THE ROLE OF RENEWABLE ENERGY IN REDUCING CARBON EMISSIONS IN CIREBON DISTRICT

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Abstract

The adverse effects of the use of fossil energy such as global warming make people slowly decrease the use of fossil energy including in the electric power generation sector. Emissions from burning fossil fuels such as carbon dioxide are one of the components that make up and dominate the composition of greenhouse gases. It is this greenhouse gas that prevents the sun's heat from being reflected back into the atmosphere, so that it accumulates over many years which causes the temperature of the earth's surface to increase.

Slowly the use of fossil energy is stopped and replaced with new renewable energy which produces less greenhouse gases. In meeting the demand for electricity supply, Cirebon Regency is still relying on Steam Coal Power Plants to supply electricity demand. According to projection, Cirebon's total electricity demand will be 109,860.28 GWh by 2050. If Cirebon still continues to use Steam Coal Power Plants until 2050 it's estimated that it will emit 100,489,721.74 tons of carbon dioxide emissions.

Cirebon Regency has alternative energy potential from municipal solid waste (MSW) that can be utilized. Every day, every person in Cirebon Regency can produce 0.541 kg of waste. From the observations, the electrical energy that can be generated and utilized from waste until 2050 is 8,360.45 GWh, of which 2,462.34 GWh is generated from organic waste and 5,898.12 GWh is generated from combustible waste.

The electrical energy that can be generated from city waste is sufficient for 7.61% of the electricity needs of Cirebon Regency. With an energy mix scheme between PLTU and waste-based power plants, total carbon dioxide emissions can be reduced by 3.05%.

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1. Introduction

The issue of climate change has been widely discussed since the occurrence of unusual natural phenomena such as prolonged drought, faster melting of polar ice, erratic weather and so on. All of that happens due to the earth's inability to release the sun's heat again due to the greenhouse effect.

The greenhouse effect itself is just a term that describes the condition of the earth which is unable to release the sun's heat due to the presence of greenhouse gases such as carbon dioxide.

Greenhouse gases consist of various gases such as carbon dioxide (CO_2), methane (CH_4), NO_x, CFC and O_3 (Suprihatin et al., 2012). Carbon dioxide is a gas that dominates the composition of greenhouse gases. Activities such as the use of fossil fuels are a source of producing carbon dioxide gas (Suprihatin et al., 2012).

After it is known that fossil fuels have a negative impact on the sustainability of the earth, their use is slowly being stopped and replaced with new, renewable energy sources that produce less carbon emissions.

Indonesia, in its long-term energy plan, applies the concept of net zero emissions in 2060. This means that, by 2060, the use of energy that is not environmentally friendly will begin to be stopped. This plan is contained in the 2021 – 2030 Electricity Supply Business Plan (RUPTL).

Cirebon Regency in fulfilling electricity needs still depends on Steam Coal Power Plants. This is not in line with the central government's plan to slowly abandon fossil fuels to reach net zero emissions. In fact, Cirebon Regency has the potential for new renewable energy sources that can be used as municipal waste. At least in a day it is estimated that Cirebon Regency can produce 1,200 tons of municipal solid waste (MSW) (Izan, 2022).

Garbage has an energy content ranging from 1,000 – 2,000 kcal/kg (Samsinar & Anwar, 2018). With the energy potential from waste that can be utilized and the waste problem that has not been resolved in Cirebon Regency, it is necessary to study the use of waste energy for electricity generation as an alternative energy to reduce carbon dioxide emission production and as a solution to overcome the waste problem.

2. Methodology

A. Data Collect

The data in this study are primary and secondary, obtained from the results of independent measurements and various sources as shown in Table 1. The data was collected over a 10-year time span to get a smoother data trend.

B. Projection of Electrical Energy Demand

Electrical energy demand will be projected using the trend method. Cirebon Regency electricity demand data from 2012 to 2021 is used as a trend mathematical modeling database. This data is used based on the availability of data contained in the Badan Pusat Statistik (BPS).

The trend mathematical models used are linear, polynomial and exponential models. The model is made by the trendline feature in Microsoft Excel. Each of the three models will be validated using MAPE (*Mean Absolute Percentage Error*) like Equation 1.

$$MAPE = \frac{\sum_{i=1}^{n}\left|\frac{actual - model}{actual}100\%\right|}{n} \quad (1)$$

C. Waste Electrical Energy Potential

Municipal waste in Cirebon Regency will be grouped into three types, organic waste, combustible waste and non-combustible waste.

The organic waste consists of food and plant waste. The combustible waste consists of plastic, paper, wood, rubber & leather and cloth waste. Meanwhile, the non-combustible waste consists of glass/glass, B3, metal and others.

Waste that can be utilized for energy is in the form of organic and combustible waste as shown in Figure 1. Organic waste will be converted by biodigester technology. The selection of biodigesters is based on the flexibility of the technologies that can be combined with other materials such as livestock manure. Meanwhile, combustible waste will be converted using gasification technology in accordance with the technology that is currently used by the Indonesian government for waste power plants for combustible waste.

Table 1 Data Sources and Requirements

Data	References	Disposition
Cirebon Regency electrical energy demand	Central Bureau of Statistics for West Java Province	Secondary
The population of Cirebon Regency		Secondary
CO_2 Emission factor of PLTU Batubara	PT Cirebon Electric Power	Secondary
CO_2 emission factor of biomass power plant	Literature study	Secondary
Caloric value of biogas	Literature study	Secondary
Efficiency of component's power plant	Literature study	Secondary
Caloric value of combustible MSW	Laboratory test	Primary

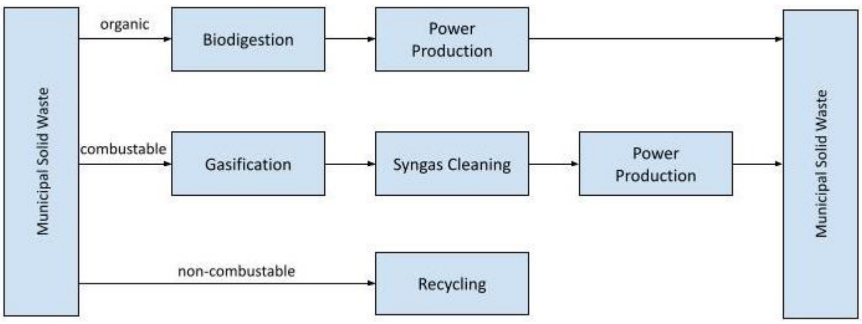

Figure 1 Waste Management Scheme

The amount of waste production will be influenced by the total population. To calculate and estimate the total population, it is calculated using Equation 2 with an estimated population growth rate calculated using Equation 3 and the amount of waste production is calculated using Equation 4. The amount of waste production and the potential for electrical energy produced will be calculated in the period up to 2050 as a reference for calculating renewable energy mix level.

$$P_t = P_0\left(1 + \frac{r}{100}\right)^{t-t_0} \quad (2)$$

$$r = \left[\left(\frac{P_t}{P_0}\right)^{\frac{1}{t-t_0}} - 1\right]100 \quad (3)$$

$$m_s = P_t S_{ps} Y 10^{-3} \quad (4)$$

P_t = population in year t (people)
P_0 = population in the base year (people)
r = population growth rate (%)
t = analysis years
t_0 = base year
m_s = mass of MSW (ton)
S_{ps} = MSW specific production (kg/people/day)
Y = amount of day per year

Organic waste will be converted into biogas first before being used to generate electricity. Meanwhile, combustible waste will be converted into syngas using the gasification method before being used to generate electricity. The amount of biogas produced from organic waste can be calculated using Equation 5.

$$V_{bi} = \frac{(m_{so})(DM)(VS)(MY)10}{\%CH_4} \quad (5)$$

V_{bi} = biogas volume (m^3)
m_{so} = mass of organic waste (ton)
DM = *dry matter content* (% weight)
VS = *volatile solids content* (% DM)
MY = *methane yields* (% VS)
$\%CH_4$ = CH_4 content in biogas (%)

The amount of electrical energy generated from organic and combustible waste can be calculated using Equations 6 & 7.

$$E_L = \frac{V_{bi} E_{bi} \eta_P}{860.42} 10^{-8} \quad (6)$$

$$E_L = \frac{m_{sc} E_{sc} \eta_P}{860.42} 10^{-5} \quad (7)$$

E_L = electrical energy (GWh)
E_{bi} = biogas caloric value (kkal/m^3)

m_{sc} = Mass of combustible waste (ton)
E_{sc} = caloric value of combustible waste (kkal/kg)
η_P = electricity generation efficiency (%)

D. Power Generation Capacity

The required power generation capacity needs to be calculated in order to accommodate the potential of existing electrical energy. Equation 8 until 10 is used to calculate the required generating capacity.

$$D = \frac{E_{LM}}{Yh} 10^3 \quad (8)$$

$$D_P = \frac{E_{Lm}}{CF_m Yh} 10^5 \quad (9)$$

$$CF_M = \frac{D}{D_P} 100\% \quad (10)$$

D = maximum power potential (MW)
D_P = power generation capacity (MW)
CF_M = maximum capacity factor (%)
CF_m = minimum capacity factor (%)
E_{LM} = maximum electrical energy potential (GWh)
E_{Lm} = minimum electrical energy potential (GWh)
h = 24 hours

E. Carbon Emissions Reduction

Carbon emissions are calculated when the power plant is operational and uses the maximum scenario, where all alternative power plants from waste are built simultaneously. The initial condition is determined that the electricity demand is fully supplied by fossil power plants and the final condition is that electricity demand is supplied by a mix between fossil power plants and waste. Each initial and final condition will be multiplied by an emission factor, so that the production of carbon dioxide emissions at the initial and final conditions is obtained. The difference in the production of carbon emissions between the initial and final conditions is the potential for carbon emissions that can be reduced due to the use of alternative power plants (MSW). The amount of emission produced by the power plant is calculated by Equation 11.

$$Em = E_L F_{Em} \quad (11)$$

Em = carbon emissions (ton CO_2)
F_{Em} = emissions carbon factor of power plant (g CO_2/kWh)

3. Results and Discussion

A. Electrical Energy Demand Projection

Cirebon Regency is recorded as having electricity consumption which tends to increase from 2012 to 2021 based on data from the Central Bureau of Statistics for West Java Province in Table 2.

Table 2 Electrical Energy Demand of Cirebon Regency

Years	Electrical Energy Demand, E_L (GWh)	Years	Electrical Energy Demand, E_L (GWh)
2012	1,688.33	2017	1,970.80
2013	1,812.43	2018	2,002.20
2014	1,856.61	2019	2,045.57
2015	1,934.13	2020	2,137.06
2016	1,816.82	2021	2,223.22

The results of fitting the mathematical model using Microsoft Excel obtained the following equations:

Linear $50.844t + 1,719.9$
Exponential $1,727.7e^{0.0261t}$
Polynomial $1.9189t^2 + 33.574t + 1,742.9$

The three equation models were then tested using MAPE as in Equation 1 with the results shown in Table 3. The polynomial trend model is the model with the smallest MAPE value of 1.96%. This means that the polynomial trend model is a model that can represent the electrical energy demand for Cirebon Regency.

Table 3 Trend Mathematical Model's Validation

Years	Years to-	Electrical Energy Demand (GWh)				Errors		
		Data	Exponential Trend	Linear Trend	Polynomial Trend	Exponential Trend	Linear Trend	Polynomial Trend
2012	0	1,688.33	1,727.70	1,719.90	1,742.90	2.33%	1.87%	3.23%
2013	1	1,812.43	1,773.39	1,770.74	1,778.39	2.15%	2.30%	1.88%
2014	2	1,856.61	1,820.28	1,821.59	1,817.72	1.96%	1.89%	2.09%
2015	3	1,934.13	1,868.42	1,872.43	1,860.89	3.40%	3.19%	3.79%
2016	4	1,816.82	1,917.82	1,923.28	1,907.90	5.56%	5.86%	5.01%
2017	5	1,970.80	1,968.54	1,974.12	1,958.74	0.11%	0.17%	0.61%
2018	6	2,002.20	2,020.59	2,024.96	2,013.42	0.92%	1.14%	0.56%
2019	7	2,045.57	2,074.02	2,075.81	2,071.94	1.39%	1.48%	1.29%
2020	8	2,137.06	2,128.87	2,126.65	2,134.30	0.38%	0.49%	0.13%
2021	9	2,223.22	2,185.16	2,177.50	2,200.50	1.71%	2.06%	1.02%
MAPE						**1.99%**	**2.04%**	**1.96%**

Figure 2 is the projected result of Cirebon Regency's electricity demand from 2022 to 2050 using a polynomial trend model. After being projected using the polynomial trend model, it is estimated that Cirebon Regency's electricity demand by 2050 will reach 109,860.28 GWh.

B. Electrical Energy Potential from MSW

Based on data from the Environment and Forestry Service (DLHK), waste in Cirebon Regency consists of 52.41% organic, 37.98% combustible and 9.61% non-combustible (DLHK, 2016).

The total population from 2012 to 2021 continues to increase by an average of 0.35% as shown in Table 4.

The population growth rate is calculated using Equation 3 with the value P_0 being the population in 2012 and t_0 being 2012.

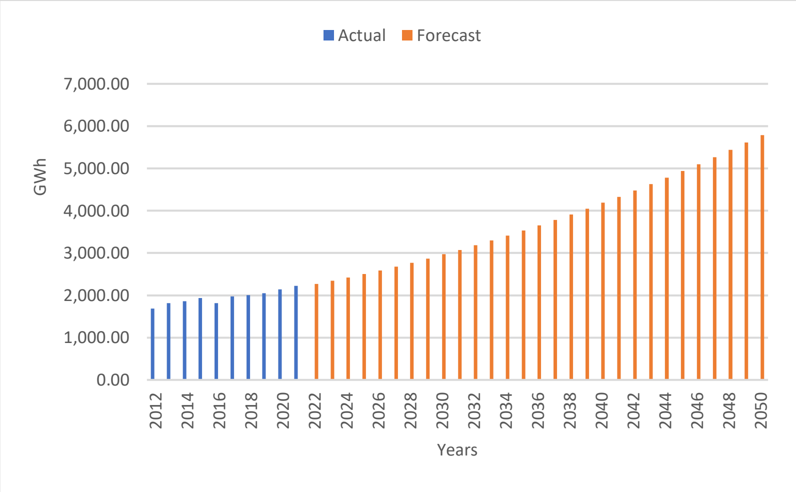

Figure 2 Electrical Energy Demand Projection of Cirebon Regency

Table 4 Population Data of Cirebon Regency

Years	Population, P_t (people)	r
2012	2,110,147	-
2013	2,093,075	-0.81%
2014	2,109,588	-0.01%
2015	2,126,179	0.25%
2016	2,143,000	0.39%
2017	2,159,577	0.46%
2018	2,176,213	0.52%
2019	2,192,903	0.55%
2020	2,270,621	0.92%
2021	2,290,967	0.92%
Average		**0.35%**

The population of Cirebon Regency with an average growth rate of 0.35% per year is estimated to reach 2,299.076 people by 2022. Each person in Cirebon Regency is estimated to produce as much waste 0.541 kg/day (DLHK, 2016). Thus, if calculated using Equation 4, in 2022 Cirebon Regency can produce 453,987.04 tons of MSW consisting of 237,934.61 tons of organic waste, 172,424.28 tons of combustible waste and 43,628.15 tons of non-combustible waste. In 2050, the population of Cirebon Regency will increase by 10.40% to 2,538.175 people with an estimated total waste production of 501,200.73 tons consisting of 262,679.30 tons of organic waste, 190,356.04 tons of combustible waste and 48,165.39 tons of non-combustible waste. Details of population and waste production in Cirebon Regency in other years can be seen in Figure 3.

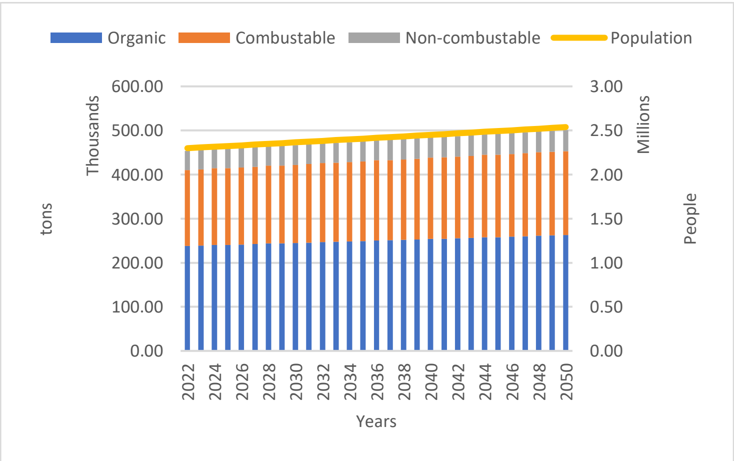

Figure 3 Cirebon Regency Waste Production Projections

Organic waste has contents as in Table 5 (Chiew et al., 2014). The content affects the size of biogas production. In addition, at least 1 kg of volatile solids (VS) organic waste can produce 0.44 – 0.48 m^3 methane (Atelge et al., 2020). Biogas itself consists of various gases, one of which is methane. The composition of methane in biogas can vary between 45 – 75% of the volume of biogas (Esye & Iswal, 2021). If, it is assumed that the methane contained in the biogas is only 60% of the biogas volume, the methane that is formed is only 0.44 m^3/kg VS, the DM and VS values respectively based on Table 5 are 28.7% and 90.1%, the amount of biogas produced in 2022 with a total organic waste production of 237,934.61 tons is 45,119,650.69 m^3.

Table 5 Organic Waste Contents

Waste Fraction	Units	Food Waste
Dry matter (DM) content	% of wet weight	28.7
Volatile solids (VS)	% of DM	90.1
C-tot biological	% of DM	48.9
N-tot	% of DM	2.6
P-tot	% of DM	0.32
Cd	% of DM	1.2E-05

In 2050, with a production of 262,679.30 tons of organic waste, it is estimated that it will produce 49,811,998.37 m^3 of biogas. Biogas production in other years can be seen in Table 8.

Biogas has an energy content of approx 4,780.11 kcal/m^3 (Samnur & Irfan, 2011). Meanwhile, the energy content in combustible waste was tested in the laboratory with the results shown in Table 6.

Table 6 Caloric Value of Combustible Waste

Kind of Waste	Fraction (%)	Caloric Value (kcal/kg)
Wood	13.93	3,953.74
Textile	3.69	2,173.78
Rubber/ leather	0.24	6,678.77
Paper	21.51	1,935.73
Plastic	60.64	7,742.72
Combustible waste	**100.00**	**5,758.02**

Based on the test results, combustible waste in Cirebon Regency has a 5,758.02 kcal/kg energy content. The combustible waste consists of various types of waste that can be burned such as plastic and others. The calorific value of combustible waste is obtained from the combined calorific value of each type of combustible waste multiplied by the respective fraction.

Table 7 Power Plant Efficiency

Power Plant Component's	Efficiency	Reference
Biogas Power Plant		
Gas engine	40%	(Hakim & Valentino, 2019)
Generator	93%	(Muharrir & Hajar, 2019)
Biogas Power Plant	37.2%	
Gasification Power Plant		
Gasifier	51.89%	(Pratama et al., 2019)
Gas engine	40%	(Hakim & Valentino, 2019)
Generator	93%	(Muharrir & Hajar, 2019)
Gasification Power Plant	19.3%	

To be able to utilize the energy contained in biogas and combustible waste, it is needed Biogas Power Plant and Gasification Power Plant. Each power plant has a capacity limit to convert electrical energy as shown in Table 7. Biogas Power Plant has an electricity conversion efficiency of 37.2%. Meanwhile, Gasification Power Plant has an efficiency of 19.3%. By knowing the efficiency value of each generator, the energy content of each fuel and the amount of fuel produced, the potential for electrical energy that can be generated from organic and combustible waste can be seen in Table 8 calculated using Equations 6 & 7.

The potential for electrical energy that can be generated from Cirebon Regency waste until 2050 is as much as 9,638.90 GWh with 2,844.48 GWh generated from organic waste and 6,794.43 GWh generated from combustible waste.

C. Power Generation Capacity

Generation of electrical energy must be through an electrical conversion equipment or what is called a power plant. In order to accommodate all the potential for electrical energy from waste, a generator with adequate capacity is needed. Calculation of power generation capacity is done by Equation 8 until 9.

In calculating the required power generation capacity, the capacity factor is an important part that must be taken into account. The capacity factor for a biomass power plant ranges from 60 – 93% (IRENA, 2022). That is, the minimum capacity factor on conditions of minimum fuel availability must be ≥ 60%.

The maximum potential of electrical energy that can be generated from organic and combustible waste is 102.95 dan 245.90 GWh. So, if it is calculated using Equation 8 to find out how much maximum electric power can be generated, the maximum electric power that can be generated from organic and combustible waste is respectively 16.52 and 28.07 MW.

Minimum value of capacity factor (CF_m) assumed for Biogas Power Plant as 70% and Gasification Power Plant as 80%. The minimum potential of electrical energy that can be generated from organic and combustible waste is equal to 93.25 and 222.74 GWh. With these data, the need of power generation capacity for Biogas

Power Plant and Gasification Power Plant calculated using Equation 9 obtained by 18 and 32 MW.

To ensure that in conditions of availability of potential maximum electrical energy, the capacity factor does not exceed 100%, it is necessary to ensure that the value of the maximum capacity factor (CF_M) is calculated using Equation 10. After calculating, the CF_M value for Biogas Power Plant is 92% and Gasification Power Plant is 88%. If they are compared by IRENA's data, the CF value of biomass power plants according to IRENA's data is in the range of 60 - 93%, the CF values obtained for Biogas Power Plant and Gasification Power Plant are still within the criteria for power plants with capacities of 18 and 32 MW. Thus, to be able to accommodate the potential for electrical energy generated from organic and combustible waste, Biogas Power Plant with a capacity of 18 MW and Gasification Power Plant with a capacity of 32 MW are needed..

D. Carbon Emissions Reduction

The carbon dioxide emissions caused by Steam Coal Power Plants is 914.7 g/kWh. The data was obtained from the measurement results of PT Cirebon Electric Power as the only electric power plant operating and supplying electrical demand in Cirebon Regency.

By 2050, Cirebon Regency's electricity demand will be as large as 109,860.28 GWh. Thus, the emissions caused by the operation of Steam Coal Power Plants will be 100,489,721.74 tons CO_2.

Table 8 Potential of Electrical Energy from Waste In Cirebon Regency

Years	Organic Waste, m_{so} (tons)	Biogas, V_{bi} (m^3)	Combustible Waste, m_{sc} (ton)	Electrical Energy, E_L (GWh)	
				Organic Waste	Combustible Waste
2022	237,934.61	45,119,650.69	172,424.28	93.25	222.74
2023	238,776.93	45,279,379.80	173,034.68	93.58	223.53
2024	240,278.64	45,564,150.40	174,122.93	94.17	224.93
2025	240,470.25	45,600,486.08	174,261.79	94.24	225.11
2026	241,321.47	45,761,902.72	174,878.64	94.58	225.91
2027	242,175.69	45,923,888.49	175,497.66	94.91	226.71
2028	243,698.75	46,212,707.62	176,601.38	95.51	228.13
2029	243,893.23	46,249,587.04	176,742.32	95.58	228.32
2030	244,756.56	46,413,299.82	177,367.94	95.92	229.12
2031	245,622.88	46,577,581.74	177,995.75	96.26	229.93
2032	247,167.74	46,870,533.59	179,115.26	96.87	231.38
2033	247,364.85	46,907,911.82	179,258.10	96.94	231.57
2034	248,240.49	47,073,959.99	179,892.65	97.29	232.39
2035	249,119.24	47,240,596.91	180,529.45	97.63	233.21
2036	250,685.92	47,537,687.36	181,664.78	98.25	234.67
2037	250,885.94	47,575,617.40	181,809.73	98.32	234.86
2038	251,774.00	47,744,020.59	182,453.28	98.67	235.69
2039	252,665.27	47,913,032.15	183,099.16	99.02	236.53
2040	254,254.32	48,214,365.71	184,250.70	99.64	238.02
2041	254,457.12	48,252,821.55	184,397.66	99.72	238.20
2042	255,357.90	48,423,638.62	185,050.43	100.08	239.05
2043	256,261.80	48,595,044.45	185,705.46	100.43	239.89
2044	257,873.47	48,900,667.04	186,873.39	101.06	241.40
2045	258,079.21	48,939,681.25	187,022.49	101.14	241.60
2046	258,992.73	49,112,912.22	187,684.49	101.50	242.45
2047	259,909.46	49,286,751.56	188,348.81	101.86	243.31
2048	261,544.10	49,596,729.10	189,533.39	102.50	244.84
2049	261,752.74	49,636,294.64	189,684.59	102.58	245.03
2050	262,679.30	49,811,998.37	190,356.04	102.95	245.90
Total	**7,257,994.58**	**1,376,336,898.74**	**5,259,657.20**	**2,844.48**	**6,794.43**

Power plants that use biogas as fuel have an emission factor of 11.84 g CO_2/kWh (Szabo et al., 2014). Meanwhile, waste that is processed by gasification will produce emissions of 771.43 g CO_2/kWh (Bianco et al., 2021).

The construction of a power plant takes quite a long time, so not all of the potential for electrical energy from waste can be utilized. Apart from that, maintenance and replacement of spare parts is also the reason why the potential for electrical energy from waste cannot be fully utilized. Construction of Biogas Power Plant takes at least

2 years for construction and Gasification Power Plant takes at least 3 years for construction. If, the construction of power plants from waste is carried out simultaneously in 2023, then only 2,462.34 GWh electric from organic waste that can be generated from the total 2,844.48 GWh until 2050. Meanwhile, the electricity that can be generated from Gasification Power plant is only 5,898.12 GWh electric from the total 6,794.43 GWh until 2050. With the amount of electricity that can be generated, the emissions generated from Biogas Power Plant and Gasification Power Plant until 2050 are 29,154.07 dan 4,549,985.11 tons CO_2

Electrical energy generated from waste cannot meet all of the electrical energy needs in Cirebon Regency, only 7.61% electrical demand of Cirebon Regency that can be fulfilled by MSW power plants. The shortage will be filled by the existing Steam Coal Power Plant until other alternative energy sources are used. As much as 92.39% of the electrical demand in Cirebon Regency will be supplied by the Steam Coal Power Plant. Thus, the carbon emissions generated from the Steam Coal Power Plant to cover the shortage of supply is 92,842,373.79 tons CO_2. The total carbon emission produced in the mixed conditions between Steam Coal and MSW Power Plants is 97,421,512.96 tons $C0_2$. There is a reduction in carbon emissions of 3,068,208.77 tons CO_2 or 3.05%. This can be seen in Figure 4 which shows the distance of the green line representing carbon emissions in the full condition of the coal-fired power plant as the main electricity supply and the bar graph representing carbon emissions resulting from the energy mix of waste power plants in Cirebon Regency.

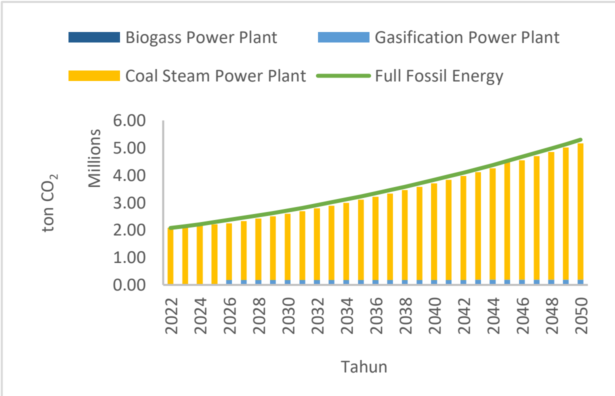

Figure 4 The Potential for Reducing Carbon Emissions in Cirebon District

4. Conclusion

Cirebon Regency has the potential for electrical energy from MSW of 9,638.90 GWh. However, due to technological limitations and conditions, only 86.74% could be realized.

In order to sustain the potential of existing electrical energy, Biogas Power Plant with a capacity of 18 MW and Gasification Power Plant with a capacity of 32 MW is needed.

Of the total electrical energy demand of Cirebon Regency until 2050, only 7.61% can be supplied from MSW Power Plants..

With the alternative energy mix from MSW, the production of carbon emissions can be reduced by 3.05%.

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