International Journal of Education and Humanities
ISSN: 2770-6702 | Vol. 15, No. 1, 2024

Comprehensive Benefit Analysis of Coal Gangue Resource Utilization

Zhisheng Huang

Shaanxi Dijian Hotel Management Group Co., LTD, Xi'an 710075, China

Abstract: This paper discusses the environmental, social, and economic benefits of coal gangue resource utilization, as well as the associated technical challenges and policy analysis. Coal gangue, a common industrial waste, plays a significant role in promoting sustainable development. The paper defines coal gangue and explains its origins, emphasizing the necessity of resource utilization. It then analyzes the application of physical, chemical, and biological methods in coal gangue treatment and explores integrated utilization approaches, such as transforming coal gangue into building materials and soil amendments. In discussing the comprehensive benefits of coal gangue resource utilization, the paper highlights contributions to environmental protection, including pollution reduction and energy conservation. Socially, resource utilization provides new job opportunities for local communities and contributes to public health improvement. Economically, the paper points out that resource utilization can promote industrial chain development and economic growth through cost analysis and market potential assessment. The discussion on technological innovation and future trends reveals the potential of emerging technologies to enhance resource utilization efficiency and support sustainable industry development. The paper also identifies technical challenges and research directions, emphasizing the importance of continuous R&D and interdisciplinary collaboration.

Keywords: Coal Gangue Resource Utilization, Environmental Protection, Technological Innovation, Socio-economic Benefits.

1. Introduction

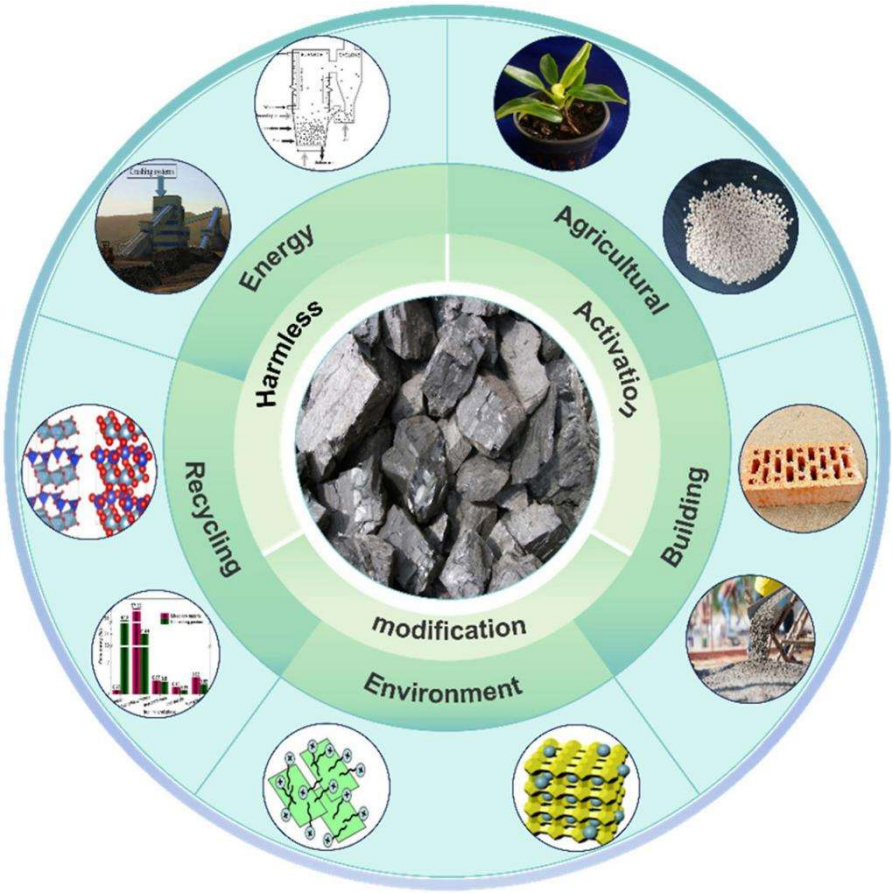

Figure 1. Comprehensive utilization of coal gangue[7]

While pursuing economic development, human activities have significantly impacted the environment, particularly in energy-intensive industries like coal mining. Coal gangue, the primary solid waste produced during coal mining, has become one of China's urgent environmental issues. With the goals of "carbon peak and carbon neutrality," the green transformation and upgrading of the coal industry have become especially

important. The resource utilization of coal gangue not only helps reduce environmental pollution but also promotes the recycling of resources, which is a vital pathway to green and sustainable development.

Coal gangue formation is closely related to coal mining. During coal formation, rocks formed by a mixture of organic and inorganic compounds are typically distributed in thin layers within or at the top and bottom of coal seams. Due to its low carbon content, hardness, and high ash content on a dry basis, the storage and disposal of coal gangue can cause a series of environmental problems, such as spontaneous combustion, acid rain, underground seepage, and river blockage[1-3]. Currently, the comprehensive utilization rate of coal gangue remains low, and a standardized and feasible research system has not yet been established. The resource utilization pathways for coal gangue include energy production, valuable metal recovery, and building material production. For instance, coal gangue can be used to prepare photocatalysts[4], adsorbents, and zeolite molecular sieves for wastewater treatment; it can also replace clay minerals in the production of concrete, cement, bricks[5], and other building materials; moreover, it can be used to improve soil, prepare seedling substrates, fertilizers, etc[6] (Figure 1).

However, research on coal gangue resource utilization should consider regional differences, phased resource utilization, and secondary pollution issues. Future research directions should include increasing the resource utilization rate of coal gangue, developing new technologies for high-value utilization, and exploring the application of coal gangue in preventing heavy metal pollution, soil remediation, and erosion control. In summary, coal gangue resource utilization is an important direction for the transformation and upgrading of China's coal industry and a necessary path to achieve green and sustainable development. Only through relentless efforts and continuous innovation can we better address the accumulation of coal gangue, promote its resource utilization towards more efficient, environmentally friendly, and sustainable development, and make a greater contribution to the sustainable development of China's economy and society.

2. Methods of Coal Gangue Resource Utilization

Coal gangue, a by-product of coal mining, has long been treated as waste. However, with the increasing awareness of resource scarcity and environmental protection, people have begun to explore ways to utilize coal gangue as a resource. The resource utilization of coal gangue can not only reduce environmental pollution but also provide new impetus for socio-economic development. Currently, the methods of coal gangue resource utilization mainly include physical, chemical, biological, and comprehensive utilization methods.

2.1. Physical Methods

Physical methods mainly include sorting, flotation, magnetic separation, etc., which separate the useful components from coal gangue through physical actions. For example, flotation technology can effectively recover coal powder from coal gangue, which can be used as industrial fuel[8, 9]. Magnetic separation technology can separate ferromagnetic substances from coal gangue, which can be used in the metallurgical industry. The advantage of physical methods is that the process is simple and the cost is low, but the disadvantage is that the recovery rate and purity are relatively low. The researchers proposed a physical method that uses high-concentration acid and microwave heating to extract high-purity silicon from coal gangue, and then adds Na_2SO_4 to prepare water glass, effectively achieving high-value utilization of coal gangue[10].

2.2. Chemical Methods

Chemical methods mainly use chemical reactions to extract valuable metals from coal gangue or change its properties. Acid washing is a common chemical method that can remove sulfur and other impurities from coal gangue. Leaching technology can extract valuable metals such as aluminum and silicon from coal gangue[11, 12], which have a wide range of applications in construction, chemical, and other industries. The advantage of chemical methods is that they can achieve higher recovery rates and purity, but the disadvantage is that secondary pollution may occur during the process. By using high-temperature calcination and low-temperature acid leaching processes to leach gallium from coal gangue, and then using solvent extraction from the above two leaching solutions, gallium can be enriched by more than 100 times, with a recovery rate of about 90%.

2.3. Biological Methods

Biological methods use the biological actions of microorganisms or plants to treat coal gangue[13-15]. Microbial treatment technology uses specific microbial communities to transform harmful substances in coal gangue into harmless substances. Phytoremediation technology uses the growth process of plants to absorb and transform harmful substances such as heavy metals in coal gangue. The advantage of biological methods is that they are environmentally friendly and sustainable, but the disadvantage is that the treatment cycle is long and greatly affected by environmental conditions. In Ningxia Dawukou coal washing plant, coal gangue hills were mixed planted with ash seedlings inoculated with and without arbuscular mycorrhizal fungi. The experimental results showed that 13 months after inoculation with mycorrhizal fungi, the vegetation survival rate was effectively improved (15%), plant growth was promoted (the coverage of inoculated plants was 9% higher than the control), and the infection rate was over 90%. The length of mycelium was 1.4 times longer than the control, expanding the range of the root system, which greatly promoted the resource utilization of coal gangue and the ecological restoration around the gangue hills.

2.4. Comprehensive Utilization Methods

Comprehensive utilization methods combine physical, chemical, biological, and other methods to optimize the resource utilization of coal gangue. For example, first, use physical methods to separate coal powder and ferromagnetic substances from coal gangue, then use chemical methods to extract valuable metals, and finally use biological methods for environmental remediation. The advantage of comprehensive utilization methods is that they can fully utilize the advantages of various methods to maximize resource utilization, but the disadvantage is that the technology is complex and the cost is high.

3. Comprehensive Benefits of Coal Gangue Resource Utilization

3.1. Environmental Benefits

The environmental benefits of coal gangue resource utilization are mainly reflected in reducing environmental pollution and ecological restoration. By transforming coal gangue into useful resources, its pollution to land and water bodies can be reduced. For example, coal gangue can be used to produce building materials[16], which not only reduces the exploitation of natural resources but also decreases the land occupation and environmental pollution caused by coal gangue dumping. Additionally, the organic matter and trace elements in coal gangue can be used for soil improvement, promoting vegetation growth, and contributing to the recovery and stability of ecosystems.

3.2. Economic Benefits

The economic benefits of coal gangue resource utilization are primarily manifested in reducing treatment costs and creating new economic value. Resource-based products from coal gangue, such as building materials and chemical raw materials, have high market demand and can bring considerable economic benefits. Furthermore, the resource utilization of coal gangue can also promote the development of related industrial chains, such as building materials, chemicals, agriculture, etc., providing new growth points for socio-economic development[17].

3.3. Social Benefits

The social benefits of coal gangue resource utilization are mainly reflected in promoting employment and improving public health. The resource utilization of coal gangue can create new job opportunities, especially in industries such as building materials and chemicals. At the same time, by improving environmental quality, the living standards of residents in mining areas and surrounding areas can be enhanced, promoting social stability and development.

3.4. Sustainability Benefits

The sustainability benefits of coal gangue resource utilization are reflected in promoting sustainable development. By effectively utilizing coal gangue, dependence on natural resources can be reduced, environmental pollution can be lowered, and the coordinated development of the economy, environment, and society can be achieved, aligning with the concept of sustainable development.

4. Technological Innovation and Future Trends in Coal Gangue Resource Utilization

Against the backdrop of achieving the "carbon peak and carbon neutrality" goals, technological innovation and future trends in coal gangue resource utilization have become hot research topics. Coal, as the cornerstone of national energy security, plays a crucial role in China's economic construction and social development. Coal gangue, as a major by-product associated with coal, has become the foremost bulk solid waste that China urgently needs to address.

4.1. Technological Innovation

Technological innovation is key to advancing the resource utilization of coal gangue. Currently, the comprehensive utilization rate of coal gangue is still low, and a standardized and feasible research system has not yet been formed. Therefore, in response to the water, air, and soil environmental pollution caused by coal mining and coal gangue accumulation, research progress shows that breakthroughs are continuously being made in the resource utilization of coal gangue in energy production, valuable metal recovery, building material production, and other directions. For example, the application of coal gangue in preventing heavy metal pollution, soil remediation, and erosion control has demonstrated its enormous potential in environmental governance. Additionally, research on the physical and chemical properties of coal gangue provides a scientific basis for its resource utilization.

4.2. Future Trends

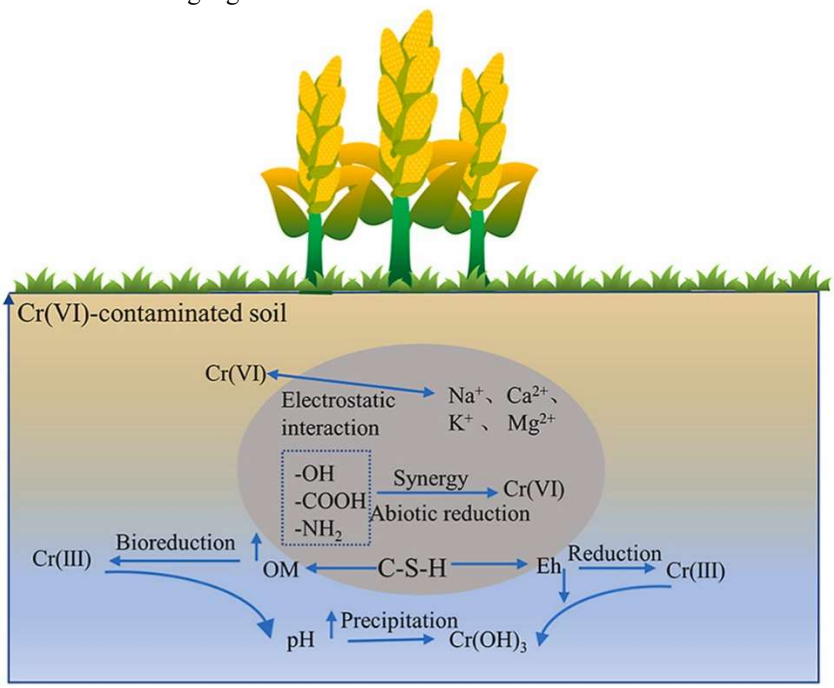

Figure 2. Immobilization of hexavalent chromium in soil-plant environment[21]

The future development direction of coal gangue resource utilization will involve overall planning and resource integration. There will be a large number of conventional purposes for coal gangue resource utilization, as well as special uses for producing high-value-added products. By combining both, comprehensive and resource utilization of coal gangue can be achieved, providing a reference for its "reduction, resource-based, and recycling" development.

The future development directions of coal gangue resource utilization include: (1) High-value utilization: Researching how to transform coal gangue into high-value-added products, such as advanced ceramic materials, rare metal extraction, etc[18]. (2) Ecological environment: Using coal gangue for soil reclamation and ecological restoration to improve the environmental quality of mining areas and surrounding regions[19] (Figure 2). (3) New process development: Developing new coal gangue resource utilization processes, such as interlayer zone grouting filling technology, to achieve effective bulk utilization of coal gangue[20].

5. Driving Forces Behind the Resource Utilization of Coal Gangue

The policy environment provides the necessary legal, economic, and social support for the resource utilization of coal gangue, while the driving forces are the internal impetus that propels this process forward.

5.1. Policy Environment

The policy environment includes a series of laws, regulations, standards, and guiding principles established by national and local governments. These policies aim to promote the resource utilization of coal gangue, protect the environment, and simultaneously promote economic development. For example, the Chinese government has introduced several policies to encourage the comprehensive utilization of coal gangue, including tax incentives, financial subsidies, and project support.

5.2. Development Drivers

Development drivers include factors such as market demand, technological advancement, and increased awareness of environmental protection. Market demand is one of the main drivers of coal gangue resource utilization. As the markets for building materials and chemical products expand, the value of coal gangue utilization has been recognized. Technological progress has made the resource utilization of coal gangue more efficient and economical, while the rise in environmental protection awareness has prompted all sectors of society to pay attention to the impact of coal gangue on the environment and seek sustainable solutions.

5.3. Future Outlook

In the future, the policy environment and development drivers for the resource utilization of coal gangue will place even greater emphasis on sustainability and environmental friendliness. Policies are expected to be further refined to support more technological innovation and industrial development in coal gangue resource utilization. At the same time, with the public's increasing awareness of environmental protection and the development of clean energy technologies, the resource utilization of coal gangue will become an important way to promote the development of the green economy.

6. Conclusion

The resource utilization of coal gangue has significant benefits for environmental protection. By adopting advanced physical and chemical methods, the production and dumping of coal gangue can be effectively reduced, thereby alleviating environmental pollution. At the same time, biological methods such as microbial management and phytoremediation not only improve soil quality but also promote the recovery of ecosystems. Furthermore, the resource utilization of coal gangue has also had a positive impact on the social level. It has provided new job opportunities for local residents, especially in industries related to resource utilization. This not only helps to improve the economic level of the community but also improves public health and the quality of life for residents. The exploration and application of emerging technologies have opened up new possibilities for the resource utilization of coal gangue. These technologies not only improve the efficiency of resource utilization but also support the sustainable development of the industry. Faced with technological challenges and research directions, we must continue to invest in R&D and encourage interdisciplinary cooperation to promote technological progress and innovation. The resource utilization of coal gangue is not only an effective way to solve environmental problems but also an important strategy to promote the sustainable development of society and the economy. Future policy-making should focus more on the comprehensive benefits of resource utilization, encourage technological innovation, and through cooperation and exchange, achieve the internationalization and standardization of resource utilization.

References

[1] Yu CL, Huang WH, Jiu B, Hao RL. Geochemistry Characteristics and Paleoenvironmental Significance of Trace Elements in Coal and Coal Gangue in the Yangcheng Mining Area, Qinshui Basin. ACS Omega. 2022. doi: 10.1021/acsomega.1c06935.

[2] Wang G, Xie YW, Qin Y, Wang JX, Shen J, Han BB, et al. Element geochemical characteristics and formation environment for the roof, floor and gangue of coal seams in the Gujiao mining area, Xishan coalfield, China. Journal of Geochemical Exploration. 2018. doi: 10.1016/j.gexplo. 2018. 04.007.

[3] Guo WK, Chen B, Li GY, Liu MY, Liu X, Chen Q, et al. Ambient PM2.5 and Related Health Impacts of Spontaneous Combustion of Coal and Coal Gangue. Environmental Science & Technology. 2021. doi: 10.1021/acs.est.1c00150.

[4] Xu Q, Chen C, Yan Y, Jiao YZ, Wang J, Wang XQ, et al. Interfacial charge transfer in coal gangue/NiO-x composites photocatalyst for efficient-degradation of ciprofloxacin. Materials Chemistry and Physics. 2024. doi: 10.1016/j.matchemphys.2024.129238.

[5] Gao S, Zhang SM, Guo LH. Application of Coal Gangue as a Coarse Aggregate in Green Concrete Production: A Review. Materials. 2021. doi: 10.3390/ma14226803.

[6] Fan Y, Jia HQ, Pino V, Wu HB, Cheng FQ. A Si-K-Based Amendment Prepared by Coal Gangue and Plant Ash Could Improve the Growth of Maize Plants in Saline Soils. Journal of

Soil Science and Plant Nutrition. 2023. doi: 10.1007/s42729-023-01582-z.

[7] Zheng QW, Zhou Y, Liu X, Liu M, Liao LB, Lv GC. Environmental hazards and comprehensive utilization of solid waste coal gangue. Progress in Natural Science: Materials International. 2024;34(2):223-39. doi: https://doi.org/10.1016/j.pnsc.2024.02.012.

[8] Zhang T, Yang HF, Zhang HB, Zhang P. Study on electrochemical improvement of flotation reagents for carbon recovery from coal gangue. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2022. doi: 10.1080/15567036.2021.2024303.

[9] Zhang L, Chen HC, Pan JH, Wen ZP, Shi SL, Long X, et al. The Effect of Physical Separation and Calcination on Enrichment and Recovery of Critical Elements from Coal Gangue. Minerals. 2022. doi: 10.3390/min12111371.

[10] Zhang T, Yang HF, Zhang HB, Zhang P. Preparation of monodisperse silica powder from acid residue after extracting alumina from coal gangue. Asia-Pacific Journal of Chemical Engineering. 2022. doi: 10.1002/apj.2845.

[11] Zhang T, Yang HF, Zhang HB, Zhang P, Bei RN. Aluminum extraction from activated coal gangue with carbide slag. Journal of Analytical and Applied Pyrolysis. 2022. doi: 10.1016/j.jaap.2022.105504.

[12] Zhao JC, Yu T, Zhang H, Zhang Y, Ma LT, Li JL, et al. Study on Extraction Valuable Metal Elements by Co-Roasting Coal Gangue with Coal Gasification Coarse Slag. Molecules. 2023. doi: 10.3390/molecules29010130.

[13] Chen D, Feng QY, Zhang Y. Enrichment and response of iron-metabolizing microorganisms and metabolic genes in the contaminated area of stratified stacking coal gangue dumps, Northern China. Environmental Science and Pollution Research. 2023. doi: 10.1007/s11356-023-26775-y.

[14] Li M, Peng YF, Zhang JX, Zhao Y, Wang ZJ, Guo Q, et al. Properties of a backfill material prepared by cementing coal gangue and fly ash through microbial-induced calcite precipitation. Construction and Building Materials. 2023. doi: 10.1016/j.conbuildmat.2023.131329.

[15] Zhu Q, Ruan MY, Hu ZQ, Miao KX, Ye C. The Relationship between Acid Production and the Microbial Community of Newly Produced Coal Gangue in the Early Oxidation Stage. Microorganisms. 2023. doi: 10.3390/microorganisms11112626.

[16] Fu FH, Hu NY, Ye YC, Chen G, Guan WC, Yang SW, et al. Production of high-value-added lightweight glass ceramics based on phosphorus tailings and coal gangue. Ceramics International. 2024. doi: 10.1016/j.ceramint.2024.02.245.

[17] Zhang ZT, Xu YX, Liao JB, Liu SK, Liu Z, Gao WH, et al. Study on the Particle Strength and Crushing Patterns of Coal Gangue Coarse-Grained Subgrade Fillers. Sustainability. 2024. doi: 10.3390/su16125155.

[18] Sun ZH, Hu YJ, Zeng K, Li M, Zhao S, Zhang JX. Turn “Waste” Into Wealth: MoO2@coal Gangue Electrocatalyst with Amorphous/Crystalline Heterostructure for Efficient Li–O2 Batteries. Small. 2023. doi: 10.1002/smll.202208145.

[19] Du T, Wang DM, Bai YJ, Zhang ZZ. Optimizing the formulation of coal gangue planting substrate using wastes: The sustainability of coal mine ecological restoration. Ecological Engineering. 2020. doi: 10.1016/j.ecoleng.2019.105669.

[20] Yao YN, Yan H, Chen JY, Xu JF. Mining-induced off-layer space evolution law and gangue grouting filling control mechanism. Bulletin of Engineering Geology and the Environment. 2023. doi: 10.1007/s10064-023-03489-6.

[21] Zhang Q, Liu GJ, Peng SC, Zhou CC, Arif M. Immobilization of hexavalent chromium in soil-plant environment using calcium silicate hydrate synthesized from coal gangue. Chemosphere. 2022. doi: 10.1016/j.chemosphere.2022.135438.