

Solutions to Strengthen Multi-Industry Linkages to Promote the Circular Economy in the Vietnamese Coal Mining Industry

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Abstract: *After a long period of operating the linear economic model, humans are now facing its consequences: resource depletion, environmental pollution and climate change. In this situation, the transition to the green economy and the circular economy is the necessary task for countries around the world, including Vietnam. The circular economy is an economy that is actively designed to recycle, reuse and prolong the life of materials. Therefore, this economy helps to save resources, slow down resource depletion, environmental pollution and climate change. In the transition to the circular economy, the mining and processing industry is one of the priority sectors and fields for implementation. The coal mining industry provides means of production to ensure national energy security. The output of the industry is the input of many other industries. Therefore, to promote the circular economic model in the industry, there must be close links with related industries. In the paper, the authors use case study method. In conjunction with the theoretical analysis of the circular economy model and its application within the mining sector, the paper analysed several domestic and international case studies about multi-sectoral linkages in the coal mining industry to achieve circular economy goals. Basing on the analysis, the paper proposed the inter-sectoral circular economy model tailored to Vietnam's coal mining industry. The paper also recommends some solutions to foster multi-sectoral linkages to facilitate the implementation of the circular economy model within the industry.*

Keywords: *Multi-sectoral linkages; the circular economy; mining industry*

1. Introduction

In light of the serious consequences humanity faces from the traditional linear economy, the transition of the current economic model is an inevitable trend for countries around the world (Rashid and Malik, 2023). The circular economy is an economic model that offers numerous benefits to address the consequences of the linear economy model, such as mitigating environmental pollution by minimizing waste discharged directly into ecological systems and reducing reliance on raw resources, etc. (European Parliament, 2023). Therefore, the circular economy model is the most suitable replacement for the traditional linear economy model, especially given the current context of a population boom and the severe consequences of the linear economy.

The mining industry, including coal mining, is a fundamental economic sector that extracts underground resources to meet the demand of national economy for mineral raw materials. However, this industry also has very negative impacts on both the ecological and geological environments due to its large volume of solid, liquid, and gaseous waste. The enormous amount of waste from this industry, such as spoil, wastewater from mining and screening operations, and gas released from coal seams during extraction, etc. is a source of pollution but also has the potential for circular economy initiatives. Therefore, implementing the circular economy model in this industry not only solves environmental problems by minimizing waste discharge but also creates significant value by leveraging the recycling and reuse of that waste. Therefore, in Vietnam's National Action Program on the implementation of the circular economy until 2035, the mineral mining and processing industry is one of the prioritized economic sectors (Vietnam Government, 2025).

In the national economy, every economic sector operates in close relationship with other sectors. These relationships are formed by providing input resources, consuming output products, or cooperating to solve issues related to resource use and environmental protection. Therefore, to implement the circular economy model in any economic sector, including the coal mining industry, it is essential to have collaboration and cooperation among different economic sectors. Thus, to accelerate the implementation of

the circular economy in the coal mining industry, it is necessary to enhance multi-sector cooperation and collaboration.

A variety of research has been conducted on the circular economy model within the mining and coal mining industries in Vietnam. These researches primarily focus on specific issues, such as analyzing the potential for recycling and reusing mine waste rock (Do Manh Dung et al., 2023b); (Nguyen Viet Cuong and La Manh Hai, 2023), treating and circulating mine wastewater (Tran Mien, 2023), and leveraging mine tailings from processing plants as construction materials (Pham Duc Phong and Tran Thi Hien, 2023). Other research has explored technologies for recycling and reusing waste from the mining industry, including methods for recycling and reusing waste from mineral extraction and processing (Pham Van Luan and Le Viet Ha, 2023), or technologies for recycling waste fly ash and red mud for use as green cement additives (Bui Xuan Nam et al., 2023), etc. However, there is a notable lack of research on multi-sectoral linkages to promote a circular economy model in this industry. As analyzed previously, collaboration among different economic sectors is crucial for implementing a circular economy model. The paper will focus on developing the inter-sectoral circular economy model tailored to the coal mining industry in Vietnam to provide a comprehensive view of these multi-sectoral linkages. Subsequently, it will propose solutions to foster these linkages within the industry, aiming for the goals of the circular economy and sustainable development.

2. Literature review

2.1. Overview of the circular economy and the circular economy in the mining sector

2.1.1. The circular economy

Currently, there are over 114 different definitions of the circular economy (Kirchherr et al., 2017). Such as, according to the Ellen MacArthur Foundation, “the circular economy is a restorative and regenerative system by design. It replaces the “end-of-life” concept for materials with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals that harm reuse, and aims to minimize waste through the design of materials, products, technical systems, and business models within its scope” (Ellen MacArthur Foundation, 2012); or according to the European Parliament's definition “The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended” (European Parliament, 2023).

Despite a variety of existing concepts, the circular economy has several core characteristics: (1) the circular economy is fundamentally linked to reducing waste and pollution and minimizing resource consumption and loss from the very beginning of the design stage of operating processes instead of just addressing the consequences of development; (2) It keeps products and materials in use for as long as possible through activities like repair, maintenance, refurbishment, or reuse; (3) It recycles waste from operational processes, transforming it into a secondary resource to supplement and reduce the economy's demand for raw materials; and (4) It conserves and regenerates natural systems, moving toward the use of renewable energy sources. Thus, in a circular economy, natural resources are exploited and used rationally; renewable energy sources are harnessed and prioritized to gradually replace fossil fuels; materials are maintained for as long as possible within their life cycle; waste is recycled as much as possible; and natural systems are restored and regenerated. Cleaner production and sustainable consumption within a circular economy help reduce the demand for natural resources and energy; minimize waste discarded into the environment; and, in turn, systematically address the consequences of the linear economy, such as resource depletion, environmental pollution, climate change, biodiversity loss, and ecological imbalance, all while striving to achieve sustainable development goals.

2.1.2. The circular economy in the mining sector

The mining industry extracts mineral resources to meet the national economy's demand for raw materials. In the linear economy, characterized by the extraction of natural resources and the disposal of waste into the ecological environment, the mining industry operates on a one-way, linear model: extracting raw resources - screening and processing - using resources to produce goods - consuming - and finally, disposing of waste into the environment. The mining industry provides the necessary foundation for a significant portion of modern society's infrastructure. However, its operations often leave a large impact on the surrounding environment as well as wider implications for the environmental health of the planet. The industry's activities negatively affect land, water, and air (Witchalls, 2022).

As countries transition to the circular economy, the mining industry remains a priority sector in many nations, particularly in developing countries like Vietnam. This is because economic development, especially in industrialized economies, continues to rely on mineral resource extraction to supply raw materials for various other sectors. Moreover, the huge amount of solid, liquid, and gaseous waste from this industry presents a significant opportunity to implement the principles of the circular economy. However, within this new model, the mining industry must also transform its operational framework to align with the core principles of the circular economy. “Mining circular economy refers to an economic system, which follow the characteristics and natural ecological rules of mineral resources and mineral products and take highly efficient exploit and comprehensive utilization of mineral resources as the core. It constitutes a closed-loop material flow as “mineral resources - mineral products - renewable mineral resources” according to mineral exploration, exploiting, processing, melting, deep processing, consumption and other processes” (Zhao et al., 2012). Thus, in the mining circular economy model, resources are thoroughly utilized, and waste is leveraged for recycling and reuse to create renewable resources. This approach enhances resource efficiency, slows the depletion of mineral resources, and mitigates the negative environmental impacts of mineral extraction, processing, and consumption.

Several circular economy models currently exist, such as the 3R, 5R, 7R, or 9R frameworks. However, most scholars agree that the foundation of the circular economy remains the 3R model: Reduce, Reuse, and Recycle. The mining circular economy model also adheres to these 3R principles (Zhao et al., 2012). Accordingly, implementing a circular economy model in the mining industry requires adherence to the following principles:

- Reduce: This principle is specifically demonstrated through (1) Increased resource recovery and reduced loss during extraction and processing, including the recovery of tailings and associated minerals; (2) Enhanced resource utilization efficiency; and (3) Reduced release of untreated waste from the mining industry into the natural environment, and a decreased demand for new materials and equipment through the use of modern technology and repair and maintenance to extend the lifespan of them.

- Reuse: This principle is specifically demonstrated through (1) The reuse of tailings and other waste (especially solid waste) from mineral extraction, processing, and consumption for alternative purposes. For example, utilizing mine spoil, waste rock from mineral processing, and slag, fly ash from coal-fired thermal power plants as leveling materials in construction and transportation projects; (2) The re-mining of old mine dumps that still contain valuable resources due to outdated recovery technologies; (3) The repurposing of mine waste dumps for reforestation or the post-closure use of mines for cultural, educational, or tourism purposes, etc.

- Recycle: This principle is specifically demonstrated through (1) The treatment and circulation of mine wastewater; (2) The recycling of tailings, mine spoil, slag, and fly ash from coal-fired power plants, etc. into valuable products like fertilizers and construction materials; (3) The recovery of gas from coal seams and mineral deposits for use in thermal power generation; and (4) The recovery and recycling of material waste generated by companies within the industry, such as waste oil and metal scraps, etc.

To achieve these principles, it is essential to build policy mechanisms and reform management and production organizing, but it is also very important to research and apply modern technology. Modern technology is being developed to support resource extraction, processing, and use in an environmentally friendly manner, while also maximizing resource recovery and efficiency and minimizing waste. Modern technology is also used to collect and recycle waste from this industry, such as technologies for recovering gas from coal seams and mineral deposits or for treating and recycling waste oil and other hazardous waste, etc. This presents a major challenge in applying the circular economy model to the mining industry, as its operational efficiency is heavily dependent on natural geological conditions. However, successfully implementing this model will bring numerous benefits.

Macro-level benefits: From a macro perspective, applying the circular economy model in the mining industry helps to maximize resource utilization and extend their lifecycle, thereby slowing down resource depletion and reducing environmental pollution. It also contributes to ecological restoration through land reclamation and environmental treatment activities, creates additional value for the economy from waste reuse and recycling, and generates green jobs for society, etc.

Benefits for mining companies: For mining enterprises, adopting the circular economy model helps create additional revenue from extracting and selling waste and by-products. It also reduces costs through waste reuse and extended equipment lifespan, thereby improving business efficiency. Furthermore, it creates new business opportunities for companies through recycling activities, etc.

2.2. The levels of the mining circular economy

To achieve the goals of the circular economy, it is necessary to implement a synchronized set of solutions from the macro to the micro level. Research by Z. Yuan et al. has shown that China has implemented the circular economy model at all three levels (i) macro-level (large-scale circulation) includes cities, regions, and provinces; (ii) meso-level (medium-scale circulation), involves symbiotic groups or industrial parks; and (iii) micro-level (small-scale circulation) is at the enterprise level (Yuan et al., 2006). In the mining industry, the circular economy model could be implemented at three levels of enterprise itself, mine area, mineral value chain and system (Zhao et al., 2012). Thus, the circular economy model in the mining industry in general, and the coal mining industry in particular, is structured into three levels.:

(1) Enterprise Level (Micro-Level): At the enterprise level, the circular economy model is expressed through specific actions and solutions adopted by mining companies. Circular economy activities at this level include: Designing production processes that are safe and environmentally friendly; Selecting appropriate technologies and organizing production rationally to increase resource recovery rates and reduce losses during extraction, screening, processing, and consumption; Treating and circulating wastewater or collecting and reusing waste to extend the lifecycle of materials and resources; Optimizing production by choosing equipment that saves materials and energy; Utilizing renewable energy sources; Implementing regular maintenance and repair of machinery and equipment to extend its lifespan and reduce material and energy consumption during operation; Managing practices, such as setting quotas for material consumption to raise employees' awareness of efficient resource use; Undertaking other reclamation and environmental restoration activities.

(2) Industry Level (Meso-Level): The meso-level of the circular economy model in the mining industry is directly demonstrated through industrial symbiosis. This involves a collaborative network between companies within the mining industry and those in related sectors that directly consume their output (Le et al., 2023), in which the mining industry enterprises are the center of symbiotic activities. Mining enterprises will engage in symbiosis and share resources with other companies within the sector and with those in industries directly related to mining, such as the coal-fired power, chemical, and construction materials industries. From the circular economy perspective, symbiosis is directly manifested through cooperation between mining companies and related enterprises to transform the waste, energy, and by-products of the mining industry into raw materials or energy for other companies. For instance, in the coal mining industry, symbiosis is specifically demonstrated through activities such as selling coal to a thermal power plants; extracting gas from coal seams and collecting coal sludge from coal preparation plants to supply to thermal power plants; providing waste rock from coal mining and screening, along with slag and fly ash from thermal power plants, to construction materials manufacturers, etc. The circular economy park model is a prime example of the meso-level application of the circular economy within the mining industry in general and the coal mining industry in particular (Le et al., 2025).

(3) Inter-Industry Level (Macro-Level): This level is manifested through multi-industry linkages within the mining industry's value chain and system. The mining sector is not only involved in the production and trade of minerals but also connects with other industries such as animal husbandry, environmental protection, tourism, and public services to provide society with products, materials, energy, water, gas, and services (Zhao et al., 2012). The mining industry would link with these other sectors to expand and develop the value chain, thereby increasing its contribution to society. This level also involves state policies related to building circular economy infrastructure and creating mechanisms that encourage multi-industry and intra-industry links, as well as circular economy activities within mining enterprises. Furthermore, it includes policies that incentivize behavioral changes among the public to use resources more sparingly and reduce demand, which extends the lifespan of resources within their cycle and slows the depletion of mineral resources.

These three levels are not isolated; they interact with and support one another. To comprehensively and effectively implement the circular economy model in the mining industry, and particularly in the coal mining sector, it is essential to go beyond enterprise-level solutions and industrial symbiosis within mining areas. It is crucial to engage in multi-industry linkages with various related sectors and fields across the mining industry's value chain and system, supported by proactive macro-level policies and mechanisms.

3. Research methodology

This paper conducts an in-depth analysis of several representative case studies, which serve as a foundational basis for constructing a circular economy model at the inter-industry level. By examining these typical situations, the study aims to identify practical approaches and strategic frameworks that can be

adapted to Vietnam's coal mining sector. These case studies not only illustrate successful applications of circular economy principles in various contexts but also highlight the importance of fostering collaboration across multiple industries to achieve sustainable development goals. Through this analysis, the paper proposes actionable solutions to strengthen multi-industry linkages, which are essential for accelerating the adoption and implementation of circular economy practices within Vietnam's coal mining industry.

The selected case studies include examples from countries with mature and technologically advanced coal mining industries, such as Australia, Germany, and China. These international cases offer valuable insights into how circular economy models have been integrated into mining operations, waste management, land rehabilitation, and resource efficiency. Lessons learned from these countries provide a benchmark for Vietnam to assess its current practices and identify areas for improvement. In addition to global examples, the paper also examines several domestic cases that reflect the current realities and challenges faced by Vietnam's coal mining enterprises. These include initiatives related to mine closure, environmental restoration, and intersectoral cooperation with forestry, water management, and energy industries.

By synthesizing both international and domestic experiences, the paper lays the groundwork for designing a comprehensive inter-sectoral circular economy model tailored specifically to the conditions and needs of Vietnam's coal mining industry. Furthermore, it outlines a set of recommendations and policy directions aimed at enhancing cross-sector collaboration, optimizing resource use, and promoting long-term environmental and economic sustainability.

3.1. Reusing closed mines in some European countries for cultural, tourist and educational purposes

Over the last few decades in Europe, coal mines have gradually been closed, partly due to operational efficiency and partly due to the economic and energy development strategies of European nations. Mine closures could lead to significant issues, such as job losses, the disappearance of sports and cultural facilities, a decline in social life, and abandoned properties. After being handed over to the government, these mines are gradually liquidated. However, the existing infrastructure of post-closure mines is often preserved and could be repurposed (Pactwa et al., 2020). In Austria, Germany, and Slovenia, former mining sites have been repurposed into attractions that include mining heritage showcases (museums), sporting events (off-road motorcycle races), cultural events (music and art festivals) and recreational facilities (Harfst, 2015).

In Poland, similar to other European nations, post-closure mines are being repurposed for cultural, educational, and tourism activities. For example, the "Former Mine" Science and Art Centre was built in the area of a former hard coal mine - the Thorez mine (1950–1992) and is now used for tourism and educational purposes. Another example is the Guido Mining Museum, which first opened in 1982 and was reopened in 2007 to welcome visitors (Pactwa et al., 2020).

Building cultural, tourism, and educational facilities at post-closure mines requires collaboration between the coal mining industry and related sectors like culture, education, and tourism. This must also be supported by overarching development policies and direction from the state.

3.2. Developing reforestation activities on mine waste dumps in Indonesia

In Indonesia, the Government mandates that mining companies must concurrently carry out land reclamation and restoration alongside their operations as an environmental obligation (Setiawan et al., 2021). In response to these strict regulations, coal mining companies have had to effectively reclaim land in mining areas, especially in open-pit spoil heaps, for reforestation. However, studies in Indonesia have shown that this land reclamation for reforestation not only addresses environmental issues but also yields economic benefits. Specifically, the emission of gases related to land reclamation at coal mines is 25.4–26.6 tons of CO₂/ha, whereas the CO₂ absorption capacity of plants grown on the reclaimed land is estimated to be 26.4 tons of CO₂/ha, and the O₂ generated is up to 143 tons of O₂/ha. The economic value of ecosystem services provided by reclamation is \$27,750 per hectare, which is significantly higher than the cost of reclamation projects, approximately \$8,642–\$9,417 per hectare. This activity can continue to generate annual profits of 10% to 20% over 20 years (Setiawan et al., 2021).

To achieve this, close collaboration between the coal mining and forestry industries is essential. Simultaneously, there is a need for policy mechanisms to foster the development of markets for ecosystem services, such as carbon credit markets. This will also promote synergy between the forestry and coal mining sectors, thereby stimulating reforestation activities and enhancing the long-term sustainability of these operations.

3.3. Project to convert an open-pit mine into a regulating lake

In Quang Ninh province, Vietnam, the 917 pit operated by Vinacomin – Hon Gai Coal Company, a subsidiary of the Vietnam National Coal and Mineral Industries Holding Corporation Limited (Vinacomin), officially ceased mining operations at the end of 2022. After years of coal extraction, the pit reached a depth of approximately 160 meters and spanned several dozen hectares. According to the original mining license and environmental restoration plan, the site was to be completely backfilled, a process estimated to cost over 38 million USD. However, in February 2023, the Ministry of Natural Resources and Environment issued an environmental license allowing the company to convert the pit into a freshwater reservoir instead of backfilling. This marked a significant shift in post-mining land use strategy, aligning with sustainable development goals and adaptive environmental planning.

Under the new plan, Vinacomin will undertake reclamation and restoration activities across a total area of 90.62 hectares. Specifically, the pit will be transformed into a regulating lake, and a drainage culvert will be constructed to connect the reservoir to the sea, ensuring proper water flow and quality management (Minh Ky, 2023). This approach not only reduces the financial burden of land restoration but also addresses the challenge of sourcing fill materials. More importantly, it opens up new possibilities for economic and ecological utilization of the site, such as freshwater storage, biodiversity conservation, and even recreational development.

To fully realize the potential of such regulating lakes, it is essential to foster strong intersectoral collaboration. The coal mining industry must work closely with water resource management agencies, environmental protection authorities, and tourism developers. This integrated approach can help transform former mining sites into multifunctional assets that contribute to regional resilience, environmental sustainability, and community well-being.

3.4. Implementing projects to rehabilitate coal mine dumps in Quang Ninh province for reforestation and environmental restoration

With over 170 years of continuous coal mining activity, Quang Ninh province has accumulated a vast volume of waste rock and a dense network of mine dumps. These dumps have caused significant environmental degradation, including soil erosion, landscape disruption, and air and water pollution. In response to these impacts, and in accordance with the Environmental Protection Law (first enacted in 1994), all entities engaged in mineral exploitation are legally obligated to rehabilitate and restore the environment of mine dumps.

To meet these requirements, a strategic partnership has emerged between the coal mining sector and the forestry industry. This collaboration focuses on converting mine dumps into reforested areas, thereby restoring ecological balance and improving landscape aesthetics. Various plant species—including cogongrass, bougainvillea, acacia, pine, and casuarina—have been studied for their adaptability to the nutrient-poor, rocky soils typical of mine dumps. These species were selected based on their resilience, growth potential, and ecological benefits. By the end of 2022, the total area of rehabilitated dumps and mining sites across the coal industry exceeded 2,000 hectares, with 1,752 hectares located in Quang Ninh province alone (Do Manh Dung et al., 2023a).

Although comprehensive economic evaluations of these reforestation projects are still pending, initial findings suggest promising outcomes. Acacia, in particular, has shown strong growth performance and is expected to generate future economic returns through timber production and carbon sequestration. Beyond economic benefits, this initiative contributes to environmental restoration by reducing dust emissions, absorbing greenhouse gases, and increasing oxygen levels. It also enhances biodiversity and provides green spaces for local communities.

Promoting this cross-sectoral collaboration is vital for advancing the circular economy and achieving long-term sustainable development. By integrating mining rehabilitation with forestry and environmental stewardship, Quang Ninh sets a precedent for responsible resource management and post-mining land use transformation..

4. Improving multi-sector collaboration to promote a circular economy within Vietnam's coal mining industry

4.1. Developing an inter-industry circular economy model tailored to Vietnam's coal mining industry

The proposed inter-industry circular economy model for Vietnam's coal mining industry is illustrated in Fig. 1.

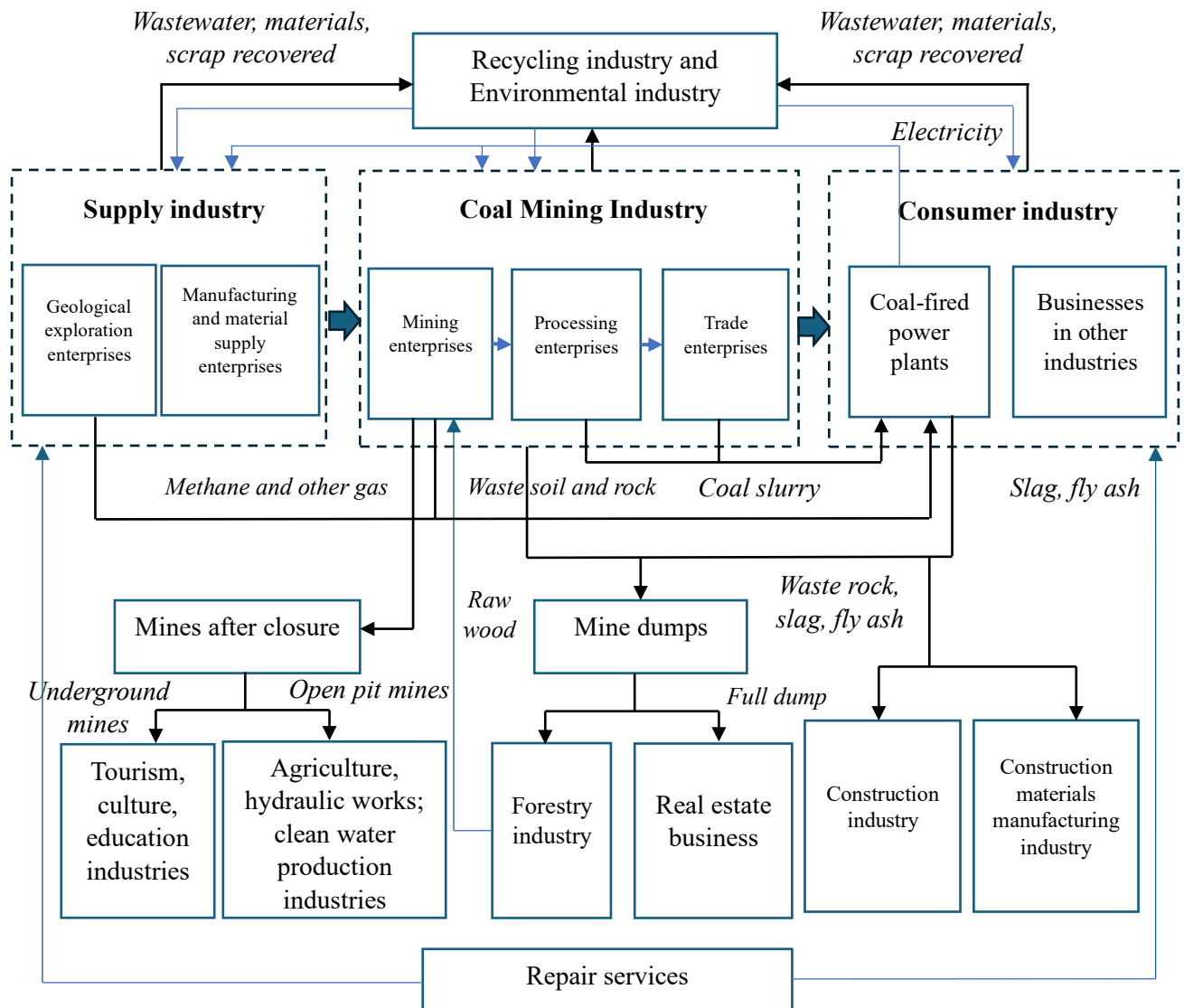


Fig. 1. The inter-industry circular economy model tailored to Vietnam's coal mining industry

According to this model, the coal mining industry will establish cooperative linkages with sectors such as input suppliers; the environmental and recycling industries; tourism, culture, and education; agriculture, hydraulic works, and clean water production; forestry; real estate; construction; construction materials manufacturing industry; and repair services, etc. The cooperative relationships among these sectors are demonstrated as follows:

- Input-supplying industries provide inputs for the coal mining industry. Specifically:
 - + Geological enterprises offer exploration drilling services and methane recovery drilling from coal seams prior to mining.
 - + Material and equipment manufacturing companies supply materials and machinery to the coal mining industry.
- The coal mining industry supplies clean coal to consuming enterprises in various sectors, especially the thermal power industry. By-products of the coal mining industry, such as coal slurry recovered from the screening process and methane gas extracted from coal seams, are also supplied to thermal power companies and other consumers.
- By-products and waste from the coal mining industry (e.g., waste rock from mining and screening) and the thermal power industry (e.g., slag and fly ash) are supplied to construction material manufacturing companies to produce products like artificial sand, unburnt bricks, and cement additives. These materials are also provided to construction companies for use as backfill. The remaining waste is disposed of in designated dumps.

- Wastewater, recovered materials and equipment, and other waste from the mining industry could be collected and supplied to environmental companies or recycling companies for treatment and repurpose if they could not be handled in-house. The mining companies could then use the recycled products and reclaimed water from these businesses.

- Stabilized and treated dumpsites, once filled, could be repurposed to provide land for reforestation or real estate projects.

- Post-closure mines could be reclaimed and converted into tourist attractions or mining museums for cultural, educational, and tourism purposes. Similarly, open-pit mines could be repurposed as regulating lakes or freshwater reservoirs for agricultural use or as a source of clean water for residential areas.

- Finally, mechanical and repair enterprises provide maintenance, restoration, and production capacity upgrades for equipment used by other businesses.

Therefore, through cooperation among enterprises in different sectors and fields of the economy, unwanted outputs are processed and re-enter subsequent production and business cycles. By applying the circular economy model, not only are new business cooperation opportunities created, but it also addresses the issue of environmental management in the current context of resource depletion, environmental pollution, and climate change.

4.2. Some solutions to promote multi-sector linkage in the circular economic model of Vietnam's coal mining industry

To promote the circular economy model in Vietnam's coal mining industry, enhancing multi-sectoral collaboration is crucial. The following are some solutions to strengthen this collaboration and advance the circular economy within the Vietnamese coal mining sector:

a) Optimizing the value chain through the use of by-products and waste

This industry generates a significant number of by-products and waste, necessitating closer collaboration with enterprises in related economic sectors and industries for waste management. Specifically:

- Collaboration with the construction materials industry: Mine waste rock and thermal power plant ash, etc. are major by-products. These should be utilized as backfill materials in construction and transportation projects. Additionally, it is essential to promote research and technological applications to transform these by-products into construction materials, such as unburnt bricks, lightweight concrete, etc. This requires close cooperation between coal mining companies, thermal power plants, construction companies and construction material manufacturers.

- Collaboration with the construction industry to reuse mine waste rock as backfill material.

- Collaboration with the environmental sector to Treat hazardous waste from the coal mining industry, such as wastewater and waste oil, etc.

- Collaboration with the tourism, forestry, and water management sectors in utilizing mine dumps and closed mines for reforestation, geotourism, or converting open-pit mines into regulating lakes, etc.

b) Developing the industrial symbiosis cluster or the circular economic parks

An industrial symbiosis cluster is a model where different enterprises within a shared geographical area collaborate to use each other's waste, by-products, energy, and water as input resources. In the context of the coal industry, such an industrial symbiosis cluster could include:

- Coal mining enterprises: Supply raw coal and generate coal slurry, wastewater, and other mine waste.

- Thermal power plants: Consume coal and produce ash, slag, and waste heat.

- Cement/construction material plants: Use ash, slag, and waste rock as input materials.

- Environmental companies: Treat mine wastewater for reuse as clean water and manage other hazardous waste, etc.

c) Some other solutions

- Promote technological innovation and digital transformation. Encourage the application of technology in resource and waste management. This would optimize production processes, minimize waste, and enhance recycling efficiency. Additionally, develop advanced mining and processing technologies to maximize coal recovery from operations, thereby reducing coal losses and the volume of waste.

- Advance green financial policies to create sustainable funding for circular economy initiatives.
- Develop and train human resources. Organize specialized training courses on the circular economy for employees in the coal and related industries. Encourage universities to offer more majors related to the circular economy and resource management.
- Increase public communication and awareness. Intensify communication about the benefits of the circular economy in the coal sector to shift the perception of "waste" to "resources" among both businesses and the wider community.

Implementing these solutions simultaneously, with close cooperation among ministries, sectors, businesses, and research organizations, would create a major push for Vietnam's coal mining industry to transition to the circular economy model, contributing to the sustainable development of the Nation.

5. Conclusion and recommendations

Through this paper, the authors have analyzed the theoretical foundations of the circular economy and its application within the mining industry. It also provides an analysis of several case studies, both domestic and international, that highlight multi-sectoral collaboration to advance the circular economy model in the coal mining industry. Based on this, the paper proposes a suitable inter-industry circular economy model for Vietnam's coal mining sector and offers solutions to foster multi-sectoral collaboration, aiming for the circular economy and sustainable development goals.

Deploying a circular economy model in general, and promoting multi-sectoral linkages toward a circular economy in Vietnam's coal mining industry, will face several barriers:

- Policy and Legal Framework Barriers: In Vietnam, the concept of a circular economy is currently only mentioned in a few legal documents, such as the Environmental Protection Law. A comprehensive legal framework and supportive policies are necessary to promote a circular economy in the coal mining industry specifically, and the broader economy in general.
- Market Barriers: A clear market for recycled and reused waste products has not yet been well-established.
- Technological Barriers: Adopting a circular economy model, both in the general economy and the coal mining industry, requires modern technology. This includes not only production technology but also technologies for waste collection and recycling.
- Awareness Barriers: The awareness of the public, society, and employees within enterprises regarding the circular economy and its benefits remains low.

To promote multi-sectoral linkages and facilitate the realization of the circular economy model, this article proposes several recommendations.

**) For the Government*

- Establishing a specific roadmap and goals for the circular economy in the coal mining sector. Instead of just general concepts, there needs to be a legal framework (regulatory documents) that clearly outlines specific, phased goals for the coal industry.
- Developing investment incentives and tax breaks. Projects that invest in circular economy technologies often require large initial capital and carry certain risks. To attract the private sector, appealing incentive policies are necessary. Some types of incentives include:
 - + Tax incentives: Reducing corporate income tax on profits earned from producing recycled products or providing waste treatment services within the circular model. Providing exemptions or reductions on import duties for machinery, equipment, and technological lines used for circular economy purposes.
 - + Credit incentives: Offering preferential access to loans from development banks and other green credit sources.
- Establishing standards and regulations for recycled products is crucial. It is essential to have clear quality standards to ensure that products made from recycled materials, such as unburnt bricks, backfill materials from slag, fly ash or waste residue are widely accepted by the market.
- Establish mechanisms to promote inter-sectoral linkages. The government can take on a guiding and directing role for these collaborations.

**) For Local Governments*

- Provide investment incentives for waste recycling and reuse projects.

- Offer land rent exemptions and prioritize land allocation for projects that build ecological industrial parks or recycling facilities

References

- Bui Xuan Nam, Tran Quang Hieu, Nguyen Hoang, Le Qui Thao, Pham Duy Thanh, Le Huu Tien, Nguyen Van Duc, 2023. CCUS technology solution for recycling waste fly ash and red mud as additives for green CSA cement production: Moving closer to the goal of achieving net-zero emissions by 2050. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Do Manh Dung, Tran Mien, Giap Van Kien, 2023a. Rehabilitating dumps combined with developing a forest economy on mine dumps: Reality and potential at coal dumps in the Quang Ninh coal region. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Do Manh Dung, Tran Mien, Nguyen Hoang Huan, Tran Thi Thu Ha, Pham Hung Son, 2023b. The current state and potential of reusing and recycling mine waste rock from coal mining operations by Vinacomin in Quang Ninh. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Ellen MacArthur Foundation, 2012. Towards The Circular Economy: Economic and business rationale for an accelerated transition.
- European Parliament, 2023. Circular economy: definition, importance and benefits [WWW Document]. Top. Eur. Parliam. URL <https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits> (accessed 7.23.25).
- Harfst, J., 2015. Utilizing the past: Valorizing post-mining potential in Central Europe. *Extr. Ind. Soc.* 2, 217–224. <https://doi.org/10.1016/j.exis.2015.01.003>
- Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the Circular Economy: An Analysis of 114 Definitions. *SSRN Electron. J.* <https://doi.org/10.2139/ssrn.3037579>
- Le, D.C., Nguyen, N., Dong, T.B., Le, M.T., 2025. The Development Of Circular Economy Park Model Within Vietnam's Coal Mining Sector. *Int. J. Bus. Manag. Stud.* 06. <https://doi.org/10.56734/ijbms>
- Le, D.C., Nguyen, N., Dong, T.B., Le, M.T., 2023. Industrial Symbiosis Applied to Vietnam Coal Mining Industry to Promote the Circular Economic Model towards Sustainable Development Goals. *Inż. Miner.* 1. <https://doi.org/10.29227/IM-2023-02-12>
- Minh Kỳ, 2023. Quang Ninh: The first coal mining pit is approved for rehabilitation into a freshwater reservoir. *Newspaper of Industry and Trade*. URL <https://congthuong.vn/quang-ninh-moong-khai-thac-than-dau-tien-duoc-chap-thuan-cai-tao-thanh-ho-chua-nuoc-ngot-243958.html> (accessed 8.18.25).
- Nguyen Viet Cuong, La Manh Hai, 2023. Planning for the utilization of mine waste rock as backfill and common construction materials. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Pactwa, K., Woźniak, J., Dudek, M., 2020. Sustainable Social and Environmental Evaluation of Post-Industrial Facilities in a Closed Loop Perspective in Coal-Mining Areas in Poland. *Sustainability* 13, 167. <https://doi.org/10.3390/su13010167>
- Pham Duc Phong, Tran Thi Hien, 2023. Assessing the potential of using tailings from several mineral processing plants as construction materials. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Pham Van Luan, Le Viet Ha, 2023. An overview of recycling and reuse methods for mining and mineral processing waste. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Rashid, S., Malik, S.H., 2023. Transition from a Linear to a Circular Economy, in: Bandh, S.A., Malla, F.A., Hoang, A.T. (Eds.), *Renewable Energy in Circular Economy, Circular Economy and Sustainability*. Springer International Publishing, Cham, pp. 1–20. https://doi.org/10.1007/978-3-031-42220-1_1

- Setiawan, I.E., Zhang, Z., Corder, G., Matsubae, K., 2021. Evaluation of Environmental and Economic Benefits of Land Reclamation in the Indonesian Coal Mining Industry. *Resources* 10, 60. <https://doi.org/10.3390/resources10060060>
- Tran Mien, 2023. The application of a circular economy in mine wastewater management: Practices and experiences from coal mines in the Quang Ninh region. The 28th National Mining Science and Technology Conference, topic " Circular Economy in Vietnam's Mining Industry", Industry and Trade Publishing House, Hanoi.
- Vietnam Government, 2025. Decision No. 222/QĐ-TTg issued by the Prime Minister: On the promulgation of the National Action Plan for the implementation of the circular economy until 2035
- Witchalls, S., 2022. The Environmental Problems Caused by Mining. Earth.Org. URL <https://earth.org/environmental-problems-caused-by-mining/> (accessed 8.17.25).
- Yuan, Z., Bi, J., Moriguchi, Y., 2006. The Circular Economy: A New Development Strategy in China. *J. Ind. Ecol.* 10, 4–8. <https://doi.org/10.1162/108819806775545321>
- Zhao, Y., Zang, L., Li, Z., Qin, J., 2012. Discussion on the Model of Mining Circular Economy. *Energy Procedia* 16, 438–443. <https://doi.org/10.1016/j.egypro.2012.01.071>.

