Industrial Symbiosis Applied to Vietnam Coal Mining Industry to Promote the Circular Economic Model towards Sustainable Development Goals

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Abstract

Industrial symbiosis associated with the eco-industrial parks is the cooperative activities between businesses to optimize using of inputs and outputs such as raw materials, energy, water, waste materials, etc. in the orperation of businesses. In the industrial symbiosis model, the overall benefits of the symbiosis activities are more than the ones when working individually. Applying the model could help to reduce the demand of raw materials and increase the waste that be treated – an important part of the circular economy model. The coal mining industry includes many different stages from exploration, exploitation, processing, and trading. Each stage could be performed by different businesses which could corporate with each other. Besides the contributions to the socio-economic development, the industry also emits lots of waste into the environment to cause environmental pollution that needs to be treated. The paper summarizes the theoretical basis of the industrial symbiosis, the circular economy and clarifies the relationship between the industrial symbiosis, the circular economy and the sustainable development goals. From analyzing some typical situations of industrial symbiosis activities in Vietnamese coal mining industry; analyzing some characteristics and potential application of industrial symbiosis in the industry, the paper proposes the model of industrial symbiosis for Vietnamese coal mining industry. The paper also proposes some solutions to promote symbiotic activities in the industry.

Keywords: *coal mining industry, industrial symbiosis, circular economy model, sustainable development*

1. Introduction

Industrial symbiosis is the collective approach to competitive advantage in which separate industries create a cooperative network for the exchange of materials, energy, water or by-products (Baldassarre et al., 2019). The keys of industrial symbiosis are the cooperation and synergistic possibilities offered by geographical proximity (Chertow, 2008). Industrial symbiosis associated with the treatment, recycling, reuse of waste and other undesirable outputs that has close relationship with the circular economy to achieve the sustainable development goals. It is the tool to realize the circular economy to achieve the goals.

The traditional mining production is operating in the model: mineral exploration – exploitation – primary product processing – fine product manufacturing – product consumption – waste dumping (Mu QJ, 2003). For each country, especially the developing countries, mineral resources including coal resources plays an important role in providing mineral materials for the need of development of the national economy. It is even more important in the context of resource depletion, environmental pollution and climate change. However, with the traditional approach, we will quickly face to the problem of resource depletion and environmental pollution. In the coal mining industry, the approach would cause increased resource loss, and also increasing of environmental pollution due to deeper and further mining operation. Therefore, it is urgent to promote industrial symbiosis in coal mining industry towards the circular economy and sustainable development goals.

The application of industrial symbiosis in the coal mining industry could not be separated from the formation of the industrial symbiosis model, which were built from synthesizing of the relevant theories and analyzing the characteristics and potentials to apply the model.

2. Theoretical basis

2.1. Industrial symbiosis

"Symbiosis" is a concept that is built on the notion of biological symbiotic relationships in nature, in which at least two unrelated species exchange materials, energy or information in a mutually beneficial manner – the specific type of symbiosis known as mutualism (Miller & Spoolman, 2012). The concept of industrial symbiosis originates from the field of industrial ecology (Chertow, 2008); The underlying concept of industrial symbiosis is the metaphor of an industrial ecosystem that mimics a natural ecosystem (Chertow, 2000). There are different concepts of industrial symbiosis. Industrial symbiosis is defined as a collective approach to achieving competitive advantage in which separate industries exchange raw materials, energy, water and/or by-products that plays an important role in the transition towards sustainable development goals (Chertow, 2000, Chertow, 2008). In Vietnam, the concept of industrial symbiosis is mentioned in some governmental documents. Industrial symbiosis in an industrial park is a cooperative activity between companies in an industrial park or companies in different industrial parks to optimize the use of inputs and outputs such as raw materials, water, energy, waste, scrap, etc. in the operation of the companies. Through the cooperation, companies estab-

Tab. 1. Statistics of large coal mining enterprises in Vietnam

No.	Companies' names	Mining area
I	**VINACOMIN members**	
1	Vinacomin – Mao Khe Coal Company	Dong Trieu - Uong Bi/ Quang Ninh Province
2	Vinacomin – Nam Mau Coal Company	
3	Vinacomin – Uong Bi Coal Company	
4	Vinacomin – Vang Danh Coal Join Stock Company	
5	Vinacomin – Hon Gai Coal Company	Ha Long/ Quang Ninh Province
6	Vinacomin – Nui Beo Coal Join Stock Company	
7	Vinacomin – Ha Tu Coal Join Stock Company	
8	Vinacomin – Ha Lam Coal Join Stock Company	
9	Vinacomin – Quang Hanh Coal Company	Cam Pha/ Quang Ninh Province
10	Vinacomin – Thong Nhat Coal Company	
11	Vinacomin – Khe Cham Coal Company	
12	Vinacomin – Duong Huy Coal Company	
13	Vinacomin – Ha Long Coal Company	
14	Vinacomin – Tay Nam Da Mai Joint Coal Stock Company	
15	Vinacomin – Coc Sau Coal Join Stock Companies	
16	Vinacomin – Deo Nai Coal Join Stock Companies	
17	Vinacomin – Cao Son Coal Join Stock Companies	
18	Vinacomin – Mong Duong Coal Join Stock Company	
19	Vinacomin – Vietbac Mining Industry Holding Corporation	Thai Nguyen Province, Lang Son Province
II	**Non-Vinacomin member**	
20	Dong Bac Corporation	Quang Ninh Province (majority)

Tab. 2. Volume of soil and rock waste of Vinacomin in Quang Ninh area (1000 m3). Source: Thao Vu Manh et al., 2019

No.	Areas	Volume of soil and rock waste by each period		Total
		2018-2020	2021-2030	
1	Uong Bi area	45,306	100,573	145,879
2	Ha Long area	324,956	289,741	614,697
3	Cam Pha area	339,421	928,083	1,267,504
	Total	**709,683**	**1,318,387**	**2,028,080**

Tab. 3. Volume of waste rock of Vinacomin after classification for construction materials (1000 m3). Source: Thao Vu Manh et al., 2019

No.	Areas	The period of 2018 - 2020			The period of 2021 – 2030		
		Crushed sand	Building stone	Total	Crushed sand	Building stone	Total
1	Uong Bi area	4,077	23,106	27,183	9,051	51,292	60,343
2	Ha Long area	29,245	165,728	194,973	26,082	147,762	173,844
3	Cam Pha area	30,547	173,105	203,652	83,527	473,322	556,849
	Total	**63,869**	**361,939**	**425,808**	**118,660**	**672,376**	**791,036**

Tab. 4. Estimated volume of wastewater from coal mining. Source: Vinacomin Industry Investment Consulting JSC, 2018

Norms	Unit	2021÷2025	2026÷2030
Raw coal production	Million tons /year	52.5	57.5
Mine wastewater on average one ton of raw coal	m^3/ton	2	2
Average annual mine wastewater	Million m^3/year	105	115

lish the network to exchange factors (inputs and/or outputs) for production, use the common infrastructure and services for production, improve technological processes and improve production and business efficiency (Vietnam Government, 2018). Industrial symbiosis does not necessarily take place within the boundaries of an industrial park, although the term eco-industrial park is commonly used to describe organizations engaging in exchanges (Chertow, 2000).

Although there are many different concepts, industrial symbiosis has some essential characteristics:

- Industrial symbiosis is the cooperation between businesses in sharing infrastructure and also inputs and outputs (including unwanted outputs);
- The overall benefits of cooperation in industrial symbiosis outweigh the separate benefits of independent businesses;
- Cooperation in industrial symbiosis could take place within an industrial park and also in different industrial zones.

Industrial symbiosis addresses issues related to resource depletion, waste management and pollution by using waste streams to generate value more efficiently across networks of industrial actors (Chertow, 2008). Industrial symbiosis benefits both micro and macro level:

**) Micro level:*

- Creating more opportunities for businesses to take advantage of resources, inputs, outputs, especially waste and other unwanted outputs, thereby increasing revenue and profit for the business;
- Developing business relationships between companies to create more business cooperation opportunities.

**) Macro level*

- Optimizing national resources; creating more values to increase the national GDP;
- Increasing revenues for the state budget from companies that are increasing the operational efficiency in industrial symbiosis.

- Protecting the environment, using resources sparingly by using unwanted outputs. It helps countries responding to the current situation of resource depletion, environmental pollution and climate change.

2.2. The circular economy

The circular economy is a concept that has recently gained traction in policy, business administrators and academia to support the transition from a linear economic model with raw materials on one end and waste at the other, towards a circular economy model, in which waste is a resource that is valued through recycling and reuse (Gregson et al., 2015). There are lots of different definitions of the circular economy. The circular economy describes an industrial economy that be designed to produce no waste or pollution (Littleboy et al., 2016); the circular economy is a new economic model with huge economic potential in zero waste (Ellen-MacArthur-Foundation, 2013); or the circular economy describes an economic system based on business models that replace the concept of "end of life" by reducing, reusing, recycling and recovering materials in manufacturing, distributing and consumming processes at the micro level (products, companies, consumers), intermediate levels (eco-industrial parks) and macro levels (cities, regions, countries and furthermore) with the aim of sustainable development by ensuring environmental quality, economic prosperity and social justice, serving the interests of both present and future generations (Kinnunen, 2019).

Thus, it could be understood that the circular economy is an economy which the undesired outputs (waste) of production processes are fully utilized. These undesired outputs will become inputs of the further production processes. So it could extend the value chain, and also reduce environmental pollution, towards sustainable development goals.

2.3. The relationship between industrial symbiosis, circular economy and sustainable development

a) The relationship between industrial symbiosis and the circular economy

In recent years, industrial symbiosis has become a subfield of a new concept, the circular economy concept (Cecchin et al., 2020). Industrial symbiosis is a business-focused approach to promoting sustainability by recovering waste from one entity for using in another (Chertow, 2000). It is the core content of the circular economy model that focus on recycling the waste of production processes to turn it into a resource for the other processes.

The circular economy is to be implemented at 3 function levels: individual businesses, eco-industrial parks and eco-cities/municipalities (Kalmykova et al., 2018); Research by Z. Yuan et al. has shown that China has implemented the circular economy model at all three levels: (i) the macro level – the large cycle (city, region and province); (ii) the medium level – the medium cycle (symbiotic groups); and (iii) micro level – the small cycle (enterprise level) (Yuan et al., 2008). Thus, the circular economy model is basically divided into three levels: (i) the economy level (or regional level); (ii) industry or interdisciplinary level (symbiotic); and (iii) enterprise level. Industrial symbiosis is the cooperation between many companies in the same industry or in different industries; in the same industrial park or in different industrial zones in sharing infrastructure, inputs, outputs (including unwanted outputs). The same goal of both the industrial symbiosis and the circular economy is saving resources, utilizing wastes of production processes to reduce environmental pollution and create more value for businesses and society. It could be seen that the industrial symbiosis is similar to the circular economy model at the medium level (industry level).

b) The relationship between circular economy and sustainable development goals

The term circular economy has emerged rapidly and notably to become one of the widely studied and applied approaches to achieving sustainable development goals (Korhonen et al., 2018). Sustainable development is the development that meets the needs of the present generations without compromising the satisfaction of those needs of the future generations on the basis of harmonious development of the three extremes: economy, society and environment (WCED, 1987). The resources on the earth are finite (regenerative resources could regenerate but the regeneration rate is also finite), therefore, if resources are not exploited properly, they would quickly be exhausted. Thus, the application of the circular economy model is a practical measure to achieve the sustainable development goals by using resources economically, prolonging the life of products, and using tailings from production processes to minimize wastes into the environment. Following the circular economy model would ensure all three aspects of sustainable development: economic goals (the utilization of resources and wastes, extending the life of machinery and equipment), social goals (creasing more jobs in the areas of recycling, reuse, and waste treatment), and environmental protection goals (reducing wastes). Out of the 169 sustainable development targets outlined by the UNEP, 21 targets could be directly achieved by adopting circular economy, and an additional 28 of them could be indirectly supported by circular economy practices (Lamba et al., 2023).

3. Research methodology

The paper uses the case study method to study some typical situations.

a) Cooperation in exploiting and recovering waste rock for leveling

Currently, the amount of soil and rock that excavated and dumped by Vietnam National Coal and Mineral Industries Holding Corporation Limited (Vinacomin) in Quang Ninh province is over 150 million m3/year. After decades of open-pit mining, the amount of soil and rock in wastedumps in Quang Ninh province has reached over 1 billion m3 (vinacomin.vn, 2022). This amount of waste occupies a large space. It causes serious environmental pollution (dust, water pollution), and also landslides in the rainy season. In recent years, along with the development trend of Quang Ninh province, the demand for leveling materials for traffic and construction projects is huge. Annually, Quang Ninh needs 130 million m^3 of soil and rock for ground leveling material. It is expected that by 2030, the need for leveling materials of projects in the province is about 1 billion m^3 (vinacomin.vn, 2022). Before huge opportunities, Vinacomin has assigned Vinacomin - Quang Ninh Coal Processing Company to realize the project of exploiting and recovering mine soil and rock waste to

serve for leveling of civil and industrial projects. This is the first waste recovery project for ground leveling of Vinacomin that licensed by the Ministry of Natural Resources and Environment. In the short term, it is expected that the soil and rock waste of the project would be provided for some projects in Quang Ninh province such as Cua Luc No3 Bridge, Coal Industry Urban Area and some other projects of Vingroup, etc. (vinacomin.vn, 2022).

In the perspective of industrial symbiosis, it is the cooperation between the parties: Open-pit coal mining companies – Vinacomin Quang Ninh Coal Processing Company – other companies/organizes that are partners of Vinacomin in using soil and rock waste. In the cooperative relationship, as open-pit coal mining companies and Vinacomin – Quang Ninh Coal Processing Company are all subsidiaries of Vinacomin, they are under the general management of Vinacomin. The cooperation benefits all parties. For Vinacomin, the cooperation makes revenue and profit through the selling soil and rock waste as leveling materials; creates more jobs for labours; and also helps reducing pressure about dumping site. For construction or traffic compnanies, etc. (the partners using soil and rock waste of Vinacomin as leveling materials), it provides materials for leveling that could instead for sand. It is so important in the context of sand resources is increasingly depleted; sand mining activity is limited; and the prices tend to increase. It could help the companies to ensure materials for ground leveling and also helps them to save costs to improve business efficiency. In the perspective of macro management, the cooperation helps to reduce waste that pollutes the environment; creates favorable business environment for construction, traffic companies, etc. and also could increase revenue for the province budget and/or state budget. Therefore, the project has been received the great support by Quang Ninh provincial authorities.

However, the cooperation could face big challenges for projects regarding long distance from the mine dumps, as transportation costs could be the barrier for promoting the cooperation.

b) Producing artificial sand of Thien Nam Joint Stock Company

Thien Nam Joint Stock Company is a non-state enterprise that operating in Cam Pha – Quang Ninh. Realizing that the soil and rock waste dumps of the coal industry contain up to 42% of sandstone that could be recycled into construction materials, the company has invested a technological line to produce artificial sand (www.vinacomin.vn, 2017). The company has carried out the project to recover soil and rock waste at Dong Cao Son Dump to produce artificial sand. Artificial sand products of the company have been assessed and certified by Vietnam Institute for Building Materials (Ministry of Construction) to meet the quality standards TCVN 9025-2012. The artificial sand of the company has been evaluated to be more fine and even grain than natural sand. Artificial sand is about 18% cheaper than the natural one, helping to increase the competitiveness (www.scp.gov.vn, 2017).

Similar to the above situation, the cooperation brings benefits to all parts, including coal mining companies, companies that produce artificial sand from soil and rock waste, and the community.

c) Waste treatment activities of Vinacomin Environment Company Limited

In 2009 Vinacomin Environment Company Limited (VEC) was transformed from the Vinacomin Mining Construction Company. VEC operates in several fields, including the treatment of mine wastewater and hazardous industrial wastes, planting and tending forests, etc. In 2021, VEC treated about 140 million m^3 of mine wastewater, collected and treated 3,300 tons of hazardous waste (www.congthuong.vn, 2022).

VEC provides mining wastewater treatment and hazardous industrial waste collection and treatment services to mining companies. The services are also the internal cooperation in Vinacomin to treat waste from mining, processing and trading activities to reduce the waste entering the environment. Treated mine wastewater would be used for daily life (of mine labour), production, road irrigation, etc. Thus, it helps to protect the environmental and also provide more natural resources (water) to serve operation of the companies.

d) Quang Ninh Province aims to convert open pit mines into freshwater reservoirs for mine closure and develop urban areas on mining waste dumps

Nowadays, there are a few surface mines in Cam Pha city of Quang Ninh province, which will be gradually closed in the forthcoming years as planned in the strategy of Vinacomin. Quang Ninh has to face many challenges of managing the open pit ponds thereafter. Consequently, Quang Ninh released a policy to reform these open pits into freshwater reservoirs for local people, and agriculture. Rently, the open-pit pond 917 of Vinacomin – Hon Gai Coal Company has been granted the environmental license by the Ministry of Natural Resources and Environment and would be researched to improve into a freshwater reservoir (www.congthuong.vn, 2023).

Besides, after decades of exploitation, Quang Ninh province also has a lot of waste dumps. Many waste dumps have been planted with trees to restore the environment, becoming suitable for construction of urban areas. In the context that the land storage for urban development in the province is increasingly limited, Quang Ninh Province has a policy of researching and developing sustainable urban areas on stable mine waste dumps (laodong.vn, 2023).

In the short term, the provincial government would lead the implementation of these projects, but after that, the projects must be assigned to companies. Therefore, it would be essentially the cooperation between entrepreneurs. The activity could take advantage of natural resources (reservoirs, urban land), and also reduce the negative impacts of post-mining pits and waste dumps on the environment.

4. Building the industrial symbiosis model that suitable for the Vietnamese coal mining industry

4.1. The possibility of applying industrial symbiosis model

The coal mining in Vietnam are mainly concentrated in Quang Ninh province. Coal mining companies are located in three main areas of Dong Trieu – Uong Bi, Ha Long, and Cam Pha. In each area, there are also other auxiliary companies, such as coal processing and trading companies, repair services, supply materials, etc. Therefore, an (unofficially) industrial park of the coal industry could be formed. As most of these companies

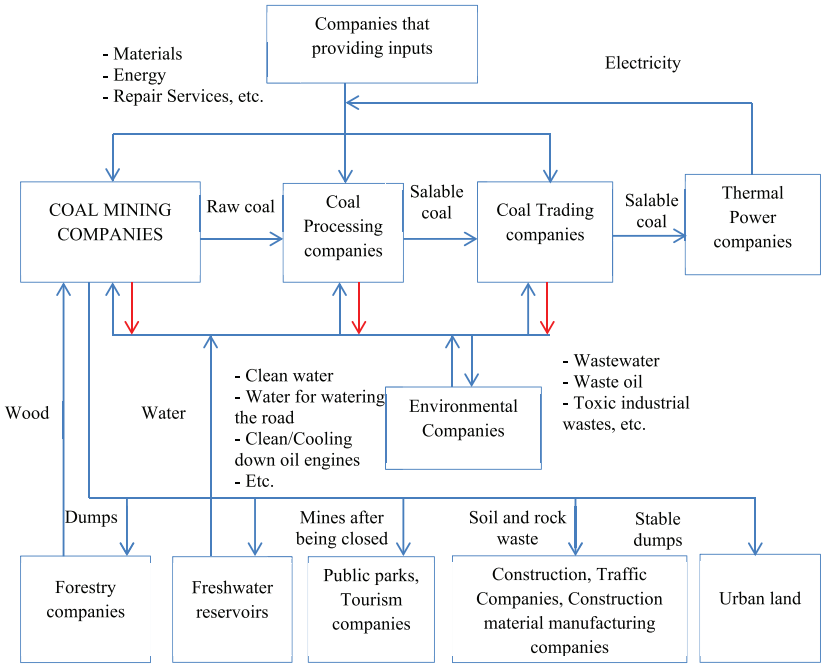

Fig. 1. Industrial symbiosis model for the Vietnamese coal mining industry

are subsidiaries of Vinacomin, their partnership is rather stable and close. It facilitates the development of industrial symbiotic networks. Tab. 1 lists coal mining companies in Vietnam that contribute largely to the national mining industry.

Tab. 2 and 3 show the volume of soil and rock waste, the potential input for materials construction production, and volumne of mine water in the largest coal mining production area in Vietnam.

Moreover, as the government strongly encourages the development of the private sector in resource utilization, environmental protection towards the circular economy, it is very supportive for other companies (neither are members of Vinacomin or Dong Bac Corporation) to establish their mutual cooperation in auxiliary services towards coal mining, processing and trading. In other words, the current conditions for the development of industrial symbiosis in Vietnam coal industry are very supportive.

4.2. The proposed industrial symbiosis model for the Vietnamese coal mining industry

From the abovementioned analysis, the authors propose an industrial symbiosis model into three areas of Dong Trieu – Uong Bi, Ha Long, and Cam Pha in the Quang Ninh coal region of Vietnam. Each area could form an (unofficially) concentrated industrial park, especially in Cam Pha area with many large coal mines.

In each area, the authors propose the industrial symbiosis model as shown in Fig. 1.

In this model, coal mining companies are in the center of the symbiotic network, and industrial symbiosis activities would be developed around these companies. Other companies in the model are partners of coal mining companies. Accordingly, the symbiotic activities would be carried out as follows:

- Input suppliers provide materials, energy, equipment, repair services, etc. to the main stream companies (coal mining companies, coal processing companies, coal trading companies, etc.);
- The main products of the coal industry (salable coal) would be supplied to thermal power companies in the market. Vice versa, coal mining companies would use electricity from power plants;
- Environmental companies provide services to treat wastewater, engine oil waste and other hazardous industrial wastes. Wastewater after being treated could be supplied back to companies for production or road irrigation to reduce dust;
- Waste dumps could provide land for forestry companies to plant forests. On the other way round, the wood from this afforestation could be provided for coal mining companies;
- Open-pit ponds after being closed could be renovated to become freshwater reservoirs; Water from these reservoirs could be supplied to mining companies, industrial zones or residential areas;
- The mines after being closed could be renovated to become public parks or tourist destinations;
- Soil and rock waste is provided to construction and traffic companies as ground leveling materials or construction material manufacturing companies to produce building materials such as artificial sand, etc.
- Stable waste dumps (perennial, reforested, etc.) could be researched and improved to provide the land for urban areas development.

The industrial symbiosis helps sharing local resources to save costs and increasing competitive advantages for businesses. Other advantages are improving the business environment, developing the partnership among companies in one industry and/or in different industries. However, the greater benefit of the collaboration comes from the combination in the recycling, reuse of waste and other unwanted outputs. If companies do it themselves, they could not have sufficient resources, because the resources of companies must be spent on their main operation. The coopera-

tion would mobilize resources from many subjects to help recycling and reusing waste and other unwanted outputs more thoroughly and effectively, and consequently, reducing the amount of waste that pollutes the environment. In other words, implementing industrial symbiosis in the coal mining industry is a step to approach the circular economy towards the goal of sustainable development.

5. Recommendations

Industrial symbiosis could bring overall benefit that be greater than the total benefit of individual firms. However, the economic benefits of symbiotic activities could be the benefits in the long term that could prevent companies from not seeing clearly the benefits of collaboration. Moreover, the social and environmental effectiveness of industrial symbiosis in the coal mining industry are enormous. Therefore, to promote industrial symbiosis in the coal mining industry, the authors propose some recommendations:

a) For the state and local

- The authorities should release encourage policies to motivate and support symbiosis activities between companies, such as tax reductions or subsidies (for symbiotic activities that related to recycling, reuse of waste and unwanted outputs with low economic efficiency), simplifying administrative procedures in projects's approval and licensing that associated with symbiotic activities in the industry;
- It is essential to have the master plan for industry development, in which refers to industrial symbiosis activities. It provides the basis to orientation for companies to establish strategies and plans to deploy industrial symbiosis activities;
- The authorities should promote connection among businesses to generate collaborative activities such as organizing forums, seminars, etc. to create opportunities for meeting and exchanging cooperation; creating a dynamic business environment, promoting innovation activities for businesses.

b) For companies

- It is important for companies to realize the meaning of industrial symbiosis, thereby finding their potential to be able to carry out industrial symbiosis activities;
- Companies need to concern of finding new partners, understand the necessity of sharing resources and mobilizing more resources into industrial symbiosis activities, especially cooperation activities in recycling, reuse of waste and other unwanted outputs;
- Companies must constantly research and learn to innovate or transfer technology on production, waste treatment, recycling and reuse.

6. Conclusions

Industrial symbiosis has great significance at both the macro level (of state management) and the micro level (of companies). Coal mining companies with mining and processing activities are complicated complex, producing large amount of waste to the environment. Thus, the application of the industrial symbiosis model in the industry is absolutely necessary. The paper has systematized the theoretical basis of industrial symbiosis, circular economy and analyzed to show the relationship between industrial symbiosis, circular economy and sustainable development. From some cases in Vietnam recently, and the analysis of the application of the industrial symbiosis model into Vietnam coal mining industry, the paper offers the industrial symbiosis model for Vietnam coal mining industry. This model demonstrates the symbiotic relationship of the coal mining companies with its partners in production and business activities, especially in the treatment, recycling, reuse of waste and other unwanted outputs of the industry.

In the paper, the authors only analyzed the typical situations without making more specific surveys. The above recommendations are for guidance only and need to be researched in details in further work. The author aim to overcome these limitations in upcoming research.

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