Thai Environmental Engineering Journal Vol. 35 No. 2 (2021) : 81-91
www.eeat.or.th

Evaluation of Alternative Municipal Solid Waste Management Option Towards Circular Economy and Smart City Model

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Abstract

The increasing urbanization is a great challenge for city development and management. One major problem is the rising amount of municipal solid waste due to food product demand and other living essentials. One of the Circular Economic's concepts is keeping products and material in use, so adding a sorting list and extracting more items can reduce waste before ending up at the landfill. Therefore, to understand a variety of characteristics and composition of waste for proper waste management. This research main identifies waste composition and develops the material flow diagram of integrated municipal solid waste by applying the alternative model towards Circular economics. Chiang Mai University had been selected as a study area and represented the Smart City model. The generated waste averaged 10.2 Ton per day of area 2,493 rai and 144 grams per day per person. The waste composition is organics, plastic, paper, general, metal, glass, and hazardous waste as ratio 59:15:12:10:2:1:1, respectively. Applying the integrated material flow diagram shows the overall base case and offers two alternatives for waste management. Although the increasing capacity of IBMC is a practical solution that causes sorting and separating by machine as increasing recycling rate 14.5%. And the implementation of circular practice is prompt as increasing recycling rate 7.2%. The benefit of the model and alternative demonstration of waste management based on Ching Mai university can also be applied to work with various organizations, communities, and cities.

Keywords : municipal solid waste; circular economy; zero waste; smart city; mass flow analysis

Introduction

The increasing urbanization is a great challenge for city development and management. One major problem is the rising amount of municipal solid waste due to food product demand and other living essentials. The overflowing garbage is also a significant problem that has been chronic for the long term in Thailand. However, all sectors have worked earnestly to solve the problem after the government declared that waste management is a national agenda. In 2020, municipal solid waste generated approximately 27.35 million tons (4% decrease from 2019), 11.93 million tons with sorted at sources and utilized (5% decrease from 2019), sanitary disposed of 11.19 million tons (41% of generated), and approximately 4.23 million tons is unsanitary disposal [1]. As one of the Circular Economy's concepts [2] is keeping products and material in use. Adding a sorting list and extract more items from the garbage bin can reduce waste before ending up at the landfill. Therefore, to understand a variety of characteristic and composition of waste for proper waste management, in this research work is the object to 1) identifying waste characteristic and composition 2) developing the Material Flow Analysis of integrated municipal solid waste 3) Applying the alternative model base on the Circular Economy concept [3]. This research selected Chiang Mai University as represented by the Smart City model since the season that the university won "the National Master Plan Development Model and Smart City Design Project" contest by the Thai Green Building Institute [4]. The university set up the Integrated Biomass Management Center-IBMC to handle over by separating and transforming 20-30 tons of solid waste per day into renewable energy with a "Zero Waste" aim [5]. The main in this study is collected waste composition and demonstrated on the diagram with alternative towards Circular Economy. The result of the model and alternative waste management based on Ching Mai University can also be applied to work with various organizations, communities, and cities.

Methodology

The research procedure is five steps as: and the following steps.

1. Defining the system and boundary of municipal solid waste management.
2. Collecting data from the composition of municipal solid waste according to the activities of each source in the university and interview experts by linear snowball sampling technique.
3. Analyzing and developing Material Flow Analysis of integrated municipal solid waste of current situation with the Sankey Diagram.
4. Developing the alternative scenarios of management models based on the Circular Economy.
5. Applying alternative scenarios with the Material Flow Analysis model.

Study Area

The boundary of the study area is determined from material flows of the municipal waste generated sources, transferring, storage, and disposal. There are 4 mains area whereas are currently responsible by the Integrated Biomass Management Center (IBMC)'s waste management system. and as following; 1) Suan Sak campus is home to most faculties and the first-year dormitory, it is approximately 1,488 rai, with have 23 mains waste stations. 2) Mae Hia campus (1,293 rai), the faculty of Veterinary medicine, Agro-industry and research and training centers. 3) Suthep District Municipality passed on only organic waste from Suthep market and restaurants. 4) The Chiang Mai Municipality’s

transfer station located at Hai-Ya district where is gathered the daily municipal waste from the city before unloading to landfill. Figure 1 shows the layout of the study boundary.

Collecting Data

1. The compositing waste was collected from twenty-eight sources. (twenty-three sources from Suan Sak campus, three sources from Mae-Hia campus, and two sources from the Suthep sub-district municipality). The collecting durations are four periods, six days in a period, and conducted on semester 1/2019 and semester 2/2019. The municipal solid waste composition defines into six main categories as organics, hazard, paper, metal, glass, plastic, and general waste, and the 28 sub-categories are deveined.

2. The recyclable waste (paper, metal, plastic) of dormitories data was collected from May 2019- December 2020.

3. The recyclable waste ratio of faculties was collected from February - March 2021.

4. The waste loading and utilize products of the Integrated Biomass Management Center-IBMC were collected from August 2020 – March 2021, one hundred and sixty-one days of operating records.

Expert Opinion and Interview

The expert opinion method is conducted on 1-30 March 2021 by Linear Snowball Sampling: The formation of a sample group starts with Suan Sak municipal solid waste flow by providing amount, categories, and process information about to interview with the manager of the Integrated Biomass Management Center. The method asked for the next connecting subject to another and one referral. And then, the chain continues with only one referral from one subject until the loop is closed.

In this study, there are five referrals and one initiative, as shown in Figure 2.

Sankey Diagram

In this study, the Material Flow Analysis is expressed by the Sankey Diagram. The Sankey Diagram is consisted with 2 parts as “Node” a process to access or distribute a set of quantity of municipal waste, and “Links” is connected volume of municipal waste that is related to each Node by the width of arrow is a proportional of the flow volume. This study uses computer software as E! Sankey which is developed by ifu Institut für Umweltinformatik, Hamburg GmbH [6]

Results and Discussions

1. The municipal solid waste loads and composition from each source

The municipal solid waste record was loading into the Integrated Biomass Management Center's process and averages 10.2 Ton per day (6.2:2:2 from Suan Sak campus, Mea Hia campus, Suthep Municipality). The data was collected from August 2020 – March 2021. The data showed the ratio of waste from each source. The CMU Canteen had maximum waste loading into the disposal process. The data collected from eight groups. (2 sources from Mae Hia, 4 sources from Suan Sak campus, and 2 from Suthep sub-district municipality sources) as shown in Figure 3.

Moreover, the waste loading trend was slightly upward and downward, as shown in Figure 4. The maximum loading was in September 2020, as in the full operating of the university. Figure 5 shows the municipal solid waste distribution and waste generating ratio with several residents of each source in the Suan Sak campus. The total waste generating average was 144 g per day per person, as the Figure 5.

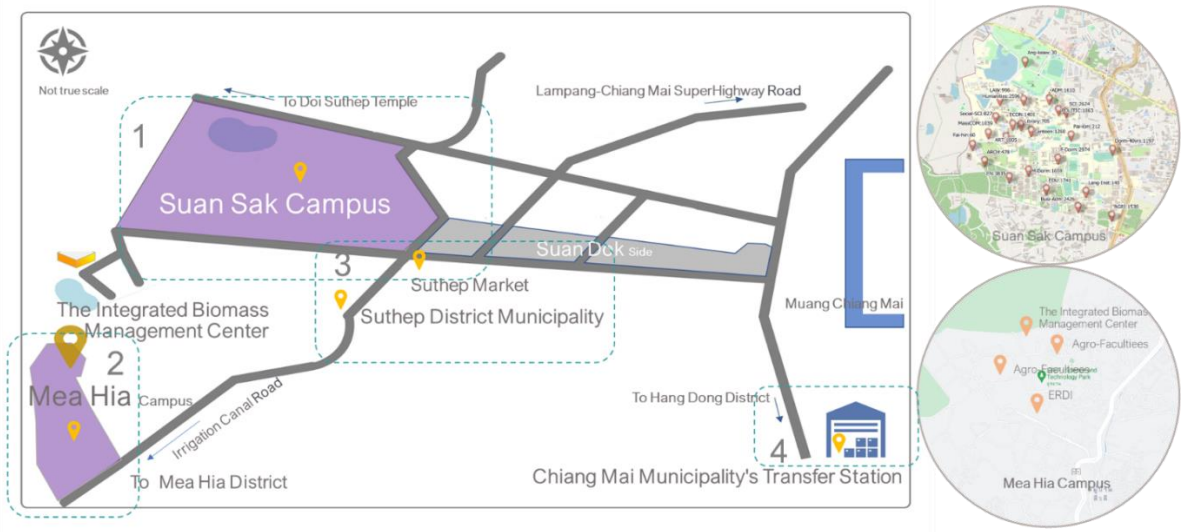


Figure 1 The Location of Gathering Municipal Solid Waste Station, Chiang Mai Municipality's Transfer Station, and the Integrated Biomass Management Center-IBMC

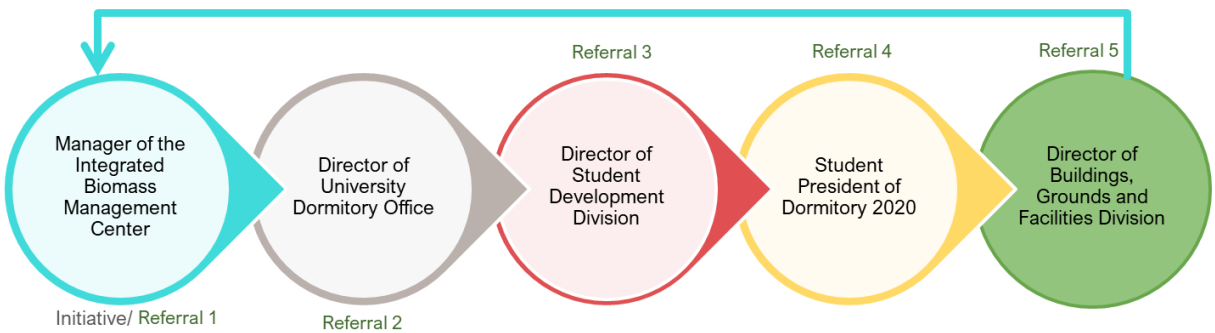


Figure 2 Interviewing Expert Opinions

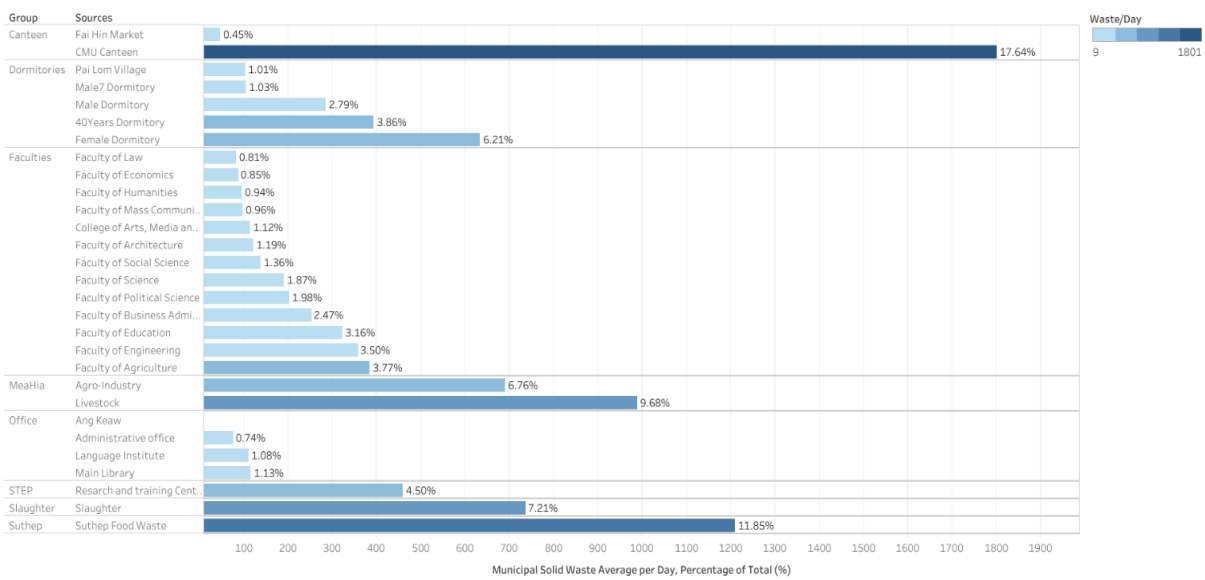


Figure 3 The Ratio of Municipal Solid Waste, Percentage by Sources

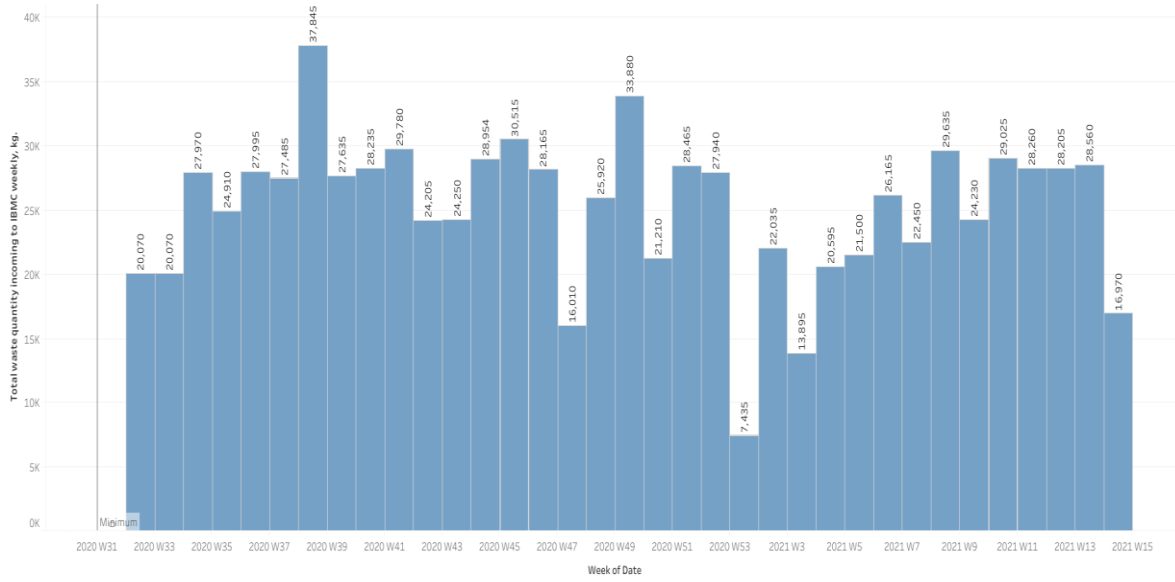
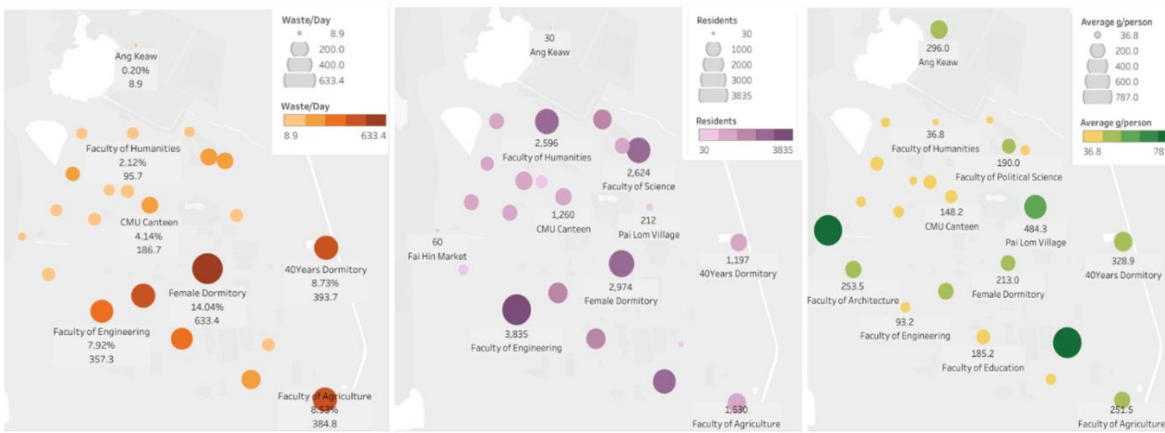


Figure 4 Total Weekly Municipal Solid Waste Quantity incoming to IBMC, kg



Rank	Source	Waste/Day, kg
1	Female Dormitory	633.4
2	40Years Dormitory	393.7
3	Male Dormitory	390.3
4	Faculty of Agriculture	384.8
5	Faculty of Engineering	357.3
6	Faculty of Education	322.5
7	Faculty of Business Administration	252.3
8	Faculty of Political Science	202.0
9	Faculty of Science	190.8
10	CMU Canteen	186.7

Rank	Source	Resident, person
1	Faculty of Engineering	3835
2	Female Dormitory	2974
3	Faculty of Science	2624
4	Faculty of Humanities	2596
5	Faculty of Business Administration?	2426
6	Faculty of Education	1741
7	Male Dormitory	1659
8	Administrative office	1610
9	Faculty of Agriculture	1530
10	Faculty of Economics	1401

Rank	Source	Waste/day/person, gram
1	Language Institute	787.0
2	Fai Hin Market	773.7
3	Pai Lom Village	484.3
4	40Years Dormitory	328.9
5	Ang Keaw	296.0
6	Faculty of Architecture	253.5
7	Faculty of Agriculture	251.5
8	Male Dormitory	235.2
9	Female Dormitory	213.0
10	Faculty of Political Science	190.0

Figure 5 Municipal Solid Waste Amount per Day in Suan Sak Campus

By the Figure 5, although the female dormitory was the maximum waste generating source, 633.4 kg per day when the calculation with several residents in these areas found the generating waste of each resident was only 213 gram per person per day. The composition of municipal solid waste is conducting in this result, as shown in Figure 6. The study showed a

composition of from 9 sources. (3 sources from Mae Hia campus, four sources from Suan Sak campus, and two from Suthep sub-district municipality sources). The main waste category is organics, plastic, paper, general, metal, glass, and hazardous waste as 59.1%, 14.9%, 12.5%, 9.6%, 2.3%, 1.1%, and 0.6% of total municipal solid waste, respectively.

2. The Material Flow Analysis of integrated municipal solid waste

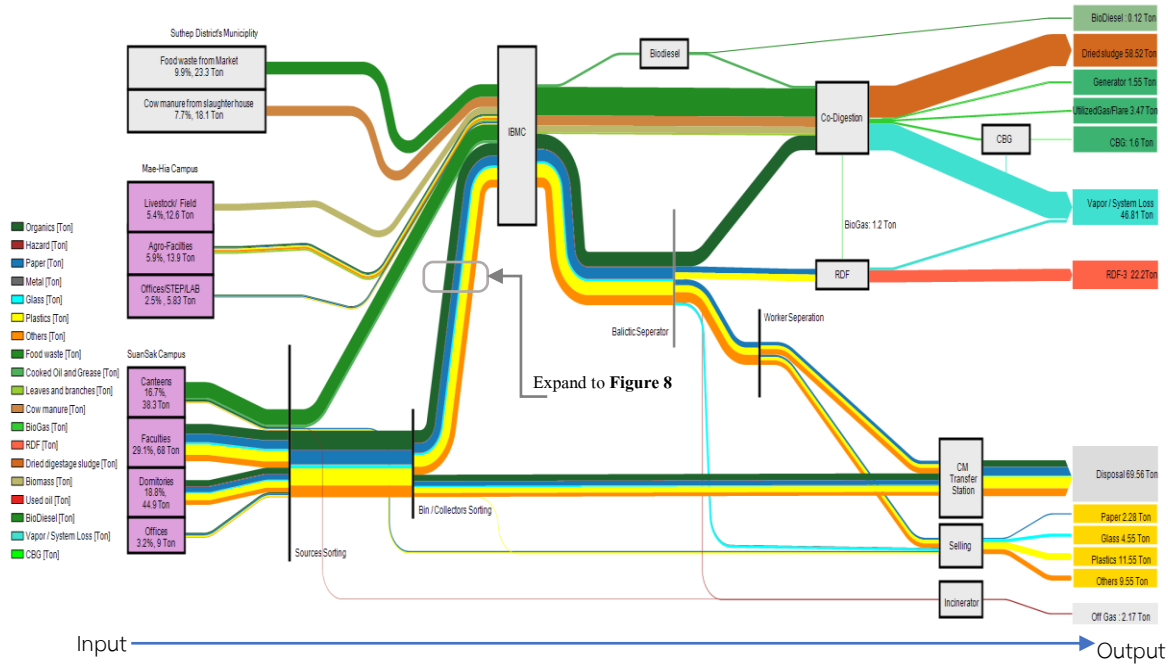
The Material Flow Analysis of integrated municipal solid waste showed in Figure 7. The waste flow started from each sorting source with two buckets - separating garbage bin as general waste (blue bin) and recyclable waste (yellow bin). From the survey and interview, the housekeeper has responsibility for sorting, collecting, and cleaning. From 15 housekeepers of 6 buildings is found that 87 percent of housekeepers sorted recyclable waste for selling. Usually, the garbage is in the general waste, and the housekeepers do not hesitate to sort it because some buildings have limit working times and no place to restore it. After that, the housekeepers transfer the unsalable waste to the waste gathering station. The red plastic bag is for hazardous waste, and the black plastic bag for disposal waste. Chiang Mai Municipality services garbage trucks into two routes. Route-1 collects the municipal solid waste from the waste gathering station to the Integrated Biomass Management Center-IBMC, and Route-2 transfers the disposal waste to Chiang Mai Transfer Station.

The Integrated Biomass Management Center-IBMC integrated two sections to achieve sustainable waste management. First, waste separation technology starts from receiving municipal solid waste - Receiving & Storage unit. And then, the waste inputs through the belt conveyer – Belt Conveyer unit. After that, the worker shreds the garbage bag to separate reusable waste such as glass bottles, plastic bottles, and some toxic waste as batteries from the conveyor belt. Then, the waste is transferred into the Primary Separator & Magnetic Separator unit for preliminary separating. This system deals with separating organic waste, plastic waste, and metal waste with a preliminary waste sorting system.

For producing renewable energy, Inorganic waste (such as plastic bag scraps, papers - 78.64 Tons/month) is used to produce refuse-derived fuel: RDF and used in a method for producing asphalt (16.38 Tons/month). Furthermore, the second technology is co-digestion Biogas (CMU Hybrid) and Dry Fermentation technology. The organic waste (such as food waste, vegetable waste, animal waste-118.6 Tons/month) inputs the dry aerobic digestion to produce Biogas. Moreover, the next step is the compressed biomethane gas (CBG) producing process. Biogas uses as renewable energy for generators and RDF - dryer. CBG (1.6 Tons/month) uses as renewable energy for the university's public transportation system. For grease residue and fat uses as biodiesel for the transfer of food waste trucks. The system also gains the utilization of Bio-Sludge to produce soil conditioner (58.5Tons/month).

The Figure 8 shows the expansion of material flow by 28 categories.

Figure 6 Composition of Municipal Solid Waste, %



Note; *IBMC: The Integrated Biomass Management Center*

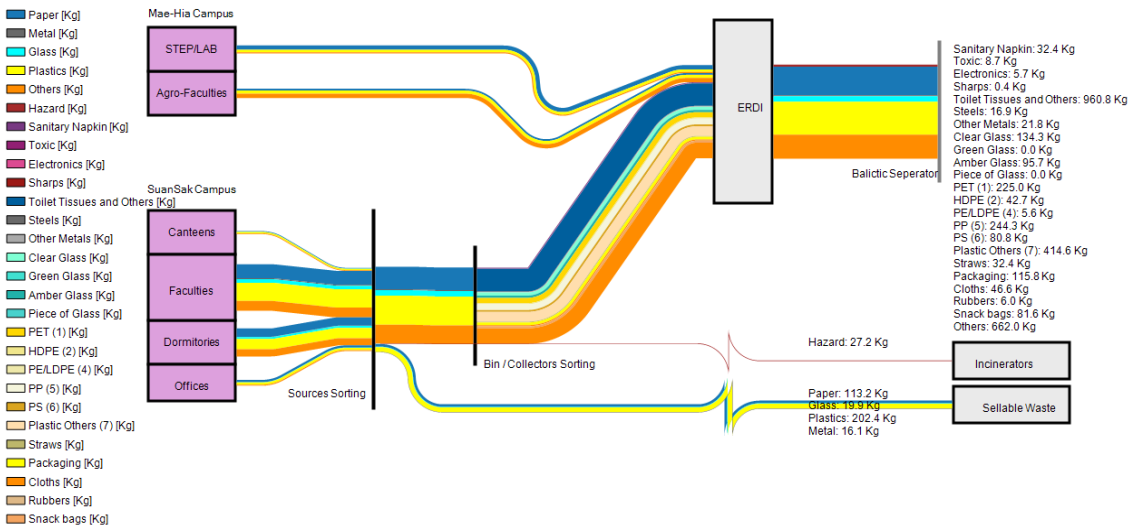
Co-Digestion: Co-digestion Biogas (CMU Hybrid) and Dry Fermentation technology

RDF: refuse-derived fuel produce process

CBG: compressed biomethane gas produce process

CM Transfer Station: Chiang Mai Chiang Mai municipality's Waste Transfer station at Hai Ya district

Figure 7 Material Flow Analysis of Municipal Solid Waste-Base Case, Ton/Month



Note: In this figure shows only inorganics materials, and recyclable paper is existed.

Figure 8 The Material Flow Analysis of Municipal Solid Waste-Base Case, Ton/Month

3. The alternative 1: Increasing of IBMC working capacity.

According to working day record in this research found that the IBMC worked 161 days from in 8 months (August 2020-March 2021). There are caused by weekend and holiday and had to inevitable shut down for system maintenance. IBMC's manager informed that the IBMC plans to adjust the working time from 20 days per month to 25 days per month, will be start the mid of 2021. However, this plan is still in the feasibility study status and still have the human resources and operating schedule problems. If this plan is approved and gains sufficient workers, the working capacity increases 24 percentage. So, by this planning information, will be the possible activity to increasing operating time and able to collect all the municipal solid waste from Suan Sak campus. In this research set up as the alternative 1: Increasing of IBMC working capacity.

The assumption is the municipal solid waste from Suan Sak campus will transfer to the IBMC and disposed of from 81 Ton per month to 120 Ton per month. The advantage result of alternative-1 is the capacity of preliminary separating of the Primary Separator & Magnetic Separator Unit-Ballistic separating. The assumption of this alternative will increase the sellable waste amount (especially metal and glass, 100% calculated from on the base case) from 27.9 Ton per month to 41.2 Ton per month. And RDF-3 production is 31.4 Ton, increasing 91% of Base case. Figure 9 shows an alternative to the Material Flow Analysis of integrated municipal solid waste by increasing working capacity.

4. The alternative 2: Enhance waste source separation and circular practice.

All interviewees agree that garbage sorting at source and plastic refusing are reasonable alternatives to reduce disposal waste. Chiang Mai University is continually launching campaigns and taking action to educate and raising awareness, such as "Waste Bank," "Chang Chang Cut," "Green Office," and "Thing at One Point (event's activity policy)." These projects are successful and still active. However, all previous projects are unfocused on the unsellable waste but are able to reuse, refurbish and repair. This alternative suggests three more circular practice destinations that receive non-sellable waste to recycle,

reuse, refurbish and repair. As the alternative 2: Enhance waste source separation and circular practice.

First, "Green Roof" is organized by Friend in Need (of "PA") that receives UHT milk carton for roof production [7]. Second, "Won" is organized

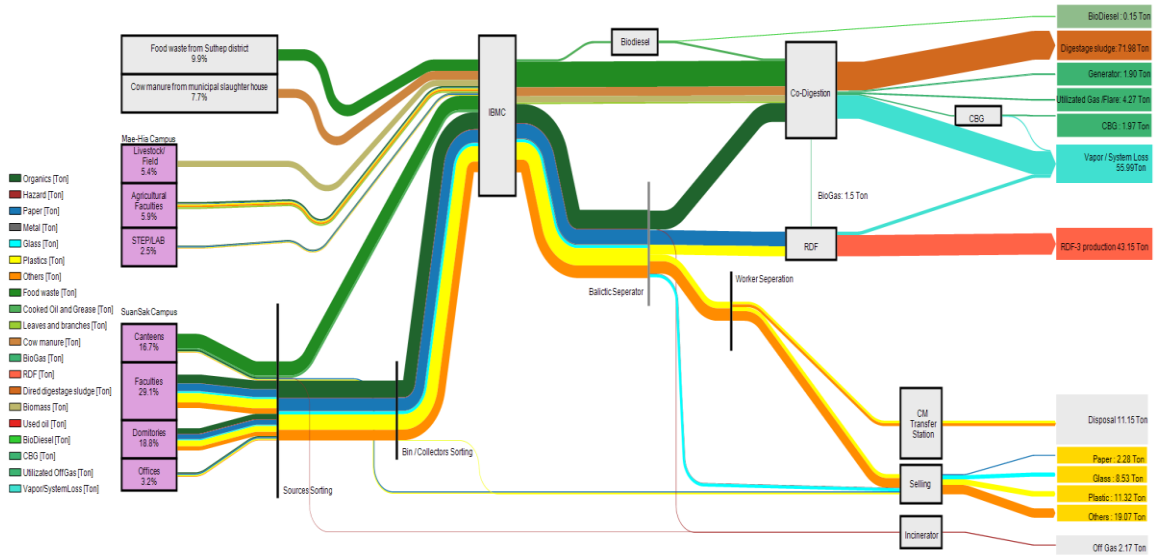


Figure 9 The Alternative 1: Increasing of IBMC working capacity, Ton/Month

by TPBI Public Company Limited that receives stretchy plastic (PE) that clean and dry. Examples of stretchy plastic are t-shirt bags, shopping bags, ice bags, shrink film (cover of bottled water or UHT beverage containers), bubble film, bread bags, sugar bags, fruit bags, mailing bags, zip-lock bags. For every 1 kilogram of plastic that "Won" received, TPBI Public Company Limited will convert such into 5 Thai Baht for donation to well-established Environment Foundations [8]. Furthermore, the last recommend destination is "Precious Plastic Bangkok," which operates as an independent, not-for-profit organization, a part of Precious Plastic's organizations worldwide, founded in 2018. This community base received plastic for an upcycling solution that uses simple-to-build machines to turn plastic waste into new products. The type of plastic that accepts donations is plastic bottle caps (HDPE2), plastic glass, and convenience store food containers (PP5) [9].

Moreover, the University Dormitory Office secretary suggested a smartphone application for senior students who want to donate or sell secondhand stuff to junior students, especially electricity equipment, clothes, shoes. Every end of the semester, the dormitory had a problem with this type of waste that is abandoned and difficult to manage.

The assumption of the alternative 2 by enhancing waste source separation and circular practice is increasing the sorting and separation of unsellable waste with 50 percentage of receiving types. As the result of this scenario shows a circularity amount of 14.1 Ton/month. Figure 10 shows an alternative to the Material Flow Analysis of integrated municipal solid waste by enhancing waste source separation and circular practice.

As the Material Flow Analysis performed, the evaluation of alternatives shows in Table 1.

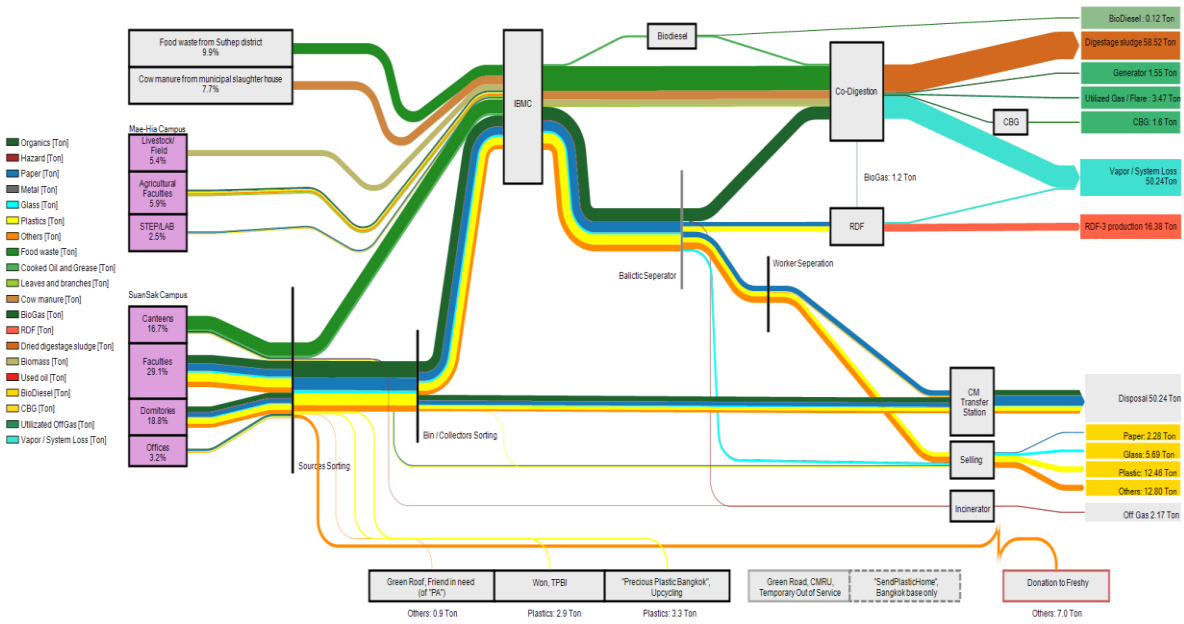


Figure 10 The alternative 2: Enhance Waste Source Separation and Circular Practice, Ton/Month

Table 1 The evaluation of waste input, recycling, circularity and utilized effective rate

Out Put, Ton/Month	Base Case	Alternative-1	Alternative-2
Energy	8.00	8.00	8.00
Soil Conditioner	58.50	58.50	58.50
RDF	22.20	31.38	16.38
Recyclable	28.70	41.10	47.40
Utilized Total, Ton/month	117.40	138.98	130.28
Disposal, Ton/month	70.0	11.2	50.2
Utilized Effective Rate, %	50.2%	59.4%	55.7%
Disposal Reduced Rate, %	-	84.0%	28.3%

Discussion

From the disposal reduced rate, the alternative 1 (-84%) is better than alternative 2 (-28%) because the sorting and separating process by the mechanical system is productive. However, the increase of capacity of human resources and working times need more steps to proceed. Thus, alternative 2 can be the better choice to prompt action. Although the disposal reduced rate is lower than alternative-1 and only one person unable to succeed, at least this action affects the valuable resources. This study found that the material flow of integrated municipal solid waste and waste composition of source allows us to extract valuable and usable materials and can be traced back to the origin to unified management. Although the calculation as shown in the diagram is still excessively to be Zero Waste, understanding the composition and

volume of each material will be able to plan and effectively analyze solutions.

Conclusion

In conclusion, the characteristics and composition of each waste source are not the same. Therefore, the type and quantity understanding are necessary to identify each source. The integrated municipal solid waste management must overview the process from the cradle to the grave to be adequately defined and planned for the community scale. This study finds the waste composition and exposes it by developing a material flow diagram. Using the Chiang Mai University model, this study showed the Smart City's waste management performance and suggested two practical alternatives. The results showed that increasing the capacity of IBMC can be effective in stepping up to Zero Waste. Furthermore, the outcome from this study gains the model can be applied to pilot with another community or expand the scale to the municipality later.

However, there are many alternatives that can be applied as smart city scenarios. Whether the use of IOT to help manage waste separation, the packaging reusing and return activity or the plan route for garbage truck. All more alternatives are the possible way to manage municipal solid waste with investment. The alternative 2: Enhance waste source separation and circular practice are promptly act and low cost.

Acknowledgement

Thidarat Kridakorn Na Ayutthaya has received the TA/RA Scholarship from Graduate School, Chiang Mai University.

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