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Environmental Management of Industrial Estate Based on Eco-Industrial Parks: A System Dynamics Modeling

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ABSTRACT

This research aims to develop a dynamic model of environmental management of Modern Cikande Industrial Estate Indonesia based on eco-industrial parks. The model is designed using a system dynamics approach with Powersim Studio 7 Express software. It is simulated using 3 scenarios: 1) business as usual, which is oriented towards economic growth only; 2) conservationism, which is just oriented to environmental protection; and 3) new urbanism, which is oriented to the integration of economic growth and environmental protection. The use of system dynamics in modeling eco-industrial parks is useful for elaborating future development opportunities. A dynamic model built based on predetermined scenarios can be used as an alternative in decision making for managers and government. The results show that new urbanism is the best scenario for this environmental management. When it is compared to other scenarios, new urbanism has a significant impact on controlling the growth of industrial structures, restraining the decrease of land available for industries, managing the growth of raw input, decreasing waste quantity, bridling the need for water, escalating employment, and increasing contribution to regional income.

Keywords: Environmental Management, Eco-industrial Parks, System Dynamics Approach

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1. INTRODUCTION

Industrialization plays an important role in the growth of the world economy. The drive towards industrialization for developing countries is highly recommended, especially after the success of industrialization in East Asian countries (Opoku and Yan, 2019). Manufacturing is an industrial sector that acts a significant role in the economic growth of many countries in the world. The growth of the manufacturing industry will affect the growth of other sectors both in the short and long term (Su and Yao, 2017). In Croatia, for example, the competitiveness of the manufacturing industry has even been the most determining factor for share of national companies in the 2013-2015 period (Buturac *et al*., 2019). The development of supporting technology also enacts a key role in industrial growth. High-tech industry has proven to have a significant impact on the regional economic growth (Ho, 2007). Through social and institutional processes, low-tech industry has also contributed to the development of regional innovation in Indonesia (represented by the Pekalongan batik industry) (Maninggar *et al*., 2018). Another important factor that is crucial is the industry associations. In Ireland, for example, industry associations have proven to play a role in stimulating economic growth through improving physical infrastructure and improving social networks; where both of these factors greatly determine regional competitiveness (Power and Brunt, 2007).

In addition to its leading role for economic growth, industrialization has also had a significant impact on the decline of environmental quality. The use of fossil fuels in various industrial processes has produced CO_2 emissions which are the main cause of global climate change. Among more than 200 countries in the world, United States (US) and China are the two biggest CO_2 emitters in the world (Li *et al.*, 2018). In the decade before 2007, CO_2 emissions of US increased by an average of 0.7% per year. Starting in 2007 the US CO_2 emissions declined to reach 5,284 Mt in 2012 (12% lower than 2007 levels and 5% lower than 1997 levels) (Feng *et al.*, 2015). In China, the use of standard coal actually increased from 585.87 million tons in 1980 to 3.62 billion tons in 2012; this condition caused China's CO_2 emissions to increase from 1,424 billion tons in 1978 to 7,955 billion tons in 2011 (Ge *et al*., 2017). Globally it is known that despite a decrease in industrial CO_2 emissions in developed countries, CO_2 emissions tend to increase in developing countries (Dong *et al*., 2019).

Based on these conditions, an industrial development model is needed that is not only oriented towards economic growth but also integrated with environmental protection. In this context, circular economy (CE) is seen as the best solution towards a more sustainable economic model (Gómez *et al*., 2018). CE grows from the reality that the earth has limited resources so that extraction of resources must not exceed its regenerative capacity; the environment has the ability to absorb limited waste so that waste disposal into the environment must always pay attention to its assimilation capacity (Whalen and Whalen, 2018). To guarantee the implementation of CE, an industrial metabolism-based approach, called eco-industrial parks (EIPs), becomes very important. In EIPs, a collective collaboration between industrial actors involved in it is a basic requirement for achieving common goals (Ramos *et al*., 2018). EIPs are built from a set of manufacturing and service businesses in a particular area that are interconnected in industrial symbiosis (IS) and aim to improve environmental, economic and social performance (Kuznetsova *et al.*, 2017). To achieve the best performance, in IS it is always prioritized mutually beneficial interactions between industrial actors, especially in the aspect of material exchange (energy, water, byproduct, infrasctucture, and habitat) (Susur *et al*., 2019; Chertow, 2014).

EIPs are complex systems and are composed of a large number of components (units, processes, plants and networks) at different operating levels (Zhou *et al*., 2017). To overcome the complexity of problems in decision making, system dynamics (SD) has been used as a complex method of modeling and simulation conditions (Sukholthaman and Sharp, 2016) and to recognize interdependent relationships between different systems and processes (Saavedra *et al*., 2018). The complexity of SD problems is clearly seen in the form of uncertainty, nonlinear causal relationships between variables, interactive feedback loops, and time delays (Mutingi *et al*., 2017). The use of SD in various disciplines shows a unique perspective and capability in overcoming problems in a dynamic socio-economic-environmental system (Barisa and Rosa, 2018).

Although the use of SD in various researches in industrial sector has been widely carried out, but the use of SD in EIPs research is still not yet. Several researches from the following 3 years show this condition. Shi *et al*. (2017) use eco-efficiency evaluation indicators to analyze the ecosystem service value of an EIPs. Kim *et al*. (2018) use a technological assessment of energy balance to estimate the co-benefit potential of industrial and urban symbiosis. de Dios *et al.* (2018) use flow analysis material to measure water quality before and after reconfiguration of EIPs. Yu *et al.* (2018) use a new data envelopment model to measure industrial eco-efficiency. Baldassarre *et al*. (2019) use a case study and literature study to integrate the perspective of circular economy and industrial ecology. Susur *et al*. (2019) use a literature review and case survey to explain the mainstreaming and transition of industrial parks development into EIPs. Thus, the use of SD in this research can be seen as a new perspective in solving EIPs problems effectively and comprehensively.

Modern Cikande Industrial Estate (MCIE) is a developing industrial estate and it is a prospective new growth center. The development of MCIE based on EIPs is a necessity because of its great contribution to economic growth and its high commitment to protecting the environment. The biggest challenge for the management of MCIE is complexity of problems related to the dimensions of ecology, social and economy. Thus, the right policy implementation is needed to ensure the sustainability of management in the future. The purpose of this research is to develop a dynamic model of MCIE environmental management based on EIPs in order to increase economic growth and prevent environmental deterioration. This is in line with MCIE managerial point of view: obtaining high economic benefits for the company, creating employment for the communities, and playing an active role in environmental protection efforts. The problem explored in this research is how to develop a dynamic model of MCIE environmental management based on EIPs to enhance economic growth and protect the environment.

2. LITERATURE REVIEW

2.1 Circular Economy

Environmental degradation and scarcity of natural resources has encouraged the implementation of a new management concept that is more environmentally friendly, called circular economy (CE). In the latest decades, CE is increasingly promoted as an alternative model that can replace linear economy because of its advantages in dealing with environmental degradation issues, social justice and long-run economic growth (Millar *et al*., 2019). CE is a concept that preserves and maintains environmental and economic value by extending product life and reusing waste materials into the production process (den Hollander *et al*., 2017). CE supports a significant reduction in primary resource exploitation and promotes the flow of secondary material through the internal loop (Lèbre *et al*., 2017). Diagrammatically, CE is described as an integrated system in which there is a cyclic flow of organic and inorganic material through biophysical environment and production-consumption sub-system (Figure 1) (Velenturf *et al*., 2019). People get natural materials from reserves (thick arrows) in biophysical environment. These natural materials are then processed in a production-consumption system (thin arrows) and will be engineered in such a way that if the utilization period has ended, they can be reabsorbed through natural processes and without causing negative impacts. Natural materials are in the biophysical environment and are not controlled by humans directly. These materials may be natural or are the result of engineering and become an important part in chemical, biological and geological processes.

'Design' is the most important stage in production-consumption systems because this stage will determine how long a product is useful and the most effective ways to reduce waste. The 'design phase' (1) will be followed by 'shared consumption' (2), 'reuse and repair' (3), 'remanufacturing' (4) and 'recycling' (5). The whole set of stages is considered to be able to increase the productivity of resources per functional unit and can support positive environmental impacts. In-adequate waste treatment infrastructure can cause products/materials that have expired to become non-recyclable. This condition must be anticipated by redesigning the product. As long as the product is in the redesign period, storage must be carried out in a controlled environment. Products/materials that must be available in the future, should be stored in a controlled environment through a resource engineering system. Thus the need for important materials in the future will be fulfilled without over-exploitation and does not leave waste that devastates the biophysical environment. Leakage of industrial materials (solid waste, liquid waste and gas emissions) must be managed in an integrated manner so as not to burden the environment. Industrial materials which are no longer utilized in the production process must be returned to the biophysical environment safely; so that through the integration of chemical, biological, and geological processes, these materials will become reserves that can be utilized in the next production cycle (Figure 1).

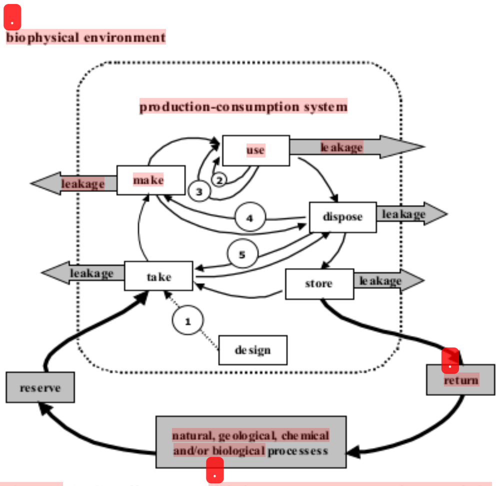


Figure 1. CE diagram (thick arrows = natural materials; thin arrows = industrial materials; dotted arrow = immaterial; 1 = design to reduce all forms of waste; 2 = shared consumption; 3 = reuse & repair; 4 = remanufacturing; 5 = recycling (Velenturf *et al*., 2019).

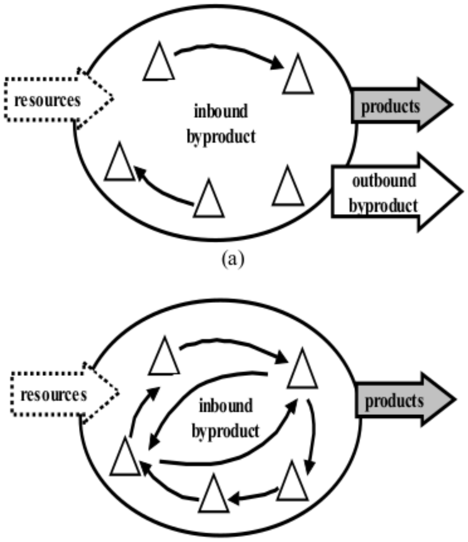
In the context of achieving sustainable development goal (SDG) targets, CE practices have the potential and can importantly contribute to the achievement of the targets: SDG 6 (clean water & sanitation), SDG 7 (affordable & clean energy), SDG 8 (decent work & economic growth), SDG 12 (responsible consumption & production), and SDG 15 (life on land) (Schroeder *et al*., 2018). In praxis, CE can be implemented at the regional, industrial estate, and individual companies level (Zhu *et al*., 2011).

2.2 Eco-industrial Parks

Today the development of industrial parks (IPs) has become an important part in the economic development of the countries in the world. On the other hand, the development of EIPs has now become an alternative after considering many environmental problems as an impact of industrial agglomeration in IPs (Susur *et al*., 2019). Developing EIPs is now recommended as a way to increase economic growth while reducing the level of environmental deterioration (Huang *et al*., 2019). EIPs are defined as industrial systems that apply the strategies of IS. The application of this concept is considered very beneficial because it can reduce economic, energy and material costs, improves efficiency and quality of operations, and provides the possibility to utilize waste through exchange of waste, energy efficiency, and other creative efforts (Song *et al*., 2018). IS is a collective approach to achieving competitive advantage. Within IS, separate industries build a cooperative network and exchange of energy, materials and/or byproducts. Because of its ability to overcome problems related to resource depletion and waste management, IS has a significant role in supporting sustainable development. IS concept is closely related to CE (Baldassarre *et al.*, 2019). According to Figure 2, there are two types of symbiosis that occurs in EIPs: natural and ideal symbiosis (Felicio *et al.*, 2016).

In both types, the process starts from the entry of raw materials from outside the EIPs, then are used for the production process in each company. These companies produce a variety of byproducts that can be used by other companies. In each symbiotic process, there are two types of byproducts: outbound and inbound byproducts. Outbound byproducts are all material that is released and not reused internally in EIPs; while inbound byproducts are products that are retained and reused in the production process in EIPs. Figure 2 (a) is an illustration of a natural symbiosis, where most byproducts out of EIPs become outbound byproducts; meanwhile, only a few byproducts have been successfully reused in the production process within the EIPs. Figure 2 (b) is an illustration of an ideal symbiosis, where through the engineering process, all byproducts have been successfully reused in the production process in EIPs, while there are no byproducts that are not reused and exit the EIPs.

Because of its great contribution to improving the efficiency of resource use and waste reduction, EIPs have been promoted throughout the world (Song *et al*., 2018). The encouragement to develop EIPs is getting stronger after this concept has been successfully implemented in Kalundborg Denmark and Shandong Lubei China (Zhang *et al.*, 2015a). EIPs in Kalundborg are the most influential examples of IS in the academic literature (Branson, 2016) and have become a trigger for the 21st century eco-industrial revolution because of its success in managing waste through environmentally friendly mechanisms (Gulipac, 2016). IS at Kalundborg is a network of economic actors who jointly implement the principles of industrial ecology through 4 driving factors: 1) pragmatic environmental mindset, 2) opportunities to explore various possibilities, 3) mutually beneficial initiatives, 4) shared needs that stimulate the search for proactive solutions (Valentine, 2016). EIPs in Shandong Lubei are very well-known ecological industry models in the world (Zhang *et al.*, 2015b) and can be used as references to improve economic performance and environmental protection for developing countries (Jiutian, 2013). EIPs in Shandong Lubei utilize the reuse and recycle mechanism for industrial wastes and byproducts with efficiency reaching 95.6%; while the efficiency of energy use reaches 85.9% (Zhang *et al.*, 2015a). Overall, there are 4 main factors that affect the eco-efficiency of managing industrial parks in China: 1) industrial added value per capita, 2) industrial structure, 3) environmental policy, and 4) scale of industrial development (Fan *et al*., 2017).



(a)

(b)

Figure 2. Two types of symbiosis that occurs in eco-industrial parks: (a) natural symbiosis; (b) ideal symbiosis (Felicio *et al.*, 2016).

2.3 System Dynamics

System dynamics (SD) is a methodology based on non-linear dynamics and the theory of feedback control (Martínez-Jaramillo *et al*., 2019; Papachristos, 2019; Daneshzand *et al.*, 2019) and is very suitable to be used to model complex socioeconomic problems (de Wit *et al*., 2018). SD are used to model complex interrelationships of various factors in a system to determine the effect of nonlinear interactions on system behavior over time (Daneshzand *et al.*, 2019). SD starts with systems thinking patterns and is closely related to sustainability themes. Systems thinking is a holistic approach that considers the relationship between various factors in a system and builds relationships between these factors through modeling (Jonker *et al.*, 2017). Systems thinking patterns on various sustainability themes began with the work of Forrester “World Dynamics” in 1971; Forrester interprets sustainability as the effect of a dynamic process (Honti *et al.*, 2019). The relationship between SD and sustainability found its peak in the masterpiece “Limits to Growth” for the Club of Rome. At that time by using SD the researchers could assess how human foot-print affects sustainable development on earth in the future (Iandolo *et al*., 2018).

Practitioners and researchers have used SD in various scientific fields, for example: Drmola *et al*. (2015) on cybersecurity research; Elias (2012) in environmental conflict research; Walrave and Raven (2016) on the system of technological innovation; Ansell and Cayzer (2018) on energy and climate change; Machado *et al.*, (2015) on forestry projects; Walters *et al*. (2016) on agricultural production systems; You *et al*. (2018) on coastal management; Wei *et al*. (2016) on water resource management; Recio *et al*. (2018) in health research, and Sjaifuddin *et al*. (2019) on food security behavior. In the industrial sector, research using SD has been carried out, for example in the performance of automotive industrial production (Gary *et al*., 2018); CO_2 mitigation policy in the cement industry (Jokar and Mokhtar, 2018); energy savings in the food industry (Xu and Szmerekovsky, 2017); development of biomass electricity industry (Zhang *et al*., 2017) and behavior-based safety programs in the construction industry (Guo *et al*., 2018).

3. METHOD

Environmental management of MCIE based on EIPs is a process that involves multi-stakeholders, so a systemic approach is needed to solve the complexity of the problem (Sjaifuddin, 2018). The use of SD in this research can fulfill these interests (Luo *et al*., 2017) because MCIE is characterized by the complexity of problems such as multiple decision makers, the complexity of the behavior of suppliers and consumers, and various delays. SD is a conceptual framework for manipulating system complexity in showing the effects of change on both the sub-system and the system as a whole (Phonphoton and Pharino, 2019). The SD software used in this research is Powersim Studio 7 Express. The design of dynamic model of MCIE environmental management based on EIPs considering the following principles: 1) Integrating 3 dimensions of management as a whole: biophysical, social, and economic dimension; 2) Linking all factors involved in the management: 5 factors in the biophysical sub-model (industrial structure, land available for industries, raw input, total waste, and the need for water); 1 factor in the social sub-model (employment) and 1 factor in the economic sub-model (contribution to regional income); 3) Comparing model behavior in 3 management scenarios (business as usual, which is oriented towards economic growth only, conservationism, which is just oriented to environmental protection, and new urbanism, which is oriented to the integration of economic growth and environmental protection) (Sjaifuddin, 2018).

The modeling steps using SD (Jokar and Mokhtar, 2018) are as follows: 1) Identification of the problems: the problems being studied need to be explored and the objectives need to be clearly defined; 2) Conceptualization of the system: causal relationships between variables need to be identified and developed through causal loop diagrams (CLD). Development of flow diagrams (FD) is carried out to convert models from qualitative to quantitative forms. 3) Model validation: aims to compare the behavior of the model to the real situation. The model is said to be valid if its behavior resembles the actual state of the system. 4) Policy evaluation: aims to establish policies that are relevant to the conditions that are expected to occur in the future.

SD tools consist of CLD and FD which function to describe various feedback loops that connect variables in the system (Chia *et al*., 2015). Stocks and flows have feedback loops that work to form a non-linear relationship (Nuhoğlu and Nuhoğlu, 2007). Feedback loops are represented in CLD. In SD methodology, CLD is the first representation of a system that functions to help analyze the structure of the system qualitatively (Strauss and Borenstein, 2015). In CLD, the direction of the relationship between variables is identified using the letters R and B. R (reinforcing loop) will occur if the variables change in the same direction so that they strengthen each other; while B (balancing loop) will occur if the variables change in the opposite direction so that neutralize each other. Figure 3 shows the direction of the relationship between variables in SD. Figure 3 (a) describes a reciprocally corroborating relationship (R) between two variables: if X increases then Y will increase (+); an increase in Y will increase X back (+). Figure 3 (b) describes a mutually equalizing relationship (B) between two variables: if Z increases then W will increase (+); otherwise, increasing W will decrease Z (-).

Development of FD was carried out after the preparation of CLD. The simple FD which illustrates the relationship between variables involved in the structure of the model is presented in Figure 4. Fundamentally, there are 3 components in FD: stocks, flows, and converters/auxiliaries (Chen and Chen, 2007; Nuhoğlu and Nuhoğlu, 2007).

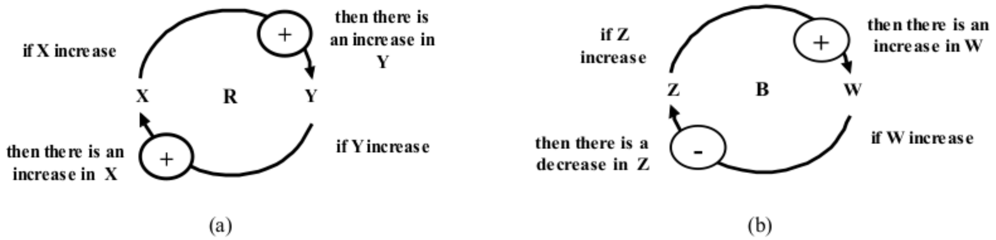


Figure 3. The direction of the relationship between variables in system dynamics.

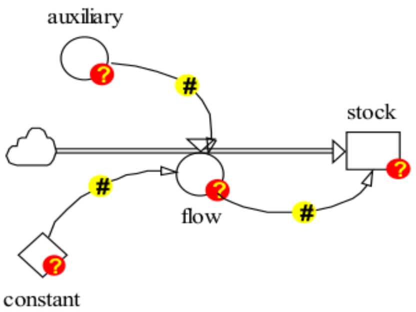


Figure 4. The simple flow diagram.

Stocks (symbolized by rectangles) are state variables that represent the main accumulation in the system. Flows (symbolized by valves) are the rate of change in the stock that both increases or decreases accumulation. Converters/auxiliaries (represented by circles) are intermediate variables that are used for various calculations. In addition to these three components, there are 2 other components: connectors and constants. Connectors (symbolized by simple arrows) represent causal links contained in the structure of the model. Constants reflect a fixed amount that influences a particular variable (Sjaifuddin *et al*., 2019).

4. RESULT AND DISCUSSION

4.1 Causal Loop Diagram

Completely, CLD on the environmental management of MCIE is presented in Figure 5. There are 3 R in this CLD: R1, R2, R3. R1 shows a mutually reinforcing relationship between industrial structures and raw inputs. The more industrial structures are built, the more raw inputs will be needed. Conversely, the more raw inputs produced, the more industrial structures will be needed.

R2 indicates a mutually corroborating relationship between industrial structures and contributions to regional income. The more industrial structures are built, the higher contributions to regional income will be. Contrarily, the higher the contributions to regional income, the more industrial structures will be built. R3 exhibits a mutually confirming relationship between industrial structures and employment. The more industrial structures are built, the higher the potential of employment in such a way that employment will also increase. Otherwise, increasing employment will also encourage the development of industrial structure.

Figure 5 also indicates that there are 3 B in the CLD: B1, B2, B3. B1 points a relationship that mutually neutralizes between land available for industries and industrial structures. The wider the land available for industries, the more industrial structures will be built. Conversely, because land resources are limited, more industrial structures are built causing less available land for industries. B2 denotes a mutually balancing relationships between industrial structures and total waste. The more industrial structures are built, the higher the waste contribution per industrial structures so that total waste will also increase. Contrarily, increased total waste will encourage a decline in the construction of new industrial structures. B3 represents a mutually countervailing relationship between industrial structures and the need for water. The increasing total waste due to industrial structure development will cause the need for water to be higher. Otherwise, because of its limited availability, the need for water which is increasingly high will encourage a decline in the new industrial structure development.

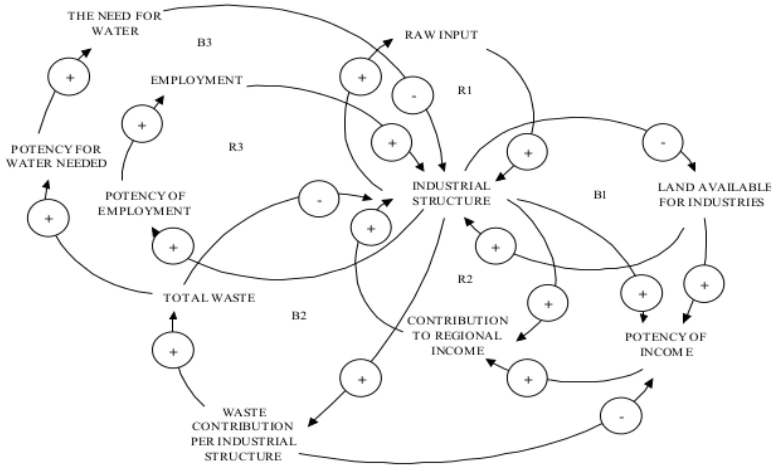


Figure 5. CLD on the environmental management of MCIE.

4.2 Flow Diagram

Based on the CLD in Figure 5, an FD was developed (Figure 6) and called the Modern Cikande Industrial Estate Model (MCIEM). There are 3 sub-models in MCIEM: biophysical sub-models (represented in blue), social sub-models (reflected in black), and economic sub-models (illustrated in red). The biophysical sub-model is a main model that has 5 stocks: 'industrial structure', 'land available for industries', 'raw input', 'total waste', and 'the need for water.' The social sub-model is a co-model that has 1 stock: 'employment.' The economic sub-model is also a co-model that has 1 stock: 'contribution to regional income.'

4.2.1 'Industrial Structure'

According to Figure 6, 'industrial structure' is a stock with an initial value of 1,578<<units>>. This stock has increased through flow 'increasing number of industrial structure' with powersim equation 'industrial structure' * 'real need of industrial structure' * 'constant of increasing number.' 'Real need of industrial structure' is a graph function with powersim equation GRAPHCURVE ('potency of industrial structure,' 0.0, 0.2,{1.76, 1. 74, 1.81, 1.82, 1.77, 1.65, 1.08, 1.02, 0.44, 0.29//Min: 0; Max: 2.5//}). 'Constant of increasing number' is a constant with a value of 3.7<<%/yr>>. 'Potency of industrial structure' is an auxiliary with powersim equation 'constant of industrial structure' * 'industrial structure.' 'Constant of industrial structure' is a constant with a value of 0.96 <<%/unit>>. Completely, values and powersim equations for each component related to 'industrial structure' are presented in Table 1.

4.2.2 'Land Available for Industries'

Figure 6 shows that 'land available for industries' is a stock with an initial value of 3,175<<ha>>. This stock has decreased through flow 'decreasing land' with powersim equation 'actual land for industry' * 'factor of industrial land' * 'land available for industries.' 'Actual land for industry' is a graph function with powersim equation GRAPHCURVE('potency of industrial land', 0, 1, {0.83, 0.52, 0.374, 0.3, 0.17, 0.11, 0.1, 0.03, 0.03, 0.03//Min: 0; Max: 1//}). 'Factor of industrial land' is a constant with a

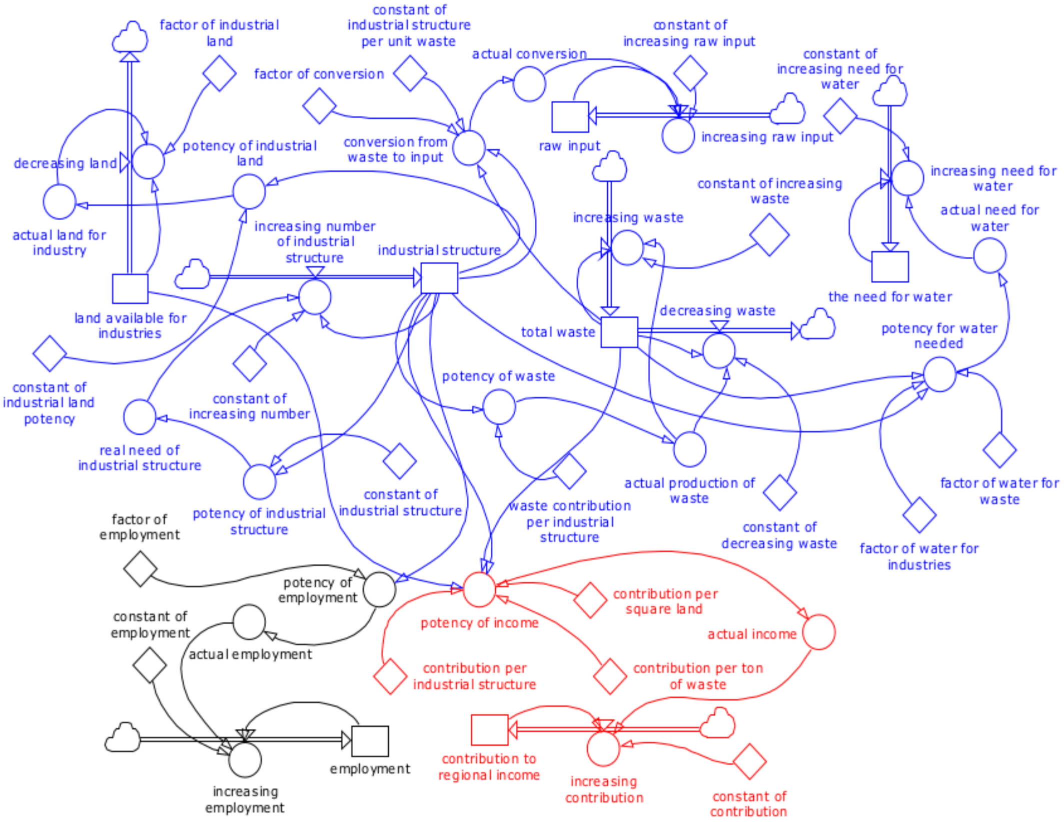


Figure 6. Modern Cikande industrial estate model.

Table 1. Values and powersim equations for each component related to 'industrial structure'

Components	Values	Powersim equations
Industrial structure (stock)	1,578<<unit>> (primary data)	
Increasing number of industrial structure (flow)		'industrial structure' * 'real need of industrial structure' * 'constant of increasing number'
Real need of industrial structure (graph function)		GRAPHCURVE('potency of industrial structure', 0.0, 0.2, {1.76, 1.74, 1.81, 1.82, 1.77, 1.65, 1.08, 1.02, 0.44, 0.29//Min: 0; Max: 2.5//})
Constant of increasing number (constant)	3.7<<%/yr>>	
Potency of industrial structure (auxiliary)		'constant of industrial structure' * 'industrial structure'
Constant of industrial structure (constant)	0.96<<%/unit>>	

value of 148.8<<%/yr>>. 'Potency of industrial land' is an auxiliary with powersim equation 'constant of industrial land potency' * 'industrial structure.' 'Constant of industrial land potency' is a constant with a value of 0.0023<<1/unit>>. Overall, values and powersim equations for each component related to 'land available for industries' are presented in Table 2.

4.2.3 'Raw Input'

Figure 6 indicates that 'raw input' is a stock with an initial value of 15,000<<ton>>. This stock has increased through flow 'increasing raw input' with powersim equation 'actual conversion' * 'constant of increasing raw input' * 'raw input.' 'Actual conversion' is a graph function with powersim equation GRAPHCURVE ('conversion from waste to input', 0, 1, {1.1, 1.316, 1.35, 1.445, 1.53, 1.61, 1.68, 1.735, 1.755, 1.8//Min: 1; Max: 2//}). 'Conversion from waste to input' is an auxiliary with powersim equation 'factor of conversion' * 'total waste' * 'industrial structure' * 'constant of industrial structure per unit waste.' 'Factor of conversion' is a constant with a value of 0.01<<1/unit>>. 'Constant of industrial structure per waste unit' is a constant with a value of 0.01<<1/unit>>. 'Constant of increasing raw input' is a constant with a value of 0.45<<%/yr>>. Fully, values and powersim equations for each component related to 'raw input' are presented in Table 3.

Table 2. Values and powersim equations for each component related to 'land available for industries'

Components	Values	Powersim equations
Land available for industries (stock)	3,175<<ha>> (primary data)	
Decreasing land (flow)		'actual land for industry' * 'factor of industrial land' * 'land available for industries'
Actual land for industry (graph function)		GRAPHCURVE('potency of industrial land', 0, 1, {0.83, 0.52, 0.374, 0.3, 0.17, 0.11, 0.1, 0.03, 0.03, 0.03//Min: 0; Max: 1//})
Factor of industrial land (constant)	148.8<<%/yr>>	
Potency of industrial land (auxiliary)		'constant of industrial land potency' * 'industrial structure'
Constant of industrial land potency (constant)	0.0023<<1/unit>>	

Table 3. Values and powersim equations for each component related to 'raw input'

Components	Values	Powersim equations
Raw input (stock)	15,000<<ton>> (primary data)	
Increasing raw input (flow)		'actual conversion' * 'constant of increasing raw input' * 'raw input'
Actual conversion (graph function)		GRAPHCURVE('conversion from waste to input', 0, 1, {1.1, 1.316, 1.35, 1.445, 1.53, 1.61, 1.68, 1.735, 1.755, 1.8//Min: 1; Max: 2//}).
Conversion from waste to input (auxiliary)		'factor of conversion' * 'total waste' * 'industrial structure' * 'constant of industrial structure per unit waste'
Factor of conversion (constant)	0.01<<1/unit>>	
Constant of industrial structure per waste unit (constant)	0.01<<1/unit>>	
Constant of increasing raw input (constant)	0.45<<%/yr>>	

4.2.4 'Total Waste'

According to Figure 6, 'total waste' is a stock with an initial value of 600<<ton>>. This stock increases through flow 'increasing waste' with powersim equation 'actual production of waste' * 'constant of increasing waste' * 'total waste.' The decline occurs through flow 'decreasing waste' with powersim equation 'actual production of waste' * 'constant of decreasing waste' * 'total waste.' 'Actual production of waste' is a graph function with powersim equation GRAPHCURVE ('potency of waste,' 0, 0.1, {1.36, 1.31, 1.168, 1.132, 1.174, 1.165, 1.097, 1.145, 1.158, 1.16//Min:1; Max: 1.5//}). 'Constant of increasing waste' is a constant with a value of 0.07<<%/yr>>. 'Constant of decreasing waste' is a constant with a value of 0.01<<%/yr>>. 'Potential of waste' is an auxiliary with powersim equation 'industrial structure' * 'waste contribution per industrial structure.' 'Waste contribution per industrial structure' is a constant with a value of 0.9<<1/unit>>. Completely, values and powersim equations for each component related to 'total waste' are presented in Table 4.

4.2.5 'The Need for Water'

Figure 6 exhibits that 'the need for water' is a stock with an initial value of 1.5<<million m^3>>. This stock has increased through flow 'increasing need for water' with powersim equation 'actual need for water' * 'constant of increasing need for water' * 'the need for water.' 'Actual need for water' is a graph function with powersim equation GRAPHCURVE ('potency for water needed,' 0, 0.1, {1.31, 1.29, 1.27, 1.316, 1.35, 1.39, 1.574, 1.69, 1.71, 1.76//Min: 1; Max: 2//}). 'Potency for water needed' is an auxiliary with powersim equation 'factor of water for industries' * 'factor of water for waste' * 'industrial structure' * 'total waste.' 'Factor of water for industries' is a constant with a value of 0.06<<1/ton>>. 'Factor of water for waste' is a constant with a value of 0.01<<1/unit>>. 'Constant of increasing need for water' is a constant with a value of 0.02<<%/yr>>. Overall, values and powersim equations for each component related to 'the need for water' are presented in Table 5.

Table 4. Values and powersim equations for each component related to 'total waste'

Components	Values	Powersim equations
Total waste (stock)	600<<ton>> (primary data)	
Increasing waste (flow)		'actual production of waste' * 'constant of increasing waste' * 'total waste'
Decreasing waste (flow)		'actual production of waste'*'constant of decreasing waste'*'total waste'
Actual production of waste (graph function)		GRAPHCURVE ('potency of waste', 0, 0.1, {1.36, 1.31, 1.168, 1.132, 1.174, 1.165, 1.097, 1.145, 1.158, 1.16// Min: 1; Max: 1.5//})
Constant of increasing waste (constant)	0.07<<%/yr>>	
Constant of decreasing waste (constant)	0.01<<%/yr>>	
Potential of waste (auxiliary)		'industrial structure' * 'waste contribution per industrial structure'
Waste contribution per industrial structure (constant)	0.9<<1/unit>>	

Table 5. Values and powersim equations for each component related to 'the need for water'

Components	Values	Powersim equations
The need for water (stock)	1.5<<million m^3>> (primary data)	
Increasing need for water (flow)		'actual need for water' * 'constant of increasing need for water' * 'the need for water'
Actual need for water (auxiliary)		GRAPHCURVE ('potency for water needed,' 0, 0.1, {1.31, 1.29, 1.27, 1.316, 1.35, 1.39, 1.574, 1.69, 1.71, 1.76//Min: 1; Max: 2//})
Potency for water needed (auxiliary)		'factor of water for industries' * 'factor of water for waste' * 'industrial structure' * 'total waste'
Factor of water for industries (constant)	0.06<<1/ton>>	
Factor of water for waste (constant)	0.01<<1/unit>>	
Constant of increasing need for water (constant)	0.02<<%/yr>>	

4.2.6 'Employment'

Figure 6 shows that 'employment' is a stock with initial value of 5,800<<ppl>>. This stock increases through flow 'increasing employment' with powersim equation 'actual employment' * 'constant of employment' * 'employment.' 'Actual employment' is a graph function with powersim equation GRAPHCURVE ('potency of employment,' 0, 0.1, {1.1, 1.226, 1.69, 1.574, 1.78, 1.84, 1.65, 1.794, 1.88, 1.892//Min: 1; Max: 2//}). 'Potency of employment' is an auxiliary with powersim equation 'factor of employment' * 'industrial structure.' 'Constant of employment' is a constant with a value of 1.0 <<%/yr>>. 'Factor of employment' is a constant with a value of 0.07 <<1/unit>>. Completely, values and powersim equations for each component related to 'employment' are presented in Table 6.

4.2.7 'Contribution to Regional Income'

Figure 6 denotes that 'contribution to regional income' is a stock with initial value of 4.6<<%>>. This stock increases through a flow 'increasing contribution' with powersim equation 'actual income' * 'constant of contribution' * 'controbution to regional income.' 'Actual income' is a graph function with powersim equation GRAPHCURVE ('potency of income,' 0, 0.1, {0.194, 0.194, 0.226, 0.283, 0.36, 0.49, 0.52, 0.626, 0.66, 0.73//Min: 0; Max: 1//}). 'Potency of income' is an auxiliary with powersim equation 'contribution per industrial structure' * 'contribution per square land' * 'contribution per ton of waste' * 'industrial structure' * 'land available for industries' * 'total waste.' 'Constant of contribution' is a constant with a value of 0.00008 <<1/yr>>. 'Contribution per industrial structure' is a constant with a value of 0.02<<%/unit>>. 'Contribution per square land' is a constant with a value of 0.002 <<1/m^2 >>. 'Contribution per ton of waste' is a constant with a value of 0.0003<<1/ton>>. Overall, values and powersim equations for each component related to 'contribution to regional income' are presented in Table 7.

4.3 Simulation of the Model

From MCIEM in Figure 6, a simulation is performed to determine system behavior. The simulation starts from 2016 to 2036 using euler method (fixed step) at the 1st order. Simulation is carried out according to 3 environmental management scenarios: business as usual, conservation, and new urbanism. Assumptions underlying the development of MCIEM are as follows: 1) The government always maintains the consistency of policy in the

Table 6. Values and powersim equations for each component related to 'emplyment'

Components	Values	Powersim equations
Employment (stock)	5,800<<ppl>> (primary data)	
Increasing employment (flow)		'actual employment' * 'constant of employment' * 'employment'
'Actual employment (graph function)		GRAPHCURVE ('potency of employment,' 0, 0.1, {1.1, 1.226, 1.69, 1.574, 1.78, 1.84, 1.65, 1.794, 1.88, 1.892//Min: 1; Max: 2//})
Potency of employment (auxiliary)		'factor of employment' * 'industrial structure'
Constant of employment (constant)	1.0<<%/yr>>	
Factor of employment (constant)	0.07<<1/unit>>	

Table 7. Values and powersim equations for each component related to 'contribution to regional income'

Components	Values	Powersim Equations
Contribution to regional income (stock)	4.6<<%>> (primary data)	
Increasing contribution (flow)		'actual income' * 'constant of contribution' * 'controbution to regional income'
Actual income (graph function)		GRAPHCURVE ('potency of income,' 0, 0.1, {0.194, 0.194, 0.226, 0.283, 0.36, 0.49, 0.52, 0.626, 0.66, 0.73//Min: 0; Max: 1//})
Potency of income (auxiliary)		'contribution per industrial structure' * 'contribution per square land' * 'contribution per ton of waste' * 'industrial structure' * 'land available for industries' * 'total waste'
Constant of contribution (constant)	0.00008<<1/yr>>	
Contribution per industrial structure (constant)	0.02<<%/unit>>	
Contribution per square land (constant)	0.002<<1/m^2 >>	
Contribution per ton of waste (constant)	0.0003<<1/ton>>	

field of industrial development and environmental management; 2) The government provides incentives of investment in the financial services industry sector; 3) Political stability is always protected.

Simulation of industrial structures is shown in Figure 7. In the business as usual scenario, from 1,578 units in 2016, industrial structures developed according to the exponential growth pattern to 8,641 units in 2036. These conditions need to be watched out because the rapid development of extractive industries often causes conflict of interest with biodiversity conservation. In Peruvian Andes, for example, 16% of endemic species hotspots overlap with current industrial concession areas, while the geographical distribution of 21 endemic vertebrate species overlaps with more than 90% of the concession area (Bax *et al*., 2019). In addition, land use for various interests (including for industry) will also have an influence on the occurrence of urban heat island (UHI) which will have an impact on climate change and other ecological processes (Rao *et al*., 2018). Information about land surface equipped with demographic data can be used as a basis for understanding the atmospheric and surface thermal variations in the city (Zhang and Sun, 2019). In the conservationism scenario, from 1,578 units in 2016 industrial structures only grew to 3,240 units in 2036. The growth of industrial structures in this scenario is lowest if it is compared to other scenarios because of its orientation only to the environmental protection. In the new urbanism scenario, from 1,578 units in 2016 industrial structures developed to 5,384 in 2036. This growth is lower if it is compared to the growth in the business as usual scenario, but higher than the growth in the conservationism scenario. The development of industrial structures in the new urbanism scenario is most recommended because this scenario has the potential to increase economic growth in a balanced manner with environmental protection.

Simulations of land available for industries are exhibited in Figure 8. In the business as usual scenario, from 3,175 ha of land available for industries there was a very drastic decline in 2016, leaving only 203.99 ha in 2036. These conditions indicate that this scenario very quickly produces built-up industrial land so that leaves little green open space. High temperature areas in the cities are always concentrated in industrial zones (Rao *et al*., 2018); while the industrial zone is increasingly widespread as industrialization progresses. In North China Plain, for example, there is a trade-off between land use competition and sustainable land use so it is recommended that the Government reduce the growth rate of built-up industrial land and balance it with a significant ecological space for a healthier life (Jin *et al*., 2019). Land use activities in the conservationism scenario are relatively limited, so that from 3,175 ha of land available for industries in 2016, there was still a significant area (2,374.12 ha) in 2016. In the new urbanism scenario, land use for industry is still relatively under control, thus remaining 1,563.01 ha in 2016. This scenario is recommended because it has the potential to sustain economic growth and protect the environment.

Simulation of the raw input is indicated in Figure 9. In the business as usual scenario, from 15,000 tons of raw input in 2016 there was a very drastic increase to 118,842.61 tons in 2036. This condition shows that business as usual scenarios require large raw inputs. In fact, currently, security resources have become a top priority for many countries in the world, especially developed countries (Careddu *et al.*, 2018). Without eco-efficiency measures, the use of large raw inputs will put heavy pressure on the environment. Increasing eco-efficiency will contribute to economic and social benefits, reduction in resource consumption, and protection of ecological functions (Wang *et al.*, 2019). In the conservationism scenario, the utilization of raw inputs is still very slow, from 15,000 tons of raw input in 2016 to only 62,264.76 tons in 2036. However, this scenario is indeed economically disadvantageous. Adequate economic and environmental benefits can be obtained from the new urbanism scenario, where the development of raw input utilization in this scenario is still very controlled, from 15,000 tons of raw input in 2016 to 83,628.72 tons in 2036.

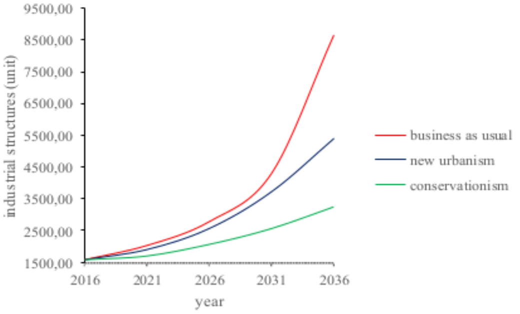


Figure 7. Growth patterns of industrial structure in 3 environmental management scenarios.

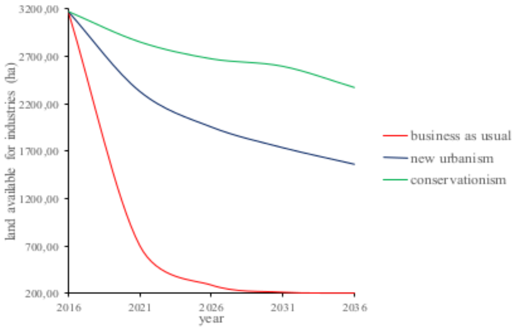


Figure 8. Pattern of decreasing of available land for industries in 3 environmental management scenarios.

Simulation of the total waste is represented in Figure 10. In the business as usual scenario, from 600 tons of waste in 2016 there was a significant increase to 2,323.80 tons in 2036. Currently, the main source of hazardous waste is industrial activity because it has an impact on environmental factors such as water, air, land, and the health and safety of workers and the community (Alidadi *et al.*, 2019). Nevertheless, through detailed analysis at all stages of management, the waste can still bring economic and environmental benefits to both industry and society (Koolivand *et al.*, 2017). In the conservationism scenario, from 600 tons of waste in 2016, there was a very significant decline to only 0.14 tons (near zero waste) by the end of 2036; while in the new urbanism scenario, there was a decrease in waste to 4.43 tons.

Simulation of the need for water is illustrated in Figure 11. In the business as usual scenario, from 1.5 million m^3 need for water in 2016 there was a significant increase to 17.25 million m^3 in 2036. This very high increase needs to be watched out, considering that in developing countries, the monetary value of water used in the production process often does not reflect its scarcity or the cost of procurement. For manufacturing industries it is very important to consider the opportunity cost of water consumed in the production process (Revollo-Fernández *et al.*, 2019). Excessive use of water has the potential to cause water scarcity. Water shortages will have an impact on social, economic and ecological consequences; such as obstacles to various industrial processes, obstacles to the shipping process due to the low water level of the river, constraints on water use for household and tourism purposes, increase fish mortality due to rising water temperatures, and decreasing water quality due to the low dilution effects (Brunner *et al.*, 2019). Conservationism scenario shows that from 1.5 million m^3 need for water in 2016 only slightly increased to 3.85 million m^3; whereas in the new urbanism scenario the increase was relatively stable to 5.25 million m^3 in 2036.

Simulation of employment is represented in Figure 12. In the conservationism scenario, increasing employment is not significant; only increased from 5,800 employment in 2016 to 11,396 in 2036. In the business as usual scenario, from 5,800 employment in 2016 there was an increase to 39,423 in 2036. This scenario is oriented towards the use of conventional industry, so that enough jobs can be created. In the new urbanism scenario the increase in employment is even more significant (becoming 47,683 employment in 2036). Increased employment

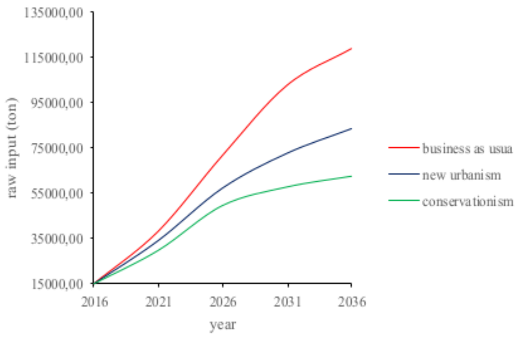


Figure 9. Growth pattern of raw input in 3 environmental management scenarios.

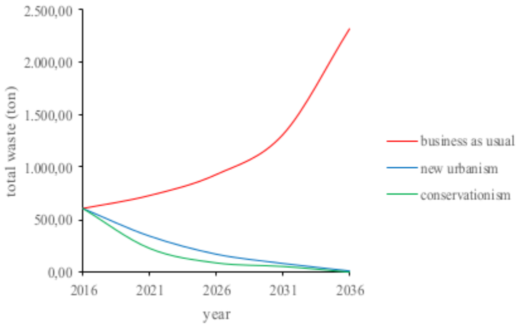


Figure 10. Growth pattern of total waste in 3 environmental management scenarios.

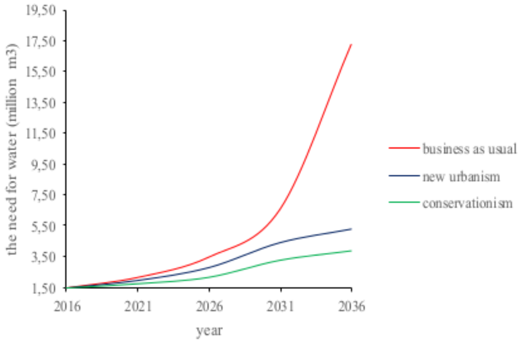


Figure 11. Growth pattern of the need for water in 3 environmental management scenarios.

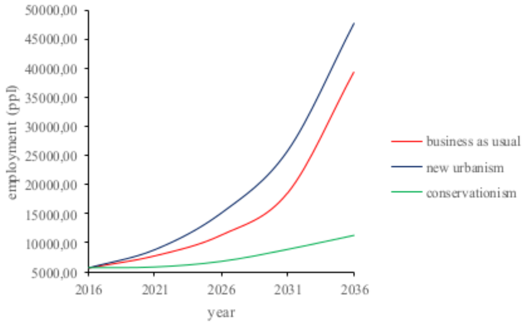


Figure 12. Growth pattern of employment in 3 environmental management scenarios.

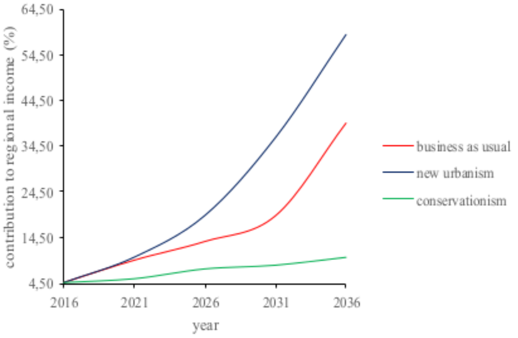


Figure 13. Growth pattern of the contribution to regional income in 3 environmental management scenarios.

is very important, racing against high population growth. In the management of the industrial environment it is not only the function of environmental protection that must be prioritized but also economic growth and employment (Costantini *et al.*, 2018). Meanwhile, to ensure that the industry stays in the tight competition, employment must be filled with high-quality, educated and highly skilled human resources so that it always produces innovation (Zouaghi *et al.*, 2018).

Simulation of the contribution to regional income is shown in Figure 13. In the conservationism scenario, the growth of contribution to regional income is not significant; only rose from 4.60% in 2016 to 10.23% in 2016. In the business as usual scenario, contribution to regional income increased from 4.60% in 2016 to 39.46% in 2036. Significant contribution to regional income increased in the new urbanism scenario, from 4.60% in 2016 to 58.75% in 2036. This condition is identical with industrial contribution which is one of the sectors that largely determines the regional income in China (Qi and Liang, 2016). With full support of the Chinese Government, green industry has grown rapidly and can still be improved in the long term; and with full attention from managers and decision makers, green industry can make a better contribution to the society and economic growth (Chen *et al.*, 2016).

4.4 Validation of the Model

Model validation is held to ensure that the model mimics the actual conditions. The validation technique used is model structure validation; carried out through construction validity tests. The validity of construction shows the construction of a model that can be accepted scientifically. Simulation results show that industrial structures grow exponentially in business as usual scenarios (Figure 7). Its orientation to economic growth has led to industrial growth causing an increase in employment (Figure 12) and contribution to regional income (Figure 13) through the same pattern. Still in business as usual scenarios, the lack of orientation on environmental protection causes the growth of industrial structures to have an impact on the rapid production of total waste (Figure 10), increased raw input (Figure 9), the need for water (Figure 11) and decrease in land available for industries (Figure 8). This description indicates that the simulation results follow a pattern that commonly occurs in developing industrial systems so that they are in accordance with the rules of logical thinking and follow systems archetype basics (Kim and Anderson, 1998).

The simulation results also exhibit that the growth of industrial structures (Figure 7) in the new urbanism scenario is more controlled than in the business as usual scenario. Its orientation to the economic growth and environmental protection has led to the growth of industrial structures have an impact on employment growth (Figure 12) and contribution to regional income (Figure 13) through a more significant pattern than the business as usual scenario. In addition, waste production (Figure 10) leads to a zero waste pattern; raw input (Figure 9), the need for water (Figure 11) and land available for industries (Figure 8) are relatively more controlled. This condition can be realized through the implementation of policies that are in accordance with the stated objectives. Thus the simulation results in this scenario are also in line with the policy of environmental management of MCIE based on EIPs.

5. CONCLUSION

MCIE is a developing industrial estate and is a prospective new growth center. Environmental management of MCIE based on EIPs is a necessity because of its great contribution to economic growth and its high commitment to protecting the environment. The biggest challenge of environmental management of MCIE is the complexity of the problems related to the dimensions of ecology, social and economy. Thus the right policy implementation is needed to ensure the sustainability of management in the future. The purpose of this research is to develop a dynamic model of environmental management of MCIE based on EIPs in order to increase economic growth and prevent environmental deterioration. Dynamic model is designed using Powersim Studio 7 Express software. Modeling steps using SD are as follows: 1) Identification of the problems; 2) Conceptualization of the system; 3) Model validation; 4) Policy evaluation. Model simulation is carried out using 3 scenarios: business as usual, conservationism, and new urbanism scenario. Simulation results show that new urbanism is the best scenario for MCIE environmental management. When it is compared to other scenarios, new urbanism has a significant impact on controlling the growth of industrial structures, managing the decline in land available for industries, restraining growth in raw inputs, decreasing quantity of waste, bridling the need for water, increasing employment, and enlarging contribution to regional income.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17