Potential Energy Benefits and GHG Emissions Reductions From Biogas in Wisconsin

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Introduction

Biogas is a renewable energy resource that results from the breakdown of organic matter in the absence of oxygen, producing a gas similar to natural gas containing methane (65%) and carbon dioxide (35%). Its production offsets methane emissions—having 21 times the warming impact of carbon dioxide over a 100-year time frame[1]— that would have occurred through the degradation of organic materials into the atmosphere. Methane's combustion and use as an energy resource offsets carbon dioxide emissions that would result from fossil fuel energy use. This study provides a mathematical aggregate analysis of the potential energy benefits and greenhouse gas (GHG) emissions reductions from biogas in Wisconsin, which has not been done to the knowledge of the researcher.

Methodology

The conclusions from this study were drawn from the comparison of two scenarios:

1. Status quo: Emissions from manure, wastewater, landfills, and food waste and emissions from coal electricity generation continue as usual and
2. Biogas is produced and used for electricity generation, replacing emissions from Scenario 1 with emissions from the combustion of biogas.

Calculation of Scenario 1

Table 1 lists emissions sources, their emission factors reported in CO_2 equivalents, and their total annual GHG emissions. Annual emissions were calculated via dimensional analysis with the annual amount of each source and their respective emission factors, which were gathered from previous research.

Generating electricity from coal has an average efficiency of 32%[8], so the unburned energy needed from coal is

$$E_{coal}(kWh)=e_{biogas}(kWh)/0.32$$

Where e_{biogas} is the electricity that could potentially be generated from biogas, as calculated in scenario 2 with a high and low boundary. Therefore, the energy needed from coal is 976,562,500 kWh or 1,757,812,500 kWh.

Figure 1

Emission Source Type	Annual Amount	Emission Factor	Annual Emissions (kg CO_2 eq/yr)
Broiler manure	0.4 million tons[2]	.0569 kg CO_2/kg[4]	20,647,525
Dairy manure	32.4 million tons[2]	.7545 kg CO_2/kg[4]	22,176,850,720
Swine manure	554,000 tons[2]	.004598 kg CO_2/kg[4]	2,310,864
Food waste	1.8 million tons[2]	540 kg CO_2/ton[5]	972,000,000
Landfill waste*	4,421,479 tons[3]	1460.57 kg CO_2/ton[6]	6,457,879,583
Wastewater	158,045 gal[2]	.00788 kg CO_2/gal[7]	1245
Total			2.963×10^{10}

*Municipal solid waste only

The CO2 emission factor for coal that is typically burned in Wisconsin is .3242 kg CO2/kWh electricity produced[9]. So, the total CO2 emissions that result from producing this amount of electricity follows the equation

$$GHG_{coal\ electricity\ generation}=E_{coal} * .3242$$

Where E_{coal} was calculated in the previous step. This results in having the low boundary value of 316,601,562 and the upper boundary of 569,882,812 kg CO_2.

Calculation of Scenario 2

Wisconsin has the potential to generate 90,000,000 kg[10] of methane (CH_4) annually (211,069,418 m^3 biogas). CH_4 has a lower calorific value of 50.0 MJ/kg CH_4[11]. So, the energy yield from the assumed 100% combustion of this CH_4 is 4.5×10^9 MJ. The electricity that can be produced from this amount of biogas energy with a conversion efficiency of 25-40% as stated for the average efficiencies of small and large generators[12] is

$$e_{biogas}=0.2778\ (kWh/MJ)*E_{biogas}*\mu$$

Where E_{biogas} is the energy yield of biogas and μ is the conversion efficiency. The electricity generated from biogas energy has a low boundary 312,500 MWh and a high boundary of 562,500 MWh.

The chemical relationship of the complete combustion of methane is:

$$CH_4+2O_2 \longrightarrow CO_2+2H_2O+energy$$

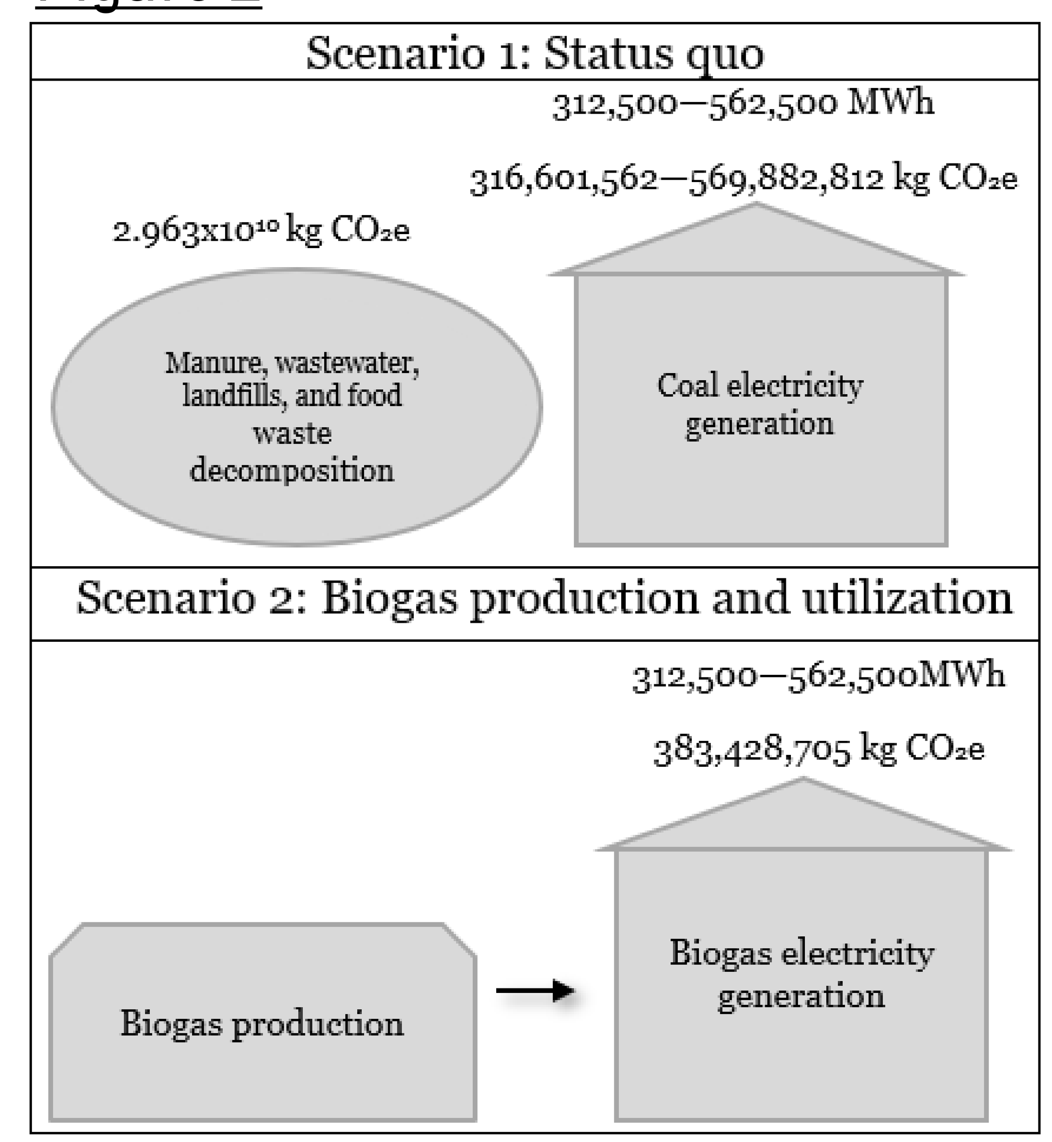
This relationship can be used to find the emissions that would result from the combustion of 1 m^3 of biogas

$$GHG_{biogas\ combustion}=\%_{CH4}*\rho_{CH4}*2.75+\ \%_{CO2}*\rho_{CO2}$$

where $\%_{CH4}$ is the percent composition of CH_4 of biogas, ρ_{CH4} is the density of CH_4, and 2.75 is the molecular weight relationship between CO_2 and CH_4. This value is 1.82 kg CO_2 emitted in the combustion of 1 m^3 of biogas. Notably, this is true no matter the composition of the biogas. Therefore, it can be concluded that 383,428,705 kg CO_2 are emitted from the combustion of biogas.

Results and Conclusion

Figure 2



As seen in the Figure 2, biogas production and utilization resulted in an annual electricity generation of 312,500-562,500 MWh, which is 0.45-0.82% of the state's annual electricity consumption. Scenario 2 also resulted in a net GHG emission reductions of 2.956×10^{10}—2.982×10^{10} kg CO_2e.

The results of this study show that biogas potential in Wisconsin has been undervalued by policymakers, and that this value should be reflected in Wisconsin energy policy through further incentivizing biogas production across Wisconsin's economic sectors.

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