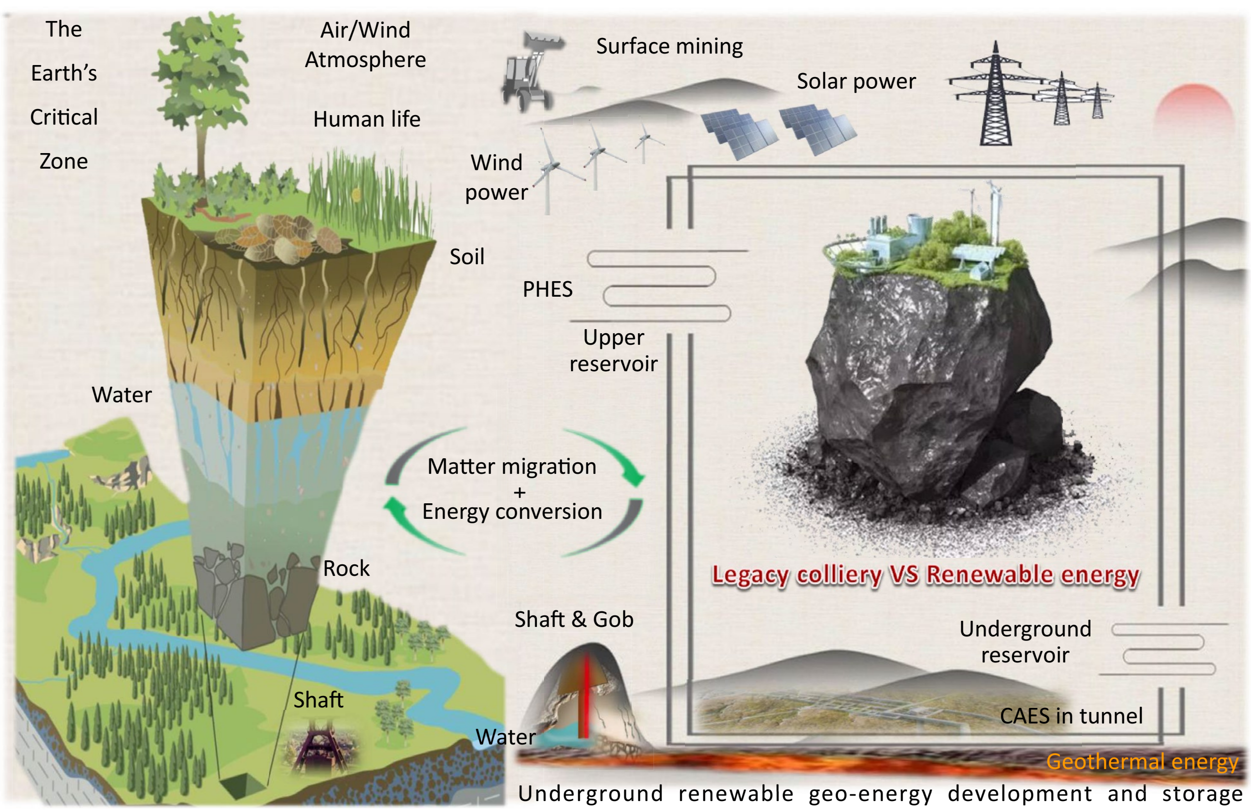

Fig. 1 Legacy colliery vs renewable energy within the Earth's Critical Zone (The design of the Earth's Critical Zone in the left part is revised from the reference 'Chorover J, Kretzschmar R, Garcia-Pichel F, et al. Soil Biogeochemical Processes within the Critical Zone. Elements, 2007(5): 321–326')

renewable energy at abandoned coal mines or any type of abandoned mines is challenging. Further joint efforts conducted by scientists and consultants from many different backgrounds, e.g., miners, geologists, biologists, chemists, civil engineers, environmentalists, lawyers, regulators, etc., are required. Only in this way, can we complement various gaps in legacy mines' renewable energy development and storage and shift the mining industry from traditional people's impression (carbon intensive) into a new insight (clean alternative). Notably for China, in could aid decarbonization (Bao et al. 2023) in its energy sector.

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Author contributions
The first and corresponding author ZC: conceptualization, writing draft. The second author YW: graph visualization, writing and editing. The third author YJ: graph visualization, software. The fourth author XL: conceptualization, supervision, review and editing.

Availability of data and materials
Not applicable.

Declarations

Competing interests
We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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