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Dynamic Delphi Multi Criteria based Analysis for Collaborative Solid Waste Management Decision Making in Baubau Municipality, Indonesia

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***Abstract*—Recent studies have shown that the multi-criteria decision analysis (MCDA) is able to be used for solid waste management decision-making that involving many parties. Although it could be used for multi-party decision making, decision resulted should not considered as consensus, but merely an aggregation of individual decisions. This study was aimed to investigate (1) relative importance measure among environmental, social, economy and technology aspects on solid waste management strategy decision making in Baubau, (2) stakeholder preference to solid waste management strategies in Baubau, and (3) CH_4 emission from solid waste management strategies in Baubau.**

This study was conducted in Baubau municipality, Southeast Sulawesi Province, Indonesia and involving local government, community and technician/expert to represent solid waste stakeholders. A set of questionnaire were distributed to stakeholders and an analysis were carried out using Analytical Hierarchy Process (AHP) and Delphi method. Preferred solid waste management strategy then was examined its CH_4 emission potential using First Order Decay Model from Intergovernmental Panel on Climate Change for year 2010 to 2018.

This study has shown that consensus among stakeholders was reached after three stages. Relative importance measures in Baubau solid waste management decision making were environmental aspect (48.19%), social aspect (31.21%), economy aspect (14.42%) and technology aspect (6.18%). A solid waste management strategy that consist of separation and recycling, controlled landfilling, sanitary landfilling and composting was most preferable by stakeholders. Investigation to CH_4 emission potential has also demonstrated that solid waste management strategy that is made of 5% recycling, 15% controlled landfilling, 37% through sanitary landfilling and 7% composted has 41.99% lower CH_4 emission compared to current strategy

Keywords*— *Solid Waste Management, Analytical Hierarchy Process (AHP), Delphi Method, System Dynamics, First Order Decay (FOD)

I. INTRODUCTION

High population growth stimulates higher solid waste generation in many municipalities in Indonesia. World Bank [1] stated that Indonesia has quite high as 2.26% annual population growth during 2005 to 2009. Basel Convention estimated solid waste generation in Indonesia will increase as well from 0.76 kg per capita in 1995 to 1 kg per capita in 2025 [2]. Unfortunately, municipal solid waste management is considered as an expensive service while its coverage only range from 30 percent to 80 percent of solid waste generated [3]. This circumstance worsen since solid waste has significant influence to soil and groundwater condition [4][5][6][7], green house gases emission [8] and economy of community [9]. Solid waste has contributed also to expand opportunity for job creation [10] and public health [11][12].

In order to cope with solid waste constraints such as solid waste generation growth, facility efficiency and capacity and its impacts to meet the requirements in increasing solid waste service, it is necessary to conduct solid waste decision making and modeling correctly. However, some challenges take place in solid waste modeling process, such as [13]: complexity of the problem requires decision maker to take into account various aspects simultaneously, degree of uncertainty of some aspects in solid waste management is relatively high, numerous objectives exist where each objective has no single accepted general measure that consequently makes a tradeoff between objective is difficult to be made, and there is opportunity for different viewpoint among decision makers that may produce distinctive decision from each decision maker. Multidiscipline nature of solid waste management causes the problem should be possibly resolved collectively [14]. This situation makes government is not longer making decision solely without involving another stakeholder. When each stakeholders, experts and community with their distinct know-how participate in strategy planning then the quality of decision resulted will be improved significantly [15].

Baubau is a small municipality situated in Southeast Sulawesi Province, Indonesia. It has quite high annual population growth rate as of 2.61% [16] while population growth rate at the same period at national level is only 1.1% [1]. Currently, municipal government has been able to collect and manage 300 m^3 solid wastes per day in government owned facility. Lack of funding has restricted government to expand solid waste transport and treatment facility. Beside budget constraint, municipal government has regarded proper strategy planning as major issues in municipal solid waste management [17]. Both issues have interlinked elements since accurate budgeting requires proper strategy planning.

In order to analyze complexity emerged in solid waste management decision making, [18][19][20][21] and [22] (2011) have determined relative importance level among associated factors. In general, these studies classified solid waste management decision making dimension into four general aspects i.e. environment, economy, social and technology. However, relative importance level among these studies varied depends on study subject and location.

Several studies were also assigned to determine suitable solid waste management strategy. Reference [18][21][22][23][24][25][26] and [27] have recommended a certain solid waste management strategy to be implemented. Although stakeholder were involved in these studies, yet final decision resulted was a pseudo-consensus comes from aggregation of individual decision.

In order to deliver a more efficient and credible decision, environmental impact evaluation is strongly required for each environmental strategy, [14][28][29][30][31] have demonstrated an analysis of environmental impact from various solid waste strategies. However, environmental evaluation for solid waste management strategy in Baubau municipality currently does not exist yet.

This study then was intended to investigate (1) relative importance measure among environment, social, economy and technology aspects in order to make a decision on solid waste management strategy in Baubau, (2) stakeholder preference to solid waste management strategies in Baubau, and (3) CH_4 emitted from solid waste management strategies in Baubau.

II. Literature Review

Several methods have been utilized for analyzing and determining solid waste management strategy i.e. mathematical programming (see [13][32][33][34][35][36][37][38]), system dynamics simulation (see [39][40][41]), multi criteria decision analysis (MCDA) (see [18][21][22][23][24][25]), environmental evaluation method (see [28][30][42][43][44]), economic evaluation method (see [45]) and multi method (see [19][20][26][27][29][46][47].

Among all, [18][19][20][21][22][25][29] have not only identified important factors associated with solid waste decision making but also demonstrated that stakeholder involvement could be accomplished in decision making. MCDA is capable to incorporate a group decision maker in decision making process but yet decision produced a pseudo-consensus formed from aggregation of individual decision.

Life Cycle Analysis (LCA) and *First Order Decay* (FOD) method from Intergovernmental Panel on Climate Change so far has been few utilized for solid waste management environmental evaluation despite its applicability to improve credibility of decision made.

A. Delphi Method

Delphi method allows decision maker to examine multifaceted problem as usually take place in solid waste management where decision maker has limited source of information and time to make decision [29]. Delphi method is considered as a procedure to arrange group communication process in such way that allows individual in group could meet an agreement effectively when solving complex problem [48]. There are four basic feature of Delphi method i.e. anonymity, iteration, controlled feedback and statistical aggregation of group response [49].

B. Multi Criteria Decision Analysis (MCDA)

MCDA is capable to incorporate sustainability since it allows integration of multiple factors and participation of relevant stakeholders into decision making. Sustainable decision making should not only put economic, environment and social aspect altogether but also bring public participation into decision making process [19]. MCDA allows constructing a compromise option among stakeholder and balance systematic decision making process with stakeholder values. And solid waste management may have benefited from MCDA method from this particular attribute. MCDA has some benefit for implementation in solid waste management, for instance [29]:

- Allows many criteria and objectives put into consideration altogether.
- Gives decision maker flexibility to choose criterion used
- Could combine quantitative and qualitative data

C. System Dynamics Simulation

System dynamics (SD) is a computer assisted simulation that enables to generate a model to simulate the relationship among various variables in a certain range of time. At the end of the time range, several variables will be adjusted as a result of variables change in preceding time [50]. Since it was introduced in 1960s, system dynamics has been used to study and examine complex feedback loop by developing a model that consist of a causal loop diagram or stock and flow diagram [51]. System dynamics is usually engaged in complex problem associated with feedback, time delays, stocks and flows (accumulations) and nonlinearity [52].

System dynamics model is developed using causal loop diagram and stock and flow diagram that represents the relationship between the elements that shape whole system [53]. In practice, modeling, process and simulation are performed using computer simulation such as Stella® [54].

D. First Order Decay Model

The IPCC has released two models in order to assist in estimating methane (CH_4) emission in a solid waste dumpsite. In 1997 IPCC published a guidebook to calculate methane emission based on mass balance method. However, this method is then replaced with FOD method in year 2006.

The IPCC FOD model is based on the assumption that degradable organic carbon (DOC) in waste material decays gradually and generates CH_4 and CO_2. In steady condition, CH_4 generated only depends on carbon remaining in solid waste material and subsequently CH_4 generated is highest in a few first year and gradually decline as the bacteria responsible for decaying process constantly consume degradable carbon in solid waste [55].

III. Methods

In order to investigate relative importance measure among environment, social, economy and technology aspects between stakeholders, stakeholder response were examined using a set questionnaire distributed to a group of stakeholders. The questionnaire consists of pairwise

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comparison between factors and strategy options where each panelist assign a relative importance measure using scale number 1 to 9 [56][57]. Each panelist was allowed to assign different response, however a controlled feedback was given in the next stage until agreement was met. Delphi method was used to organize communication process in pairwise comparison process. Relative importance level was determined from measure resulted from pairwise comparison where its measure ranged from 0 to 1. The highest measure indicates that a factor relatively more important among factor. Using the same process and indicator, it was produced most preferred solid waste strategy as well.

From recent study associated with solid waste management (see [18][19][[21][22][27][28][58][59][60][61]), there are four major aspects considered for solid waste management decision making i.e. environment, social, economy and technology. These four factors were used for assessing relative importance among stakeholder in this study.

There are six strategies were considered in this study (Table 1). Solid waste management strategy is defined as a combination of solid waste treatment commonly used to reduce solid waste mass. Five treatment methods were put in predetermined strategy i.e. separating and recycling, controlled landfilling, sanitary landfilling, composting and incinerating.

TABLE I. SOLID WASTE MANAGEMENT STRATEGY OPTIONS

Strategy	Description
S1	Controlled landfill+ sanitary landfill
S2	Controlled landfill+ sanitary landfill + composting
S3	Controlled landfill+ sanitary landfill + incinerating
S4	Separating and recycling+ controlled landfill+ sanitary landfill + composting
S5	Separating and recycling+ controlled landfill+ sanitary landfill + incinerating
S6	Separating and recycling+ controlled landfill+ sanitary landfill + composting + incinerating

Analytical Hierarchy Process (AHP) was used due to its logical procedure particularly if used for group decision making where different knowledge and value between stakeholders exists [62]. AHP is also capable to examine consistency of decision making process in order to produce better decision [61]. AHP and its variant are also regarded as the most reliable MCDA method [63].

Environmental impact evaluation was determined after solid waste generation, composition and strategy already presented. Solid waste management strategy was obtained from previous stage while solid waste composition was already exists. Solid waste generation was estimated using system dynamics simulation where socioeconomic factors explained solid waste generation.

In solid waste generation model, there were two main variables i.e. population and solid waste generation per capita. Population sub model was a function of public health status, education level and economic income. Studies from [64][65][66][67][68] have shown relationship in direct and indirect way between health, education and economic factors to urban population growth. However, Human Development Index (HDI) has encompassed these three factors into a single aggregate score. HDI is a summary of mean performance measure of human major development dimension that consist of health, education and living standard. Health aspect is measured by life expectancy at birth while average schooling years for 25 year adult and expected years of schooling for children of school entering age are quantified for education component. The standard of living dimension is measured using gross per capita income. HDI was then used as a predictor for population sub model.

Environmental impact assessment was measured from CH_4 emitted and accumulated yearly for each solid waste management strategy. CH_4 emission was calculated using FOD tier 1 method from IPCC [55]. Modeling and simulation was performed for year 2010 – 2018. This time range was chosen due to data availability and suitability for solid waste facility planning.

A. *Study Area Description*

Baubau is one among two regions in Southeast Sulawesi Province, which gain its autonomy status as a municipality since the Government of Indonesia implement decentralization in 1999. Baubau municipality has more than 221 km^2 land area and its urban population has reached 147,576 in 2013 [69]. Currently, municipal government solely manages solid waste by Department of Solid Waste Service, Gardening, Interment and Fire while solid waste treatment facility is provided partially by Department of Public Works and Department of Environmental Protection. Even though the Department has a relatively small budget, Baubau municipality has established a 15,000 m^2 controlled landfill facility in 2012. Solid waste strategy currently applies in municipality of Baubau is for transporting and dumping solid waste to the final disposal site. A limited portion of solid waste is processed in composting facility and a small amount is separated informally by scavenger and sold to local dealer. Baubau has no incinerating facility recently and burning solid waste is commonly practiced by households occasionally.

B. *Sampling*

To perform pairwise comparison using Delphi Method, for this study purpose, nine panelists have been chosen where each 3 panelists represent government, expert and community. These parties correspond to three forms of knowledge i.e. [15]: knowledge based on general awareness and personal know-how, knowledge based on technological proficiency and knowledge based on social support.

Expert panelists were taken from environmental engineering lecturer and researcher from the local university, senior officer of solid waste related function were chosen as government panelist and member from a local house of representative represented community panelist. Instead of statistical significance importance, Delphi method is mostly based on panelist's dynamics in meeting an agreement. Then population representative is not relevant to data collection accuracy [70].

C. *Instrument*

Panelists were distributed a set of questionnaire that consist of 66 pairwise comparison close question. Each panelist required to assign a number that represent relative importance measure between two factors or solid waste strategy options. Until an agreement met, the same questionnaire was distributed to panelists with some adjustment made in order to reassign items. Panelists were

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provided also with a set of descriptive statistics that review previous stage results. This process was repeated until agreement completely met for all factors and solid waste strategy options.

D. Data Analysis

Result obtained from pairwise comparison process was summarized using descriptive statistic. Panelists responses was analyzed using descriptive statistics such as minimum value (min), maximum value (max), range (R), mean$(\overline{x})$, and mode (Mo). In each pairwise comparison stage, panelists were informed with statistics from previous stage that may influence panelist decision in the present stage.

Relative importance measure and stakeholder preference toward solid waste management strategy was analyzed using AHP and calculated using Microsoft Excel [70]. CH_4 emission was assessed for each solid waste management scenario using FOD and calculated using Microsoft Excel. Waste generation was modeled by system dynamics using Stella 9.0 version [54]. Sensitivity analysis was also performed in order to evaluate change in strategy for each alteration of some uncontrolled factors.

IV. Results

In pairwise comparison process, when an item of comparison has range = 0 or mean = 0 then an agreement is already met. Agreements among stakeholder are completely met after 3 stages of pairwise comparison process where the second and third stage in addition to questionnaire distribution, direct interview was also conducted to stakeholder. At the first stage, there is no single item was agreed by stakeholder while at the second stage only 33 item (45.83%) were agreed.

Consensus reached for all items of comparison then was put to construct pairwise comparison matrices. Normalized pairwised comparison matrices of each criteria and strategy options along with its weight and consistency computation were illustrated in table 2 to 6.

The CR value for inter-criteria pair wise comparison (C1 – C4) was 0.089 which mean that consistencies of judgment were confirmed. Consistency of judgment was also met by strategy to criteria pair wise comparison (S1 – S6) 0.085, 0.099, 0.094 and 0.083 respectively. Thereby, weight derived from criteria and strategy option pair wise comparison matrices was able to be used to determine solid waste strategy ranking.

Multiplication of criteria weight and strategy option weight is illustrated in table 7.

Based on result obtained from Table 7, it was found that factor relative importance measure for solid waste decision making in Baubau was C1 environment (48.19%), C3 social (31.21%), C2 economy (14.42%) and C4 technology (6.18%) consecutively. Solid waste management strategy S4 that consists of treatment in separation and recycling facility, controlled landfill, sanitary landfill and composting facility was most preferred by stakeholders.

In order to estimate population, HDI was proposed as explanatory variable for population. Due to limited data sets (table 1), simple linear regression was used to determine the relationship between population and HDI [51].

Using data sets available and a statistical analysis application, a linear regression analysis was performed with HDI as a predictor variable for the population. The analysis result showed that both constant and HDI coefficient in regression equation has less than 0.05 significance value of t statistic. It means that both of these values were not due to chance. The coefficient of determination for this model was 0.938 that means 93.8% of population variance in time could be explained by this model. Standard error of estimate for this model was 1949.87 that are quite small for population measure. This model was then used to develop population subsystem in a system dynamics model.

The same procedure was performed for HDI measure using dataset in table 8. HDI model estimation used time as a predictor variable. The analysis result showed that both constant and time coefficient in regression equation has less than 0.05 significance value of t statistic. The coefficient of determination for this model was 0.995 that also means 99.5% of the HDI variance in time can be explained by this model. Standard error of estimate for this model was 0.11533 that is very small for HDI score. The model was then used to develop population subsystem in a system dynamics model.

Using equation resulted from linear regression analysis, a system dynamics model to estimate population and solid waste generation (kilograms) was then developed (Fig. 1.) and the result presented in Table 9.

For tier 1 application, IPCC [55] has provided the default proportion of solid waste management strategy by country including Indonesia however solid waste management strategy from Indonesia Ministry of Environment (MoE)[88] become a controlling boundary of developed strategy for analysis (see table 10). Thereby according to MoE [88] proportion of solid waste transported to incinerator/open burning facility and composting plant in this study would not exceed 4.8% and 7.15% respectively. For solid waste composition (see table 11) an adjustment of MoE [88] solid waste composition was employed for analysis. It was assumed that 27% of other wastes category in MoE [88] solid waste strategy composed of 10% garden and park wastes.

It was estimated using solid waste carrier volume arrived at the disposal site that Baubau has transported approximately 27,375,000 kilograms solid waste in 2014. Based on simulation results, solid waste generation in Baubau was 42,674,713 kilograms at the same period. Consequently, solid waste collection efficiency in Baubau was just about 64%. From all solid waste collected and transported to disposal facility, 4% was redirected to composting facility and 2% was recycled by scavenger informally at the final disposal site. Then, the baseline strategy currently implemented in Baubau consists of 2% recycling, 58% dumped to controlled landfill and 4% processed to composting plant.

In order to examine the best potential strategy in terms of methane emitted from solid waste management, four strategies scenario were developed and compared to each other. In the first strategy, both recycling and composting was kept on regular rate while half of solid waste dumped in controlled landfill was diverted to sanitary landfill. In the second strategy, solid waste went to sanitary landfill and composting plant as well as recycling activity was raised to 37%, 7% and 5% in that order. Both third and fourth strategy has considered incineration to be included in. In the third strategy, incineration was set on 3%, while recycling and composting

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TABLE II. NORMALIZED MATRIX AND CR FOR CRITERION

	C1	C2	C3	C4	Weight	W'	λ	CI	RI	CR
C1	0.53571	0.40909	0.67021	0.3125	0.48188	4.48192	4.23711	0.079037	0.89	0.08881
C2	0.17857	0.13636	0.07447	0.1875	0.14423	4.11964				
C3	0.17857	0.40909	0.2234	0.4375	0.31214	4.28561				
C4	0.10714	0.04545	0.03191	0.0625	0.06175	4.06127				

W' : the eigenvector
λ : the eigenvalue
CI : consistency index
RI : random index
CR : consistency ratio

TABLE III. NORMALIZED MATRIX AND CR FOR STRATEGY OPTIONS IN REGARD TO "ENVIRONMENT" CRITERION

	S1	S2	S3	S4	S5	S6	Weight	W'	λ	CI	RI	CR
S1	0.05172	0.02016	0.1	0.02984	0.04237	0.09292	0.05617	6.095943	6.53332	0.10666	1.25	0.085331
S2	0.15517	0.06048	0.16667	0.04178	0.04237	0.06637	0.08881	6.381428				
S3	0.01724	0.0121	0.03333	0.02321	0.02542	0.06637	0.02961	6.183477				
S4	0.36207	0.30242	0.3	0.20889	0.38136	0.15487	0.28493	6.839474				
S5	0.15517	0.18145	0.16667	0.06963	0.12712	0.15487	0.14248	6.689316				
S6	0.25862	0.42339	0.23333	0.62666	0.38136	0.4646	0.39799	7.010266				

TABLE IV. NORMALIZED MATRIX AND CR FOR STRATEGY OPTIONS IN REGARD TO "ECONOMIC" CRITERION

	S1	S2	S3	S4	S5	S6	Weight	W'	λ	CI	RI	CR
S1	0.04286	0.01596	0.15	0.0293	0.03846	0.06466	0.05687	6.055954	6.61753	0.12351	1.25	0.098805
S2	0.21429	0.07979	0.15	0.04102	0.11538	0.09052	0.11517	6.766392				
S3	0.01429	0.0266	0.05	0.04102	0.03846	0.09052	0.04348	6.281628				
S4	0.3	0.39894	0.25	0.20508	0.34615	0.15086	0.27517	7.065582				
S5	0.12857	0.07979	0.15	0.06836	0.11538	0.15086	0.11549	6.5346				
S6	0.3	0.39894	0.25	0.61523	0.34615	0.45259	0.39382	7.001037				

TABLE V. NORMALIZED MATRIX AND CR FOR STRATEGY OPTIONS IN REGARD TO "SOCIAL" CRITERION

	S1	S2	S3	S4	S5	S6	Weight	W'	λ	CI	RI	CR
S1	0.04688	0.01596	0.125	0.07075	0.03333	0.03992	0.05531	6.102535	6.59055	0.11811	1.25	0.094488
S2	0.23438	0.07979	0.125	0.09906	0.03333	0.06654	0.10635	6.586718				
S3	0.01563	0.0266	0.04167	0.07075	0.03333	0.02852	0.03608	6.347726				
S4	0.32813	0.39894	0.29167	0.49528	0.5	0.59886	0.43548	6.806675				
S5	0.14063	0.23936	0.125	0.09906	0.1	0.06654	0.12843	6.915736				
S6	0.23438	0.23936	0.29167	0.16509	0.3	0.19962	0.23835	6.783898				

TABLE VI. NORMALIZED MATRIX AND CR FOR STRATEGY OPTIONS IN REGARD TO "TECHNOLOGY" CRITERION

	S1	S2	S3	S4	S5	S6	Weight	W'	λ	CI	RI	CR
S1	0.13125	0.15719	0.23684	0.06654	0.26923	0.2561	0.18619	6.541372	6.51861	0.10372	1.25	0.082977
S2	0.39375	0.47156	0.39474	0.59886	0.26923	0.32927	0.40957	6.747902				
S3	0.04375	0.09431	0.07895	0.06654	0.11538	0.10976	0.08478	6.475527				
S4	0.39375	0.15719	0.23684	0.19962	0.19231	0.2561	0.2393	7.029613				
S5	0.01875	0.06737	0.02632	0.03992	0.03846	0.0122	0.03384	6.221487				
S6	0.01875	0.0524	0.02632	0.02852	0.11538	0.03659	0.04632	6.095735				

was maintained similarly as baseline strategy. In fourth strategy, incineration, recycling and composting were increased to 5%, 5% and 7% respectively. Based on table 12, all of these strategies were still relied mostly on landfilling due to its carrying capacity and economic consideration.

With four solid waste management strategies and a baseline strategy, estimation of CH_4 emission was calculated for year 2010 to 2018. The result of this calculation was shown in Fig. 2. For the first year CH_4 emitted virtually near to zero and significantly growing furthermore. This was due to carbon contained in solid waste mass have inadequate time to decompose and generate considerable amount of CH_4. On the second year on, carbon accumulated has sufficient amount to generate significant quantity of CH_4.

Based on calculations, the fourth strategy that consist of 5% recycling, 7% composting, 14% controlled landfilling, 33% sanitary landfilling and 5% combusted in incinerator has the lowest CH_4 emission. This was because a significant amount of solid waste is treated using incinerator has reduced

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TABLE VII. FINAL WEIGHT OF STRATEGY OPTIONS

Criterion weight	C1	C2	C3	C4	Final Value
	0.4819	0.1442	0.3121	0.0618	
S1	0.05617	0.05687	0.05531	0.18619	0.06403
S2	0.08881	0.11517	0.10635	0.40957	0.11789
S3	0.02961	0.04348	0.03608	0.08478	0.03704
S4	0.28493	0.27517	0.43548	0.2393	0.3277
S5	0.14248	0.11549	0.12843	0.03384	0.1275
S6	0.39799	0.39382	0.23835	0.04632	0.32584

TABLE VIII. HDI AND POPULATION OF BAUBAU MUNICIPALITY IN 2004 - 2011

Year	**HDI**	**Population**
2004	68.8	120,502
2005	69.9	121,180
2006	70.6	122,339
2007	71.56	124,609
2008	72.14	127,743
2009	72.90	130,862
2010	73.50	136,991
2011	74.10	139,717

Source: [16][72][73][74][75][76][77][78][79]980][81][82][83][84][85][86]

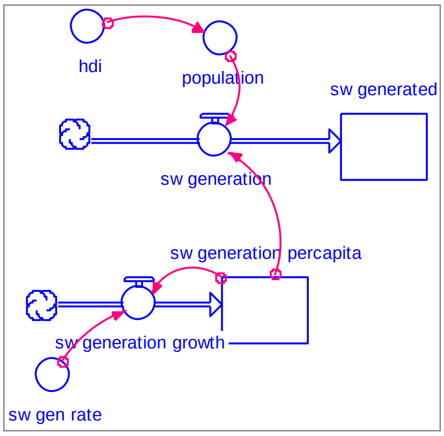

Fig. 1. System dynamics model for solid waste generation

total CH_4 emission. However, incinerator usage has generated not only CH_4 but also carbon dioxide (CO_2) as well as nitrous oxide (N_2O). And compared to CH_4 and N_2O, CO_2 emission has a more significant amount of greenhouse gases emission from incinerating activity [55].

And so the second strategy that consist of 5% recycling, 15% controlled landfilling, 37% sanitary landfilling and 7% composting has the lowest greenhouse gas emission among strategies examined in this study. Most of the CH_4 emitted in the second strategy was contributed from sanitary landfill and controlled landfill. Compared to the baseline strategy, the second strategy has 41.99% lower of CH_4 emitted from 2010 to 2018.

In order to incorporate uncertainty associated to uncontrolled factors, sensitivity analysis was performed to change in solid waste generation rate and population growth rate. World Bank [91] has projected that solid waste generation grow at a 0.919% rate per year until 2025. Sensitivity analysis was then carried out for solid waste

TABLE IX. BAUBAU POPULATION AND SOLID WASTE GENERATION PROJECTION

Year	Population (inhabitants)	Solid waste generated (kilograms)
2010	135.479	37.581.848
2011	138.687	38.825.286
2012	141.895	40.088.405
2013	145.103	41.371.461
2014	148.311	42.674.713
2015	151.519	43.998.426
2016	154.727	45.342.864
2017	157.935	46.708.296
2018	161.142	48.094.996

TABLE X. SOLID WASTE MANAGEMENT STRATEGY IN INDONESIA

To disposal site	To incinerator/ open burning facility	To composting plant	To other disposal methods	Source
(%)				
70	2	15	13	[87]
80	5	10	5	[55]
69	4.8	7.15	19.05	[88]
68.86	6.59	7.19	17.36	[89]

TABLE XI. INDONESIA SOLID WASTE COMPOSITION

Paper	Textiles	Food wastes	Wood	Garden and park wastes	Other wastes	Source
(%)						
12.9	2.7	43.5	9.9	n/a	31.0	[55]
9.0	2.0	58.0	4.0	n/a	27.0	[88]
11.0	n/a	63.0	n/a	n/a	26.0	[90]

TABLE XII. SOLID WASTE MANAGEMENT STRATEGIES IN THIS STUDY

Strategy	Recycl-ing	Control-led landfill	Sanitary landfill	Compost-ing	Incinerat-ing
	(%)				
S0	2	58	0	4	0
S1	2	30	28	4	0
S2	5	15	37	7	0
S3	2	27	28	4	3
S4	5	14	33	7	5

growth rate of 2.29% per year and the result is depicted in Fig. 3. Based upon analysis, it was found that an adjustment of CH_4 emission has occurred, but it did not change solid waste management strategy orderly. Similar result has also taken place if population growth was set to 2.5% per year (Fig. 4) and 1.42% per year (Fig. 5) respectively.

V. DISCUSSION

Based on stakeholder assessment to four contributed factors in solid waste management decision making, environment and social factors combined has contributed 79.4% out of 100%. This was quite similar with [20] study in Jakarta, Indonesia which both factors has 79.8% combined contribution. However, in [20] social factor (53.8%) has significant difference with environment factor (26%) while in this study environment (48.19%) was relatively important compared to social factor (31.21%). This may be due to social conflict caused by solid waste management practice relatively low in Baubau than Jakarta.

Investigation of stakeholder preference to solid waste management strategies in Baubau has showed that strategy 4 and 6 has a very narrow disparity. This situation regularly occurs in AHP analysis (for example see [24]) and requires further analysis for making more convincing decision. From stakeholder preference analysis, it was found also that stakeholder has preferred to use sanitary landfilling and incineration treatment method for solid waste management strategy.

Delphi method in this study was utilized in pairwise comparison process for AHP in order to foster an agreement among stakeholder and avoid final decision be made from aggregation of each individual decision. Integration of Delphi method to AHP in this study was significantly different with [56], [92], and [93]. Instead of using Delphi method in determining criteria or factor, this study employed Delphi method in pairwise comparison process. This study also showed that by integrating Delphi method in such way has made MCDA method particularly AHP able to be used for collaborative decision making. And final decision made was not only taken from compilation of individual result but actually came from a consensus.

Evaluation of CH_4 emission has showed that compared to controlled landfill, sanitary landfill has lower CH_4 emission. Among all solid waste treatment method, separation and recycling as well as composting has the lowest CH_4 emission; however these treatments utilization was limited and then avoid it to be the main components in solid waste management strategy.

Trade off among options in solid waste management strategy should be carefully considered during solid waste management facility planning. This information will be important for a facility planner in order to decide, for example to compare sanitary landfill additional capacity with financial required and its CH_4 emission yielded.

Trade off analysis has shown that municipal government should put development priority for separation and recycling facility. 1% of solid waste diversion from controlled landfill to separation and recycling treatment could reduce 490 tonne of CH_4 emitted during 2010 – 2018. Municipal government should also pay more attention for composting treatment. 1% of solid waste diverted from controlled landfill to composting facility could reduce 470 tonne of CH_4 emitted for the same period.

VI. CONCLUSION

This paper has presented a dynamic delphi multi criteria based analysis for solid waste management in Baubau municipality. Based upon analysis it was found that factor relative importance for solid waste decision making in Baubau was environment (48.19%), social (31.21%), economy (14.42%) and technology (6.18%) consecutively. Solid waste management strategy that consists of treatment in

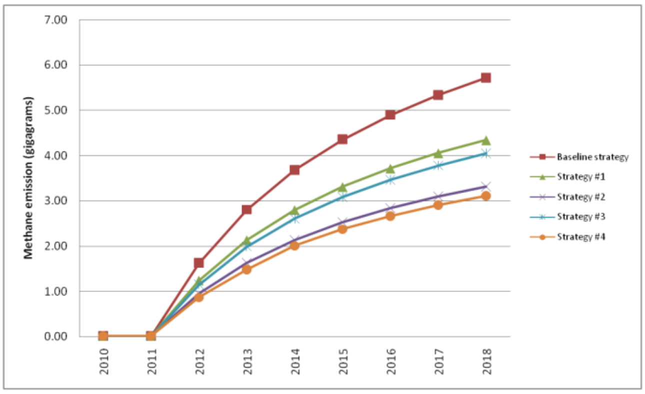

Fig. 2. CH_4 emission trend between strategies

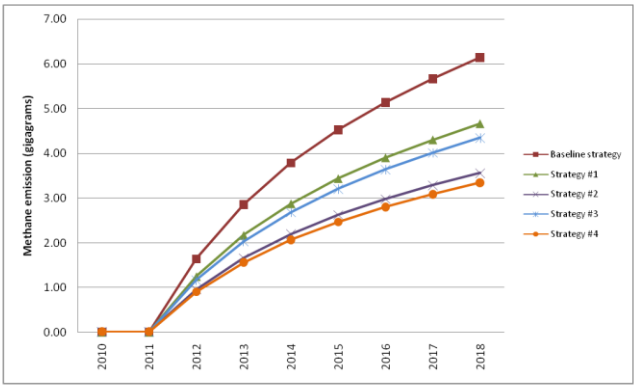

Fig. 3. CH_4 emission trend between strategies with change in solid waste generation rate

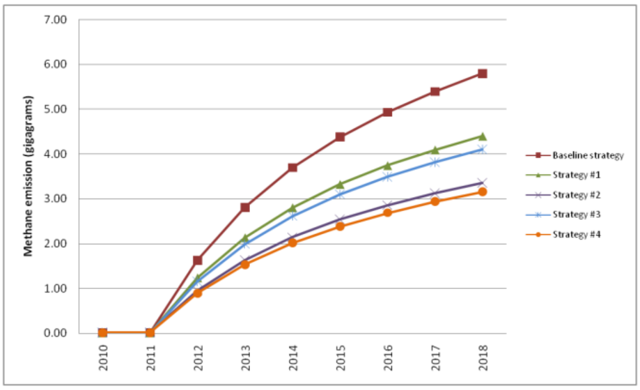

Fig. 4. CH_4 emission trend between strategies with change in high population growth rate

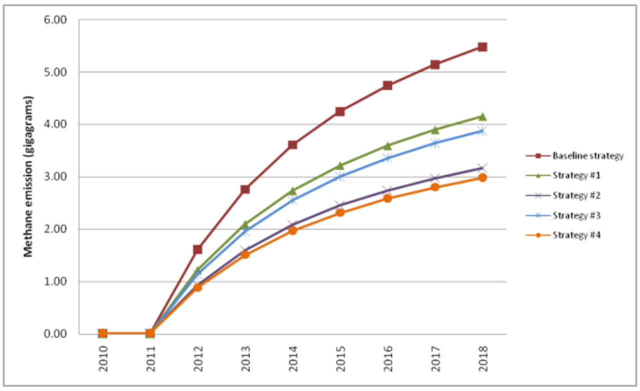

Fig. 5. CH_4 emission trend between strategies with change in low population growth rate

separation and recycling facility, controlled landfill, sanitary landfill and composting facility was most preferred by stakeholders. And a combination of 5% recycling, 15% sanitary landfilling, 37% sanitary landfilling and 7% composting has CH_4 emission 41.99% lower compared to current strategy in Baubau for year 2010 – 2018.

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