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CIRCULAR ECONOMIC MODEL OF INTEGRATED WASTE MANAGEMENT: A CASE OF EXISTING WASTE MANAGEMENT IN POPULATED URBAN AREA

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Abstract

The current waste management system does not only focus on environmental issues but also on social and economic aspects. Therefore, an integrated solid waste management system (ISWMS) has been widely implemented; however, most of the implemented systems have been addressed issues partially in such factors as technology or informal sector involvement. This study integrates three groups directly involved in waste management system particularly in developing countries comprising the government, the society, and the informal sector. This type of integration is believed to be able to reduce waste in the source, improve the waste pickers' income, and enhance regional waste management performance leading to the decrease of environmental pollution. In addition, maximizing waste reduction through recycling processes is also likely to lead to circular economy which is proven to efficiently save virgin natural resources. This study employed a dynamics system using Powersim 10 software. The simulation results showed that waste reduction in the source significantly enhanced, income of the informal sector increased, waste management performance improved yet the budgeting decreased, and exploitation of virgin natural resources decreased.

Keywords: Circular economy, Informal sector, Scavenger, Symbiosis industry, Waste bank, Waste management.

1. Introduction

Waste is a worldwide serious issue, particularly in developing countries [1, 2] including Indonesia [3]. This is due to the increasing amount of waste with more various types and in the meantime, the capacity of waste management and environmental support for landfill waste containing method is limited [4, 5]. The limited capacity might be caused by limited budget, facilities, and lack of people's awareness in low environment-friendly waste management. Despite the increasing number of the waste types, there are values contained within the waste materials which can be beneficial. Some developing countries have shown that several waste types are sold out to recycle industries, either as the main or associated materials. To this relation, waste management is not only an ecological issue, but also economic and social issues [6]. To cope with this, integrated solid waste management system (ISWMS) integrating social, economic, and ecological components have been proven to be the solution in various countries [7, 8].

ISWMS considering ecological-economic modeling has also been a trend in current urban waste management [9] as it can decrease the amount of waste sent to the dumpsites and efficiently save natural resources [4]. In developing ISWMS proposed for the indicators of material and energy recovery: one with an immediate physical meaning, and the other one that includes the market value of the products [10].

Moreover, a study by Parkes et al. [11] analysing the ISWMS using life cycle assessment (LCA) method showed that energy saving is significant if the waste materials are recycled through MRF, anaerobic digestion, incineration with energy recovery, or through advanced thermal treatment. However, location of the recycle processes have to be taken into consideration as Tascione et al. [12] stated through his study using linear programming that the selection of the recycling process location has environmental impacts due to transportation.

In Indonesia, particularly in the city of Bandung, it is proposed that the ISWMS also include informal sectors [13]. Most of the existing ISWMS systems focus on the waste material cycle from the open system which usually ends up in the nature or cradle-to-grave to the close system, which is also well-known as cradle-to-cradle turning out to the ideas of circular economy [14]. Circular economy refers to the "production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution) [15]. Economic potential utilization of waste material through circular economy concepts has not only been able to efficiently save virgin human resources but also decrease solid waste polluting the environment. One of the countries which has been implementing the concepts of circular economy is China which proved that that implementation of circular economy is a sustainable development strategy aiming to improve the efficiency of materials and energy use [16].

The implementation of CE in China, Su et al. [17] categorizes of developing CE practices into four areas: production, consumption, waste management, and other support. The Chinese government for various reasons like retaining competitiveness, intends to initially introduce the CE framework on a smaller scale through a number of pilot studies so that it has a better basis for assessing its large scale and full coverage in the longer run [18]. In addition to China, several other countries such as Japan, Germany, Sweden, and other countries have also implemented it with different strategies. Sweden, for instance, has for a long time successively introduced various incentive programs and facilitated optimal conditions for gradual and effective increase in the rate of recycling through public education [18]. Based on these facts, it can be inferred that CE can be implemented at three different levels, namely: micro-level (single company or consumer), meso level (symbiosis association), and macro-level (city, province, region, country) [19].

Previous studies related to ISWMS have not taken into consideration social, economic, and ecological aspects which play important roles. The social aspects involve the society either as waste producers or informal sector business owners; the economic aspects view this phenomenon to have economic potentials; and the ecological aspects emphasize the shift of the waste management from end-of-pipe to the 3R approach consisting of reduce, reuse, and recycle. The roles of informal sectors have always been important in developing countries including Indonesia; therefore, integrating the government and informal business sector is crucial [13, 20, 21]. In terms of research methodology, previous works, both using dynamic system and employing (LCA) did not related the issues with circular economy, especially regarding virgin natural resource decrease.

This paper involved three important groups within the context of ISWMS namely the government, society, and informal sector aiming to decrease the amount of waste and efficiently save virgin natural resources. Based on the previous study, there are 17 factors influencing the involvement of the three groups in waste management system namely: waste generation, infrastructure, handling of waste, reduction of waste, residual handling, final processing site, population/source of waste, mind-set and life style, socialisation, recognition of the informal sector, organisation of the informal sector, clarity of the role of all stakeholders, accessibility of waste, quantity and quality of recyclable waste, price of recyclable material, waste pickers' income, and incentives or financial loans [22]. All the factors are then analysed using a dynamic system approach and later analysed through Powersim software.

2. Methods

This research was conducted in Bandung City, Indonesia. This location was chosen because the city of Bandung is one of the metropolitan cities in Indonesia where the collectors of waste materials are growing and developing, including business people engaged in the recycling industry. This study is follow-up research of its previous study focusing on identification of factors influencing waste management system in Bandung. It was found on the previous study that there were three groups involved in waste management in Bandung including government, society, and informal sector. The society was those producing waste as well as doing waste management activities in its source, while the informal sector was a group of people having waste-related activities for a living.

In general, this study, as presented by Fig. 1, employed a mixed-method embedded design comprising two phases as follows:

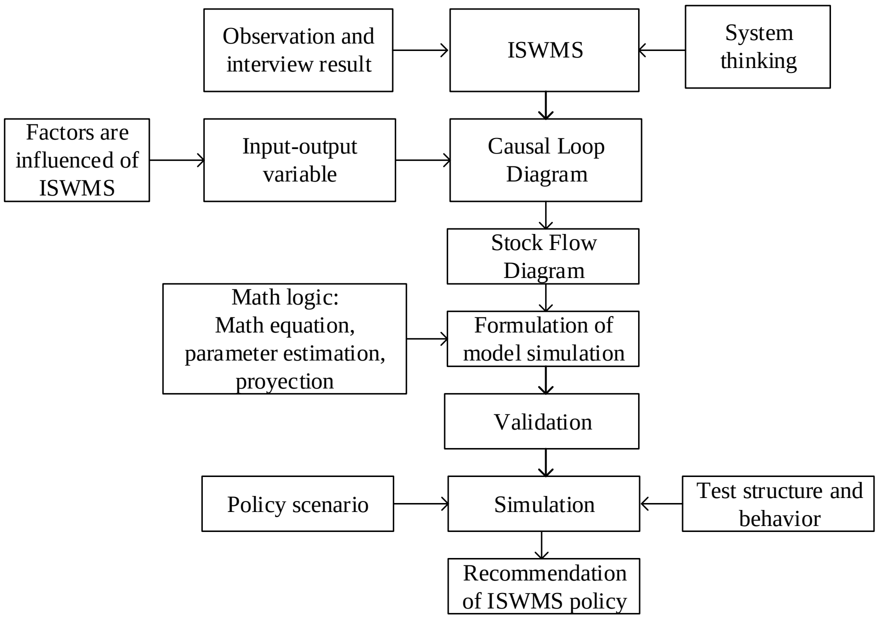

Fig. 1. Research procedure.

2.1. Phase 1: Identification of waste managers' general characteristics in Bandung

The general characteristics in this study include institutional aspects (organizational structure, job description, and human resources), operational aspects (business process: collection, treatment, etc.), ecological aspects (amount of waste collected, amount of waste reduced, etc.), social aspects (educational background, health condition, etc.), and economic aspects (financial sources, income, etc.). The characteristics were acquired through data collecting employing direct observation, interview, and questionnaire distribution in which triangulate with one another. An interview was administered to the government represented by the Environmental and Cleansing Services and Regional Cleansing Company of Bandung city as both were official institutions assigned by the government in the city waste management system. The Environmental and Cleansing Services is the regulator while the Regional Cleansing Company is the operator. A head of division and a member of directors were selected to be the interviews representing each of the government offices.

The main substantial questions of the interview were related policies on waste management system in Bandung (institutional, operational, financial, regulational, and societal aspects), policies on waste reduction in the source, performance of waste management and its obstacles. The interviews were carried out twice in which each lasted for around an hour. The first interview focused on acquiring the answers of the substantial questions and the second one confirmed the answers of the first interview. There were three types of data obtained from the interview: descriptive, quantitative, and pictorial. All of these data were then analysed in narration, tables, and figures. In the meantime, waste generation, waste composition, and finance were analysed quantitatively through tabulation and projection. The data and information analysed based on the first interview were reconfirmed both to the first resource or other respondents to finally acquire accountable narration.

Questionnaires were distribution to the informal sector society randomly selected. The sample selection was performed through cluster sampling where in each sub-district, a number of samples consisting of household, waste bank managers, and waste pickers were chosen. However, since not each sub-district had a waste bank, only those who had it represented by this sample. The number of sample from the society and waste pickers were calculated using Slovin formula [23] with significance level at 5%. Based on the calculation, there are 40 households, 364 waste pickers, and 50 waste banks. The questionnaires were distributed offline to their houses (for the society) and dumpsites or their rest areas (for the waste pickers). Distribution of the questionnaires commonly took place between 8 AM to 5 PM. As the questionnaires were distributed door to door and the researchers guided them to fill the questionnaires out, 100% of the questionnaires distributed were returned back. The questions asked to the waste pickers and waste bank managers comprise institutional aspects (organizational structure, job description, and human resources), operational aspects (business process: collection, treatment, etc.), ecological aspects (amount of waste collected, amount of waste reduction, etc.), social aspects (educational background, health condition, etc.), and economic aspects (finance resources, income, etc.), while questions addressed to the society producing waste were related to treatment to the waste sources. The data collected were in either qualitative or quantitative form. The quantitative data were analysed using a descriptive statistical method and qualitative data were analysed in tables and description.

2.2. Phase 2: Designing and simulation an integrated waste management system

The second phase of the research in this study was conducted through dynamic simulation system using licensed Powersim 10 software. The stages used adopted the theories by Firmansyah et al. [24] with modification in relation to an additional step on the early stage which was designing a static system regarding diagram flow describing an integrated upstream-downstream waste management system. The steps of phase 2 as follows:

2.2.1. Creating a flow diagram

This diagram describes waste material stream based on its type from the ISWMS stream to the downstream as well as the relation among the activities based on the results of observation, interview, and the researchers' professional judgment.

2.2.2. Determining input-output variables

These variables were acquired in the previous study related to influencing factors in an integrated waste management system converted to quantitative variables.

2.2.3. Designing a Causal Loop Diagram (CLD)

This step is an early stage in creating a ISWMS model, which translates to integrated waste management. This aims to give easier understanding of the model being developed which will be technically elaborated by stock flow diagram [24]. The CLD is designed using Powersim software by selecting the available "frame" tool to describe the model variables. To create interrelation among the variables, this study uses an arrow or such notifications as (+) or (-) on the arrow tip to indicate the relation, where (+) shows positive relation and (-) shows negative relation.

2.2.4. Building a Stock Flow Diagram (SFD)

Building the SFD starts with variable selection (stock, flow, auxiliary dan constanta) of the Powersim software. The next step is changing the variable names in accordance with the determined variables. Following is the process of building the SFD in accordance with CLD the previously built within the ISWMS:

- **SFD Social Dimension.** The social dimension SFD consists of citizen SFD (pdk) which is the function of the number of citizens (jpdk) and the citizens' population growth level (ppdk), or ∑pdk = f(jpdk, ppdk) and waste generation SFD (ts) which is the function of variable of the citizen number (jpdk) and the level of waste generation (tts) or ∑ts = f(jpdk, tts); socialized householders (kkts) which is a function of the socialization budgeting (as) and the number of householders (kk) or ∑pts = f(as, kk); waste sorting in the source (pss) which is a function of the effectiveness of guidance and training to the sorting householders (epkk) and socialized householders (kkts) or ∑pps = f(kkts,epkk); organic management activities in the source (post) is a function of the effectiveness of the guidance and training to the organic management (epoo) and socialized householders (kkts) or ∑pps = f(kkts,epoo); kk is the customer of waste bank (nbs) which is a function of the effectiveness of the guidance and training to the customer householders (epkkn) and socialized householders (kkts) or ∑nbs = f(kkts,epkkn); waste reduction from the source (pss) which is a function of organic management (pos), waste bank customer householders (nbs) and the DU waste collected at non-TPS USI or ∑pdd = f(pod, nbs, dunt).
- **Governmental Dimension SFD.** This SFD consists of (1) waste collection budget (aps) which is a function of waste collection load (bps) and budget of waste collection unit (bsp) or ∑aps = f(bps, bsp); (2) budget for the management in the city scope (apk) which is a function of organic waste collected (sot) and management budgeting unit (bso) or ∑apk = f(sot, bso); (3) city-scale organic management (pokk) which is a function of waste management budgeting within the city scope (apk) and the management budgeting unit (bso) or ∑pokk = f(apk, bso); (4) waste transportation budget (aas) which is a function of waste transportation load budget (bas) and transportation budgeting unit (bsa) or ∑aas = f(bas, bsa); (5) waste transportation performance (kps) which is a function of waste transportation budget (aas) and the waste transportation budgeting unit (bsa) or ∑kps = f(aas, bsa); city-scale waste management performance (kpkk) which is a function of the organic management within the city scope (pokk) and DU collection by the USI TPS (dutps) atau ∑kpkk = f(pokk, dutps).
- **Ecological Dimension SFD.** This SFD contains managed waste (stk) which is a function of the managed waste generation variable (tsto), transported waste generation variable (tsta) and capacity of the dumpsite (ktpa) or ∑ stk = f(tsto, tsta, ktpa); managed waste variable (tsto) which is a function of society-based waste management variable (ps3r), *kelurahan* (equal to sub-district) scale waste management (psskl), city-scale waste management (psskt) and informal sector waste management (pssi) or ∑tsto = f (ps3r, psskl, psskt, pssi).

- **Economic Dimension SFD.** The main aspect of this type of SFD is stock flow of recycled waste availability (ksdu) which is a function of the sorting percentage (ISWMS) and recycle waste percentage (psdu) or ∑ksdu = f (ISWMS, psdu).

2.2.5. Model simulation

Simulation of the model was performed by revealing both the graphics and tables resulted from the SFD in accordance with each formula [24]. For instance, simulation of the amount or availability of recycled waste is influenced by waste generation and percentage of the waste sorting and waste composition. The simulation results are in graphics through Time Graph tool and tables through Timetable tool.

2.2.6. Model validation

Model validation is administered to assess the objectiveness of the developed model. In modeling, objectiveness is shown by how close the model in imitating the fact [25]. The term "imitating" is not exactly the same yet having similarities between the real system and the model developed [25]. According to Muhammadi et al. [25], there are two important factors to be validated, namely structure validity and output validity. Structure validity consists of validity of construction and structure stability [25]. Construction validity was performed through two techniques using theories and critiques towards the related theories [25]. Meanwhile, the structure stability validity was administered by testing the model applicability in the time dimension [25].

Validity test was then administered to validate the output of the model. There are two steps in this validity namely excluding simulation output, particularly the results of simulation from the reference model and comparing the results with the empirical data [25]. The empirical data comparison was carried out in two ways including visual comparison and statistical test either through AME (absolute mean error) or AVE (absolute variation error). The formulation of the validity test through the statistical computation is as follows [25]:

$$AME = (Si - Ai)\ Ai \tag{1}$$

$$\underline{Si} = Si\ N \tag{2}$$

$$\underline{Ai} = Ai\ N \tag{3}$$

where: A = actual score; S = simuli score; N = observation time interval

$$AVE = (Ss - Sa)\ Sa \tag{4}$$

$$Ss = ((S - Si)^2\ N \tag{5}$$

$$Sa = ((A - Ai)^2\ N \tag{6}$$

where: Sa = actual score deviation; Ss = simulation score deviation

2.2.7. Policy formulation

The results of this study will eventually be proposed to be a policy within the city of Bandung in relation to strategies on waste management system. The policy is expected to be formulated based on the previously Taylor-made scenario prior to the simulation considering such important aspects as needs and appropriateness of the budget allocation. Therefore, the simulation results are expected to present close-to-reality situations.

3. Results and Discussion

3.1. General characteristic of solid waste management

Waste management system in Indonesia is regulated by the law No.18 of 2008 stating that each region is to make their own rules in accordance with their regions' characteristics. It is stated that the management consist of two things namely reduction and management. The reduction process comprises reduce, reuse, and recycle, while the management process includes selection, collection, management, transportation, and final processing. In relation to waste management, the local government should appoint a certain institution in charge with the local waste management. However, reality shows that the parties involve are not only governmental institutions, but also informal sectors. Therefore, the waste management system is actually a combination of the three groups: $\sum$ CWMP = $\sum$GWMP + $\sum$CoWMP + IsWMP. The contribution percentage of each of the groups in terms of waste generation is 73% for the government, 6.4% by the society, and the rest (6.8% is for the informal sector.

3.2. ISWMS design

An ISWMS systematically describing the material from the upstream to the downstream and its relation to all related parties was designed based on the results of the survey considering the characteristics of each group. The ISWMS was integrated to the 3R concepts, composting, and landfilling [7]. This is in line with the concept put forward by Marshall and Farahbakhsh [26] which states that ISWMS strives to strike a balance between three dimensions of waste management: environmental effectiveness, social acceptability, and economic affordability. To this relation, Shmelev and Powell [27] also pointed out that the whole life cycle of materials entering and leaving the waste management system consists of several stages— raw materials extraction, processing, sale, consumption, finally becoming waste when they are discarded by consumers. The designed ISWMS, as presented in Fig. 2, is also supportive upon circular economy concepts utilizing the waste materials to be another industrial input, or the so-called industrial symbiosis [28].

3.3. Establishment of system dynamic model

An interface factor serving as a connector is needed to integrate all the three groups involved in waste management. Based on the previous study, there were 17 interface factors [22], which is shrinked into 16 variables in accordance with an analysis using a dynamic system method. All the 16 variables were then turned into an integrated waste management input-output system model which comprised uncontrolled input, controlled input, desired input, undesired output. In addition to the variable groups of the input-output, there was also an environment input serving as a moderator, which was the constitution. To maintain desired output by the system, an evaluation mechanism is needed. The integrated waste management input-output system is presented in Fig. 3.

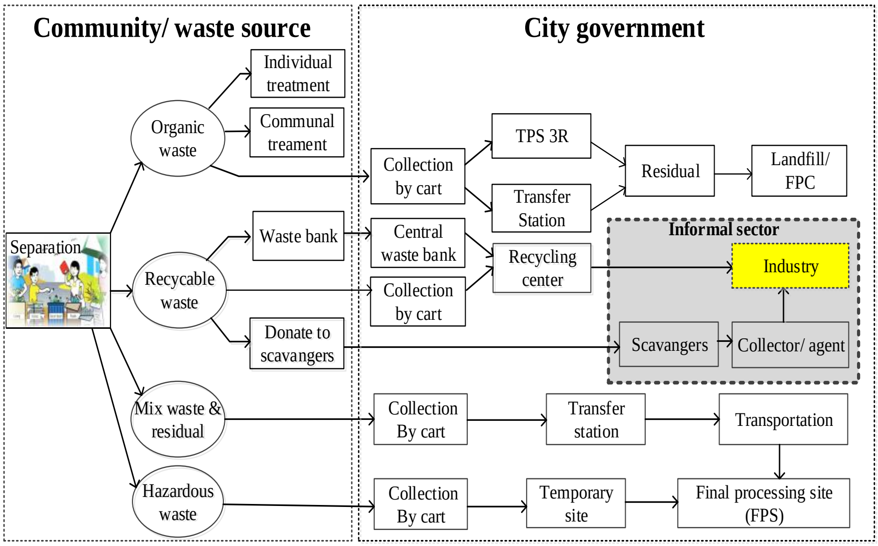

Fig. 2. Integrated Solid Waste Management System (ISWMS) design.

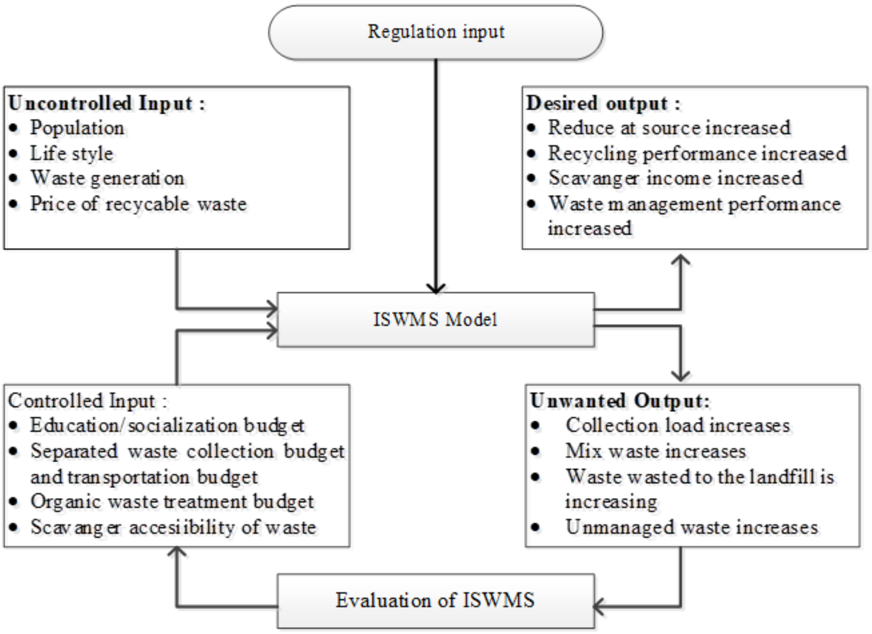

Fig. 3. Input-output-model.

Every variable is likely to relate to one another causally as it is called causal-loop diagram (CLD); this is due to the fact that one variable might create looping influencing other more complex variables. The CLD, which aims to produce easier analysis, is classified into ecological, social, economic, and governmental dimensions. In addition, the CLD is made in colours as presented in the input-output diagram except for the moderate variable made in white. The Causal Loop Diagram of ISWM is shown in Fig. 4.

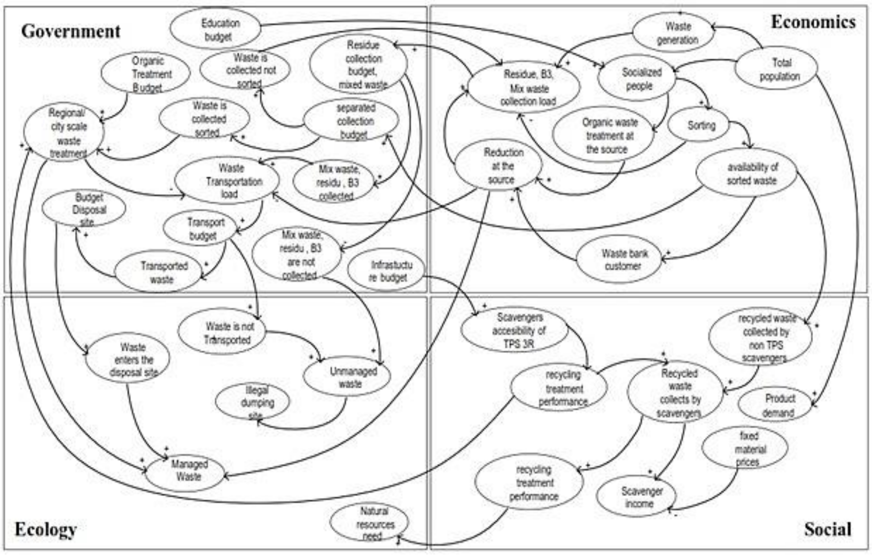

Fig. 4. Causal loop diagram of ISWM.

3.4. Simulation results of ISWMS model

Modeling and simulation of the ISWMS was performed using a dynamic system method through a licensed Powersim 10 software following the stages developed by Surjandari et al. [9]. The model is then divided into four sub-models namely social sub-model comprising number of people, waste generation projection, waste categorization, type-based waste generation; governmental sub-model consisting of waste transportation from the source to the 3R sites, waste management within the 3R sites, waste/ residue transportation from the 3R sites to the dumpsites, waste management budget; economic sub-model containing informal sector waste management (by waste pickers), waste bank, recycling process; and ecological sub-model including unmanaged waste, waste management in the dumpsites, and circular economy.

To make sure whether the model formulated is able to predict the ISWMS model close to reality either from the current system or to develop scenario in the system development, a validation process to several variables which are going to be key variables is carried out. The validation method used in this study is the calculation of Absolute Mean Error (AME) and Absolute Variation Error (AVE) as suggest ted by Firmansyah et al. [24] and Muhammadi et al. [25]. For the social sub-model, the key variables are the number of people and the waste generation. To validate both the variables, a comparison between the calculation and actual data stated within the documents of Bandung Dalam Angka 2017, Bandung in Number in 2017, and Master Plan Sampah Kota Bandung 2018-2037, Masterplan of Bandung Waste Management, 2018-2037. The results showed that the AME and AVE percentage for the number of people variable was 0.192% and 0.311, respectively. In the meantime, that for the waste generation variable was 0.192% and 0.311% respectively. All of the score is <10% indicating that the validation is good. For governmental sub-model, the key variable is waste transportation budget validated by comparing the actual budget with the simulation. The results showed that the percentage of the AME is 0.755% and that of the AVE is 0.172%. The percentage also indicates that the validation for the key variable is classified good.

After the model is validated, the simulation using Powersim Studio 10 is performed. Prior to the simulation, a scenario taking into consideration controlled input and desired output (Fig. 3), is made. It has been found that the measurably important scenario consists of level of waste reduction either within sub-district or city scope, both by the people, government, and informal sector. Waste reduction closely depends on waste categorization on the source. There are two scenarios namely moderate and optimistic scenarios. The policies of each scenario refer to the controlled input system, while quantitative data are acquired from trial and error considering congruity and flexibility aspects. The congruity aspects are related to budget to be prepared by the government and the flexibility aspects are related to the existing policies.

The main objective of the model development is waste reduction in the source (society). This is in line with the Indonesian constitution stated in Presidential Decree No.97 of 2017 that by 2025, the waste reduction should reach 30%. Related to waste reduction, waste selection starting from the source is important. Based on the simulation results featuring the scenario of the socialization budget (Fig. 5), it is found that (1) waste reduction average in the source on the current situation is 55,323 tons per year or around 9%, in which the maximum reduction reached 10% in 2017; (2) on the moderate scenario, the waste reduction average is 76,939 tons per year or around 13% in percentage with the maximum percentage at 18% by 2036; (3) on the optimistic scenario, the reduction average is 98,312 tons per year or around 16% with the maximum percentage of 23% by 2031. The results of the simulation showed that the percentage is higher than a similar simulation performed in Curtiba with the maximum reduction percentage at 23% by 2055 [29].

The second objective of the developed model is to increase an area or city-scaled waste management performance or waste reduction. The area refers to waste management served by the 3R approach-featuring sites. In the scope of area waste management, in addition to the waste selection from its source, its system and budget of the waste transportation also play an important role. In this model, the budget availability for both scenarios is 100%. This budget is allocated by the local government through the sub-districts or another appointed office. In the meantime, in terms of institutional roles related to recyclable waste collection, both the moderate and optimistic scenarios agree that 50% is performed by the waste bank and the rest is executed by the informal sector. The results of simulation presented in Fig. 6, show that the existing data of the waste reduction in 2019 is 6% per year yet that of the moderate and optimistic scenarios is 28% and 35% per year, respectively. Organic waste reduction decreases in 2032 according to the optimistic scenario as the organic waste management in the source increases.

The third objective of this model development is to increase the income of informal sector. The informal sector plays an important role in Indonesia' waste management as the number of the pickers is quite huge and the amount of the waste material to be recycled is also high. However, reality shows that the government does not include them into the waste management system leading to random methods and selection of waste picking locations. This condition leads to uncontrolled amount of recyclable waste and the existence of more waste/ residue sites. Thus, the moderate scenario plans that the accessibility of the informal sector to the dumpsites increases by 5% and the optimistic scenario plans to have a 10% increase per year. The informal sector's accessibility to the 3R sites and the dump stiped and their integration within the ISWMS affects the collection of recyclable waste and increase their income. The simulation results presented in Fig. 7 and Fig. 8 showed that the number of recyclable wastes collected by the informal sector is

60,500 tons per year. Thus, the moderate scenario has a target to increase it into 98,628 tons per year (having a 63% increase) and the optimistic scenario plans to have a 90% (115,279 tons per year) increase from the existing condition. The scenarios also plan to increase the income of the informal sector. The moderate scenario plans to have a 55% increase from the existing condition (from IDR 1,276,545 per month per person to IDR 1,974,694 per month per person. Meanwhile, the increase planned by the optimistic scenario is by 81% (IDR 2,405,278 per month per person).

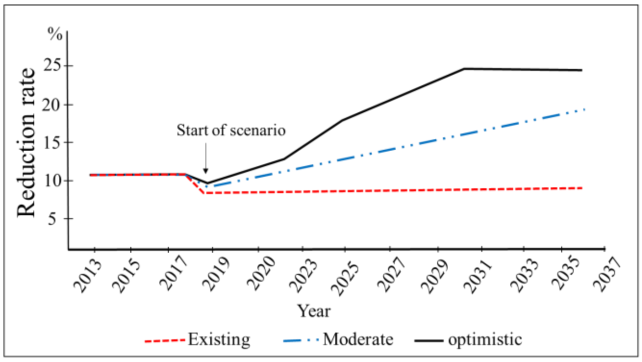

Fig. 5. Reduction rate at source.

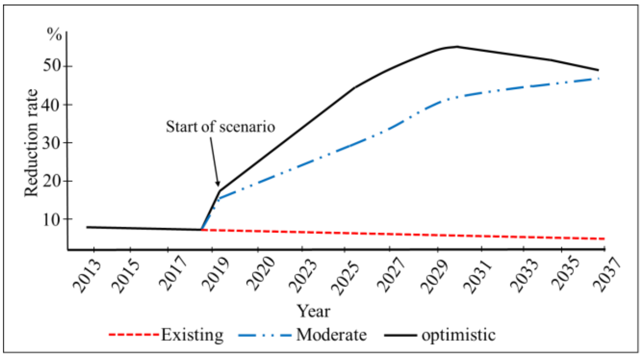

Fig. 6. Reduction rate at regional scale/ TPS 3R.

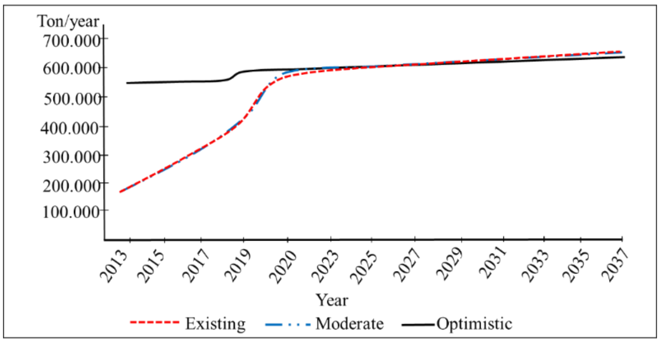

Fig. 7. Recyclable waste collected by informal sector.

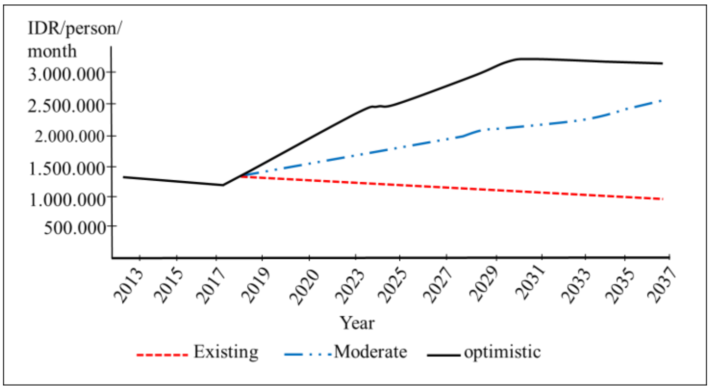

Fig. 8. Informal sector income.

The amount of managed waste is the fourth goal of developing the model and this goal is closely related to the amount of unmanaged waste that is polluting the environment. Based on the simulation results shown in Fig. 9, that there is no significant difference in managed waste for each scenario. This is because in the current system (existing conditions) the level of waste management has reached around 86% of the total generation. For this reason, the difference in the percentage increase in management is only around 1% for each scenario in 2019 and around 2-3% for 2020. All scenarios including the existing scenario, the 100% managed waste target is achieved by 2021.

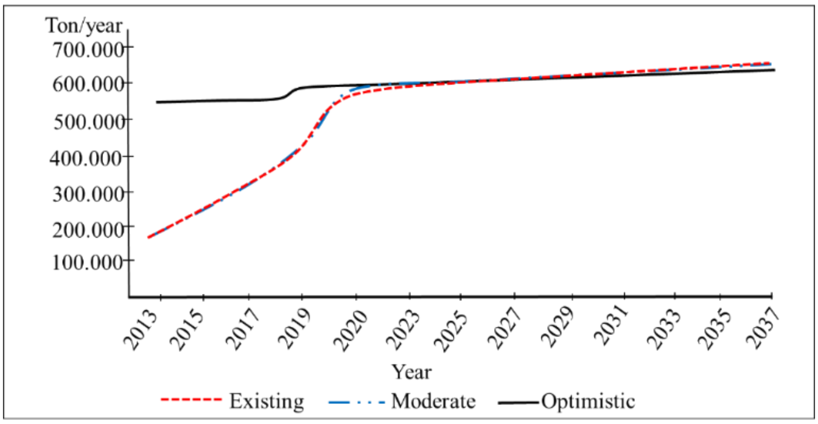

Fig. 9. The city waste management performance (reduction & handling).

Despite the insignificant difference of waste management, there is a significant difference in budgeting for each scenario. This is most likely to be caused by the waste reduction activities either in the sources or in the regions. In every region implementing waste reduction, there is a special budget for training or empowering the people. This activity is expected to decrease budgets on collection, transportation, and management of the waste in the dumpsites. In regional scale, there is a special budget for organic waste management leading to budget cut on waste transportation to the dumpsites. The average budget of the existing condition is IDR 242.6 billion per year yet that of the moderate and optimistic scenarios are IDR 234.9 billion and 216.4 billion. In other words, there will be IDR 7.7 billion saving per year if the moderate scenario is chosen and IDR 26.2 saving per year if the optimistic scenario with the same quality of waste management either in the existing condition, moderate, or optimistic scenario (see Fig. 10).

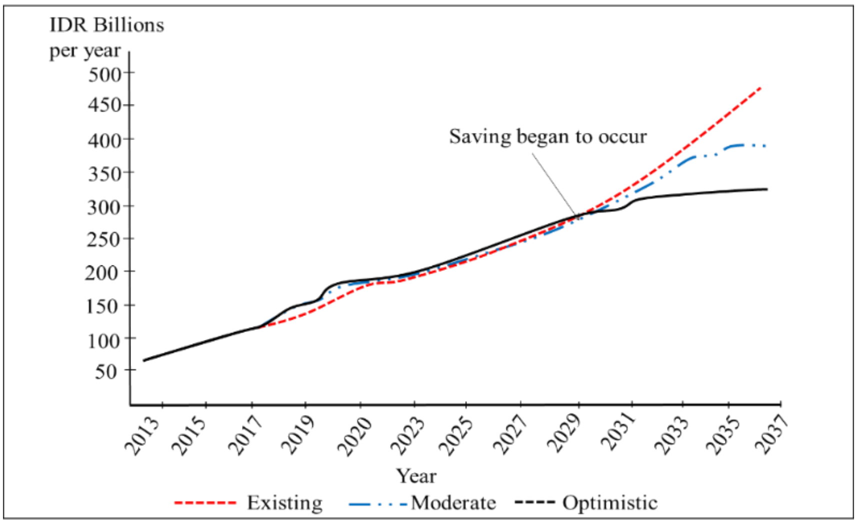

Fig. 10. Waste management cost.

3.5. Simulation results of ISWM model related with circular economics

Waste management through recycling activities for certain waste material does not only lead to reduction of waste management budget, waste reduction, increase of informal sector income, but also decrease exploited virgin natural resources. In Indonesia, the decrease of the virgin resources is as follows.

- Needs of plastics: 10 kg/ capita/ year (2012), with an annual 5% growth [30].
- Needs of paper: 32 kg/ capita/ year (2012, with an annual 7.5% growth [31].
- Needs of metals: 25.6 kg/ capita/ year (2000), with an annual 5.3% growth [32].

Material need projection for plastics, paper, and metals for the people of Bandung, after each material efficiency through recycling processes either without policy change (the existing condition), moderate scenario, or optimistic scenario (as seen in Fig. 11), shows a rather significant difference on the optimistic scenario. For plastic needs, if there is no supply from the recycling activities, the average is 58,873 tons per year, yet it reaches 39,441 tons per year for the existing, 23,657 tons per year for the moderate scenario, and 15,812 tons per year for the optimistic scenario. In the meantime, the paper need projection in Bandung without recycling activities is approximately 282,604 tons per year and it could reach 6% saving with recycling activities for the existing condition, 11% saving for the moderate scenario, and 13% saving for the optimistic scenario. Last but least, for the metal need projection, the average without supply from the recycling activities is 217,516 tons per year. Meanwhile, with supply from the recycling processes, that of the moderate scenario saves 6% and that of the optimistic scenario is 7%.

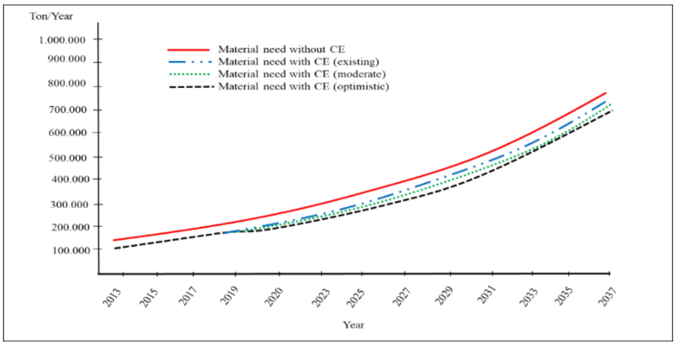

Fig. 11. Trend of material plastic, paper and metal without CE and with CE.

3.6. Implication of the simulation results in formulating policies

To maintain integrated waste management system as well as virgin resource availability for sustainable industry, governmental policies are needed. The policies should mainly cover three important areas namely economic management, waste management budgeting, and informal sector as well as waste bank. The primary policies of the ISWMS implementation are related to economic system as the policies should determine that the materials chosen by the industry are recyclable and reusable. In addition, the producers should also be responsible for the products regulated in extended producer responsibilities. After the materials are consumed, they have to make sure that the waste does not go to the nature, yet it has to go through the industrial chain with industrial symbiosis system. This is in line with Shijiang Xiao et al. [33] doing a study in Shanghai, China expanding their study using demographic regulations.

The second policy is closely related to budget availability for recycling infrastructure and educational programs, especially ones regarding waste selection or categorization. The sufficient budget availability will be able to decrease the amount of waste in the source and have long-term financial efficiently. Based on a study, for every IDR 1 million decrease per year, there will be a 58-ton waste decrease per year in the source leading to the budget decrease by IDR 65.8 million per year. Additionally, every IDR 1 million per year for organic waste management leads to financial saving as much as IDR 1.13 million per year. This idea is in line with the results of a study by Márquez and Rutkowski [34] stating that one of the main drives of circular economy is finance. The amount of budget positively correlates with waste reduction and efforts of the circular economy. To this relation, Abou Taleb and Al Farooque [35] suggested a Pay-As-You-Throw (PAYT) system.

The third policy is in relation to the informal sector of waste management system, particularly waste pickers and waste back which are inseparable parts of the system. The policy resulted from the simulation results are about their activity accessibility improvement to the waste sources and better waste selection and categorization. In such countries as Brazil, Russia, India, China, and South Africa, informal sector of waste management system has been successfully turned into formal one [36].

4. Conclusions

The results showed an optimal performance of waste management system using ISWMS. Waste reduction in the source, which is clearly stated on Indonesian Presidential Decree No.97 of 2017 is believed to be achieved in accordance with the optimistic scenario. This is also influenced by policies regarding the budget of training, facility procurement, and waste reduction in the source. It has been revealed that in every increase of IDR 1 million per year for socialization and waste reduction activities, there will be a decrease of as many as 58 tons of waste per year which is equal to the budget cut on management as much as IDR 65.8 million per year. The same pattern applies to sub-district waste management particularly related to organic waste, in which there will be a decrease of 1.6 tons of waste transported to the dumpsites or as much as IDR 1.13 million management budget saved for an annual IDR 1 million increase of budget outcome on organic waste management. In general, the comparison of waste management performance between the optimistic scenario and the existing condition is there is a 39% annual decrease of the optimistic scenario, yet the existing condition only has a 13% decrease; there is a waste management financial saving by IDR 26.2 billion per year of the optimistic scenario compared to that of the existing condition; and there is an increase of income for the waste pickers from IDR 1.3 million to IDR 2.4 million per month. In relation to the circular economy, the integrated system affected several resource savings needed by the people of Bandung, Indonesia.

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