applied sciences

Review

Advantages of Backfill Mining Method for Small and Medium-Sized Mines in China: Safe, Eco-Friendly, and Efficient Mining

Shuai Li, Peiyuan Zou, Haoxuan Yu, Boyi Hu * and Xinmin Wang

School of Resources and Safety Engineering, Central South University, Changsha 410083, China
* Correspondence: boicary@csu.edu.cn

Abstract: Despite China's position as a global mining powerhouse, tens of thousands of small- and medium-sized mines (SM mines) within the country continue to pose potential safety hazards and environmental pollution risks. Only through the identification of suitable development paths can these mines improve their economic and environmental benefits, ultimately driving significant progress in China's mining industry. Backfill mining, an environmentally friendly mining method, has emerged as a viable solution, offering the potential to ensure mining safety, reduce environmental pollution stemming from tailings stockpiles, and enhance ore resource recovery. This review article aims to provide researchers and readers with a comprehensive understanding of the current situation and challenges faced by SM mines in China. It explores the mining processes, technologies, and equipment commonly employed by these mines while addressing the specific problems and challenges they encounter. Furthermore, the article offers recommendations to guide the future development of SM mines. Additionally, the review examines the prospects and potential applications of backfill mining methods within the context of SM mines in China, emphasizing their role in promoting sustainable mining practices, environmental protection, and waste utilization. Ultimately, this comprehensive review article serves as a valuable resource, stimulating discourse and encouraging experts and scholars to further explore the unique challenges and opportunities associated with SM mines. By highlighting the significance of green mining practices, environmental protection, backfill mining, and waste utilization, the article aims to inspire innovative solutions and foster sustainable practices within the Chinese mining industry.

Keywords: environment; green mining; mining transformation; mining engineering; tailings utilization

check for updates

Citation: Li, S.; Zou, P.; Yu, H.; Hu, B.; Wang, X. Advantages of Backfill Mining Method for Small and Medium-Sized Mines in China: Safe, Eco-Friendly, and Efficient Mining. *Appl. Sci.* **2023**, *13*, 7280. https://doi.org/10.3390/app13127280

Academic Editor: Syed Minhaj Saleem Kazmi

Received: 20 April 2023
Revised: 5 June 2023
Accepted: 15 June 2023
Published: 19 June 2023

1. Introduction

China, a country rich in mineral resources, has a significant number of small- and medium-sized mines (SM mines) which are characterized by low annual ore production and inefficient equipment and mining technology [1,2]. The slow development of the mining industry and mining equipment in China has led to a generally low utilization rate of resources. Furthermore, SM mines in China have been responsible for numerous safety accidents and environmental damage during the ore mining processes [3].

Adding to these challenges, most of the ores produced in China from SM mines are of low grade and require expensive beneficiation and smelting processes to recover useful components [4,5]. This is especially true for various metallic mineral ores, where the difficulty and cost of beneficiation and smelting are significantly increased. Given these challenges, SM mines in China need to seek changes to their current development practices.

In recent years, SM mines in China have received widespread attention, and many researchers have worked to improve resource utilization and ecological conservation for these mine [6]. Based on the Google Scholar database (https://scholar.google.com (accessed on 4 November 2022)), using "small-sized mines in China", "medium-sized mines in China" and "small and medium-sized mines in China" as keywords, the number of literature (results) related to mine dust pollution for each five-year period from 1995 to 2020 was found, as shown in Figure 1. The number of related literature (results) in the last 20 years clearly has an upward trend, showing that the transformation and upgrading of small- and medium-sized mines in China are receiving increasing attention.

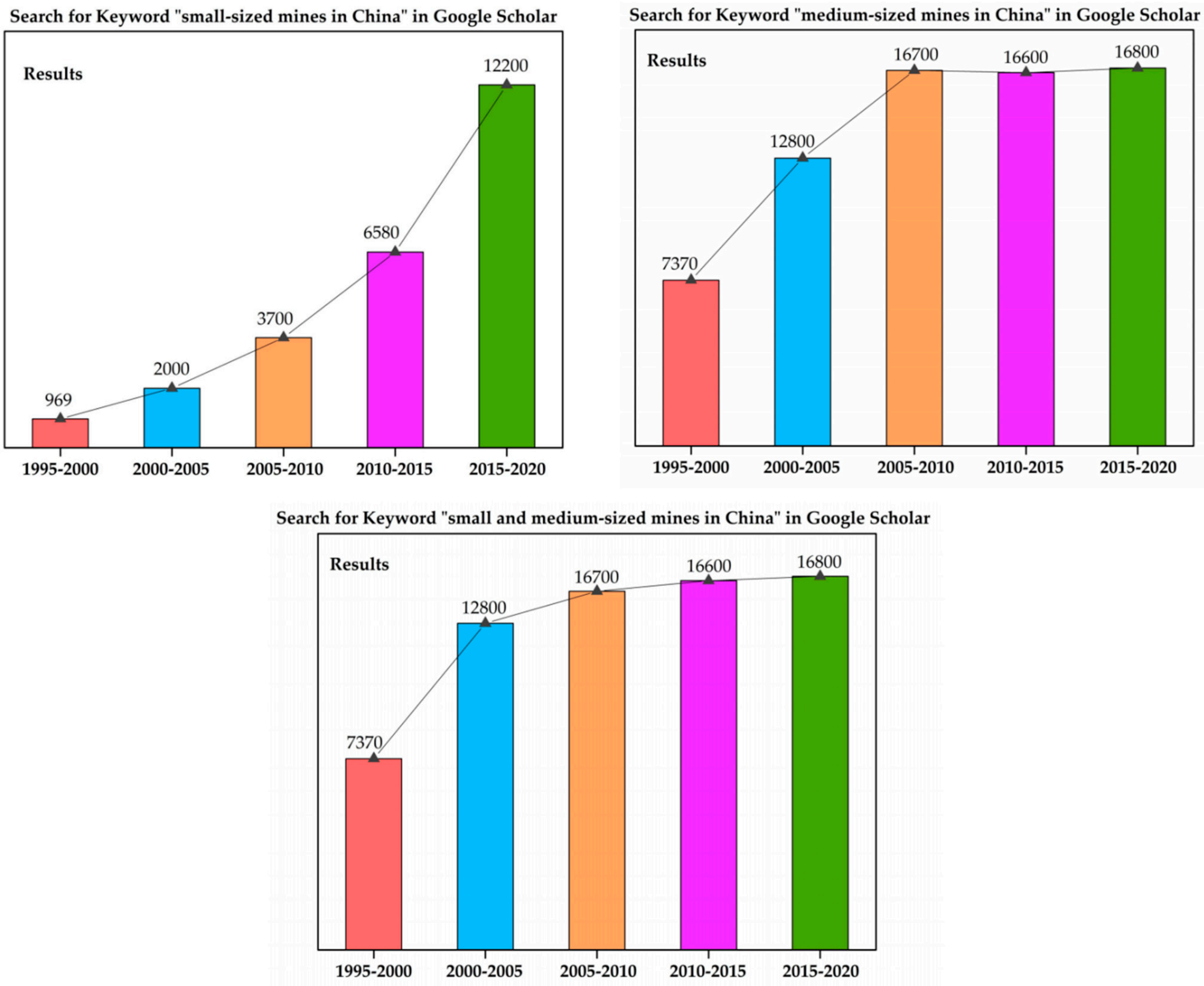

Figure 1. Changes in the number of literature related to "Small-sized mines in China", "Medium-sized mines in China" and "Small and medium-sized mines in China" from 1995 to 2020.

The research on small- and medium-sized mines has extensive applications and research value abroad, especially for developing countries with limited resources and backward economic conditions. It has a certain reference significance in the mining and management of small- and medium-sized mines. In foreign countries, some famous mining academic institutions, such as the School of Mining at Laurentian University in Canada, the Federal Institute of Science and Technology in Australia, and the School of Mining at Stirling University in the United Kingdom, have conducted research on small- and medium-sized mines multiple times, covering various aspects such as environmental governance, safety production, cost control, and mineral resource assessment. In addition, in developed countries such as the United States, Germany, Japan, and France, there are also corresponding research institutions and scholars studying the mining problems of small- and medium-sized mines, exploring more environmentally friendly, efficient, and sustainable mining methods.

Therefore, this review article mainly aims to introduce the current status and prospects for the application of backfill mining methods in SM mines in China. In the second section, it provides an overview of the current situation of SM mines in China, including the mining technology, extraction equipment, and emission methods commonly used. In the third section, it highlights the challenges faced by SM mines, such as safety hazards and environmental damage. In the fourth section, it discusses the potential for the application of backfill mining methods in SM mines in China, and how this approach could help address the challenges faced by these mines. Overall, this review article serves as a guide to begin a conversation and encourage experts and scholars to engage in research in this field.

2. Status Quo of Small- and Medium-Sized Mines in China

At present, many SM mines in China still use outdated mining methods such as the retention method, room and pillar method, and crumbling method for ore body mining [7,8]. Similarly, inefficient mining equipment such as wind-driven rock drills, electric rakes, and rock loading machines are still in use in many SM mines [9,10]. Moreover, the mining areas of many SM mines in China face significant safety concerns, environmental pollution [11], and solid waste discharge, which seriously impact their economic benefits.

2.1. Current Status of Mining Methods and Equipment in SM Mines of China

A significant number of SM mines in China still rely on the room-and-pillar method for ore mining. As illustrated in Figure 2A, the room-and-pillar method involves leaving pillars to support the roof, and its simplicity and applicability to horizontal or gently inclined stratified ore bodies make it popular in SM mines [12]. However, the method's drawbacks are evident: it results in ore loss due to the placement of pillars to support the roof, significantly reducing the recovery efficiency of the ore and having a negative impact on the economic efficiency of SM mines [13].

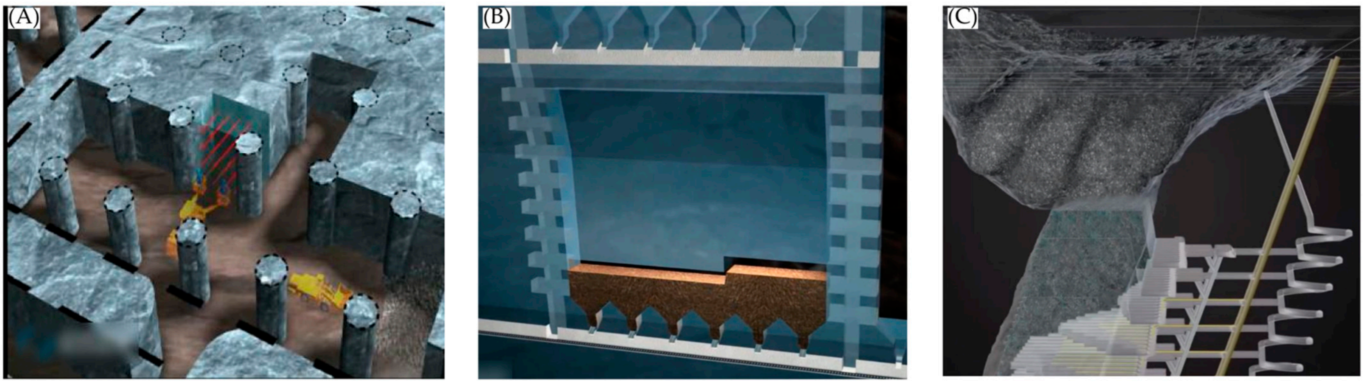

Figure 2. (**A**) Schematic diagram of room-and-pillar method; (**B**) Schematic diagram of shrinkage stoping mining method; (**C**) Schematic diagram of sublevel caving mining method.

The shrinkage stoping mining method (as shown in Figure 2B) is also a commonly used mining method in SM mines in China. It is a layered mining method that operates from bottom to top [14,15]. However, the disadvantages of the shrinkage stoping mining method are also significant. Firstly, it has a high accident rate, making it difficult to guarantee the safety of workers. Secondly, large mining equipment cannot be used, resulting in very low mining efficiency. Furthermore, the shrinkage stoping mining method leads to a high loss depletion rate of ore, which has a negative impact on the economic efficiency of the mine [16,17].

Compared to the shrinkage stoping mining method, the sublevel caving mining method is more widely used in SM mines because it does not require large extraction production equipment, and the mining and ore extraction equipment and processes are simple, with high production capacity [18]. The sublevel caving mining method is a mining method that manages ground pressure by caving the surrounding rock, as shown in

Figure 2C. However, it also has its disadvantages, such as the large amount of quasi-parallel cutting work, low mechanization of construction, and high rate of loss depletion [19].

As mentioned earlier, most of the mining equipment used in SM mines is relatively simple and inefficient. For instance, the pneumatic rock drill, which is a rock drilling machinery powered by compressed air (as shown in Figure 3A), has been widely used in SM mines in China due to its low cost and equipment investment, especially in the retention method [20]. However, the extraction efficiency of the wind-driven rock drill is too low, and upgrading the extraction machinery, such as the rock drill cart (as shown in Figure 3B), under the premise of improving the mining method, can greatly improve mining and excavation efficiency. Similarly, electric rakes and rock loaders (as shown in Figure 3C) are commonly used in SM mines in China for ore transportation, but they also have low transportation efficiency, necessitating the upgrading of these devices to more efficient transportation equipment, such as the load haul dump machine (LHD) (as shown in Figure 3D) [21].

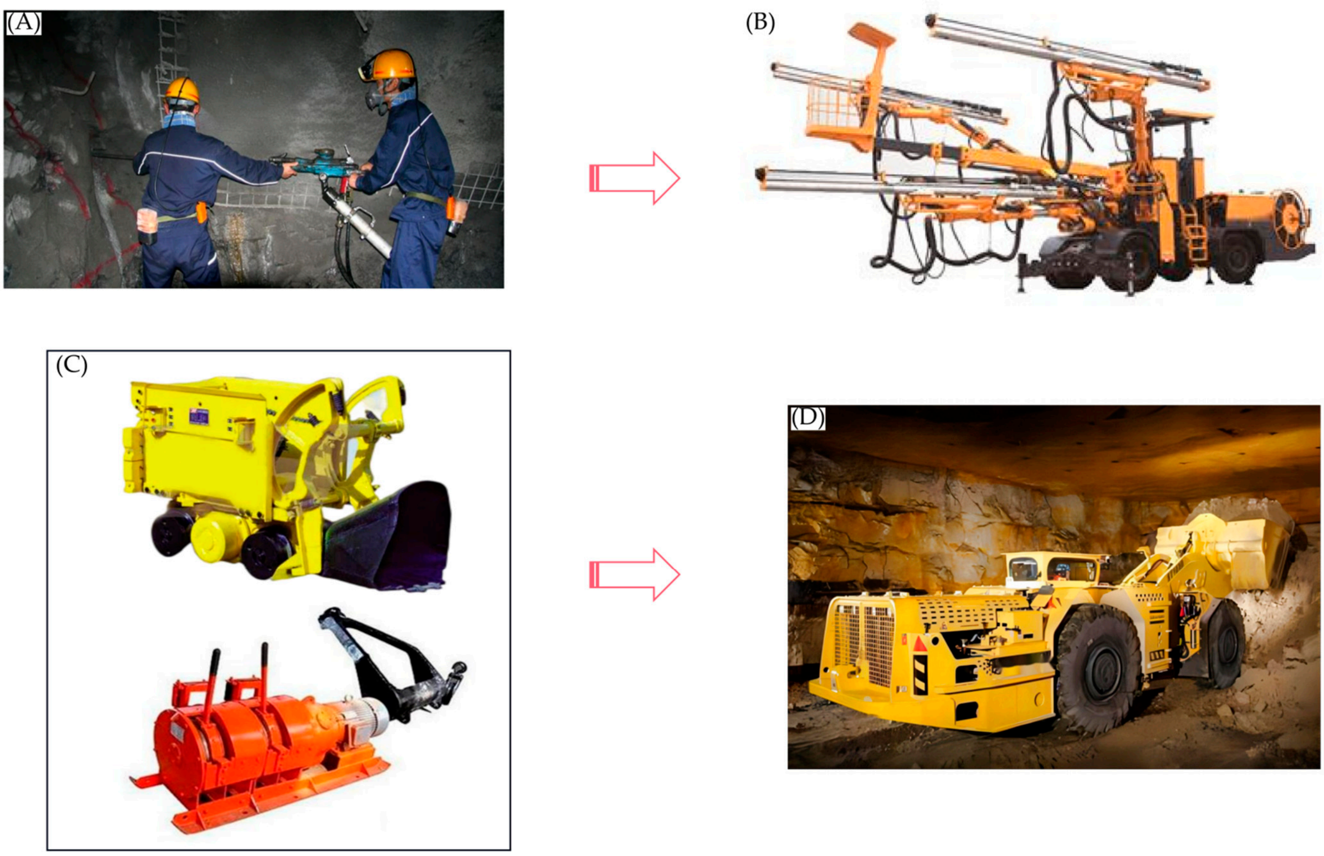

Figure 3. (**A**) Pneumatic rock drill; (**B**) Rock drill cart; (**C**) Electric rake and rock loader; (**D**) LHD.

Table 1 shows the comparison of benefits between continuous and intermittent loading for a certain set underground mining site. The comparison results show that Scheme 4 is the most economical scheme, requiring only one pass, and also the scheme with the highest concentration ratio of production operations and the highest stope and labor productivity, therefore replacing outdated mining machinery with more effective equipment not only reduces mining costs, but also improves production efficiency and guarantees.

Table 1. Comparison of Economic Benefits of Four Different Ore Transport Schemes.

Scheme	1	2	3	4
Loading machinery	Four 6.1 cubic yard scrapers	Two front-end loaders and two 26-ton low-profile dump trucks	One AL-60 continuous loader and two 26-ton low-profile dump trucks	One AL-60 continuous loader and two 50-ton low-profile dump trucks
Average transportation distance (m)	150	250	250	400
Number of ore pits required	3	2	2	1
Annual ore production (*10,000 tons)	115.2	124.8	110.4	131.0
Shipping fee per ton of ore (Yuan)	5.6	4.3	3.5	3.8

2.2. Current Status of Mine Tailings Discharge in SM Mines of China

Table 2 shows the production, integrated utilization, and combined utilization of solid emissions (including solid waste) in China in 2005, 2010, and 2015. In 2015, the combined utilization rate of mining-related solid emissions such as fly ash and coal gangue was between 65% and 75%, while the combined utilization rate of tailings was relatively low, with an average utilization rate of only 50%, as depicted in Figure 4A. Therefore, the comprehensive utilization of tailings has become a critical issue that needs to be addressed urgently (as illustrated in Figure 4B) [22].

Table 2. Discharge and comprehensive utilization of bulk industrial solid wastes in China from 2005 to 2015.

Species	Production per 10 Thousand Tons (t)			Utilization per 10 Thousand Tons (t)			Utilization Rate (%)		
	2005	2010	2015	2005	2010	2015	2005	2010	2015
Tailings	71,400	121,400	130,000	5000	17,000	26,000	7%	14%	20%
Coal Gangue	37,000	59,800	73,000	19,600	36,500	51,100	53%	61%	70%
Fly ash	30,100	48,000	56,600	19,900	32,600	39,600	66%	68%	70%
Smelting slag	18,000	31,700	44,000	9000	19,000	33,000	50%	60%	75%
Gypsum	5000	12,500	15,000	500	5000	9750	10%	40%	65%
Red mud	1000	3000	3500	20	120	700	2%	4%	20%
Total	162,500	276,400	322,100	54,020	110,220	160,150	Average 33%	40%	50%

Most SM mines in China currently discharge the low-concentration tailings slurry generated from the processing plant directly into tailings ponds (as shown in Figure 4B), which is also the main method of managing mining waste in China [23]. As of the end of 2012, there were more than 12,000 tailings ponds in use in China, accounting for over 50% of the world's total. Furthermore, there were nearly 9100 tailings ponds with lax management and prominent safety hazards, posing significant risks to the environment and people's lives [24]. Therefore, it is urgent to improve the management of tailings ponds in SM mines in China.

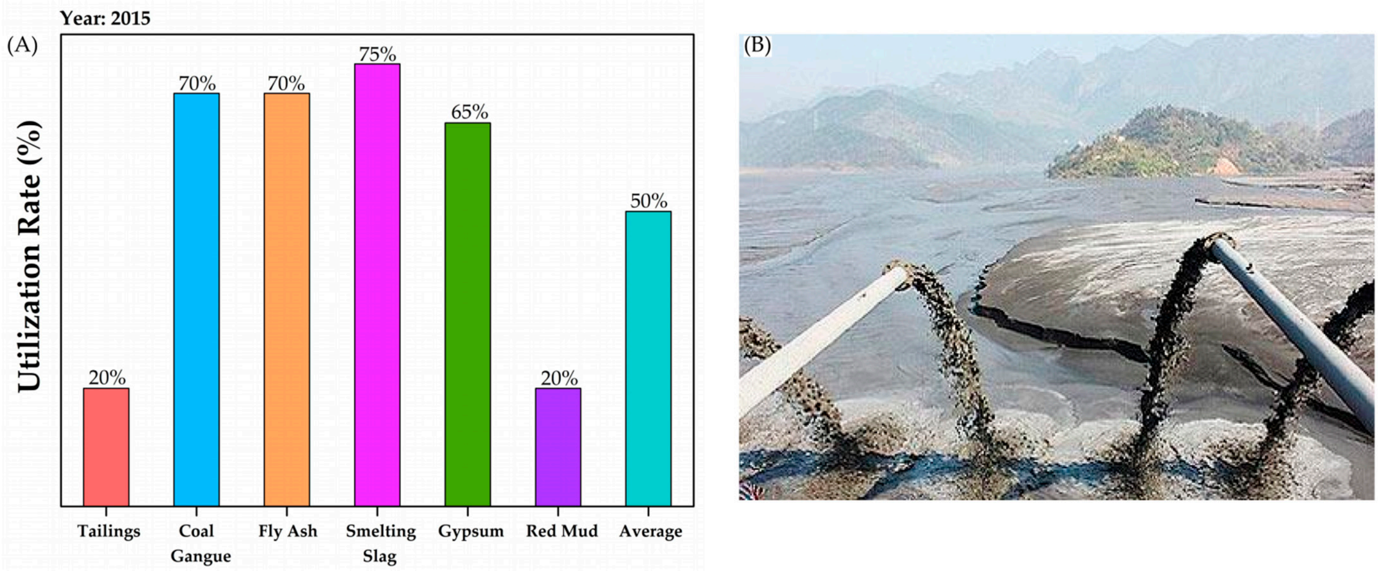

Figure 4. (**A**) Utilization rate of mining waste in 2015; (**B**) Tailings discharge.

3. Problems in Small and Medium Sized Underground Mines

3.1. Hidden Danger of Goaf Safety

Goaf collapses can cause severe environmental problems, such as surface collapse, which not only impacts the ecological and geological environment but also greatly affects the development of the local mining economy [25]. For SM mines, managing and maintaining the mining area is more challenging and can result in serious safety hazards, such as cave-ins [26]. According to available statistics, there are more than 100 mines in China with a goaf area of 1 million cubic meters or more, and the accumulated mining goaf volume is up to 356 million cubic meters, as shown in Table 3 and Figure 5.

Table 3. Scale distribution of the goafs.

Size Range of Goaf (*10,000 m^3)	Mine Quantity Distribution		Volume Distribution of Goaf (Goafs)	
	Number	Percentage	Goaf Volume (*10,000 m^3)	Percentage
<50	303	66.3%	3710.72	8.59%
50~100	54	11.82%	3866.72	8.95%
100~500	79	17.29%	17,957.98	41.55%
500~1000	14	3.06%	8871.04	20.53%
>1000	7	1.53%	8810.8	20.38%
Total	457	100%	43,217.26	100%

3.2. Hidden Danger of Goaf Safety Tailings Ponds

According to statistics, as of 2016, tailings ponds in China covered an area of more than 3×10^4 km^2, including a significant amount of agricultural and forest land, causing immense pressure and a serious burden on society [27]. Due to the strong acidity of tailings after flotation, tailings drainage water can cause immeasurable losses to occupied land, crops, surface water, underground water sources, and aquatic organisms. Moreover, long-term exposure of sulfide and other harmful components in acid tailings can produce a large number of harmful gases, which are more likely to induce dust pollution in strong winds [28].

Tailings ponds are not only a significant source of pollution but also a potential source of danger, which can lead to accidents or environmental safety hazards, as shown in Figure 6A. When a tailings pond breaches, it can cause destruction of nearby vegetation, buildings, and pose a risk to the safety of residents. For instance, in 2019, the Córrego do Feijão Mine suffered a serious tailings pond failure (as shown in Figure 6B), leading to severe pollution of rivers and soil along the route [29]. This event resulted in the death of a large number of flora, fauna, microorganisms, and fish, and created drinking water difficulties for 250,000 people due to the presence of high levels of pollutants and heavy metal ions in the tailings [30].

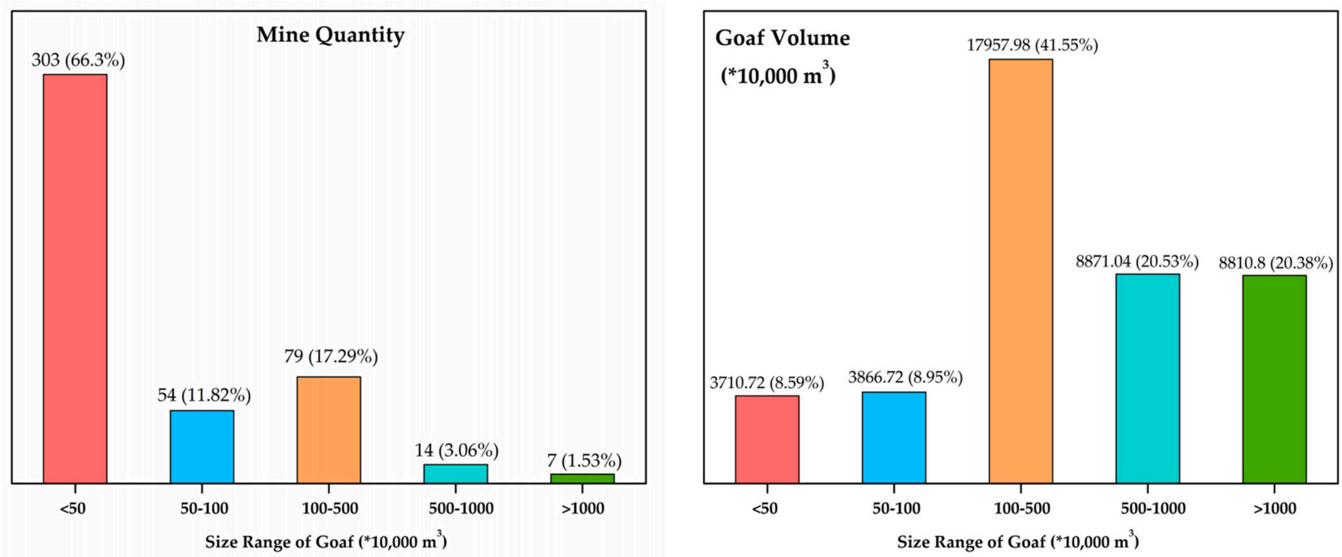

Figure 5. Mine quantity distribution (goafs) and goaf volume distribution.

Figure 6. (**A**) Tailing Pond; (**B**) Brazilian iron ore tailings dam break accident in 2019.

3.3. Depletion Losses of Ore

Most SM mines in China still use mining technologies from the last century, resulting in a significant amount of high-quality resources remaining in goafs. However, the safe and efficient recovery of residual ore resources has been a significant challenge in mining technology today [31]. There are no typical cases of success at home and abroad to facilitate large-scale promotion, mainly due to the following reasons:

Firstly, goafs have a complex form and prominent safety risks. The interior of goafs is often crisscrossed and connected from top to bottom, making it prone to caving and collapse, leading to large-scale ground pressure activities [32]. Ensuring the safety of residual ore recovery is, therefore, extremely challenging, which is a significant constraint.

Secondly, the endowment conditions of residual ore resources are complex, and the spatial morphology changes significantly. In some mines, the ore body occurrence changes from thin to thick, and the dip angle changes from horizontal to steep. The hanging wall of most of these mines has unstable rock masses, making mining technical conditions extremely complicated [33]. In addition, years of disordered mining have resulted in numerous goaf groups, leaving a large number of high-grade residual mineral resources in the goaf groups and their edges, with different forms, uneven thickness, and great difficulty in safe recovery technology.

Finally, different types of residual ore resource mining technology require different approaches. The types of residual ore resources in most goaf groups mainly include top and bottom pillar, interpillar, and corner ore. Due to the different characteristics of residual ore resource endowment and distribution of mined-out areas in each panel, the corresponding residual ore recovery process is also different. Therefore, the selected technical scheme must be targeted, safe, reliable, feasible, and economical [34].

4. Suggestions for Small- and Medium-Sized Underground Mines

The Environmental Protection Tax Law of the People's Republic of China strictly implements the safety permit system, and new mines must demonstrate and prioritize the implementation of filling mining method; For mineral resources extracted by the "three down" filling method, the resource tax will be reduced by 50%; Encourage underground filling transformation and eliminate "overhead storage"; Taxation on solid waste pollution in mines, including 15 yuan/t for red mud, 25 yuan/t for fly ash, and 1000 yuan/t for hazardous waste. On 22 June 2018, the Ministry of Natural Resources issued the "Green Mine Construction Specification for the Non metallic Mining Industry", which has passed the review of the National Land and Resources Standardization Technical Committee. It is explicitly required that the disposal rate of solid waste such as mining waste and tailings should reach 100%, and only the filling mining method can meet the above policy requirements.

Prospects for the Application of Backfill Mining Methods

SM mines within China are plagued with poor levels of mining technologies and equipment, safety hazards and environmental damage caused by research, therefore, to address these problems we suggest the following points to start with.

(1) Using backfill mining methods can not only increase the recovery rate of ore but also reduce the discharge of waste materials (such as tailings and waste rock) generated during the mining process. This approach can also increase the productivity and capacity of the mine, which has significant overall benefits. For example, the Shishudi Gold Mine in Henan Province, China, is currently conducting experimental backfill studies to explore the potential for practical applications of this mining method, as shown in Figure 7.

Therefore, SM mines need to choose the appropriate backfill mining method according to the actual situation of their mine, which can greatly improve mining efficiency while ensuring the safety of mining production. For instance, at the Shishudi Gold Mine in Henan, China, the upward horizontal cut and backfill stoping method (as shown in Figure 8) is used, which can significantly increase ore recovery while ensuring safety.

(2) Therefore, the construction of a backfill system is essential for the successful implementation of the backfill mining method. The system is designed to ensure safe and efficient mining, manage mine site safety and address the issue of mining waste disposal [2]. It is crucial for the future development of SM mines in China to actively build backfill systems, optimize the backfill mining process solutions and reduce backfill costs. Through the backfill system, the goaf (or stope) is backfilled using the backfill mining method, which can prevent subsidence and surface collapse caused by mining operations to a certain extent. If ecological cement is used in the filling system, it can reduce the emission of harmful gases such as carbon dioxide, have less impact on the environment, and greatly improve the compressive strength of the filling body compared to ordinary cement [35–37]. Additionally, while building the backfill system, it is important to further strengthen the research on the comprehensive utilization technology of remaining tailings and waste rock to achieve the secondary utilization of mine waste. This can help solve the problem of high investment costs and large occupied areas of tailings storage [38]. At the Shishudi Gold

Mine, a deep-cone thickener backfill system (as shown in Figure 9A) is being constructed, and the tailings are being reused as waste and transformed into concrete products (as shown in Figure 9B).

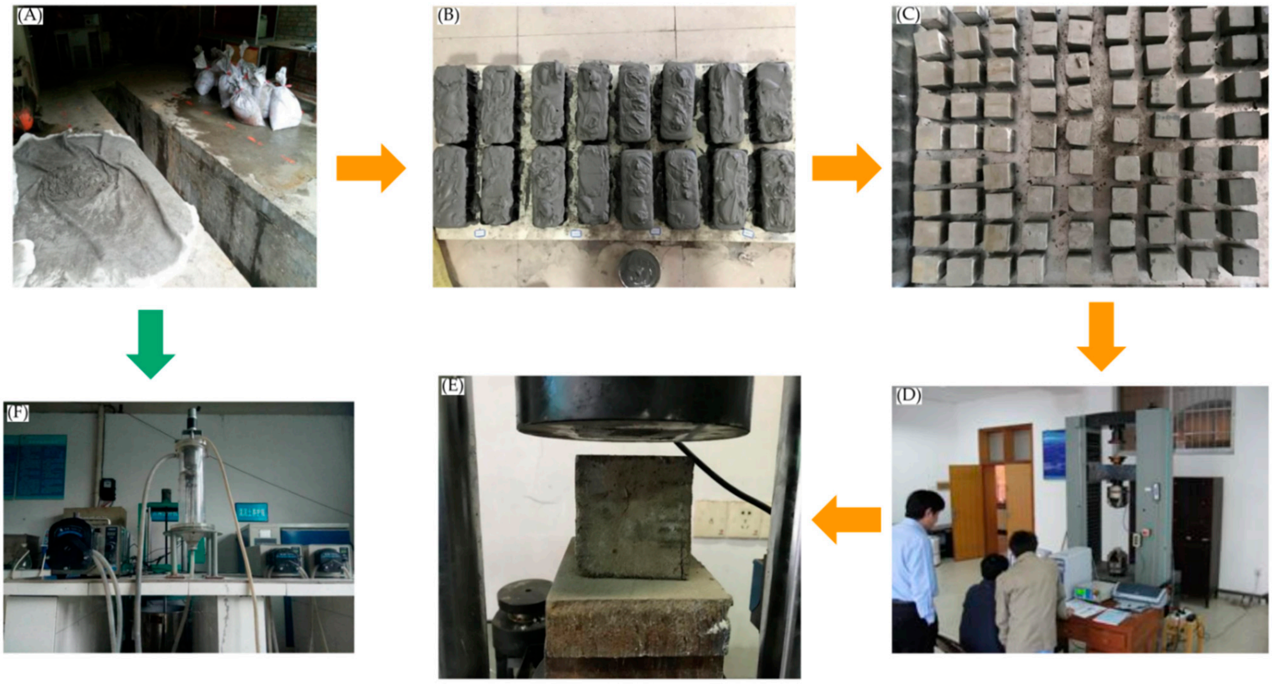

Figure 7. Shishudi Gold Mine backfill experiments: (**A**) Tailings sampling; (**B**) Test blocks making; (**C**) Test blocks finishing; (**D**) Compression testing equipment; (**E**) Compression test; (**F**) Simulation experiment: deep-cone thickener.

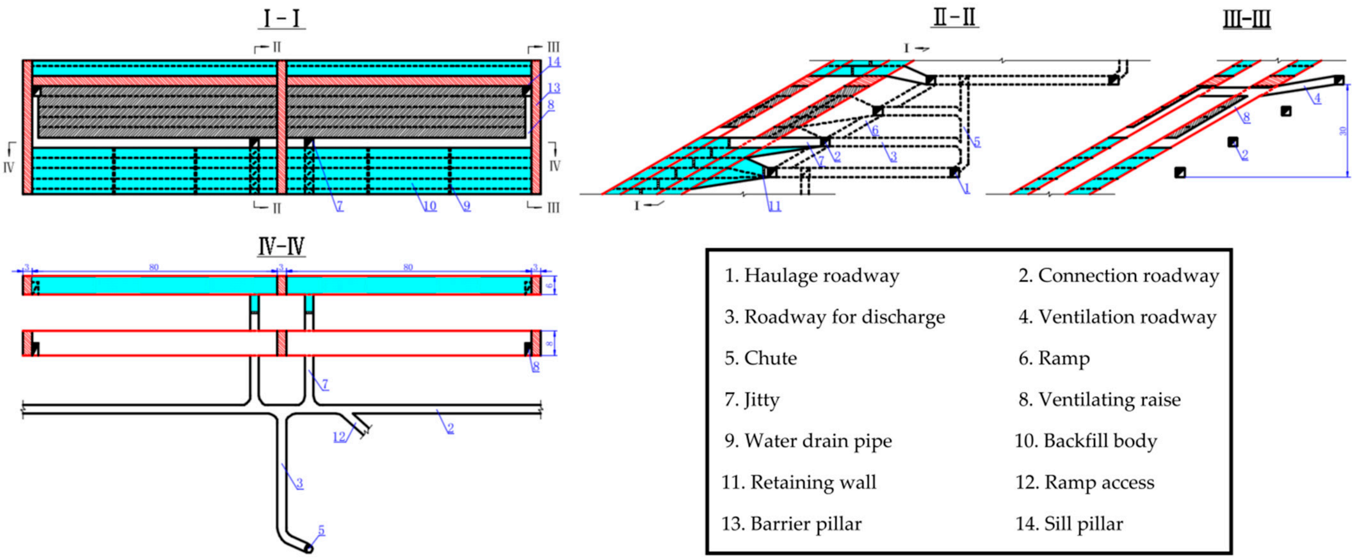

Figure 8. Shishudi Gold Mine: Schematic diagram of the upward horizontal cut and backfill stoping method.

(3) Depending on the resource endowment of each mine, it is important to develop highly efficient and cost-effective mining technology that is tailored to the existing mining conditions, while also introducing mechanized mining equipment that can maximize resource recovery efficiency and mining intensity [39]. By doing so, the entire process of mining, excavation, loading, transportation, hoisting, and beneficiation can be mechanized, reducing labor costs and safety risks. The Shishudi Gold Mine is a typical example for other

small- and medium-sized mines in China, as it actively seeks to improve mining methods while vigorously introducing advanced mining equipment, as shown in Figure 10.

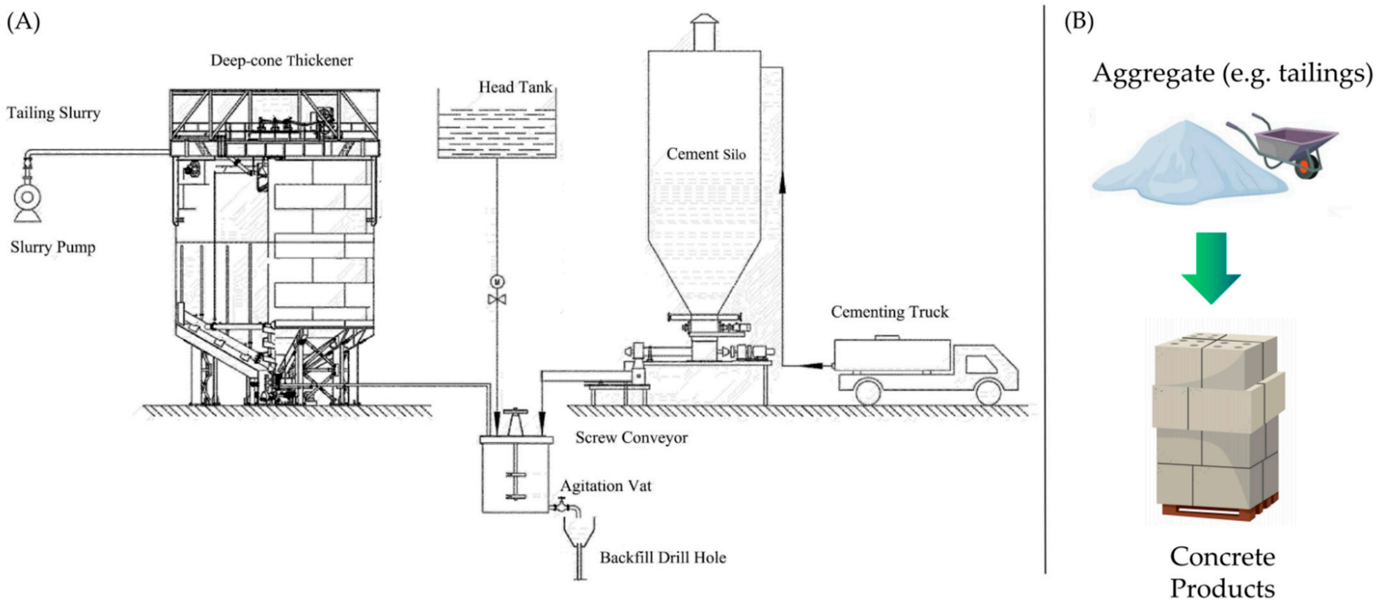

Figure 9. Shishudi Gold Mine: (**A**) Deep-cone thickener backfill system; (**B**) Tailings reuse.

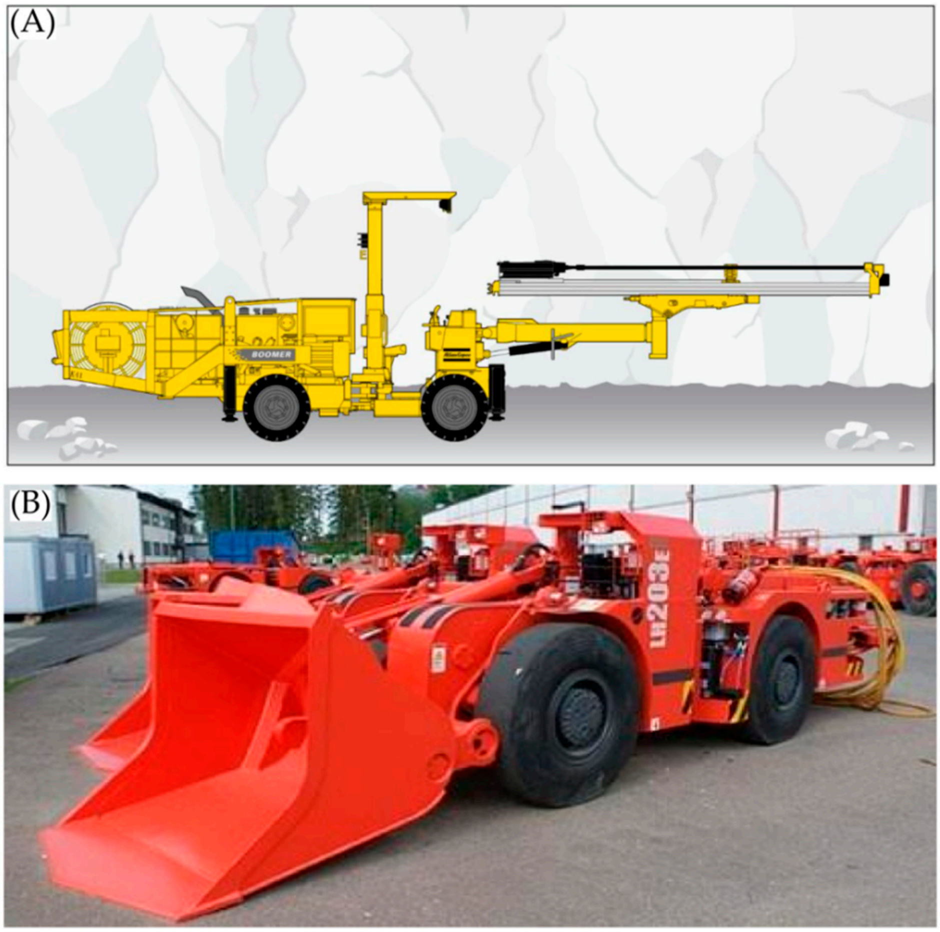

Figure 10. Shishudi Gold Mine: (**A**) Hydraulic rock drilling trolley, type: Boomer K41; (**B**) LHD.

(4) SM mines should actively manage tailings ponds and prevent potential safety hazards and environmental pollution from occurring [40]. At the same time, they should also explore ways to reuse mine solid waste in an economically and environmentally friendly manner. Mine solid waste can be used as aggregate for backfill material in the backfill mining method (as mentioned earlier) [41,42] and also as a valuable secondary resource. For example, it can be used as raw material in the production of building materials [43], glass ceramics [44,45], fertilizers [46], and other products. Proper management of tailings ponds and the reuse of mine solid waste can significantly reduce the environmental impact of mining activities and contribute to sustainable mining practices [47]. Figure 11 illustrates the potential environmental impact of tailings ponds.

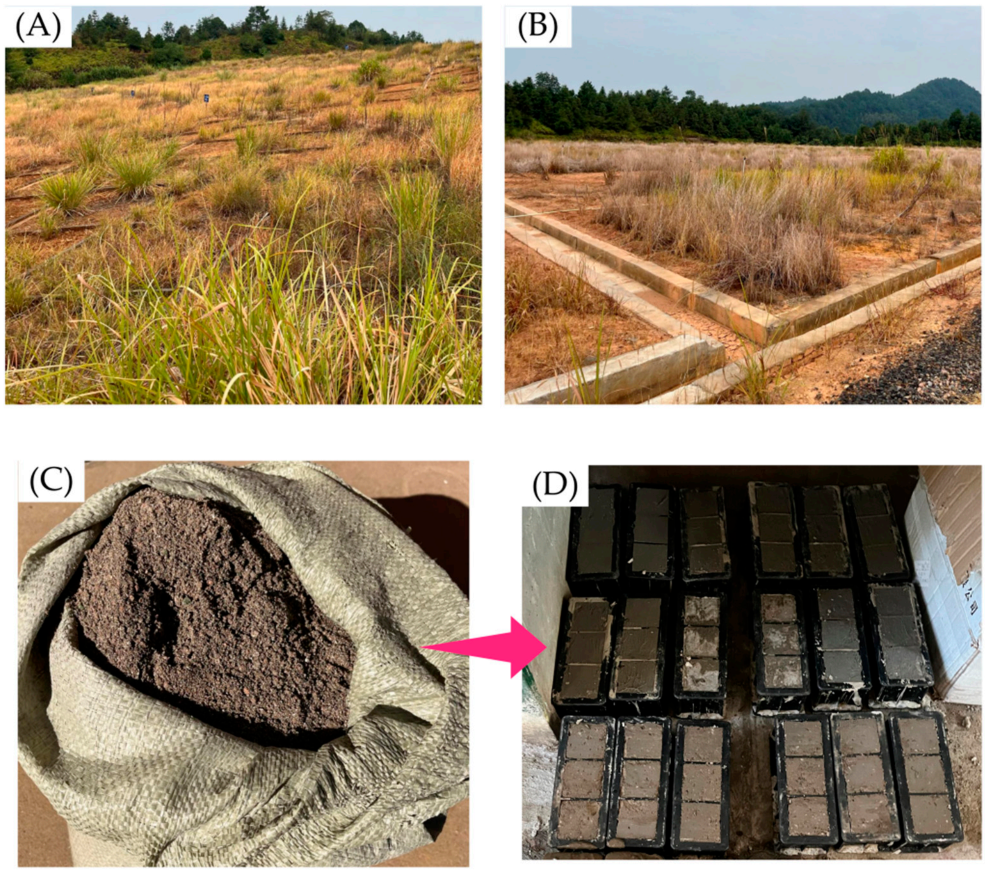

Figure 11. (**A**,**B**): Tailings pond management in Qibaoshan Fe-S Mine, China; (**C**,**D**): Waste recycle.

5. Conclusions

The purpose of this review article is to provide an overview of the current state of China's resource development and mining technology, with a focus on small- and medium-sized (SM) mines. The review article discusses the mining methods and equipment currently used by SM mines in China, as well as the challenges they face, including inadequate management of mining areas and tailings ponds, and low utilization rates of ores. The review article also provides recommendations for the development direction of SM mines in China, including the adoption of backfill mining methods, the building of backfill systems, the reuse of mine solid waste, and the introduction of advanced extraction equipment. Future research can focus on improving and optimizing the relevant technologies of backfill mining methods. This includes improving the performance and stability of backfill materials, optimizing filling processes and equipment, and exploring new types of backfill materials. Through technological innovation, the efficiency and sustainability of backfill mining methods can be further improved [48,49]. The review article concludes by calling for more research in the field of green mining technologies and the promotion of Green Mine Construction. This review article aims to spark a conversation and engage more experts and scholars in this field.

The summaries made of the paper are as follows:

(1) The second section of this paper highlights the inefficient mining methods and equipment widely used by SM mines in China. These include the room-and-pillar method, shrinkage stoping mining method, and sublevel caving mining method, which result in a high rate of ore loss depletion. The equipment used, such as pneumatic rock drills, electric rakes, and rock loaders, are also inefficient in transporting ore. Therefore, there is an urgent need for SM mines in China to upgrade their mining equipment with improved methods to increase efficiency. Additionally, the section also sheds light on the inadequate management of mine waste, which is mostly discharged into tailings ponds, causing environmental pollution and posing safety hazards that require improvement.

(2) The third section of this paper provides a review of the current challenges faced by SM mines in China. These challenges include inadequate management and disposal of mining areas, which can lead to accidents such as mining area collapse and pose a safety hazard. Additionally, there is inadequate management of tailings ponds, which can cause potential pollution and safety hazards. Finally, the utilization rate of small- and medium-sized ores in China is too low, mostly due to the loss of ore depletion caused by outdated mining technology.

(3) In the fourth section of this paper, we provided recommendations for the development direction of other SM mines in China based on the successful example of the Shishudi Gold Mine. These recommendations include introducing backfill mining methods, actively building backfill systems, promoting the reuse of mine solid waste such as tailings, and introducing advanced extraction equipment. These initiatives are well-suited to the development of small- and medium-sized mines in China, as they can improve mining productivity and economic efficiency while ensuring mining safety and environmental management.

Author Contributions: Conceptualization, P.Z.; resources, S.L.; writing—original draft preparation, S.L.; writing—review and editing, H.Y.; visualization, H.Y. and B.H.; supervision, S.L.; project administration, X.W.; funding acquisition, S.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Science Foundation of Hunan Province (Grant No. 2021JJ40745).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: First, authors thank the financial support from the Natural Science Foundation of Hunan Province (Grant No. 2021JJ40745); Second, the authors express their gratitude to the experts in the research field of green mining technology for their effort in the development of the mining industry; the authors express sincere thanks to the Central South University.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yu, H.; Li, S.; Wang, X. The Recent Progress China Has Made in the Backfill Mining Method, Part I: The Theory and Equipment of Backfill Pipeline Transportation. *Minerals* **2021**, *11*, 1274. [CrossRef]
2. Wang, J.; Huang, X.; Hu, K.; Li, X. Evaluation on community development programs in mining industry: A case study of small and medium enterprise in China. *Resour. Policy* **2018**, *59*, 516–524. [CrossRef]
3. Li, S.; Zhao, Z.; Yu, H.; Wang, X. The Recent Progress China Has Made in the Backfill Mining Method, Part II: The Composition and Typical Examples of Backfill Systems. *Minerals* **2021**, *11*, 1362. [CrossRef]
4. Song, X.; Mu, X. The safety regulation of small-scale coal mines in China: Analysing the interests and influences of stakeholders. *Energy Policy* **2013**, *52*, 472–481. [CrossRef]

5. Li, Z.Y.; Ma, Z.W.; van der Kuijp, T.J.; Yuan, Z.W.; Huang, L. A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. *Sci. Total Environ.* **2014**, *468*, 843–853. [CrossRef]
6. Wang, G.; Xu, Y.; Ren, H. Intelligent and ecological coal mining as well as clean utilization technology in China: Review and prospects. *Int. J. Min. Sci. Technol.* **2019**, *29*, 161–169. [CrossRef]
7. Yu, H.; Li, S.; Wang, X. The Recent Progress China Has Made in the Backfill Mining Method, Part III: Practical Engineering Problems in Stope and Goaf Backfill. *Minerals* **2022**, *12*, 88. [CrossRef]
8. Shen, L.; Cheng, S.; Gunson, A.J.; Wan, H. Urbanization, sustainability and the utilization of energy and mineral resources in China. *Cities* **2005**, *22*, 287–302. [CrossRef]
9. Zhai, M.; Hu, R.; Wang, Y.; Jiang, S.; Wang, R.; Li, J.; Chen, H.; Yang, Z.; Lü, Q.; Qi, T.; et al. Mineral Resource Science in China: Review and perspective. *Geogr. Sustain.* **2021**, *2*, 107–114. [CrossRef]
10. Li, C.; Wang, A.; Chen, X.; Chen, Q.; Zhang, Y.; Li, Y. Regional distribution and sustainable development strategy of mineral resources in China. *Chin. Geogr. Sci.* **2013**, *23*, 470–481. [CrossRef]
11. Yu, H.; Zahidi, I. Environmental hazards posed by mine dust, and monitoring method of mine dust pollution using remote sensing technologies: An overview. *Sci. Total Environ.* **2022**, *864*, 161135. [CrossRef] [PubMed]
12. Li, X.B.; Qiu, J.D.; Zhao, Y.Z.; Chen, Z.H.; Li, D.Y. Instantaneous and long-term deformation characteristics of deep room-pillar system induced by pillar recovery. *Trans. Nonferrous Met. Soc. China* **2020**, *30*, 2775–2791. [CrossRef]
13. Skrzypkowski, K. Case studies of rock bolt support loads and rock mass monitoring for the room and pillar method in the legnica-głogów copper district in Poland. *Energies* **2020**, *13*, 2998. [CrossRef]
14. Ataei, M.; Sereshki, F.; Jamshidi, M.; Jalali, S.M.E. Suitable mining method for Golbini No. 8 deposit in Jajarm (Iran) using TOPSIS method. *Min. Technol.* **2008**, *117*, 1–5. [CrossRef]
15. Yu, S.-F.; Wu, A.-X.; Wang, Y.-M.; Li, T. Pre-reinforcement grout in fractured rock masses and numerical simulation for optimizing shrinkage stoping configuration. *J. Cent. South Univ.* **2017**, *24*, 2924–2931. [CrossRef]
16. Kim, H.H.; Swanson, N.R. Mining big data using parsimonious factor, machine learning, variable selection and shrinkage methods. *Int. J. Forecast.* **2018**, *34*, 339–354. [CrossRef]
17. Balusa, B.C. Analysing the Role of Safety Level and Capital Investment in Selection of Underground Metal Mining Method. *Int. J. Min. Geo-Eng.* **2021**, *55*, 125–131.
18. Lin, Y. Research on Mining Technology of Steeply Inclined Thin Ore Body in High-grade Content Mine. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *632*, 022038.
19. Brunton, I.; Fraser, S.; Hodgkinson, J.; Stewart, P. Parameters influencing full scale sublevel caving material recovery at the Ridgeway gold mine. *Int. J. Rock Mech. Min. Sci.* **2010**, *47*, 647–656. [CrossRef]
20. Rempel, D.; Antonucci, A.; Barr, A.; Cooper, M.R.; Martin, B.; Neitzel, R. Pneumatic rock drill vs. electric rotary hammer drill: Productivity, vibration, dust, and noise when drilling into concrete. *Appl. Ergon.* **2019**, *74*, 31–36. [CrossRef] [PubMed]
21. Yu, H.; Zhao, C.; Li, S.; Wang, Z.; Zhang, Y. Pre-Work for the Birth of Driver-Less Scraper (LHD) in the Underground Mine: The Path Tracking Control Based on an LQR Controller and Algorithms Comparison. *Sensors* **2021**, *21*, 7839. [CrossRef]
22. Wang, J.; Yang, S.; Li, Y.; Wei, L.; Liu, H. Caving mechanisms of loose top-coal in longwall top-coal caving mining method. *Int. J. Rock Mech. Min. Sci.* **2014**, *71*, 160–170. [CrossRef]
23. Li, S.; Zhang, Y.; Feng, R.; Yu, H.; Pan, J.; Bian, J. Environmental Safety Analysis of Red Mud-Based Cemented Backfill on Groundwater. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8094. [CrossRef] [PubMed]
24. Li, S.; Zhang, R.; Feng, R.; Hu, B.; Wang, G.; Yu, H. Feasibility of Recycling Bayer Process Red Mud for the Safety Backfill Mining of Layered Soft Bauxite under Coal Seams. *Minerals* **2021**, *11*, 722. [CrossRef]
25. Jia, H.; Yan, B.; Yilmaz, E. A large goaf group treatment by means of mine backfill technology. *Adv. Civ. Eng.* **2021**, *2021*, 3737145. [CrossRef]
26. Zhou, J.; Li, X.; Mitri, H.S.; Wang, S.; Wei, W. Identification of large-scale goaf instability in underground mine using particle swarm optimization and support vector machine. *Int. J. Min. Sci. Technol.* **2013**, *23*, 701–707. [CrossRef]
27. Li, S.; Yu, Z.; Yu, H.; Wang, X. The Recent Progress China Has Made in High-Concentration Backfill. *Sustainability* **2022**, *14*, 2758. [CrossRef]
28. Li, S.; Yu, L.; Jiang, W.; Yu, H.; Wang, X. The Recent Progress China Has Made in Green Mine Construction, Part I: Mining Groundwater Pollution and Sustainable Mining. *Int. J. Environ. Res. Public Health* **2022**, *19*, 5673. [CrossRef]
29. Koppe, J.C. Lessons Learned from the Two Major Tailings Dam Accidents in Brazil. *Mine Water Environ.* **2021**, *40*, 166–173. [CrossRef]
30. Porsani, J.L.; Jesus, F.A.N.D.; Stangari, M.C. GPR survey on an iron mining area after the collapse of the tailings dam I at the Córrego do Feijão mine in Brumadinho-MG, Brazil. *Remote Sens.* **2019**, *11*, 860. [CrossRef]
31. Wang, Y.; Zheng, G.; Wang, X. Development and application of a goaf-safety monitoring system using multi-sensor information fusion. *Tunn. Undergr. Space Technol.* **2019**, *94*, 103112. [CrossRef]
32. Wang, F.; Zhang, C.; Zhang, X.; Song, Q. Overlying strata movement rules and safety mining technology for the shallow depth seam proximity beneath a room mining goaf. *Int. J. Min. Sci. Technol.* **2015**, *25*, 139–143. [CrossRef]
33. Hu, B.; Zhang, Q.; Li, S.; Yu, H.; Wang, X.; Wang, H. Application of Numerical Simulation Methods in Solving Complex Mining Engineering Problems in Dingxi Mine, China. *Minerals* **2022**, *12*, 123. [CrossRef]

34. Li, X.; Liu, Z.; Yang, S. Similar physical modeling of roof stress and subsidence in room and pillar mining of a gently inclined medium-thick phosphate rock. *Adv. Civ. Eng.* **2021**, *2021*, 6686981. [CrossRef]
35. Chin, W.Q.; Lee, Y.H.; Amran, M.; Fediuk, R.; Vatin, N.; Kueh, A.B.H.; Lee, Y.Y. A Sustainable Reuse of Agro-Industrial Wastes into Green Cement Bricks. *Materials* **2022**, *15*, 1713. [CrossRef]
36. Imbabi, M.S.; Carrigan, C.; McKenna, S. Trends and developments in green cement and concrete technology. *Int. J. Sustain. Built Environ.* **2012**, *1*, 194–216. [CrossRef]
37. Wu, M.; Zhang, Y.; Ji, Y.; Liu, G.; Liu, C.; She, W.; Sun, W. Reducing Environmental Impacts and Carbon Emissions: Study of Effects of Superfine Cement Particles on Blended Cement Containing High Volume Mineral Admixtures. *J. Clean. Prod.* **2018**, *196*, 358–369. [CrossRef]
38. Ye, Z.H.; Chen, L.; Yan, Q.; Wang, A.J. A review of exploitation, utilization and strategic research of nonmetallic minerals in china. *Appl. Mech. Mater.* **2014**, *666*, 359–362. [CrossRef]
39. Feng, X.; Zhang, Q. The effect of backfilling materials on the deformation of coal and rock strata containing multiple goaf: A numerical study. *Minerals* **2018**, *8*, 224. [CrossRef]
40. Yu, H.; Zahidi, I. Spatial and temporal variation of vegetation cover in the main mining area of Qibaoshan Town, China: Potential impacts from mining damage, solid waste discharge and land reclamation. *Sci. Total Environ.* **2023**, *859*, 160392. [CrossRef]
41. Yu, H.; Li, S.; Yu, L.; Wang, X. The Recent Progress China Has Made in Green Mine Construction, Part II: Typical Examples of Green Mines. *Int. J. Environ. Res. Public Health* **2022**, *19*, 8166. [CrossRef]
42. Guo, Q.; Yu, H.; Dan, Z.; Li, S. Mining Method Optimization of Gently Inclined and Soft Broken Complex Ore Body Based on AHP and TOPSIS: Taking Miao-Ling Gold Mine of China as an Example. *Sustainability* **2021**, *13*, 12503. [CrossRef]
43. Martins, N.P.; Srivastava, S.; Simão, F.V.; Niu, H.; Perumal, P.; Snellings, R.; Illikainen, M.; Chambart, H.; Habert, G. Exploring the potential for utilization of medium and highly sulfidic mine tailings in construction materials: A review. *Sustainability* **2021**, *13*, 12150. [CrossRef]
44. Li, B.; Guo, Y.; Fang, J. Effect of crystallization temperature on glass-ceramics derived from tailings waste. *J. Alloys Compd.* **2020**, *838*, 155503. [CrossRef]
45. Xu, W.; Shen, K.; Cao, Z.; Liu, F.; Zhang, Y.; Zhang, T.; Ouyang, S. Crystallization and thermal stability effects on tailings glass-ceramics by various heat treating processes. *Mater. Chem. Phys.* **2021**, *263*, 124334. [CrossRef]
46. Huang, L.; Li, X.; Nguyen, T.A. Extremely high phosphate sorption capacity in Cu-Pb-Zn mine tailings. *PLoS ONE* **2015**, *10*, e0135364. [CrossRef]
47. Yu, H. Mining waste: Curb risks to people and the environment. *Nature* **2023**, *615*, 586. [CrossRef]
48. Bicket, M.; Guilcher, S.; Hestin, M.; Hudson, C.; Razzini, P.; Tan, A.; ten Brink, P.; van Dijl, E.; Vanner, R.; Watkins, E. *Scoping Study to Identify Potential Circular Economy Actions, Priority Sectors, Material Flows and Value Chains*; Publications Office of the European Union: Luxembourg, 2014.
49. Asr, E.T.; Kakaie, R.; Ataei, M.; Mohammadi, M.R.T. A review of studies on sustainable development in mining life cycle. *J. Clean. Prod.* **2019**, *229*, 213–231. [CrossRef]