Mental Model Perspective of Multi-Sector Industrial Symbiosis in Indonesia Based on Waste Exchange Strategy: Introductory Study

O Pradhita¹, H N Azhar¹, M P Laksana¹ and N N Surbakti¹

¹Department of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung, Indonesia.

pradhita.oka@gmail.com

Abstract. Indonesia, as a developing country, has a long-term national vision to become a stable industrial country which will achieve in 2035. This commitment showed by an increase in industrial sector contribution to Indonesia's GDP, which is targeted to reach 30% in 2035 compared to 20.97% contribution to GDP in 2015. The global competition and current trends also become challenges for the Indonesian industry sector, where nowadays, international markets more prefer eco-labeled products than conventional ones. The green industry concept, which prioritizes the efficient use of resources sustainably to improve environmental performance, could be the answer to tackle both problems. Green industry development can be done through the concept of industrial symbiosis by implementing a waste exchange strategy. This strategy is applied by reusing waste as raw material for other industries. This study examines industrial symbiosis potential practices in Indonesia using waste exchange strategies in various industrial sectors through a mental model approach. The mental model structure in this study was built by exploring possible synergies between industries through byproduct similarity. From the psychological model, we uncovered nine waste categories as vital nodes in waste-resource networks. This preliminary study may serve as additional industrial planning guidance for the Indonesian government and other related stakeholders in the green industry development.

1. Introduction

Indonesia has the largest economy among Southeast Asian nations and considered one of the new emerging markets in the world, with its GDP growth stagnates at a 5% rate. While Indonesia macroeconomic indicators rated as stable and healthy rise [1], there are vulnerabilities on several subjects jeopardizing the nation's economy, namely global economic trends and industrial competitiveness. Trends in the global economy, such as trade protectionism and the sharp slowdown in partner countries, could halt Indonesia's export and hampered the overall economic sectors, including the industrial capabilities [1].

Confronting the industrial competitiveness issue, Indonesia designed Rencana Induk Pembangunan Industri Nasional (RIPIN) 2015-2035, the country's industrial master plan. As mandated in RIPIN, Indonesia has a long term vision in the industrial sector to become a stable industrial country in 2035.
Its top mission is to improve national economic performances, as well as people's prosperity and industrial development [2]. The masterplan itself targeted a 9.03% increase in the industrial sector's contribution to GDP from 20.97% in 2015 to a 30% contribution in 2035. After 2035, the industrial sector in Indonesia will become the economy's prime mover, which characteristics are having a synergistic linkage between industries and other subsectors, capable of growth sustainably, and highly resilient against global volatility.

One of the efforts to gradually introduce sustainable development and environmental insight into the industry is implementing the green sector, assigned by Indonesian Law Number 3 of 2014 [3]. The law mandated industrial transformation from obsolete technology to low-carbon technology to increase productivity, natural resources efficiency, and reduce losses in energy and material use. Industrial symbiosis could be the catalyst to the industrial transformation, which focused on resource management to diminish the overall inefficiency [4]. Industrial symbiosis is part of industrial ecology studies, can be described as a complementary approach to competitive advantage where separate industries involved in the material, energy, water, and byproducts exchange [5].

Uncovering existing symbioses between businesses has led to more significant sustainable industrial development [6] than through attempts to design and build new eco-industrial parks incorporating physical exchanges and services such as utility-sharing. The waste exchange between industries fulfills the requirement of the physical transfer in industrial ecology by reusing and recycling one industry byproduct into new raw material for other industries. Thus the material utilization can be optimized. The mental model approach could examine the similarity between two industries by connecting the byproduct and raw material nodes to show the re-utilization prospect. The result is networks of sectors linked by its resources uniformity.

The essential aim of this work is to build a mental model structure of industrial symbiosis to uncover the industry-resource nexus. In the next section of this paper, we review the related literature on the topics of industrial symbiosis, and the article 3 will discuss the methodology, research process' systematic thinking through literature review, and establishing the mental model. Section 4 presents findings from the mental model, discuss any additional possible industrial synergies, and examine the limitations to waste exchange implementation. Section 5 presents conclusions from this study and suggestions for further research.

2. State of the Art

2.1 Industrial symbiosis
Industrial symbiosis (IS) concept grows as industrial ecology (IE) study emerged in the last 20th century, due to concerns about the influence of industrial activities on the environment [7]. Both concepts resemble the biological process in the ecosystem, which emphasizes the mutual interrelation between its components inside a living system connected with complex processes. From various earlier literature, there are three vital elements to IS and IE approach [8]: 1) Systemic and integrated view of all components in the industrial economy, 2) Emphasize the complex of the biophysical substratum of human activity regarding the industry, 3) Considers any technological dynamics and evolutions. Most of the earlier studies agreed that IE, on significant parts of the world, diffused as a practice that can reduce the industrial collective environmental impact [9-10]. Drawn from a more detailed ecosystem analogy, IS defined as the interaction of various business entities that create a cooperative network, aiming for competitive advantage by exchanging any resources, services, and infrastructure [6][11], including by-product which considered as waste and useless residue in one establishment.

2.2 Circular economy
From over the years, social awareness towards a sustainable society is increasing as new demands of business practices. The circular economy is an economic system switching the "end of life" concept with the method of substituting or reducing raw material consumption and implementing a practice of
reusing, recycling, and recovering materials spent alongside production line, distribution, and consumption process [12]. Alongside the IS and IE perspective, the precise relationship between them is still unclear, and explicit attempts to achieving a clear view have not been made yet [11]. From the previous study [13-15], Circular Economy (CE) perspectives describe IS as a business model prototype based on equal distribution of infrastructure and byproduct to promote resource efficiency and increase the value of the waste utilization.

2.3 Waste exchange
Waste exchange is a facility that enables process wastes, by-products, surpluses, or materials that do not meet specifications to transfer from one company to another where they are used as process input [16]. Although the elimination waste or the minimization of waste generation at source are the most preferred options, recycling waste materials for reuse, either on-site or off-site, can often present a cost-effective measure to treat and dispose of waste. Waste exchange is a definite part of recycling [17]. The waste exchange program already in operation in some countries [18], employing similar methods to organize a list of available waste materials and a list of desired raw material. The progress of the waste transfer operation depends on the supply and demand for specific waste and the capacity of the exchanging parties to reach an agreement [19].

3. Methodology

3.1 Literature Review
In this study, the literature review was conducted by analyzing research papers, books, and reports on IE, IS, and waste exchange topics to expose the recent development and state-of-the-art in the related field. Literature review and systemic thinking also executed to find the pattern of industrial circularity by examining reading materials on cleaner production and manufacturing-related topics. Cleaner production and manufacture articles are used to draw information about raw material needed and waste produced from the industry. The information on raw material and residue from industry are required to develop the mental model.

3.2 Mental Model Analysis
To establish the mental model, we develop an approach for examining the synergies between industrial type rather than those between factories. The mental model was created using AnyLogic 8.5 PLE software. The conceptual model was built by examining the KBLI codes [20] (Klasifikasi Baku Lapangan Usaha, Indonesian Standard of Industrial Classification) with its particular raw material needed and possible waste generated from each system. From the identifying process, we analyzed the pattern of input-output features and grouped the most common waste into nine waste categories based on its material properties. The waste categories are an organic waste, wood chips, metal scrap, metal dust, rubber, glass cullet, plastic, waste oil/residual fluid, and masonry waste. Then, KBLI codes are assigned in pairs for each waste category, the group pairing in waste-producing KBLI codes as an input and waste-receiving KBLI codes as an output. The connection on the mental model is created based on existing synergies and possible synergies identified from the literature.

4. Result and discussion

4.1 Waste-industry network through a mental model
4.1.1 Organic waste. Organic waste is material that is biodegradable and comes from either a plant or an animal. Organic waste has particular concern environmentally due to its biodegradable properties [21] and the primary cause of environmental impacts such as odors, aesthetics, and greenhouse gases emission. The mental model from the organic waste network shown in Figure 1.
Organic waste mainly generated from food processing industries, such as meat, poultry, fish, fruits, edible oil, milk, staple food products (KBLI 101, 102, 103, 104, 105, 106, 108, 111) and bio-based manufacture (KBLI 120, 131). The biodegradable characteristic of organic wastes makes it is only suitable for energy recovery through biological degradation. The process can release methane, potent greenhouse gas, and potential green energy, which captured from landfill [22] and readily converted to electricity and heat.

4.1.2 Wood chips. Wood chips are pieces of wood from small to medium-sized, generated from cutting or chipping processes from larger pieces of wood. Its high cellulose content compared than other organic waste makes wood chips are not readily biodegradable, but preferred in energy recovery due to low fly ash and residue production [23]. The mental model from the wood chips waste network shown in Figure 2.

Wood chips mainly generated from sawmills and preserving industries for wood, rattan, and bamboo-based product (KBLI 161, 162), paper and paper product manufacturing (KBLI 170), furniture industry (KBLI 310) and metal-based manufacturing services (KBLI 251, 259). The industry which directly uses wood as the primary raw material such as paper industry (KBLI 170) and paper-based manufacturing (KBLI 161, 162, 310) can reuse the wood chip by compressed the chips into a more rigid structure [24]. Further research in wood chip recycling suggested the conversion of compressed chips into new carbon-based material for electrical use [25]. They're also a conventional energy recovery technique from wood waste via thermal incineration [23].

4.1.3 Scrap Metal. Scrap metal is the combination of waste metal, metallic material, and any product that contains minerals that is capable of being recycled from previous consumption or product manufacturing [26]. Its larger size makes scrap metal has the flexibility to be reused in other metal-related works. The mental model from the metal scrap waste network shown in Figure 3.
Scrap metal waste mainly generated from metal-related industry (KBLI 241, 242) and its processing works (KBLI 251, 252, 259, 273, 274), and vehicle-related industry (KBLI 291, 292, 293, 301, 302, 303, 304, 309). The most general recycling process for scrap metal is metal refinery through the smelting industry in large quantities (KBLI 243) [27] before further processes into the new metal product.

4.1.4 Metal dust. Metal dust is a necessary byproduct generated by a physical-mechanical process such as combustion, cutting, and grinding. Metal dust is different in size from metal scrap, comprises of sand-like structure with millimeter-sized dimension [28]. The mental model from the metal dust waste network shown in Figure 4.

Metal dust waste mainly generated from metal-based industry and its related product (KBLI 241, 242, 243, 251). This type of waste can be recovered and reused as additives in the masonry industry for construction material (KBLI 239). Due to its microstructure dimension, metal dust has the prospect to replace fine aggregates in the concrete-making industry [29] fractionally.

4.1.5 Rubber. Rubber waste, both natural and synthetic-made, is categorized as a particular waste because it is challenging to refuse using the general technique for thermoplastic material [30]. Therefore, rubber waste reuse and recycling are necessary because it is not readily biodegradable. The mental model from the rubber waste network shown in Figure 5.
Rubber waste is generated by rubber product manufacture (KBLI 221), furniture (KBLI 310), and vehicle-related production (KBLI 291, 292, 293, 301, 302, 303, 304, 309). Rubber can be recovered primarily in repair and reusing method. The mechanical and electrical properties of high-quality rubber waste can be improved [31] and have the potential to substitute electrical components (KBLI 261, 262, 263, 264, 265, 266, 273, 275, 279). Rubber waste also has a waste-to-energy prospect through combustion because of its calorific value. Rubber waste has a higher calorific value compared to other carbon-based fuels such as coal, coke, and wood [32].

4.1.6 Glass cullet. Glass cullets are glass material that shattered and crushed into small pieces. Glass cullets are the prepped glass waste that ready to be remelted into new glass after cleaning and color-separating process. The mental model from the glass cullet waste network shown in Figure 6.

Glass waste is generated from glass-making industry (KBLI 231), photography and optics-based manufacture (KBLI 267, 268), and transport-related production (KBLI 291, 292, 293, 301, 302, 303, 304, 309). Glass cullets in glass-making industry were separated by color, remelted and shaped into new glass [33]. Further development in glass recycling, glass cullets can be ground into the sand-like structure and used as a partial replacement for silica sand in cement and concrete manufacture (KBLI 239) [34].

4.1.7 Plastics. Plastics waste is waste containing polymers such as polyethylene, polypropylene, polystyrene, polyvinyl chloride (PVC), polyurethane, polyethylene terephthalate (PET), nylon [35]. Its known for durable and elasticity properties makes plastics used in almost every daily products. The mental model from the plastic waste network shown in Figure 7.
Plastic based waste primarily generated from common petrochemical industries, mainly from olefin products (KBLI 201), plastic goods industries (KBLI 222), and home appliances industry (KBLI 275). The current plastic waste recycling potential is the home appliances industry as mold raw material (KBLI 310). However, the recycling possibilities are endless because of its flexibility and easy to combine with other matrices [36].

4.1.8 Waste oil/residual fluid. Waste oil or remaining fluid is defined as petroleum-based or synthetic oil as a base fluid that contaminated with other additives such as ash dispersant, detergent, antioxidant, metal deactivator, viscosity improvers, and pour point depressant [37]. The mental model from the residual fluid waste network shown in Figure 8.

Waste oil mainly generated from automobile and its accessory manufacture (KBLI 291, 292, 293) and other transport-related production (KBLI 301, 302, 303, 304, 309). Waste oil has a secondary use as light fuels, due to its presence of volatile parts [38]. The current practice in the mining industry (KBLI 191) with a green approach uses waste oil as an ingredient in the blasting agent [39].

4.1.9 Masonry waste. Masonry waste is a general term from any waste composed of construction and demolition waste material, such as unusable concrete block, off-specs clinker, limestone, clay, brick shard, and mineral-rich sands. The mental model from the masonry waste network shown in Figure 9.
That wastes mainly produced by paper and paper product manufacture (KBLI 170), glass and glass product manufacture (KBLI 231), and non-metallic mineral product manufacture (KBLI 293). The potential use of masonry waste is being reused and recycled as released materials, or cement-treated materials in infrastructure construction, recycled aggregates for concrete and mortar production (KBLI 239) [40].

4.2 Constrain to industrial symbiosis through a waste exchange in Indonesia

To assess the feasibility of industrial symbiosis through waste exchange implementation in Indonesia, we use the Waste Framework Directive (WFD) 2008 document from the European Union's Commission for Environmental Cooperation as an indicator [41]. Four general conditions define the concepts of waste-to-product. End-products are no longer considered as residual waste, but as new materials to be reused and exchanged within the industrial system.

The first condition is how waste commonly used for specific purposes. The mental model approach to this study could overcome this constraint because the model can directly connect the possible byproducts with respective potential use. The similarity connection between byproduct and likely usage proves that there are specific purposes from the waste.

Relate to economic value. The second condition mainly deals with any market existence or demand for waste. The mental model approach in this study could partially identify these conditions. Some connection on the mental model is proven by best practices on existing industry, while the remaining connection based on potential use for substituting raw material in promising research scale. The best practices on existing production confirm that there is an economic value from reusing byproduct; thus, the market is present for particular waste. Studies on potential users are not readily proven. There should be additional studies to confirm the industrial supply and demand in a waste exchange program. Future research should be conducted through material flow analysis [42] on how waste is recirculated inside the industrial system.

The following condition relates to technical and non-technical aspect oversees the waste exchange program. Technical requirements, including standard and waste specification, legislation applicable to products exist for the waste. The mental model approach to the study could not examine the technical requirements of waste exchange between industry. The industry can set its quality specifications for the raw material they consume to control the end-product overall standard. Variability in raw material quality from a waste exchange program could lead to an unstable end-product condition [43]. Sort and splitting waste-to-product based on its physical properties are encouraged to improve industrial motivation in waste exchange participation.

Governmental support through legislation also could not be described by this model. In Indonesia, the framework to implement the waste exchange program is not implied in the relevant law [3]. The legislation only illustrates the green industry definition, which dictates the efficiency of material utilization. Waste exchange strategy is only one effort to reach the green industry ideals.

The last condition put the concerns on external impact from waste-to-product usage. No adverse environmental effects or human health impacts are generated following waste use. The mental model approach on the study could not investigate the further reaction of utilized waste on the target industries process, whether the waste could be more toxic, less toxic, or formed differently. Industrial processes often combine materials, which may reduce the probability of any manufacturing plant to be able to account for the exact material balance of their waste stream. It may also raise the risk of more toxic supplementary effects within their waste stream [44]. Further studies of waste material behavior on the other industrial process are needed to prove that utilizing waste material would be safe.

5. Conclusion

The mental model established in this study discovered the nine waste categories which has waste and raw material input-output pattern in Indonesia’s industrial sectors. This simple network model of waste and resource proved that the industrial symbiosis based on exchanging byproduct between
industries are achievable in Indonesia. This notion is supported by existing and benchmarking industries that enforced the waste exchange strategy as their material reuse and recycle control measure.

The model is part of preliminary research. Further research should focus on the material flow analysis to find the supply-and-demand of waste-to-product usage from the industries, feasibility study on more specific and technical matters regarding the IS implementation, and impact studies on how utilization of waste as new material affecting human health and environment. Based on the constraints of IS implementation in Indonesia, support from the government is needed to encourage the waste exchange program by regulating the standard and mechanism, including any economic incentive for environmental and sustainability compliance.

References

[1] OECD 2018 OECD Economic Surveys: Indonesia 2018
[2] Government of Indonesia 2015 Peraturan Presiden No. 14 Tahun 2015 tentang Rencana Induk Pembangunan Industri Nasional 2015-2035 (Jakarta: Ministry of State Secretariat)
[3] Government of Indonesia 2014 Undang-Undang No. 3 Tahun 2014 tentang Perindustrian (Jakarta: Ministry of State Secretariat)
[4] Mulrow JS, Derrible S, Ashton WS, and Chopra SS 2017 Journal of Industrial Ecology 21 (3) 559-571
[5] Chertow MR 2000 Annual review of energy and the environment 25 (1) 313-337
[6] Chertow MR 2007 Journal of Industrial Ecology, 11 (1) 11-30
[7] Frosch RA, Gallopoulos NE 1989 Scientific American, 261 (3) 144-152
[8] Cote RP, Cohen-Rosenthal E 1998 Journal of Cleaner Production 6(3-4) 181-188
[9] Ehrenfeld J, Gertler N 1997 Journal of industrial Ecology 1 (1) 67-79
[10] Boons F, Chertow M, Park J, Spekkink W, Shi H 2017 J. of Industrial Ecology 21 (4) 938-952
[11] Baldassarre B, Schepers M, Bocken N, Cuppen E, Korevaar G, Calabretta G 2019 Journal of Cleaner Production 216 446-460
[12] Kirchherr JW, Hekkert MP, Bour R, Huijbrechtse-Truijens A, Kostense-Smit E, Muller J 2017 Breaking the barriers to the circular economy. (Utrecht: Utrecht University)
[13] Bocken NMP, Short SW, Rana P, Evans S 2014 Journal of cleaner production 65 42-56
[14] Kraaijenhagen C, Van Oppen C, Bocken NMP 2016 Circular business—Collaborate and Circulate (Amersfoot: Circular Collaboration)
[15] Lombardi DR, Laybourn P 2012 Journal of Industrial Ecology 16 (1) 28-37
[16] Gaines LL 1983 Industrial waste exchange: a mechanism for saving energy and money (Lemont, IL: Argonne National Laboratory)
[17] Smith SR, Cheeseman C, Blakey N 2009 Waste management and minimization 9 (Paris: EOLSS Publications)
[18] DiPietro R 1994 Biocycle 35 75
[19] Cheremisinoff PN, Ferrante LM 2013 Waste reduction for pollution prevention (Oxford: Butterworth-Heinemann)
[20] BPS-Statistics Indonesia 2017 Direktori Industri Manufaktur (Jakarta: BPS)
[21] Speier CJ, Mondal MM, Weichgrebe D 2018 Journal of Material Cycles and Waste Management 20(4) 2150-2162
[22] Themelis NJ, Ulloa PA 2007 Renewable Energy 32 (7) 1243-1257
[23] Cheah CB, Ramli M 2012 Construction and Building Materials 30 320-329
[24] Gasol CM, Farreny R, Gabarrell X, Rieradevall J 2008 The International Journal of Life Cycle Assessment 13 (5) 421
[25] Chen C, Song J, Zhu S, Li Y, Kuang Y, Wan J, Kirsch D, Xu L, Wang Y, Gao T, Wang Y 2018 Chem 4 (3) 544-554
[26] Ayres RU 1997 Resources, conservation and recycling 21 (3) 145-173
[27] Reck BK, Graedel TE 2012 Science 337 (6095) 690-695
[28] Fiore S, Zanetti MC 2007 American Journal of Environmental Sciences 3 (3) 135-142
[29] Aggarwal Y, Siddique R 2014 Construction and Building Materials 54 210-223
[30] Yehia AA 2004 Polymer-Plastics technology and engineering 43 (6) 1735-1754
[31] Mahmoud WE, El-Mossalemy EA, Arafah HM 2011 J. of Appl. Polymer Science 121 (1) 502-507
[32] Ahmed R, van de Klundert A, Lardinois I 1996 RUBBER WASTE: Options for Small-scale Resource Recovery Urban Solid Waste Series 3 (Amsterdam: WASTE)
[33] Andreola F, Barbieri L, Lancellotti I, Leonelli C, Manfredini T 2016 Ceramics Intl. 42 (12) 13333-13338
[34] Ismail ZZ, Al-Hashmi EA 2009 Waste management 29 (2) 655-659
[35] Gnanavel G, Valli VPMJ, Thirumarimuthu M, Kannadasan T 2013 Elixir Int. J. Chem. Eng. 54 12212-12214
[36] Job S 2013 Reinforced Plastics 57 (5) 19-23
[37] Pelitti V, Dogan O, Koroglu HJ 2017 Global Journal of Environmental Science and Management 3 (1) 11-20
[38] Abro R, Chen X, Harijan K, Dhakan ZA, Ammar M 2013 ISRN Chemical Engineering 2013
[39] Smith SO, Kerpan LC 1995 U.S. Patent No. 5,397,405. (Washington, DC: U.S. PTO)
[40] Ledesma EF, Jimenez JR, Ayuso J, Fernandez JM, de Brito J 2015 J. of Cle. Prod. 87 692-706
[41] Commission on Environmental Cooperation 2008 Directive 2008/98/EC on Waste (Waste Framework Directive) (European Union)
[42] Chen PC, Ma HW 2015 Journal of Industrial Ecology 19 (6) 950-962
[43] Berget I, Naes T 2002 Journal of Chemometrics: A Journal of the Chemometrics Society 16 (6) 263-273
[44] Dunn BC, Steinemann A 1998 J. of Environmental Planning and Management 41 (6) 661-672