Exploring the Determinants of Biogas Generation Potential in California

Web address for GitHub repository

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2 Background

2.1 Rationale of the study

The transition to cleaner and renewable sources of energy requires more work to scale already existing gains, for example in the area of biogas utilization, while also seeking out new opportunities. Biogas is a form of renewable energy produced by anaerobic decomposition or thermochemical conversion of biomass such as agricultural waste, manure, municipal waste sewage, green waste and food waste. Biogas is composed mostly of methane, alongside carbon dioxide, water vapor and other gases. Similar to natural gas, biogas can be burned directly as a fuel or treated to remove the CO2 and other gases before for being used in the form of biomethane.

Utilizing biogas as an energy source helps to transform harmful gases from decomposing waste into positive use. Methane is a powerful greenhouse gas that traps heat in the atmosphere, with a global warming potential estimated to be over 25 times as potent as that of Carbon Dioxide.Transforming waste into biogas therefore reduces greenhouse gas emissions and the risk of pollution to waterways. The UNECE estimates that over a 20 year period, this ratio increases to 84-86 times. However, stored biogas limits the amount of methane released into the atmosphere and reduces dependence on fossil fuels. When stored , biogas serves as a renewable and reliable baseload power source and can even be used to rapidly meet peak power demands. When biogas is used for energy generation in place of fossil fuels, it enables even more emission reductions, sometimes resulting in carbon negative systems. According to the Environmental and Energy Study Institute, EESI ,the reduction of methane emissions derived from tapping all the potential biogas in the United States would be equal to the annual emissions of 800,000 to 11 million passenger vehicles.

Unfortunately, despite the various benefits offered by biogas energy, the United States currently only has 2,200 operating biogas systems. The EESI estimates this current capacity to be less than 20% of the total potential. It is on this basis that this study attempts to examine the factors contributing to biogas generation potential, particularly in California. California was selected because of its status as a leading state in biogas generation potential based on estimates by the National Renewable Energy Laboratory (NREL). According to the American Biogas Council, California can power nearly 200,000 homes if this biogas is utilized appropriately. The results of our analysis for California can provide the basis for further analysis across several other US states.

2.2 Research Questions

The analysis conducted was done based on two research questions:

1. Is biogas generation potential correlated with population density across California counties?

2. What additional factors must be considered in determining biogas generation potential?

3 Dataset Information

the datasets used include the following:

1. Methane Generation Potential The NREL's dataset on methane generation potential covers data for the entire United States of America. It particularly providing information for Methane generation potential across all states in metric tons from sources which include landfills, industrial organic waste, animal manure, and wastewater . All of these individual sources were aggregated to estimate total methane generation potential by state. The dataset contained estimates for 2009 to 2012, being the latest available data we could find online.

2. Population data Population data was pulled from the latest available the Social Vulnerability Index data compiled by the Center for Disease Control (CDC) and Agency for Toxic Substance and Diseace Reegistry (ATSDR). This dataset also includes details on impoverished populations and spans from 2017-2018. Since the SDI offers data that helps to effectly plan towards meeting the needs of improverished populations, this dataset also helps to dds another dimension to our analysis as it enables the exploration of impacts on socially vulnerable people.

4 Exploratory Analysis

The two datasets were wrangled and joined both datasets to have a unified dataframe that captured data on methane generation potential, population and poverty levels by county. An initial exploration of the data was done to provide a visual assessment of spatial data and determine the emergence of any any trends.

```
## Simple feature collection with 6 features and 14 fields
## Geometry type: MULTIPOLYGON
## Dimension:     XY
## Bounding box:  xmin: -122.7851 ymin: 37.45447 xmax: -119.5423 ymax: 40.15203
## Geodetic CRS:  WGS 84
##   ObjectID      NAME STATE_NAME  FIPS      OWCH4t    AMCH4t     WWTPCH4t
## 1      184   Alameda California 06001 5700.695190  0.367359 10461.687700
## 2      185    Alpine California 06003    6.483819  0.000000     6.667176
## 3      186    Amador California 06005  156.310667  3.826180   624.136548
## 4      187     Butte California 06007  817.909133 20.460013  1210.759120
## 5      188 Calaveras California 06009   97.664105 11.663426   200.148617
## 6      189    Colusa California 06011   72.199705  2.057210   104.007942
##   LFGCH4t   TotalCH4t    COUNTY                     LOCATION E_TOTPOP  E_POV
## 1   49311 65473.75020   Alameda   Alameda County, California  1643700 170884
## 2       0    13.15099    Alpine    Alpine County, California     1146    227
## 3       0   784.27340    Amador    Amador County, California    37829   3323
## 4       0  2049.12827     Butte     Butte County, California   227075  44410
## 5       0   309.47615 Calaveras Calaveras County, California    45235   5242
## 6       0   178.26486    Colusa    Colusa County, California    21464   2929
##   E_MINRTY                       geometry
## 1  1120309 MULTIPOLYGON (((-122.313 37...
## 2      468 MULTIPOLYGON (((-120.0726 3...
## 3     8066 MULTIPOLYGON (((-121.0276 3...
## 4    62685 MULTIPOLYGON (((-122.0573 3...
## 5     8330 MULTIPOLYGON (((-120.9955 3...
## 6    13792 MULTIPOLYGON (((-122.7851 3...
```

Visually, the most populated area of California, given by the county shaded yellow, Los Angeles, has the highest methane (CH_4) generation potential. The density of impoverished population appears to be similarly distributed.

Figure 1: Population Density, CA

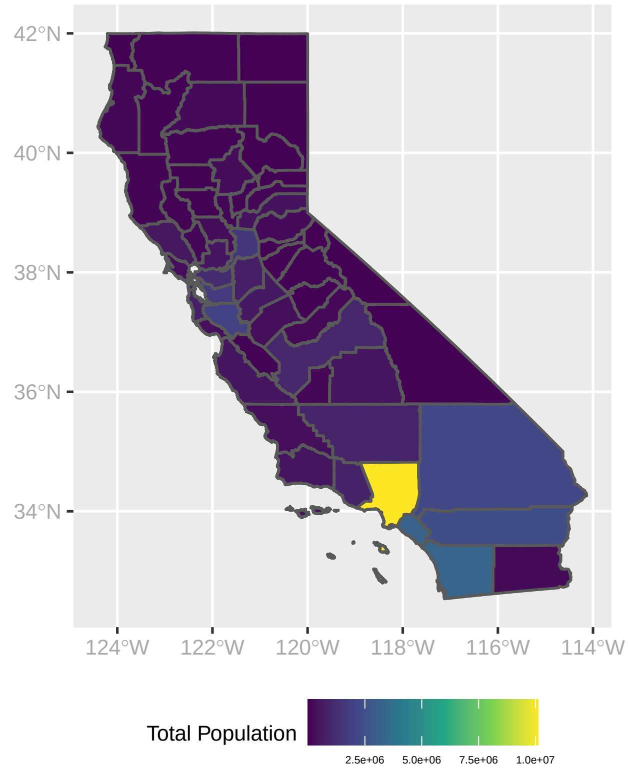
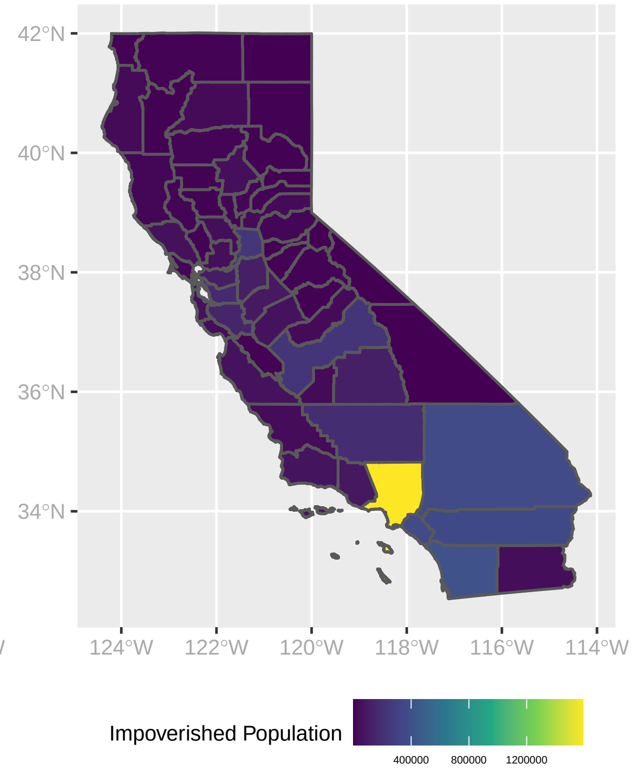


Figure 2: Impoverished Population Density, C



The total Methane generation potential is greatest at the most densely populated areas. This trend appears to continue with wastewater derived methane.

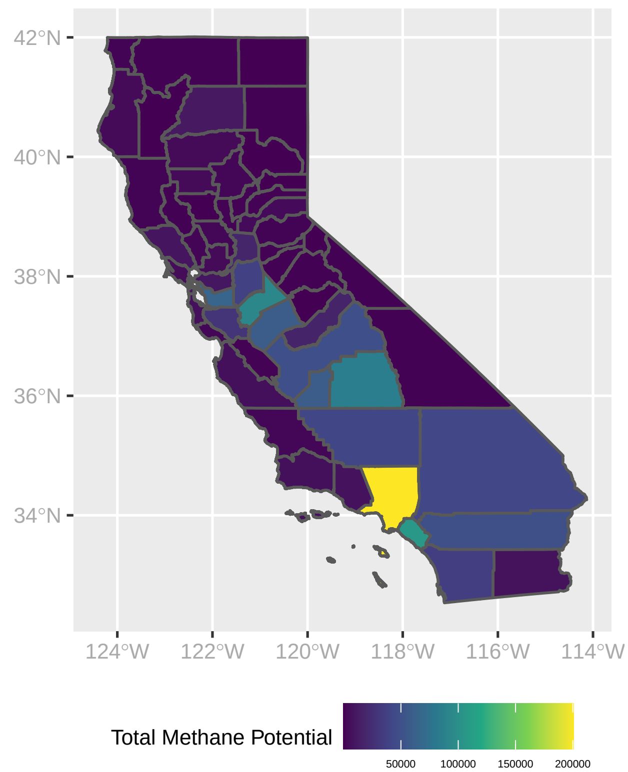


Figure 3: Total Methane Potential, CA (MT/yea

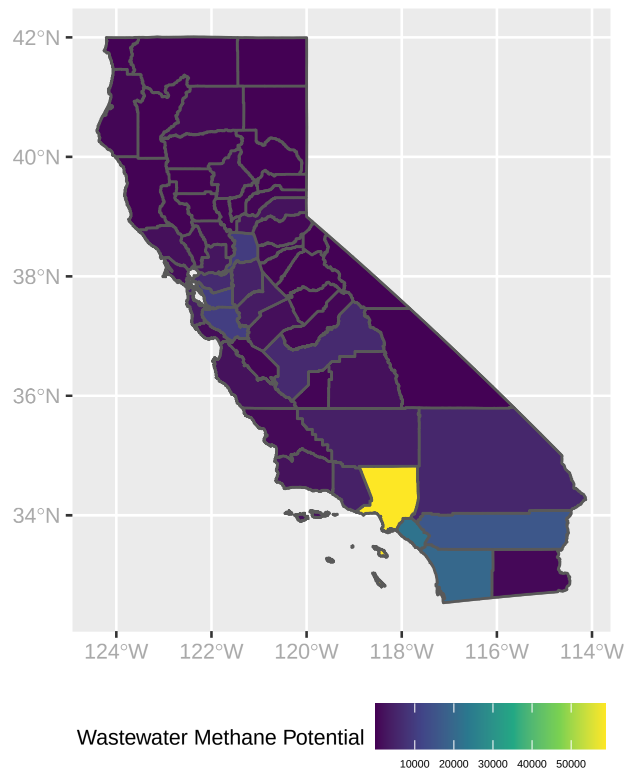
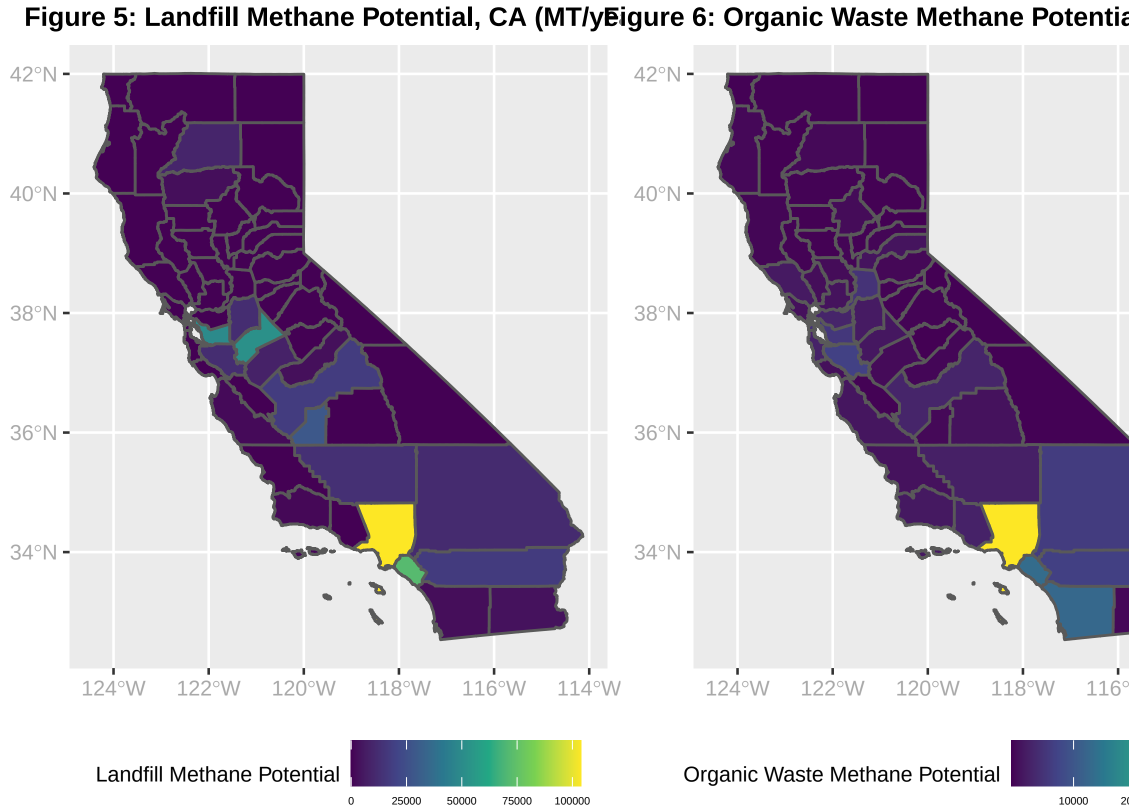


Figure 4: Wastewater Methane Potential, CA (MT/y

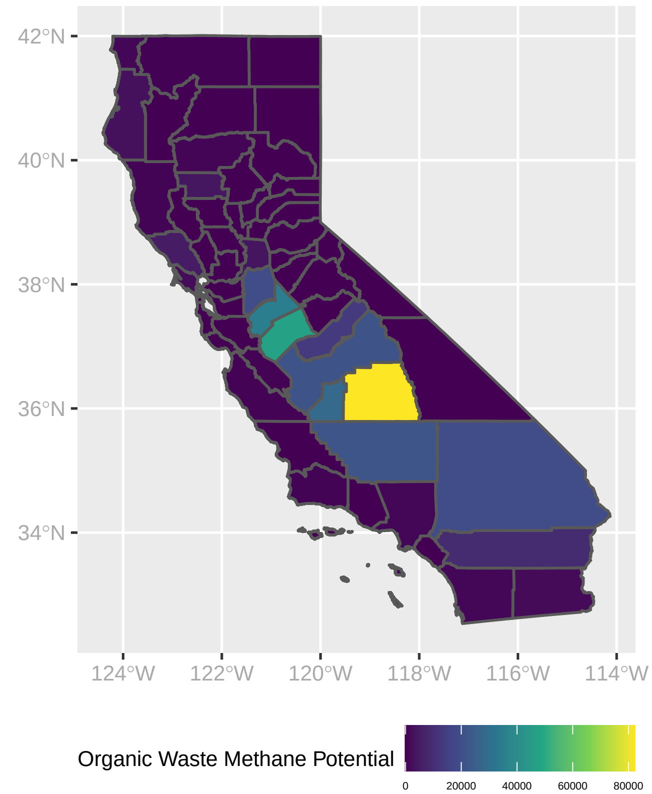
Industrial Organic waste, like wastewater, is highly correlated with population.With landfill-based methane, some counties in central CA, which do not appear to have a high population, have comparatively high methane generation potential. There may be some non-population



related factors in play.

The trend with animal-manure derived CH4 however substantially differs from the previous cases. Population does not appear to be a decisive factor.

Figure 7: Animal Manure Derived Methane Potential, CA (MT per year)



5 Analysis

5.1 Question 1: <insert specific question here and add additional subsections for additional questions below, if needed>

5.2 Question 2: Is there a relationship between methane generation potential and impoverished populations?

```
##
##  Pearson's product-moment correlation
##
## data:  svi_sf_join$TotalCH4t and svi_sf_join$E_POV
## t = 11.12, df = 56, p-value = 8.476e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.7271725 0.8959424
## sample estimates:
##       cor
## 0.8296405
```

```
##
## Call:
## lm(formula = svi_sf_join$TotalCH4t ~ svi_sf_join$E_POV)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -23578  -8007  -6799  -4377  74610
##
## Coefficients:
##                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)       6.684e+03  2.834e+03   2.358   0.0219 *
## svi_sf_join$E_POV 1.310e-01  1.178e-02  11.120 8.48e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 19840 on 56 degrees of freedom
## Multiple R-squared:  0.6883, Adjusted R-squared:  0.6827
## F-statistic: 123.7 on 1 and 56 DF,  p-value: 8.476e-16
```

```
##
##  Pearson's product-moment correlation
##
## data:  svi_sf_join$LFGCH4t and svi_sf_join$E_POV
```

```
## t = 9.3128, df = 56, p-value = 5.653e-13
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.6526255 0.8638755
## sample estimates:
##       cor
## 0.7795177
```

```
##
## Call:
## lm(formula = svi_sf_join$LFGCH4t ~ svi_sf_join$E_POV)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -24928  -3488  -1556  -1095  47103
##
## Coefficients:
##                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)       1.059e+03  1.700e+03   0.623    0.536
## svi_sf_join$E_POV 6.581e-02  7.067e-03   9.313 5.65e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 11900 on 56 degrees of freedom
## Multiple R-squared:  0.6076, Adjusted R-squared:  0.6006
## F-statistic: 86.73 on 1 and 56 DF,  p-value: 5.653e-13
```

```
##
##  Pearson's product-moment correlation
##
## data:  svi_sf_join$WWTPCH4t and svi_sf_join$E_POV
## t = 30.671, df = 56, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.9521271 0.9831025
## sample estimates:
##       cor
## 0.9715012
```

```
##
## Call:
## lm(formula = svi_sf_join$WWTPCH4t ~ svi_sf_join$E_POV)
##
## Residuals:
```

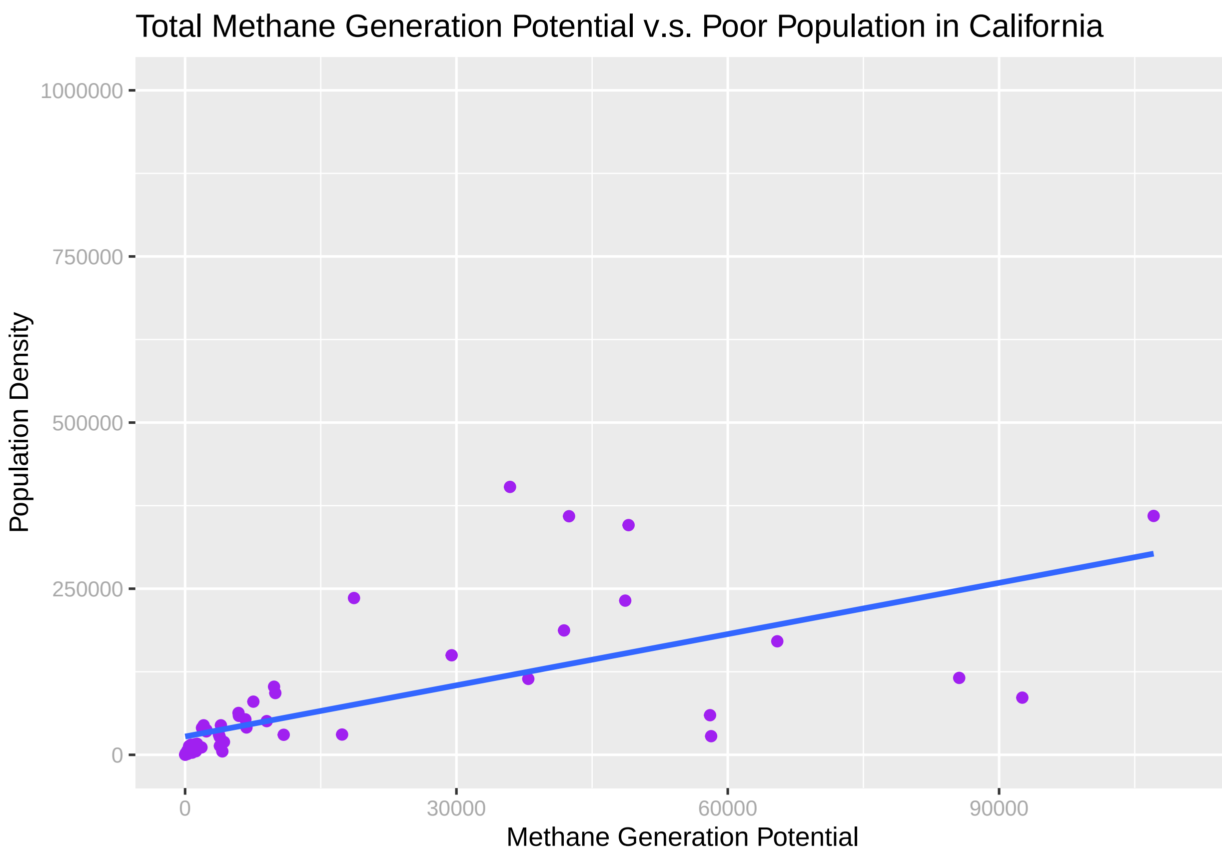
```
##     Min      1Q  Median      3Q     Max
## -8111.2  -525.9  -266.3   200.7  8372.5
##
## Coefficients:
##                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)       2.329e+02  2.977e+02   0.782    0.437
## svi_sf_join$E_POV 3.795e-02  1.237e-03  30.671   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2084 on 56 degrees of freedom
## Multiple R-squared:  0.9438, Adjusted R-squared:  0.9428
## F-statistic: 940.7 on 1 and 56 DF,  p-value: < 2.2e-16
```

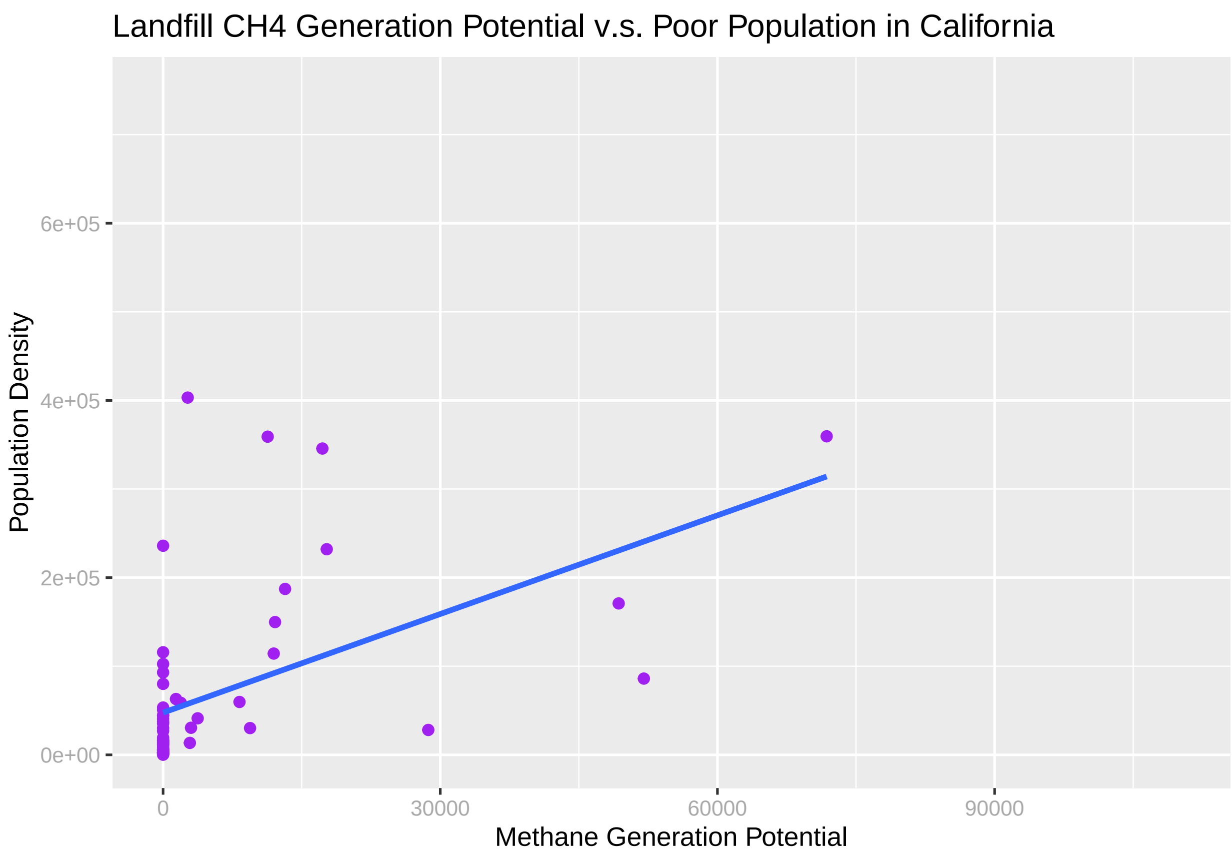
```
##
##  Pearson's product-moment correlation
##
## data:  svi_sf_join$OWCH4t and svi_sf_join$E_POV
## t = 34.256, df = 56, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.9612260 0.9863552
## sample estimates:
##       cor
## 0.9769612
```

```
##
## Call:
## lm(formula = svi_sf_join$OWCH4t ~ svi_sf_join$E_POV)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2379.5  -363.1  -195.7    96.0  4351.1
##
## Coefficients:
##                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)       1.895e+02  1.656e+02   1.144    0.257
## svi_sf_join$E_POV 2.359e-02  6.885e-04  34.256   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1160 on 56 degrees of freedom
## Multiple R-squared:  0.9545, Adjusted R-squared:  0.9536
## F-statistic:  1174 on 1 and 56 DF,  p-value: < 2.2e-16
```

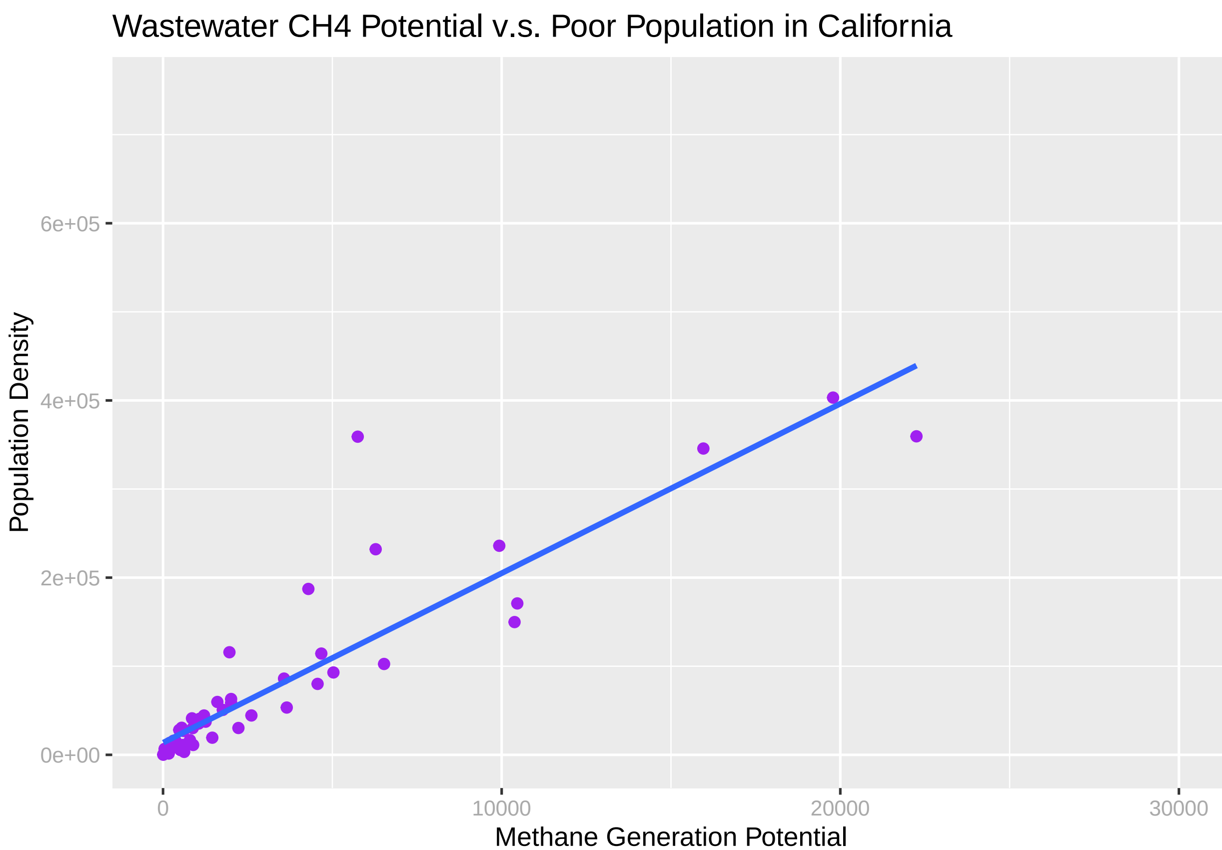
```
##
##  Pearson's product-moment correlation
##
## data:  svi_sf_join$AMCH4t and svi_sf_join$E_POV
## t = 0.43506, df = 56, p-value = 0.6652
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  -0.2033043  0.3116628
## sample estimates:
##        cor
## 0.05803922
```

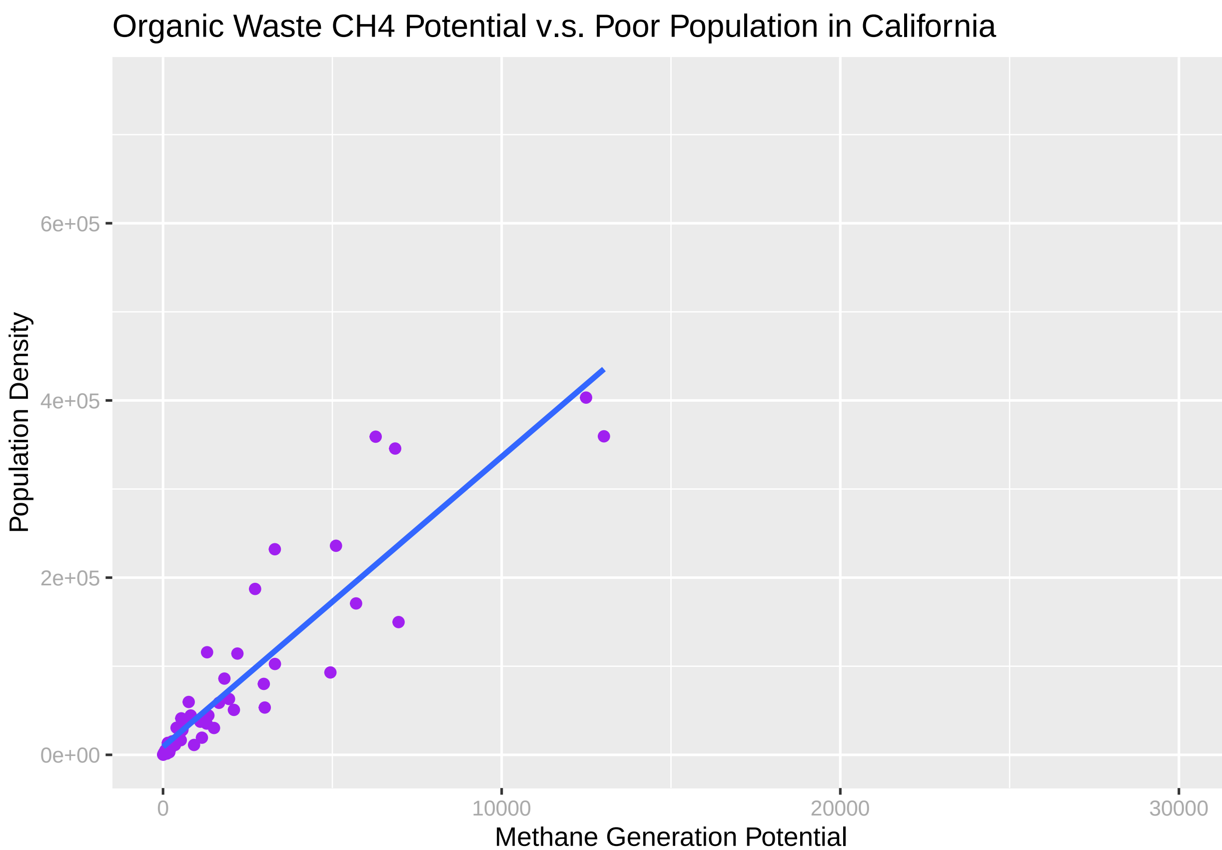
```
##
## Call:
## lm(formula = svi_sf_join$AMCH4t ~ svi_sf_join$E_POV)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -10228  -5295  -5206  -3608  76704
##
## Coefficients:
##                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)       5.202e+03  2.023e+03   2.572   0.0128 *
## svi_sf_join$E_POV 3.658e-03  8.408e-03   0.435   0.6652
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 14160 on 56 degrees of freedom
## Multiple R-squared:  0.003369,   Adjusted R-squared:  -0.01443
## F-statistic: 0.1893 on 1 and 56 DF,  p-value: 0.6652
```

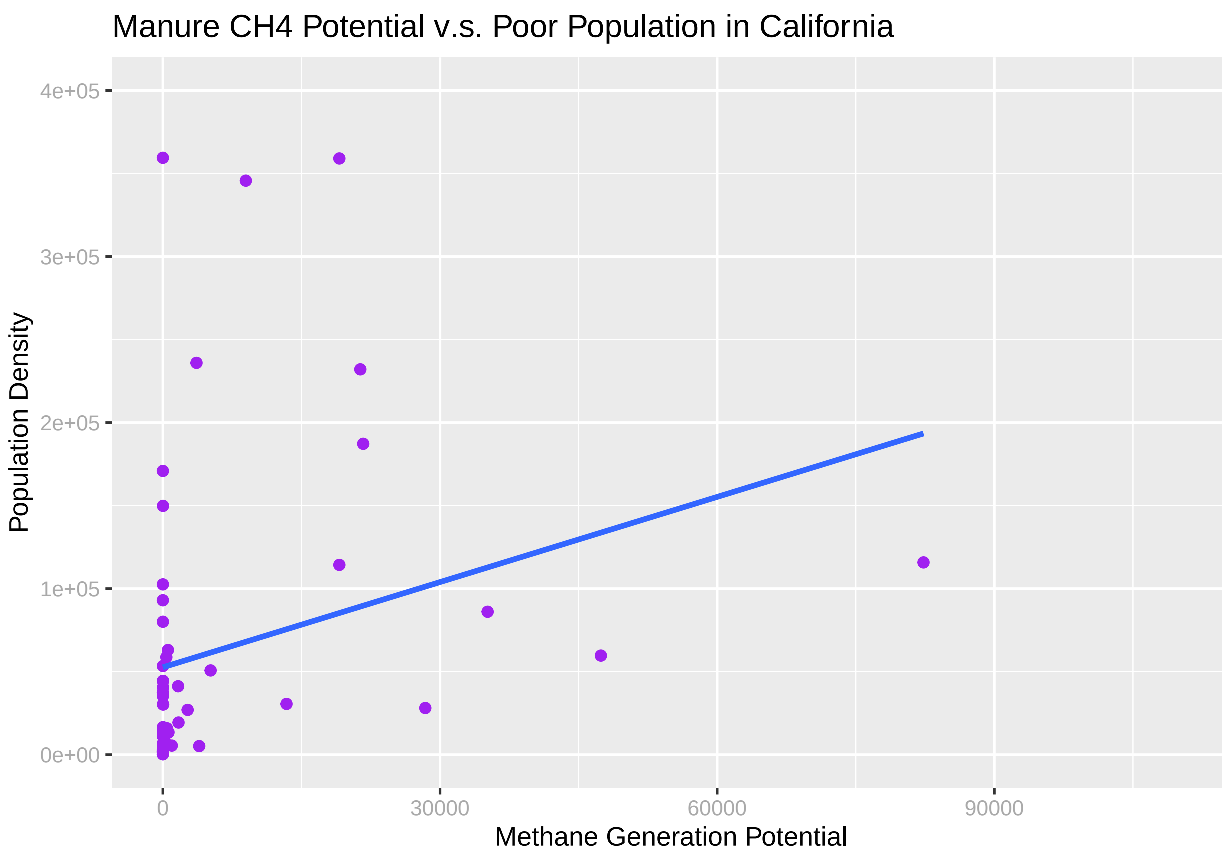

Total Methane Generation Potential v.s. Poor Population in California
Population Density
1000000
750000
500000
250000
0
0
30000
60000
90000
Methane Generation Potential



Landfill CH4 Generation Potential v.s. Poor Population in California
Population Density
6e+05
4e+05
2e+05
0e+00
0
30000
60000
90000
Methane Generation Potential


Wastewater CH4 Potential v.s. Poor Population in California
Population Density
6e+05
4e+05
2e+05
0e+00
0
10000
20000
30000
Methane Generation Potential


Organic Waste CH4 Potential v.s. Poor Population in California
Population Density
6e+05
4e+05
2e+05
0e+00
0
10000
20000
30000
Methane Generation Potential


Manure CH4 Potential v.s. Poor Population in California
Population Density
4e+05
3e+05
2e+05
1e+05
0e+00
0
30000
60000
90000
Methane Generation Potential

6 Conclusion

Overall, the analysis conducted show that biogas generation potential across counties in California is positively correlated with the population density. This implies that the higher the population in a specific area, the higher the biogas generation potential. However, the analysis also recognises that generation potential and correlation with population density varies according to the biomass source across counties. As such, results show that animal based methane appeared to be less correlated with population. Assumptions that best explain this result are that more animals will contribute to animal-based biomass and that human habitation is often less where animal population is dense. Results of our analysis also show that the potential of landfill-based biogas was not limited to densely or sparsely populated areas, while organic waste and waste water represented the most significant sources of biogas generation potential across California.

Future analysis can focus on improving the model presented in this report by eliminating some outliers and using more recent datasets. This study made use of older data sets because those were the ones most recently made available on open and credible data portals. Other areas of future analysis include exploring the level and process of utilization of California's biogas generation potential, as well as how utilization can be scaled. For example, the potential of leveraging the biogas generation potential by enabling counties with lower generation potentials to tap into the resources for those with higher generation.This also includes scoping the potential to utilize biogas energy for base load power or peaking, using various analyses including a cost-benefit analysis.

7 References

<add references here if relevant, otherwise delete this section>