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Research Article

Analysis on Waste to Energy Potential of Padang Municipal Solid Waste for Sustainable Future

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Abstract

Reduce, reuse, recycle (3R), and recovery are types of waste processing regulated in Law No. 18 of 2008. One form of recovery is Waste to Energy (WtE) which is one of the national development priorities. Currently, the implementation of 3R is less than 5% and it has not been implemented at all in Padang City. Therefore, this current research studies the WtE potential of Padang municipal solid waste. The research was conducted by collecting data on the population of Padang City, the generation, composition, and recycling potential of Padang City waste, and the calorific value of each waste composition. This research applies thermal incineration technology with three variations of scenarios. Scenario #1 is a WtE application with 3R based on existing conditions, scenario #2 is a WtE application with 3R based on government targets, and scenario #3 is a WtE application with 3R based on the results of the questionnaire. Scenario #2 is the best one because it considers the WtE idea and community-based 3R recycling in line and continues for better waste management in Padang City. The scenario may produce 394.23 MW of electricity that can serve around 1,329 houses, while also improving the 3R rate of around 1.98% per year.

Keywords: Electrical energy; incineration technology; municipal waste; waste generation; waste to energy

1. Introduction

It predicted that Air Dingin Landfill would be fulling in capacity in the next three years (Audina et al., 2018). This condition will seriously endanger the environment and residents around the landfill location. The application of reduction, reuse, recycling, recovery, and sanitary landfilling is required for the proper and sustainable waste processing solution. The waste to Energy (WtE) concept is a reasonable option for the recovery process for sustainable waste management (Hermawan, 2017).

Although WtE is one of the national priorities in the renewable energy program, the existing conditions in 2019 suggest that the achievement of 3R is only less than 5%, while it has not been implemented at all in Padang City (Raharjo et al., 2017). Previous research suggested that energy of 83,179.35 MWh/year may be produced from municipal solid waste in Indonesia by using thermal technology (Utomo and Hariningrum, 2020). Thermal conversion technology is proven and widely used in various countries, environmentally friendly, economical, suitable for the types and conditions of waste in Indonesia, and has the potential for a high Domestic Component Level (Winanti, 2018).

Power Plant from Municipal Waste is a National Strategic Project in Indonesia (Pemerintah Pusat, 2018). There are 12 provinces or cities selected as locations for the power plant from municipal waste project development. Padang City is not included in the project even though the waste generation of Padang City is higher than some of the selected cities. Currently, some studies examine the processing of waste into energy as Refuse Derived Fuel (RDF) (Rina, 2021) and briquettes (Sawir, 2016). But the researchers did not discuss the energy potential on a city scale. Therefore, the current study examines the existing management of municipal solid waste and evaluates Padang City's energy potential.

2. Methods

The literature review was studied from updated references related to the current study. Questionnaires, desk reviews, and observations were carried out to evaluate the current municipal solid waste management in Padang City. The current research calculates electrical energy generated from a 10-year projection of municipal solid waste (2020-2030) in Padang City. Questionnaires were distributed online through social media because of the ongoing pandemic conditions. There are two types, questionnaires for the public and questionnaires for the City Environmental Office of Padang City. Community respondents were divided into four groups based on their location so that the questionnaire is more representative (Raharjo and Utomo, 2021), the location is the western region (people who live in Pauh District), the eastern region (people who live in South Padang, Lubuk Begalung, Lubuk Kilangan, and Bungus Teluk Kabung District), the southern region (people who live in West Padang, East Padang, North Padang, Nanggalo, and Kuranji District), and the North region (people who live in Koto Tengah District). According to Roscoe, the number of sample members for each category is at least 30 (Sugiyono, 2016). Therefore, the number of community respondents in this study is 120 respondents. The collected information from respondents will be used for evaluating the local government policies as well as opinions, views, and knowledge of the local community regarding WtE.

The Secondary data were collected from related agencies and other relevant sources such as journals, previous final project reports, regulations, policies, planning documents, etc. Secondary data was used to calculate the potential for waste energy in Padang. Table 1 displays the secondary data required for this study.

Tabel 1 . Secondary data required

Data	Source
Total Population of Padang City	Padang City Statistical Data (Statistik, 2020)
Generation of Padang City Waste	Previous Research (Hafizh, 2016; Mursyida, 2017)
Composition of Padang City Waste	Previous Research (Hafizh, 2016; Mursyida, 2017)
Caloric Value of Each Waste Composition	Previous Research (Fernando, 2007; Kathirvale et al., 2004; Wiradarma, 2002)
Existing Condition of Waste Management in Padang City	Previous Research (Raharjo et al., 2013)
Incineration Efficiency	Previous Research (Wibowo, 2007)

The collected data is then analyzed and used as a reference in preparing the scenario. The current Municipal Solid Waste Management of Padang City were evaluated based on National Law No. 18 of 2008 and Presidential Regulation No. 97 of 2017 (Pemerintah Pusat, 2017). In this study, three scenarios were developed with a focus on the potential of WtE application with various 3R conditions. Each scenario consists of three stages over the 2020-2030 period. The best scenario is then selected based on the amount of energy generation. Furthermore, the calculations are carried out in several stages, namely:

- Calculation of the projected population of Padang City.
  The population of Padang City is projected in the period 2020-2030. There are four methods used in the calculation, namely arithmetic, logarithmic, exponential, and geometric methods (Soewarno, 1995).
- Calculation of waste generation
  The Padang City waste generation unit was collected from previous studies. The unit is assumed to be constant so that the projected waste generation is calculated by multiplying the generation unit with the number of residents each year in the projected years.
- Determination of percent unserved
  Based on the Regional Strategic Policy (Jakstrada), Padang City set its target of waste management service at least 80%. Therefore, percent unserved is assumed at 20%.
- Determination of the percentage of recycling (3R)
  Percentage of recycling (3R) includes the percentage of processing at some recycling facilities including TPST (Tempat Pengolahan Sampah Terpadu/Integrated Waste Processing Site), TPS 3R (Tempat Pengolahan Sampah 3R/Waste Processing Site - Reduce Reuse Recycle), Waste Bank, and informal sector. The percentage of each processing for the existing year is determined based on the results of research conducted by Raharjo, 2015. Meanwhile, the following years in this research period are determined based on scenarios.
- Waste to Energy percentage calculation
  WtE percentage is obtained by calculating the percentage of unserved waste that has not been processed and has not been recycled.
- Calculation of the percentage of waste dumped
  The percentage of waste that is not recycled and cannot be processed using Waste to Energy.
- Calculate the amount of energy
  The amount of energy produced depends on the level of efficiency of the tool. In the Incinerator, there are three main components with different efficiency levels, there are boilers, steam turbines, and generators. The steps for calculating the resulting energy are:
  Calculation of waste generation per composition that is processed by WtE (Wibowo, 2007):

WtE Generation per Composition = % WtE x Waste Generation (kg / day) (1)

Calculation of the total energy waste of Padang City :

Energy (kJ) = Calorific of waste (kJ / kg) x waste generation (kg) (2)

Convert kJ to kcal $= \frac{kJ}{4{,}184}$ (3)

Convert kcal to kWh = Amount of calorific (kcal) x 0.00116 (kWh / kcal) (4)

Convert kWh to kW = Energy (kWh) / 24 hours (5)

Calculation of the effect of tool efficiency:

Boiler Output Power = Energy (kW) x 80% (6)

Net Power (turbine output) = Boiler Output (kW) x 35% (7)

Generator Output Power= Net Power (kW) x 90% (8)

Net Output Electrical Power = Energy (kW) x 25.2% (9)

Calculation of the electric power generated per year = Power / day x 365 days

Convert kW to MW = kW / 1000 (10)

3. Result and Discussion

Questionnaires were distributed on 03-31 May 2020. 142 people and 1 representative of The City Environmental Office filled out the questionnaires. They show that more than 95% of respondents were answered correctly about waste, types of waste, problems that can be caused by waste, and how to handle waste, indicating the community has good knowledge. 99,3% of respondents stated that they are willing to support the processing of waste into energy. However, waste sorting habit is still a big concern since only 31,2% did the sorting at source. 25% and 2.1% of respondents admit that they still practice open burning and waste dumping into rivers, respectively. Table 2 presents data on the population of Padang City and waste generation for the next 10 years. Table 3 describes the composition of Padang city waste in 2016 (Hafizh, 2016).

Tabel 2. Generation of Padang City waste

Year	Population Projection	Waste Generation Unit (kg/o/h) (Hafizh, 2016)	Total Waste Generation (kg/day)
2020	966,968	0.269	260,114
2021	980,364		263,718
2022	993,760		267,321
2023	1,007,156		270,925
2024	1,020,552		274,528
2025	1,033,948		278,132
2026	1,047,344		281,736
2027	1,060,740		285,339
2028	1,074,136		288,943
2029	1,087,532		292,546
2030	1,100,928		296,150

Tabel 3. Composition of padang municipal solid waste

Waste Composition	Composition (% Total Weight) (Hafizh, 2016)
Food Waste	67.25
Paper	4.69
Plastic	16.17
Textiles	1.35
Skin	0.13
Rubber	0.34
Yard Junk	1.61
Wood	0.86
Total Organic	**92.50**
Glass	1.18
Metal	0.69
etc	5.64
Total Inorganic	**7.50**

Tabel 4. Estimated calorific value per composition of Padang City waste

Component	Calorific Value (kJ/kg gross weight) (Wiradarma, 2002)	Calorific Value (kJ/kg gross weight) (Fernando, 2007)	Calorific Value (kJ/kg gross weight) (Kathirvale et al., 2004)	Average (kJ/kg gross weight)
Food Waste	2,864	2,822	3,000	2,895
Paper	1,104	985	1,600	1,230
Plastic	2,077	2,093	2,324	2,165
Textile	-	3,589	2,900	3,244
Leather	585	578	-	582
Rubber	-	551	531	541
Page Trash	-	4,340	4,000	4,170
Wood	498	560	-	529
Glass	-	-	29	29
Metal	-	144	-	144
etc	1,435	-	1,100	1,268

Determination of the energy content of waste is required in the waste processing process, especially thermal processing. The energy content of waste is determined by the calorific value of each type of waste. There is no calorific value data of waste in Padang City, then the calculation of the average calorific value of several regions was used in this study. The estimated calorific value per composition of Padang City Waste can be seen in Table 4.

Around 75% of the waste generated in Padang City was transported and dumped to the Air Dingin Landfill without any prior processing in 2015. The city of Padang has 47 Waste Banks, 4 TPS 3R (TPS3R Darul Ulum, TPS 3R Koto Lalang, TPS 3R Kami Saiyo, and TPS 3R Ksm Jati Bergema) and 2 TPST (TPST DKP and TPST TPA Air Dingin). However, these processing facilities have not been able to increase waste recycling in the city (Raharjo et al., 2018). Mass balance of the current waste management in Padang City and its flowchart can be seen in Figure 1 (Ariska, 2021). It displays that around 30% of waste is not handled, while 68.417% of waste is dumped into the municipal landfill.

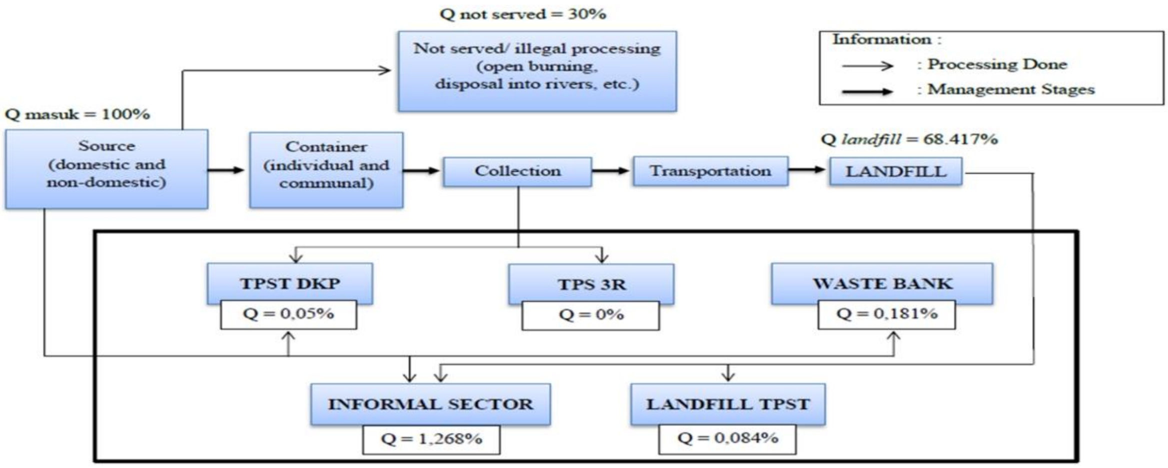

Figure 1. Mass balance flowchart of existing waste management in 2019

Based on the scenario preparation which focuses on the potential for WtE application with various of 3R conditions, the details of the designed scenarios along with the mass balance are explained below:

1. Scenario #1

   In the planning, scenario #1 will apply WtE with the 3R conditions according to the existing conditions, which are not experiencing an increase. This happens because the quantity of 3R does not increase while the quantity of generation always increases every year. So that in percentage the 3R that occurs will decrease, but in terms of quantity, the 3R condition is constant. This condition makes the percentage of WtE increase because when the quantity of waste that is processed in 3R is constant, the quantity of waste that can be processed by WtE will increase every year. The Mass Balance Flowchart for Waste Management Scenario #1 can be seen in Figure 2.

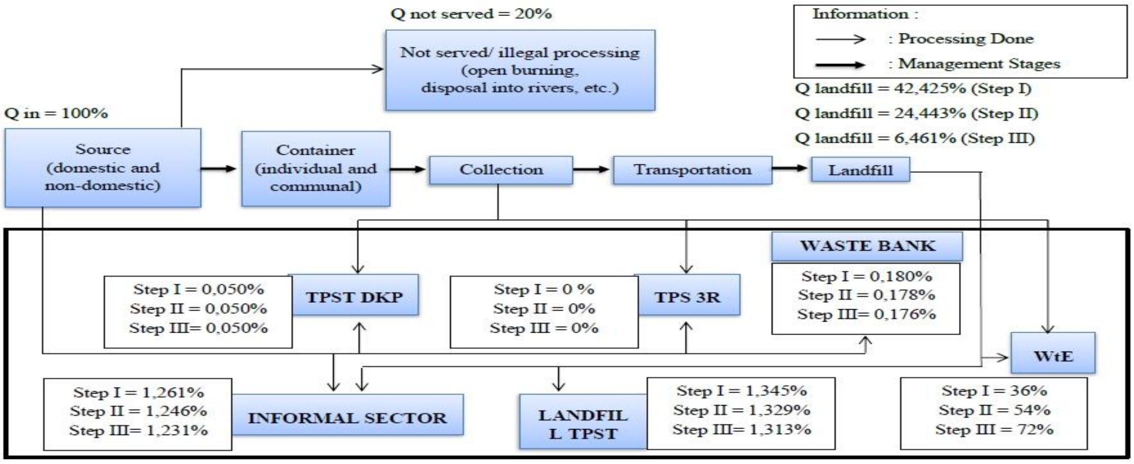

Figure 2. Mass balance flowchart of waste management scenario #1 (2020-2030)

Based on flowchart of the scenario above, there is a reduction in amount of waste dumped in landfill around 18% per stage, and an increase in amount of waste recycled to energy of around 18% per stage.

2. Scenario #2

Scenario #2 is prepared with 3R conditions according to government regulations. Based on the National Strategic Policy (Jakstranas), it is gradually targeted that 100% of waste can be processed based on the waste management hierarchy. The Padang City Government expects an increase in the 3R percentage to reach 30% and always increases. The increase in the percentage of 3R causes the percentage of WtE for stage II to be lower when compared to the percentage of WtE for stage I. The Mass Balance Flowchart for Waste Management Scenario I can be seen in Figure 3.

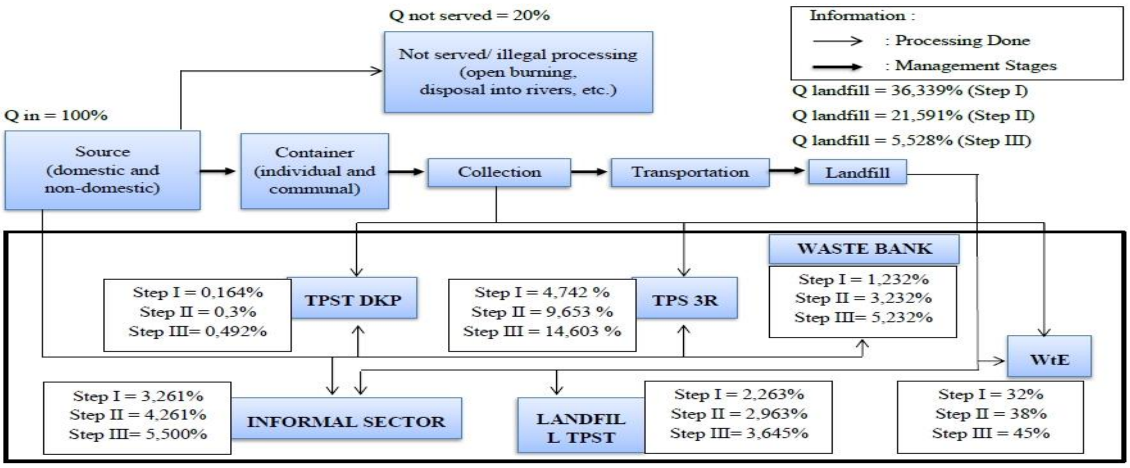

Figure 3. Mass balance flowchart of waste management scenario #2 (2020-2030)

Based on flowchart of the scenario above, there is a reduction in amount of waste dumped in landfill around 15% per stage, and an increase in amount of waste recycled to energy of around 6% per stage.

3. Scenario #3

This scenario was prepared by applying other conditions that might also occur if WtE was applied as seen from the results of the questionnaire. There is a tendency for people do not participate in waste management even though the community has good enough knowledge. It may lead to a decrease in the 3R percentage and a significant increase in WtE processing. The Mass Balance Flowchart for Waste Management Scenario #3 can be seen in Figure 4.

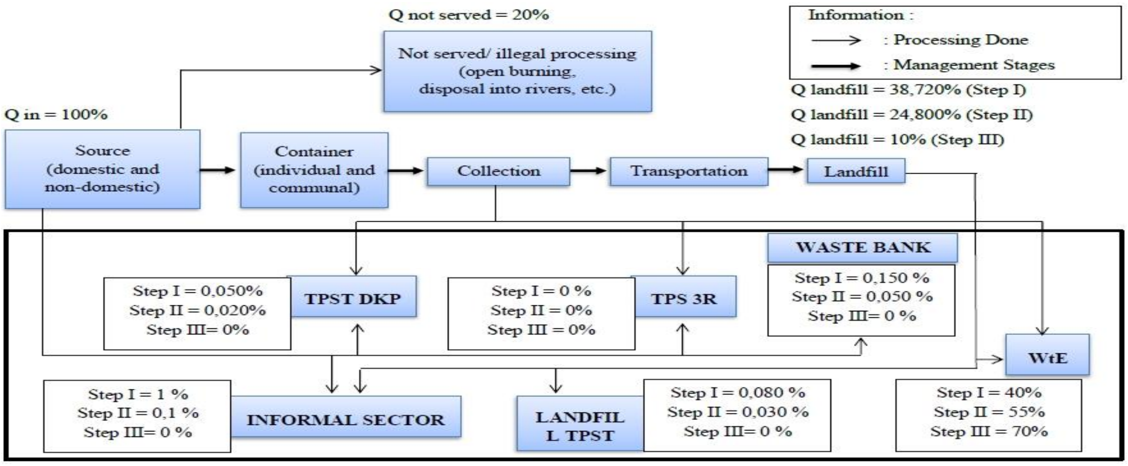

Figure 4. Mass balance flowchart of waste management scenario #3 (2020-2030)

Based on flowchart of the scenario above, there is a reduction in amount of waste dumped in landfill around 14% per stage, and an increase in amount of waste recycled to energy of around 15% per stage is obtained.

The three stages have the same level of service (80% of total waste generation), and applies WtE idea, resulting in a decrease in the percentage of waste dumped in landfill. The City applies two types of recycling including recycled waste selling and waste composting. In its implementation, 3R will be held in five sectors, namely TPST in City Environmental Office, TPS 3R, Waste Bank, TPST in landfill, and the Informal Sector. Table 5 describes the details of scenario #1, #2, #3, and the existing conditions.

Tabel 5. Scenarios

Type of Processing	2015	Existing (2019)	Type of Waste	Scenario #1	Scenario #2	Scenario #3
Waste Bank	0.182%	0.181%	Recyclable	0.180% (2020)	1.232% (2020)	0.150% (2020)
				0.178% (2025)	3.232% (2025)	0.050% (2025)
				0.176% (2030)	5.232% (2030)	0% (2030)
TPS 3R	0%	0%	Recyclable	0% (2020)	1.653% (2020)	0% (2020)
				0% (2025)	2.653% (2025)	0% (2025)
				0% (2030)	3.788 (2030)	0% (2030)
			Compostable	0% (2020)	3.089% (2020)	0% (2020)
				0% (2025)	7% (2025)	0% (2025)
				0% (2030)	10.815% (2030)	0% (2030)
TPST DKP	0.050%	0.05%	Recyclable	0.050% (2020)	0% (2020)	0% (2020)
				0.050% (2025)	0% (2025)	0% (2025)
				0.050% (2030)	0% (2030)	0% (2030)
			Compostable	0% (2020)	0.164% (2020)	0.050% (2020)
				0% (2025)	0.3% (2025)	0.020% (2025)
				0% (2030)	0.492% (2030)	0% (2030)

Type of Processing	2015	Existing (2019)	Type of Waste	Scenario #1	Scenario #2	Scenario #3
TPST TPA	0.085%	0.084%	Recyclable	0.084% (2020)	0.463% (2020)	0% (2020)
				0.083% (2025)	0.563% (2025)	0% (2025)
				0.082% (2030)	0.645% (2030)	0% (2030)
			Compostable	0% (2020)	1.8% (2020)	0.080% 2020)
				0% (2025)	2.4% (2025)	0.030% (2025)
				0% (2030)	3.0 % (2030)	0% (2030)
Informal Sector	1.276%	1.268%	Recyclable	1.261% (2020)	3.261% (2020)	1% (2020)
				1.246% (2025)	4.261% (2025)	0.1% (2025)
				1.231% (2030)	5.500% (2030)	0% (2030)
WtE	Without WtE	Without WtE	Aplication of WtE	Up to 72%	Up to 45%	Up to 70%

The service percentage of step/stage I, II, and III increased to 80%. The percentage of WtE is adjusted according to the calculation of the scenario results, while the percentage of waste dumped to landfill is the percentage of serviced waste that has not undergone processing. In scenario #1, there is a decrease in 3R by 0.004% per year, an increase in WtE by 4% per year to reach 72% WtE, and a decrease in the amount of waste dumped in landfill by 3.996% per year. Scenario #2 experienced an increase in 3R of 1.979% per year, an increase of 1.444% per year for WtE so that the average WtE is 45%, and waste dumped in the landfill decreased by 3.423% per year. Meanwhile, in scenario #3 there is a decrease in the annual 3R percentage by 0.142%, a decrease in waste dumped in the landfill by 3.191%, and an increase in WtE by 3.333% per year so that 70% WtE can be achieved. By using the energy calculation formula, it is possible to obtain the amount of electrical energy generated from waste processing using thermal conversion technology. The results of the energy calculation for each conversion scenario to become energy units of MW/year are displayed in Table 6 and 7.

Tabel 6. Energy conversion

Scenario	Stages	Energy Total (kJ/day)	Energy Total (kKal/day)	Energy Total (kWh/day)	Energy Total (kW)
#1	1	255,475,642	61,060,144	70,829.77	2,951.24
	2	407,114,191	97,302,627	112,871.05	4,702.96
	3	578,208,126	138,195,059	160,306.27	6,679.43
#2	1	228,728,044	54,667,315	63,414.08	2,642.25
	2	291,790,490	69,739,601	80,897.94	3,370.75
	3	371,025,107	88,677,129	102,865.47	4,286.06
#3	1	281,954,136	67,388,656	78,170.84	3,257.12
	2	411,282,355	98,298,842	114,026.66	4,751.11
	3	557,520,719	133,250,650	154,570.75	6,440.45

Tabel 7. Electrical power calculations and increase in WtE

Scenario	Stages	Energy Total (kW)	Boiler Output (kW)	Turbine Output (kW)	Generator Output (kW)	Electric Power/year (kW/year)	Electric Power/ year (MW/year)	Increase in WtE (MW/ 10 years)
#1	1	2,951.24	2,360.99	826.35	743.71	271,455.05	271.45	
	2	4,702.96	3,762.37	1,316.83	1,185.15	432,578.26	432.59	342.92
	3	6,679.43	5,343.54	1,870.24	1,683.22	614,373.79	614.37	
#2	1	2,642.25	2,113.80	739.83	665.85	243,034.52	243.03	
	2	3,370.75	2,696.60	943.81	849.43	310,041.31	310.04	151.20
	3	4,286.06	3,428.85	1,200.10	1,080.09	394,231.89	394.23	
#3	1	3,257.12	2,605.69	911.99	820.79	299,589.71	299.59	
	2	4,751.11	3,800.89	1,330.31	1,197.28	437,007.19	437.01	292.80
	3	6,440.45	5,152.36	1,803.32	1,622.99	592,392.41	592.39	

In applying WtE concept for sustainable future, the local government must also consider the local cultures such as the source of livelihood. 3R recycling sectors that are a source of livelihood for several people must also be continuously improved and adjusted to government targets, so that they do not only achieve government targets but also increase the income of some of the population. Therefore, the implementation of WtE and community based 3R recycling must be carried out in line and continue for better waste management in Padang City.

The calculation results show that the first scenario is the scenario with the highest increase in WtE. This scenario is quite good in terms of WtE, but not completely good because the percentage of 3R recycling (community participation) has not increased, the recycling rate of 3R by community is very small. The second scenario has the smallest WtE increment rate than the others. However, the community participation is also encouraged in this scenario, which is an increase of 3R of 1.979% per year. Since the average electricity need for each household in Padang City is 296.55 kW per year, the energy generated in the second scenario may serve ± 1,329 houses or the equivalent of 0.6% of the total households in Padang City. The third scenario still does not have a very significant impact on the waste management because the community participation is not encouraged. In addition, the amount of waste dumped in landfill in the third scenario experiences the smallest percentage decline. It means that the highest percentage of landfill usage occurs in this scenario.

4. Conclusions

The existing condition of the application of Waste to Energy in the City of Padang has not yet been implemented and the application of 3R recycling is still not optimal, which is less than 5% of the total waste generation. Padang City waste has the potential to produce considerable energy. Based on the three scenarios, the selected scenario is the scenario #2. It suggests that Padang City's waste management may apply WtE idea and 3R community-based recycling in a good combination. As displayed in scenario #2, it may produce energy of around 394.23 MW per year with a 3R recycling rate of 29.47% of total waste at the last stage.

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References

Ariska, Z.A., 2021. Kajian potensi energi dari sampah Kota Padang untuk mendukung program waste to energy. Universitas Andalas, Sumatra Barat.

Audina, M., Anwar, S., Antomi, Y., 2018. Prediksi dan analisis tempat pembuangan akhir (tpa) sampah di Kota Padang. Seminar Nasional Penginderaan Jauh Ke-5.

Fernando, A., 2007. Pemilihan teknologi pengolahan sampah, pembiayaan dan institusi. Tpa regional (studi kasus: Kota Jakarta Barat, Kabupaten dan Kota Tangerang serta Kabupaten Serang). Universitas Indonesia, Jakarta.

Hafizh, M., 2016. Studi timbulan komposisi, karakteristik dan potensi daur ulang sampah domestik Kota Padang tahun 2016. Universitas Andalas, Sumatra Barat.

Hermawan, F., 2017. Penerapan teknologi waste to energy (wte) pada rencana pembangunan intermediate treatment facility (itf) sunter Jakarta Utara. Dinas Lingkungan Hidup Provinsi DKI Jakarta, Jakarta.

Kathirvale, S., Yunus, M.N.M., Sopian, K., Samsuddin, A.H., 2004. Energy potential from municipal solid waste in Malaysia. Renewable energy 29, 559–567.

Mursyida, F., 2017. Studi timbulan, komposisi, karakteristik dan potensi daur ulang sampah komersil Kota Padang tahun 2016. Universitas Andalas, Sumatra Barat.

Peraturan Presiden (PERPRES) tentang Kebijakan dan Strategi Nasional Pengelolaan Sampah Rumah Tangga dan Sampah Sejenis Sampah Rumah Tangga

Peraturan Presiden (PERPRES) tentang Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan.

Raharjo, S., Ihsan, T., Gustin, L., 2013. Status dan potensi pengembangan 3r dalam peningkatan pengelolaan persampahan perkotaan: studi kasus Kota Padang. Seminar Nasional Teknik Kimia Teknologi Oleo & Petrokimia Indonesia, Pekanbaru.

Raharjo, S., Matsumoto, T., Ihsan, T., Rachman, I., Gustin, L., 2017. Community-based solid waste bank program for municipal solid waste management improvement in indonesia: a case study of Padang City. Journal of Material Cycles Waste Management 19, 201–212.

Raharjo, S., et al., 2018. Investigation on municipal solid waste characteristics from commercial sources and their recycling potential in Padang City, Indonesia. IOP Publishing 12134.

Raharjo, S., Utomo, A.H., 2021. Comparative study of electronic waste management in developed countries and Indonesia. Andalasian International Journal Applied Science Engineering Technology 1, 21–32.

Rina, P., 2021. Potensi pengolahan sampah kota padang menjadi refuse derived fuel (RDF). Universitas Andalas, Sumatra Barat.

Sawir, H., 2016. Pemanfaatan sampah plastik menjadi briket sebagai bahan bakar alternatif dalam kiln di pabrik PT Semen Padang. Jurnal Sains dan Teknologi Jurnal Keilmuan dan Aplikasi Teknologi Industri 16, 62–69.

Soewarno, 1995. Hidrologi aplikasi metode statistik untuk analisa data. Nova, Bandung.

Statistik, B.P., 2020. Kota Padang, Kota Padang dalam angka–penyediaan data untuk perencanaan pembangunan. Padang.

Sugiyono, 2016. Metode penelitian kuantitatif, kualitatif, dan R&D. Alfabeta, Bandung.

Utomo, S.B., Hariningrum, R., 2020. Pemanfaatan limbah sampah sebagai energi alternatif pembangkit tenaga listrik di Semarang. Journal of Marine Science Technology 1, 30–37.

Wibowo, A.B., 2007. Kajian awal pembangunan pembangkit listrik tenaga sampah di Kota Bandung. Institut Teknologi Bandung, Bandung.

Winanti, W.S., 2018. Teknologi pembangkit listrik tenaga sampah (PLTSa). Prosiding Seminar Nasional Dan Konsultasi Teknologi Lingkungan Tahun 2018 65–72.

Wiradarma, 2002. Nilai kalor sampah kota di Indonesia. Jurnal IPTEK 20, 121–125.