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Eco-industrial park: from theory to practice Case study in Kinh Mon District, Hai Duong Province, Vietnam

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Abstract. Operating eco-industrial park (EIP) based on industrial ecology theory has emerged since 1970s to reduce the impact of waste and save natural resources. It is especially meaningful for developing countries like Vietnam to reach sustainable development goals.

The study is based on the theory of industrial ecology, the previous studies of applicable capacity in Vietnam condition and the development orientations in Hai Duong province – the study area. The aim of this research is to develop an EIP model in Kinh Mon district, Hai Duong province which have been developing material industry quite fast, along with the degradation of the environment.

Kinh Mon EIP has been developed with Hai Duong thermal power plant (2x600MW) in focus, along with a paper mill, an unbaked material factory, a fly ash treatment factory and Hoang Thach cement factory's supporting; constituting a symbiotic system. The model has a material cycle among the factories, which can reduce resources demands and industrial waste emitted to the environment – one of the EIP's aims. The model has many advantages, especially the high applicability in this particular case because it is based on actual needs of the province, as well as the availability of natural resources.

Keywords: industrial ecology; eco-park; EIP; sustainable development.

1. Introduction

Industrialization has brought many economic benefits but also caused several environmental issues such as the exhaustion of natural resources, environmental pollution or the green house effect and global warming. Yet, the effects on people are not the same; although the developing countries do not emit or damage the environment the most, their people suffer the most. Due to the lax enforcement of law and inadequate policies in those countries, companies and industrial factories often ignore the step of environmental protection in their manufacturing processes. As a result, the quality of the environment is more and more degraded, the resources are running out, meantime, the local people do not receive any compensation for the lost. In brief, Vietnam can be a typical example for the situation when there have been more than 200 industrial zones

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established at the end of 2008 with a lot of environmental problems occurring in this developing country.

One of the solutions for that problem that had been implemented all over the world is the reconstructing those normal industrial zones into eco-industrial parks first known in the case of Kalundborg, Sweden in the 1970s [1]. The theory underneath this model is industrial ecology, of which the idea is reusing residue of one factory in the other within the same industrial zone, so they can save ingredients as well as use energy efficiently and protect the environment. In details, industrial ecology helps minimize the use of natural resources and the impacts of development on natural systems. The term ‘eco-industrial park’ (EIP) has emerged from the theory of industrial ecology. EIP has been developed strongly in many developed countries and very limited in developing countries including Vietnam.

The study area, Kinh Mon district, is located in Hai Duong province, a province in the Red River delta, Northern Vietnam with a total area of 112.9 km^2 [2]. Kinh Mon district is surrounded by Da Vach river in the North, Kinh Thay river in the West and the Han river in the East. The main characteristic of terrain in this area is medium mountainous, interspersing by plain.

The study area is in the tropical monsoon climate. A year has four distinct seasons. Winter is cold, summer is hot and wet, spring and autumn are transition periods. Average temperature is 22.4^{o}C, average rainfall varies from 1,500 to 1,700 mm, and average annual sunshine is 1,700 hours, facilitate the tropical and sub-tropical plant [2].

The population of Kinh Mon district is over 120 thousand people with a population density of 1,100 persons/km^2 [2]. Kinh Mon district comprises 22 communes and three towns (Minh Tan, Phu Thu, Kinh Mon) (as shown in Figure 1).

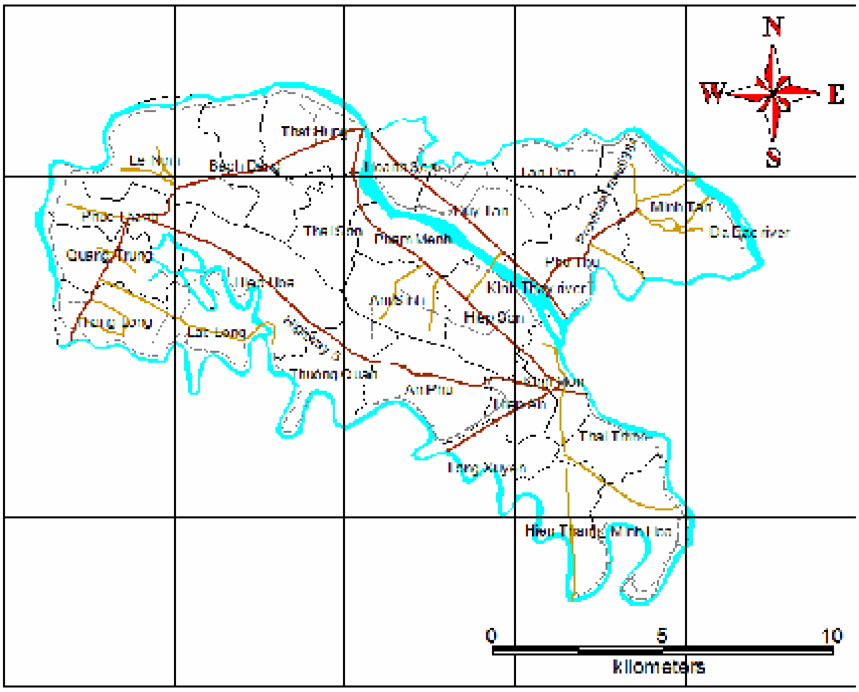

Figure 1. Kinh Mon district administrative map (Source: Atlas of Vietnam, Ministry of Science, Technology and Environment, 1997).

In the past, agricultural production dominated Kinh Mon's economic structure; however, in recent years, local people have experienced much significant industrial development and several severe environmental impacts, in addition. Clean production, green industry and sustainable development are the goals that this district would like to achieve. Building an EIP for this area is one of the measures to help achieving these goals. The aim of this research is to apply the theory of ecological industry and criteria of EIP to develop an EIP for Kinh Mon district. The result of this research is not limited to be used for that district but also can be applied to other case elsewhere.

2. Materials and methodology

2.1. Materials

Collected data includes Strategy for Socio-economic Development of Hai Duong province and Kinh Mon district until 2015 [3]; Calling for Project Investment by provincial government [2]; and the State of Environment Report (SoER) of Hai Duong province in 2009 [4]. In addition, several maps were collected and are important documents for analysis.

2.2. Eco-Industrial Park theory

Many environmental problems from industrial zone so far are attributed to the irferiority in metabolism process in comparison with a natural eco-system. A natural ecosystem has the great advantage of closing the material cycle. As a universal ecological knowledge, each active system has composed of three parts: production group, consumption group and decomposition group. The higher quantity of waste a system could renew, the more complete it becomes. Unlike a natural ecosystem, the decomposition group in an industrial system cannot fulfill the task of recovering and recycling material. Thus the industrial system is not closed, and the matter often leaks into the environment uncontrollably.

- In order to eliminate this limitation, scientists had tried to applied the advantage of natural ecosystem to the industrial system – transform into an industrial ecosystem - changing the current one into a system with natural ecological functions such as closed material, energy cycles, recycling materials, waste and so on. This is known as Industrial Ecology theory, the basic theory beneath an Eco-industrial park [5]. The word 'industrial' does not only mean manufacturing industries but also the services and construction processes involved.

The most popular application of Industrial Ecology theory is eco-industrial park (EIP). According to Ernest A. Lowe (2001), an EIP or estate is defined as a community of manufacturing and service businesses which is located together on a common property. Member businesses collaborate in resolving environmental and resource issues such as wastes, pollutions, energy-saving and resources demand. By working together, the collective benefit can be greater than the sum of individual benefit gained by each company by only optimizing its performance. The goal of an EIP is to improve the economic performance of the participating companies along with minimizing their environmental impacts. Components of this approach include green design of park infrastructure and plants (new or retrofitted); cleaner production, pollution treatment; energy efficiency; and inter-company partnering. An EIP also seeks benefits for local communities to assure that the entire impact of its development is positive.

So far, there is no official standard for an eco-industrial park. According Ernest A. Lowe (2001), to be a real eco-industrial park, an industrial zone/area must be more than:

- A single by-product exchange or network of exchanges;
- A recycling business cluster;
- A collection of environmental technology companies;
- A collection of companies making "green" products;
- An industrial park designed around a single environmental theme (i.e., a solar energy driven park);
- A park with environmentally friendly infrastructure or construction; or
- A mixed-use development (industrial, commercial, and residential).

2.3. Review of previous study on building EIP model

Developed countries have attained great achievements when applying EIP. One of the most successful is Kalundborg EIP which was developed during the latter half of 20th century [6]. This EIP is power-plant-based type, which has an Asnæs thermal power plant (1,500 MW) in the center. A by-product exchange system has been created there. Water cycle in EIP is based on the supply of Fjord Sea and Tissø Lake. About 40% - 60% of energy is redundant and emitted into the environment. To enhance economic benefits, that waste energy is transferring to Statoil refineries, Novo Nordisk pharmaceutical and enzyme plant and farms as well as for warming Asnaes Kalundborg city (about 20,000 people) in winter. Other wastes from power plant such as gypsum is reused in Gyproc plaster walls plant, ash and slag in Aalborg cement and paving materials factory, etc. Kalundborg industrial zone has been considered first eco-industrial park in the world.

The second example is an Agro-Industrial Eco-complex named Seshasayee – India [1]. In this case, the structure is much simpler, with a paper mill, a sugar mill and an alcohol plants. Paper mill was the first factory of the system. Then, to meet the demand of raw materials, a sugar factory was established. Waste from sugar cane production (bagasse) is used as raw materials for paper production, and molasses (a byproduct from sugar production) is used to manufacture ethanol alcohol. To ensure an abundant supply of sugarcane, the manufacturers strengthen the relationship with farmers, such as making agreement on buying back the products or ensuring irrigation water supply. Other eco-friendly actions of this complex are reusing treated waste water and the paper bagasse as an energy source.

2.4. Method

A number of issues should be noted when apply EIP model in case of Vietnam such as:

- Eco-industrial model of the developed countries can not be applied directly to Vietnam due to differences in technical, economical and social conditions.

- The proposed EIP model should be feasible to be applied to the existing industrial zone with many different types in Vietnam so far.

- It is necessary to consider not only technology and characteristic of each sector to optimize the material flow, but also the role of related institutions and agencies in order to put the theoretical model into practice.

In Vietnam current condition, with limitations in manufacturers' awareness, finance and technology, the application which prioritizes pollution preventing would be less practical. Instead, the priority order below should be considered as a temporary solution: (1) recycling and reusing of wastes, (2) end-of-pipe treatment, and (3) gradually shift towards preventing and minimizing waste at source once the manufacturers' awareness in environmental issues as well as the technology have improved.

Using data in Hai Duong thermal power plant's technical document, the study firstly calculated the amount of waste emitting when the factory is operating. The calculation involved the amount of water used, lost water (i.e. vaporizing); amount of coal used, ash and cinder, excessive heat and energy that can be used in other manufactories. The study also assessed the supplying capacity of mines in and around the project area.

Furthermore, the location of certain factories in the projected area have been identified based on the analysed information regarding the local demands (i.e. Hai Duong thermal factory project area). Therefore, a chain of plants and factories, which use waste and by-products from each one in its own manufacture, has been built, in order to reduce waste and the resources demand.

Next, the amount of resources demand (i.e. water and energy) and waste were accounted for, in order to find out the best way to reuse and recycle them in other factories. Thus, the expected capacity was set for each factory due to the calculation above so that each member can get most benefit from the others. As a result, the chain has been closed with a material-energy cycle.

3. Result

Basing on the data calculation above, a model constitution of five factories has been built of which operation diagram is shown as in Figure 33. The location of this eco-industrial park is shown in 2. Details of each factory in our EIP model with approximate expected capacity and area are described below.

3.1. Hai Duong thermal power plant

- Location: Phuc Thanh commune, Kinh Mon district, Hai Duong province

- Planned square: 82.86 ha

- Designed capacity: 2x600 MW; including two units: each unit has one turbine and two circulating fluidized bed boilers.

- Input:

§ Fuel: Major by 6B bran coal exploited from nearby mines (Quang Ninh and Hai Duong provinces) with total amount of 4,239,300 tons.yr^{-1} and minor by fuel oil FO 2BDesulphurized agent: limestone; 234,000 tons used each year.

§ Water supply: Source: Kinh Thay river; closed circulation; almost used for cooling and boiler purposes. Total amount: 480$m^3.hr^{-1}$.

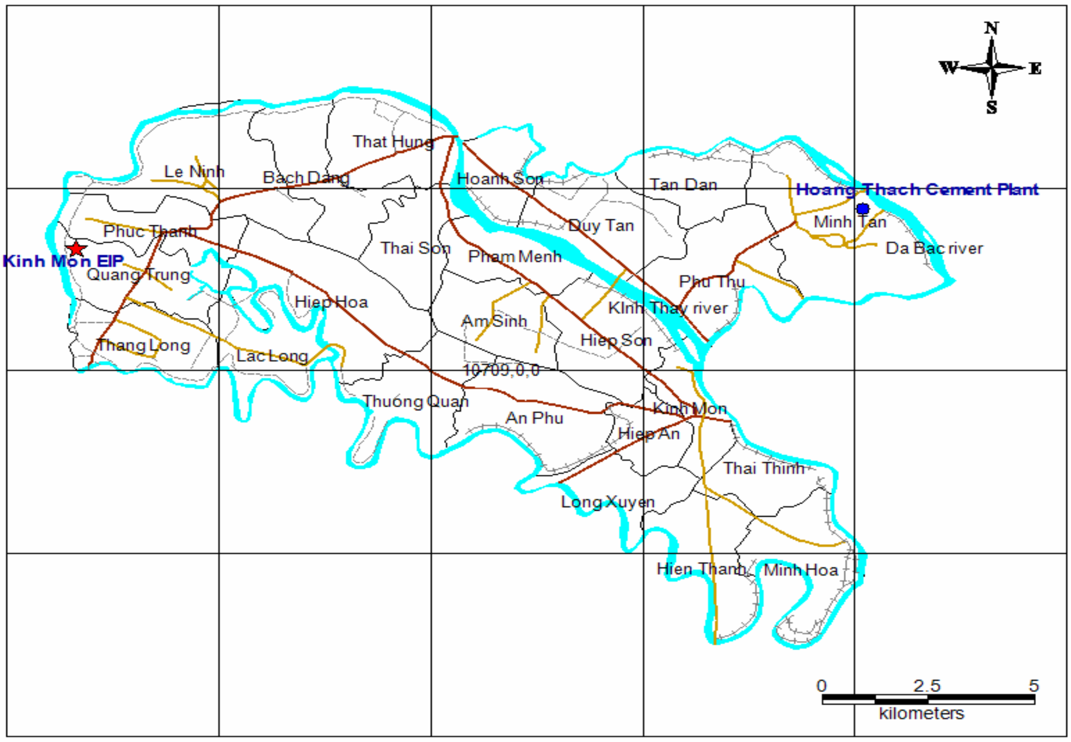

Figure 2. Location of Kinh Mon eco-industrial park.

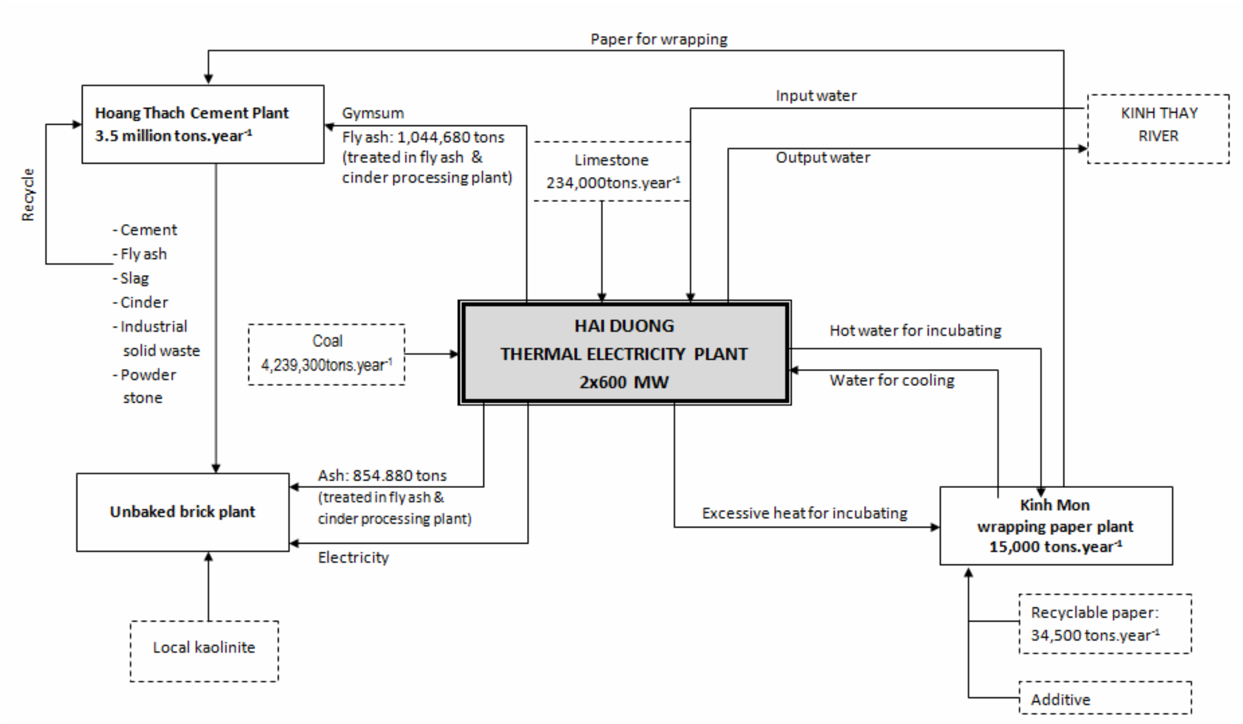

Figure 3. General diagram of Kinh Mon eco-industrial park.

Details of water demand are presented in Table 1.

Table 1. Details of water demand of Hai Duong thermal power plant [7]

No	Water demand	Raw water	Filled water	Demineralized water
1	Additional water for steam cycle (max 3%)	145.6	330	122.8
2	Additional water for closed cooling cycle	28.4	25.6	24
3	Additional water for central conditioning station	47.6	42.4	40
4	Other purpose	22.4	20	
5	Cleaning tools in coal warehouse	56		
6	Spraying for dust control in coal warehouse	40		
7	Reverting water for cleaning demineralized vessel	14.4	12.8	12
8	Domestic water	80.4	72	
	Total	434.8	302.8	198.8
	Provision (10%)	43.6		

Due to the high quality requirements, water must be treated through a two-step system: general treatment and then demineralization.

- Output:

§ Cinder and ash: total amount of 1,899,560 tons.yr^{-1}, detail:

- Cinder: from burning coal in combustion chamber, almost fall down to containing funnel in the bottom.
- Ash: also emitted from coal burning, ash is the small, light one escaping through chimney, of which almost is later trapped in dust removing equipment and the little amount remaining is released to the environment.

§ Waste from limestone used in coal desulphurization.

§ Excessive heat: according to the technical document, the useful heat rate that will convert into electricity later is only 38.15% and the remaining is partly waste escaping through exothermic process of boiler as well as other equipments, other part is emitted indirectly by this process happening in condenser. Besides, there is also an amount of heat radiating to the environment from cooling activities.

§ Gases emission, including:

- Emission from coal fired boiler: SO_2, NOx, CO and VOCs
- Emission from vehicle such as: coal dust, SO_2, NOx, CO_2, VOC, Pb
- VOCs leakage from pouring, loading, exporting, transporting fuel or from gases tank.

§ Waste water: total amount of $400m^3.hr^{-1}$, often contains one or more pollutants that are acidic, alkaline; suspended solid; malnutrition with redundant of antibiotics N, P; high COD; as well as dust oil, heavy metals, and bacteria (Coliform).

Waste water will be treated following regulations mentioned in National standard 5945-2005 and then released to the cooling channel and finally to the environment.

3.2. Unbaked material factory

Products of factory are bricks and roof tiles, commonly used for construction. They are made of various materials through different technologies.

Raw materials used in production include cement, sand, gravel, coal slag, etc Unbaked material has many advantages compared to traditional one such as saving resources, avoiding coal so not polluting the air, bearing high-pressure as well as taking benefits from waste...

Specific proposal of unbaked materials plant in Kinh Mon EIP as follows:

- Expected area: 2 ha

- Input material: Depending on the each recipe, the amount of coal ash in unbaked bricks varies from 30-60%, the remaining (ore slag, solid waste, rock and cement powder) accounts for 8-10% the whole ingredient. Depending on the source of coal slag, ore slag available, a suitable blending recipe should be applied for highest economical benefit.

3.3. Kinh Mon wrapping plant

Scale:

- Location: Phuc Thanh commune, Kinh Mon district, Hai Duong province
- Expected area: 10 ha.
- Main product: wrapping paper.
- Capacity: 15,000 tons.yr^{-1};

Inputs:

- Recyclable paper: 34,500 tons.yr^{-1}
- Additives:
  - § Pine resin (glue): ($C_{19}H_{29}COOH$): 6 kg.ton^{-1} products.
  - § Starch: 0.1 - 0.2 kg.ton^{-1} of product.
  - § Aluminum sulfate $Al_2(SO_4)_3.18H_2O$: 34 kg/ton paper product.
- Energy requirement: about 21,780,000 kWh.yr^{-1}, 72,600 kWh.day^{-1}, used for production and lighting. All types of machinery and electric equipment will use electricity from Hai Duong thermal power plant, while excessive heat from thermal power plant is reused for drying paper.
- Water input: 10,000m^3.day^{-1}

Output:

- Wrapping paper: 15,000 ton.yr^{-1}; supplying wrappings for Hoang Thach cement factory and the others in this area.
- Water for cooling and washing machines: 30,000m^3.day^{-1}: Getting into the treatment system before being transferred to Hai Duong thermal power plants.
- Plastics and residues: 1 kg.ton^{-1} of product.

3.4. Fly ash and cinder processing factory

Fly ash and cinder from Hai Duong thermal power plant once be recycled and reused will give much economic and environmental benefits by cycling waste or saving land for disposing waste.

- Location: Phuc Thanh, Kinh Mon district, Hai Duong province
- Expected area: 5 ha
- Expected capacity: about 2,000,000 tons of cinder and ash per year.
- Input material: fly ash and cinder from Hai Duong thermal power plant and Hoang Thach cement plant.
- Technique: use of rapid self-settled technology to enhance sedimentation rate (the technology which be used successfully in fly ash processing factory, Pha Lai, Chi Linh, Hai Duong). After treatments, the output of this factory will be high-quality material for the two others in Kinh Mon EIP: fly ash for Hoang Thach cement factory and cinder for unbaked material factory. This Fly ash and cinder treated factory could be considered an intermediate factory in the whole chain.

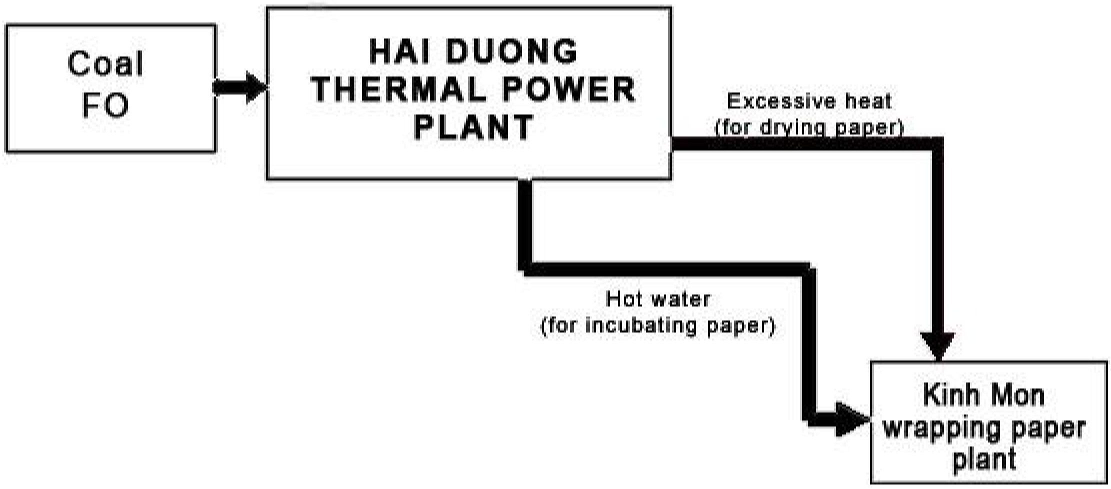

Figure 4. Diagram of Energy flow.

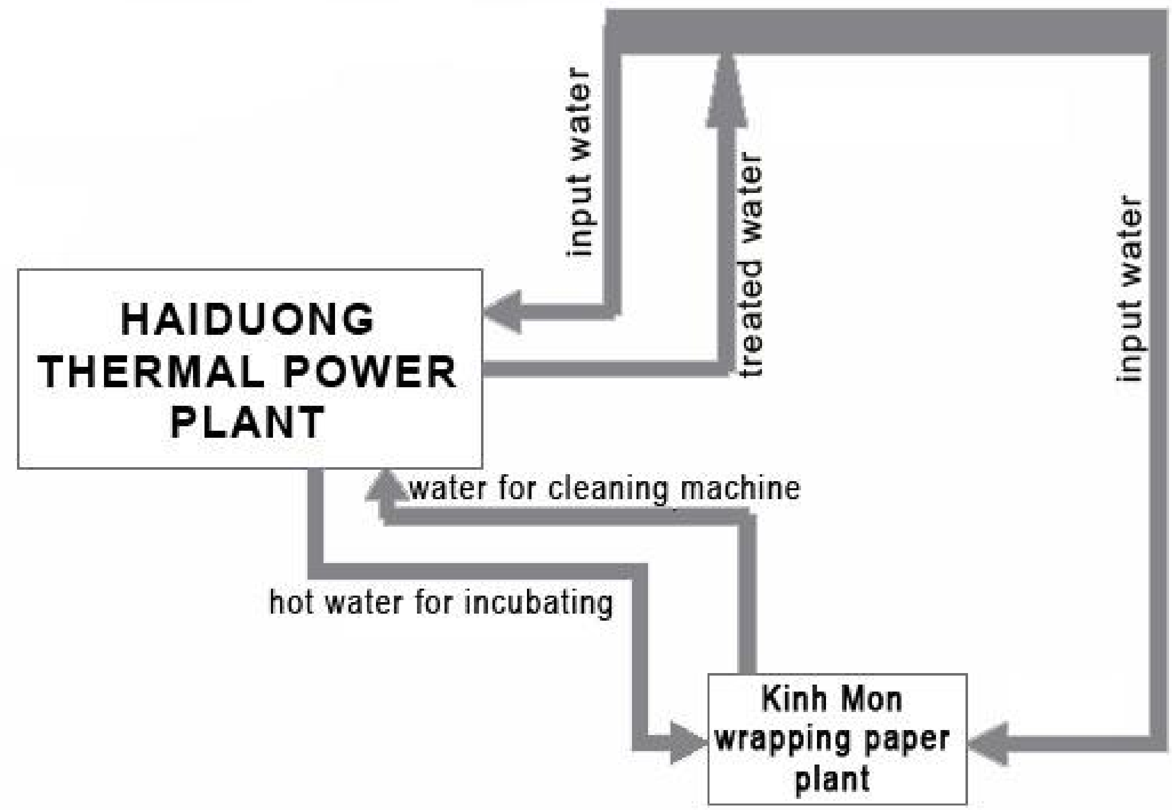

Figure 5. Diagram of water flow.

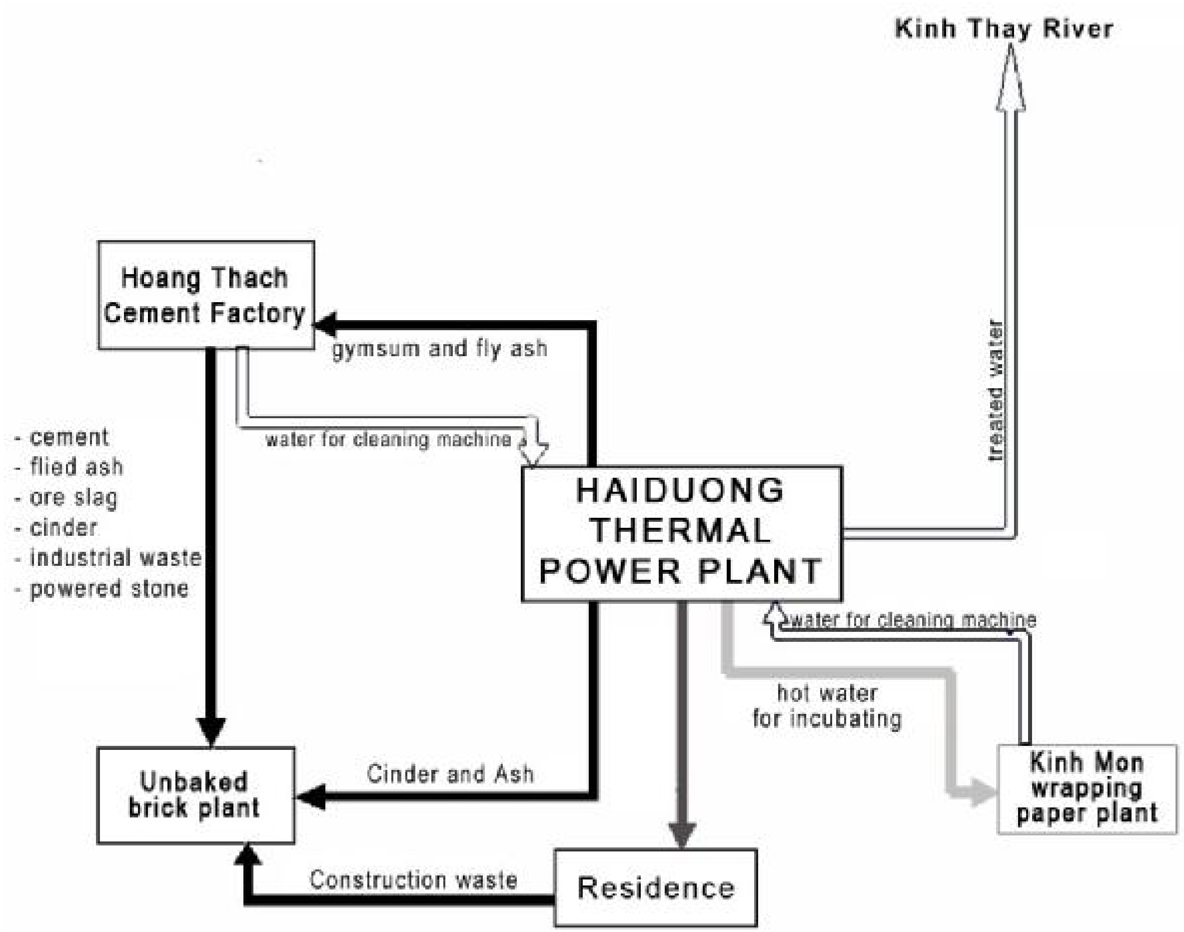

Figure 6. Diagram of material cycle.

4. Discussions and Recommendations

4.1. Discussion of Findings

Implementing an EIP brings not only economic but also environmental benefit. Unfortunately, there are a number of risks which hamper the realization of an EIP. Below is some main points of it pros and cons.

4.1.1. Benefits

For member businesses, performing an EIP could not only reduce costs by saving material and energy, sharing cost for services viz. waste management, personnel training, supply and environmental information systems, but also increase production efficiency through a by-product exchange mechanism. Particularly, cement manufacture process requires gypsum as an additive at about 2 million tons per year. Domestic natural gypsum is not available, so the supply of this mineral totally depends on import source. Meanwhile, the SO_2 treatment process in Hai Duong power plant produces artificial gypsum which can be used in Hoang Thach cement factory. This combination is a great idea to solve both economic and environmental issues: it can not only reduce cost for additive but also reduce pollution and resource demand.

In addition, EIP could also improve local economic because its development could create more employment opportunities and support the development of local small industries and traditional handicraft. For the environment quality, performing EIP could reduce the sources of pollution to the environment, waste and resource demand through cleaner production, reusing and recycling.

4.1.2. Challenges

Developing an EIP is a complex task, requiring cooperation between the communities, planners, contractors, and enterprises in the industrial zone. This will be a huge risk if the relationship between these groups is not strengthened. Since EIP development depends on collaboration, interaction, interdependence of enterprises, it may be difficult to ensure the quantity and quality of supply of inputs; collecting waste data and predicting the development becomes more difficult. In particular, enterprises using by-product or waste of each other as inputs are also facing the risk of losing an important market or supply if any plant is closed, even the whole system may be collapsed. The problem is especially serious in Vietnam where the link among industrial branches is not tight.

On the one hand, developing an EIP may require extra costs than the traditional industrial zone, which may arise from the design process, site preparation, infrastructure, construction, and so on to ensure the proper functioning according to the criteria of an EIP. On the other hand, profit from it is only clear to see in long-term, so the payback time may be longer. That makes financial risk more ominous for the investors, especially in a developing country like Vietnam.

4.2. Recommendations

Becoming an industrial country and making sustainable development reality are the goals of every developing country, including Vietnam. To achieve both of these targets, one way is building an industrial production model concerning an eco-friendly industrial facilities and high scientific intellectual involvement.

This study presented here has proposed an EIP model, which is basically involving the industrial metabolism process, aims to minimize the amount of waste emitted to the environment, together with maximize the economic benefits. The model based on the theory of industrial ecology has many advantages and is highly practical because it also takes into account the industrial development's orientation in Hai Duong province as well as all facilities, infrastructure and resources raw material available there.

In order to enhance the feasibility of the project, following recommendations have been made:

For Hai Duong province

- Adjusting the projects (i.e. the project of unbaked material factory, the wrapping paper factory) by locating them in the Kinh Mon EIP to reuse by-products and save resources.

- For future industrial projects, considering the possibility of merging them into industrial park, creating an efficient material cycle.

- Giving priorities (i.e. simplifying administrative procedures, reducing tax, etc.) to businesses involved in formulating and developing eco-industrial parks.

- Establishing a multi-objectives communication program for local people raising awareness as well as supporting the project.

For businesses

- Performing deeper research in technical processes to minimize resources using, utilize and cycle the material.

- Tightening the relationship between enterprises in the industrial park to use byproducts of each other.

For environmental scientists and other relevant stakeholders

- Contributing experts' opinion for completing EIP performance in order to operate properly functions of an ecological industrial park.

Conclusions

The study has reviewed EIP theory and applied it to develop an EIP model for Kinh Mon industrial area in Hai Duong province. This is the first initiative of applying EIP theory into practice in Vietnam. This model can help to provide several economic, social and environmental benefits for the communities which in turn, can contribute to promote sustainable development in the research area.

In further researches, it is intended to make study on the benefits of the Kinh Mon EIP for local communities; moreover, developing the more completed models, taking more advantages from waste byproducts, industrial zones and implementing thoroughly waste treatment by adding some other factories according to local demands, socio-economic development's orientation and market needs. In addition, a residential centre would be considered an alternative option; to raise living standard of local and satisfy other critera suggested by Ernest A. Lowe (2001) in his handbook (i.e. an EIP should be an mixed development area with industry, commerce and residential).

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