Methane Emissions Status for Manure Management Across the USA

https://github.com/sultzerk/SultzerSwit_ENV872_EDA_FinalProject.git

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1 Rationale and Research Questions

For this project, the area of interest was manure management and greenhouse gas emissions created by livestock. The initial dataset considered methane, nitrous oxide, and carbon dioxide. Research revealed that "livestock are reckoned to be responsible for up to 14% of all greenhouse emissions from human activities" (Watts, 2019). Considering the magnitude of industrial agriculture, we wanted to see how livestock factored into emissions. When examining different emission types, this study focused on methane because it is a very detrimental greenhouse gas, trapping heat at a rate 25 times greater than carbon dioxide (Watts, 2019). Pertaining to this study, methane gas is produced by the anaerobic decomposition of manure stored or treated. Research and data availability led to these two research questions:

- Question 1: Have methane emissions changed over time?
- Question 2: Does the average methane emission rate differ between livestock?

2 Dataset Information

The dataset used for this project was retrieved from the Food & Agriculture Organization of the United Nations (FAO), specifically from FAOSTAT. FAOSTAT provides free access to statistics pertaining to agriculture for over 245 countries. This analysis focused on emissions in the United States. Emissions were computed following the 2006 Guidelines for National GHG Inventories of the Intergovernmental Panel on Climate Change (IPCC). Methane emissions were estimated at the country level by multiplying the number of livestock in heads by the IPCC emission factors (FAO, 2020).

2.1 Data Wrangling Steps

The first step of data wrangling was viewing a summary of the full raw data to determine how to best filter it for our research question needs.

Next, to make the dataset more manageable, specific columns to retain were filtered. The main variable of interest, methane emissions, was included, and we only focused on historical data.

In order to effectively conduct a time series analysis, we grouped by years and summarized the mean methane emissions for all livestock.

Next, the pivot_wider function was used to separate the livestock from the same column into separate variables with their associated methane emission values. This allowed separate time series to be run on the desired livestock.

2.2 Data Structure

Table 1: Structure of Variables of Interest in Analysis

Variables	Units	Ranges	Central Tendencies
Total Methane Emissions	gigagrams (gg) CH4	0-670.9518	102.2441
Item	Animal	13 animals: asses, cattle, chicken, ducks, goats, horses, mules, sheep, swine, turkey	
Time	years	1980-2018 (predicted 2030 and 2050)	

3 Exploratory Analysis

When considering our first research question, it is apparent there is a general increasing trend over time (Figure 1). Analysis focused on investigating whether this trend was significant. There is a sharp decrease in methane emissions at the beginning of the dataset (~1980-1985) that might warrant investigation later.

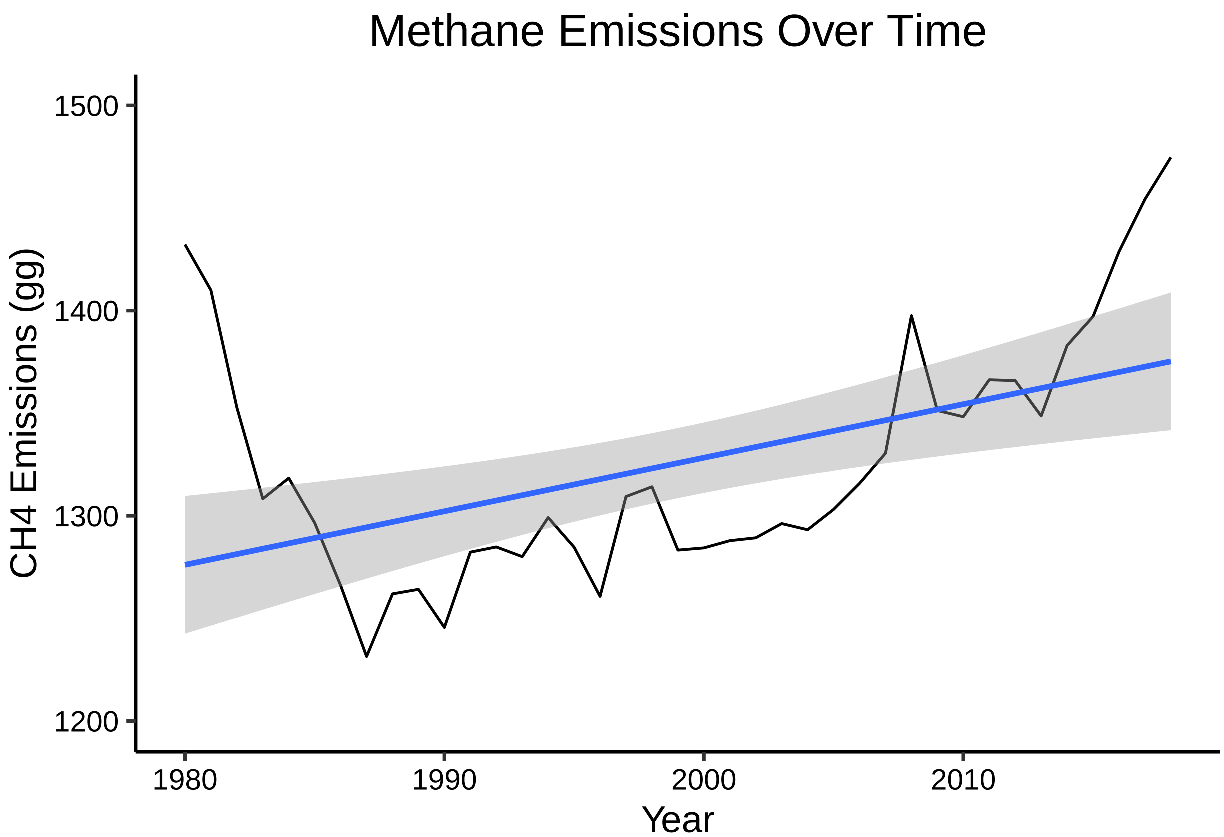

Figure 1: Methane Emissions Over Time

We also visualized total methane emissions for each animal from 1980-2018 (Figure 2). It is evident that dairy cattle and market swine had the highest emission rates. Analysis focused on investigating whether these two livestock had significant emission trends.

Our second research question focused on the different emission rates between animals. When exploring a boxplot showing the different rates (Figure 3), it is suspected that there might be statistical differences. For example, dairy cattle and market swine had much higher rates than others. Analysis focused on investigating which rates were statistically different from others.

Additionally, to understand how the number of animals can influence total methane emissions, we visualized how head of animals differed between livestock category. Total livestock was visualized in Figure 4. To control for the the higher proportion of chickens, we removed them from the plot in Figure 5.

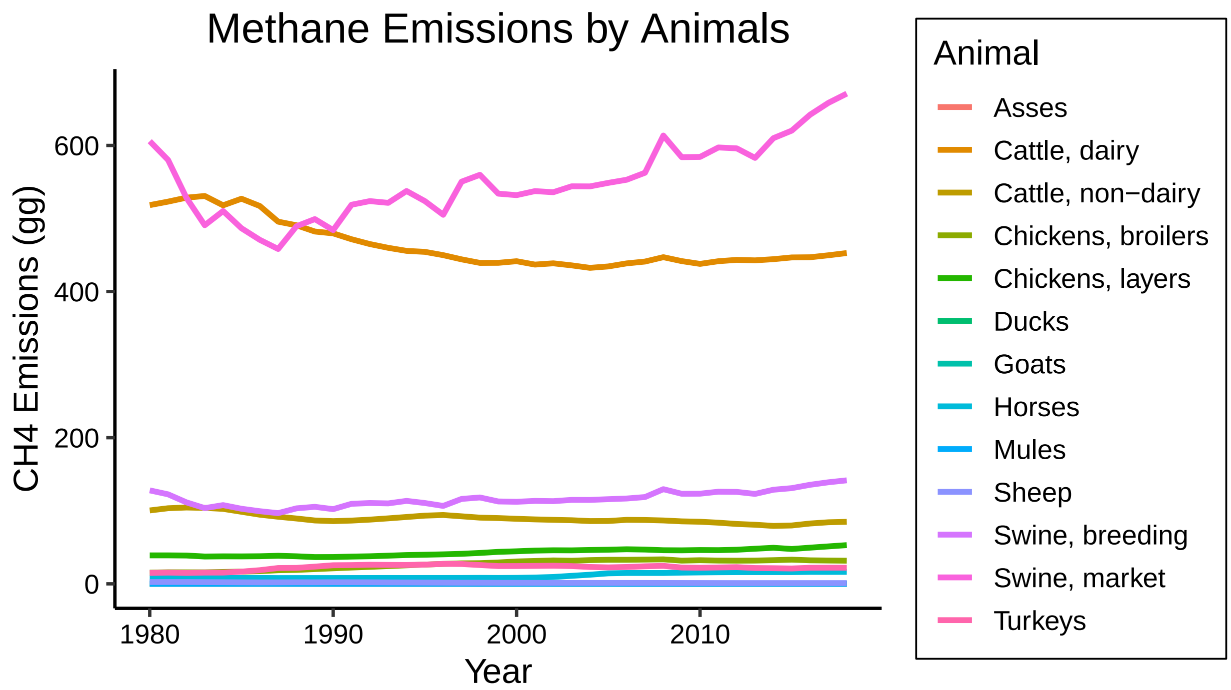

Figure 2: Methane Emissions by Animals

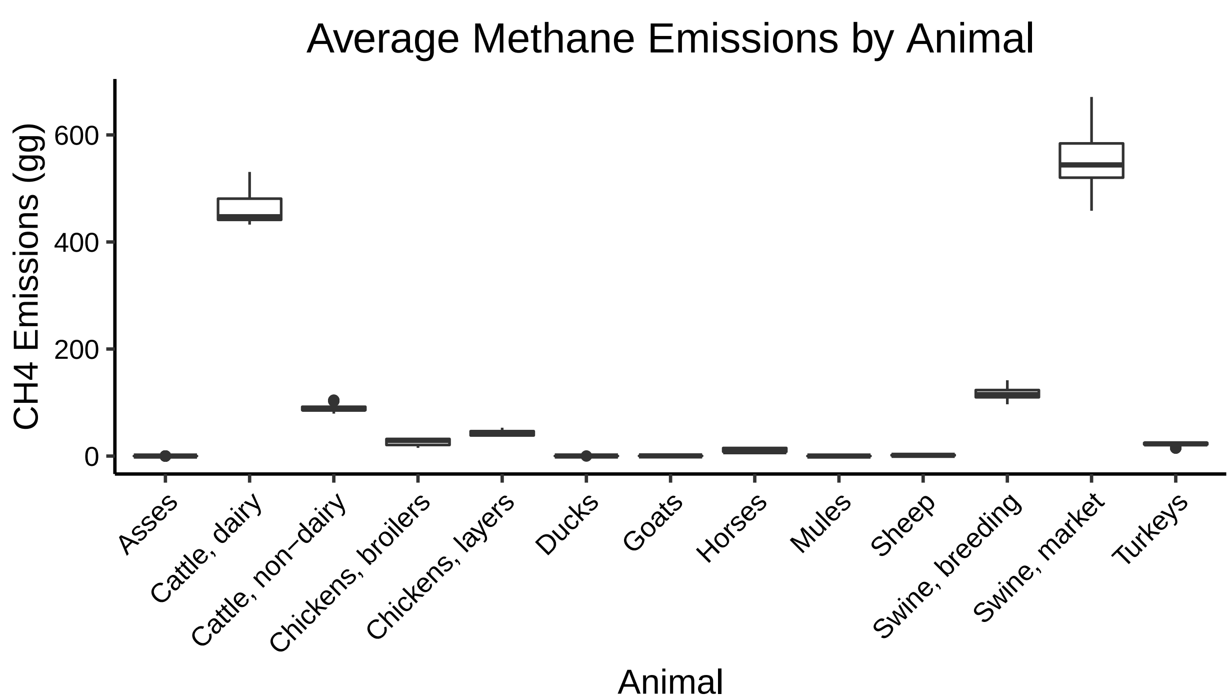

Figure 3: Average Methane Emissions by Animal

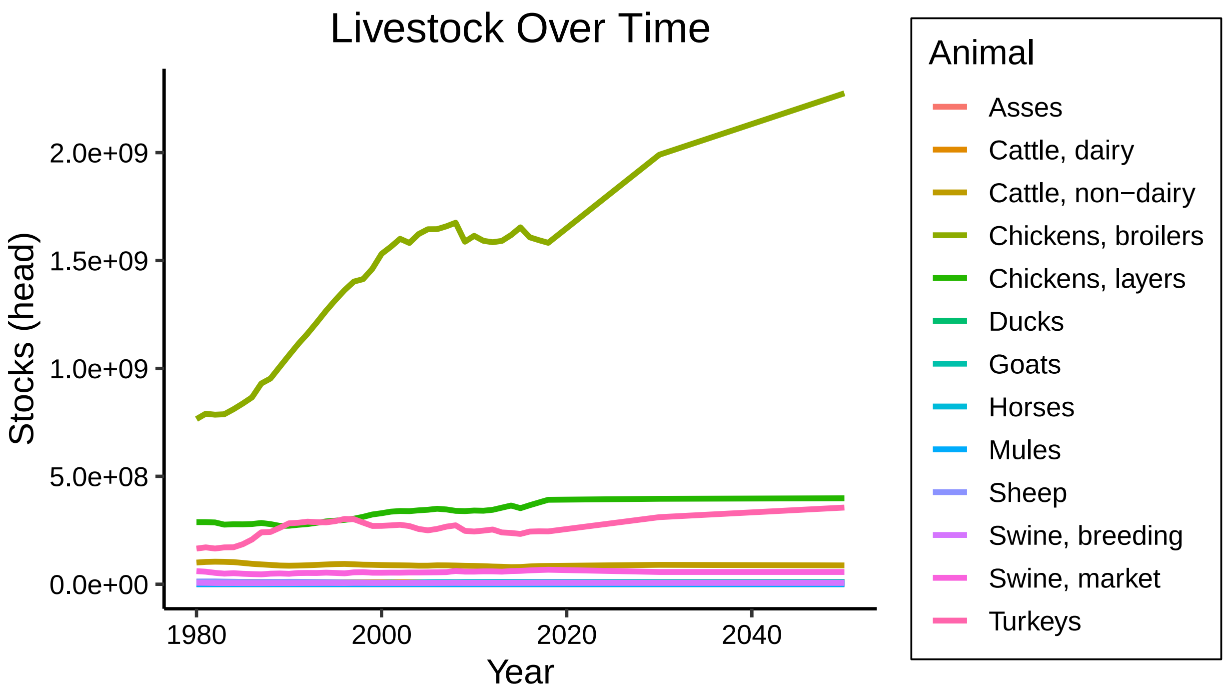

Figure 4: Livestock Over Time

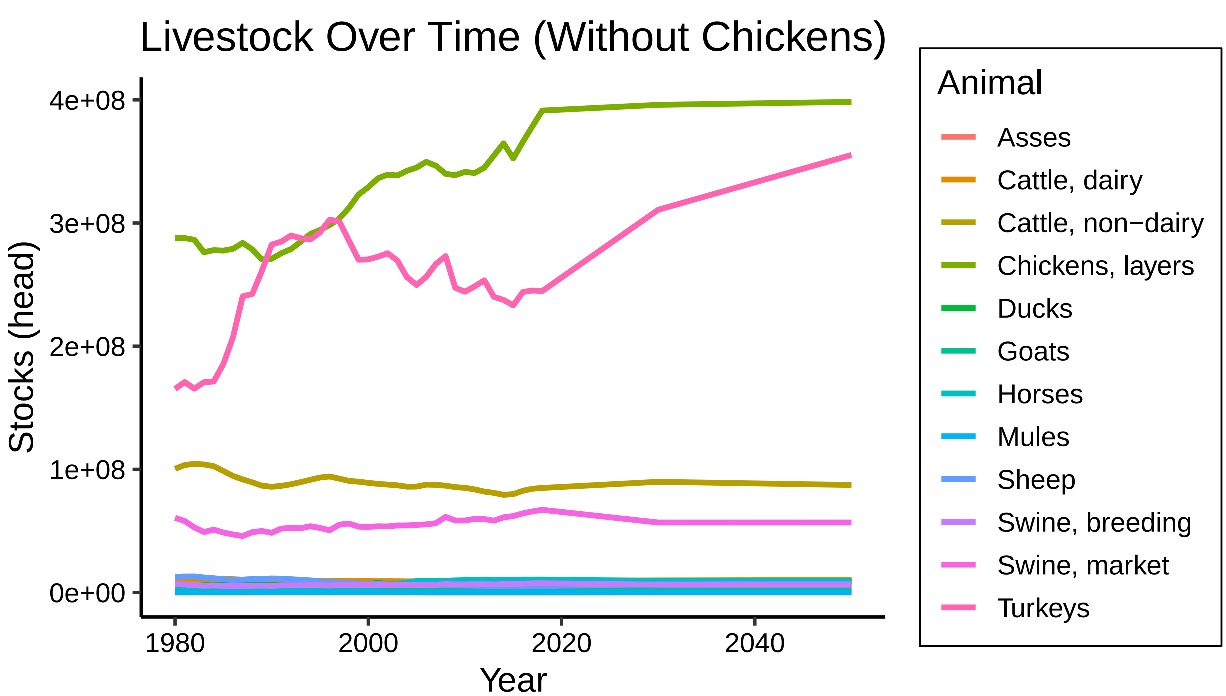

Figure 5: Livestock Over Time (Without Chickens)

4 Analysis

4.1 Research Question 1

To answer the first research question, the overall methane production for all livestock was evaluated with a time series analysis. Since methane was only calculated once a year, there was no seasonality to the data, and the time series was not able to be decomposed. However, a Mann-Kendall test was performed, which confirmed that there was a significant trend (p-value = 0.00011). From data exploration, it can be seen that overall the trend is increasing: methane emissions between 1980 and 2018 have increased across 13 livestock in the United States (Figure 1).

From visualizing the total emission rates, dairy cattle and market swine showed the highest emission rates. A time series analysis was conducted to determine if there was a significant trend. The Mann-Kendall test confirmed that a significant trend was present for both animals (p-value for cattle < 0.001, p-value for swine < 0.001). Dairy cattle (Figure 6) had an overall negative trend in emissions while market swine had a positive trend (Figure 7).

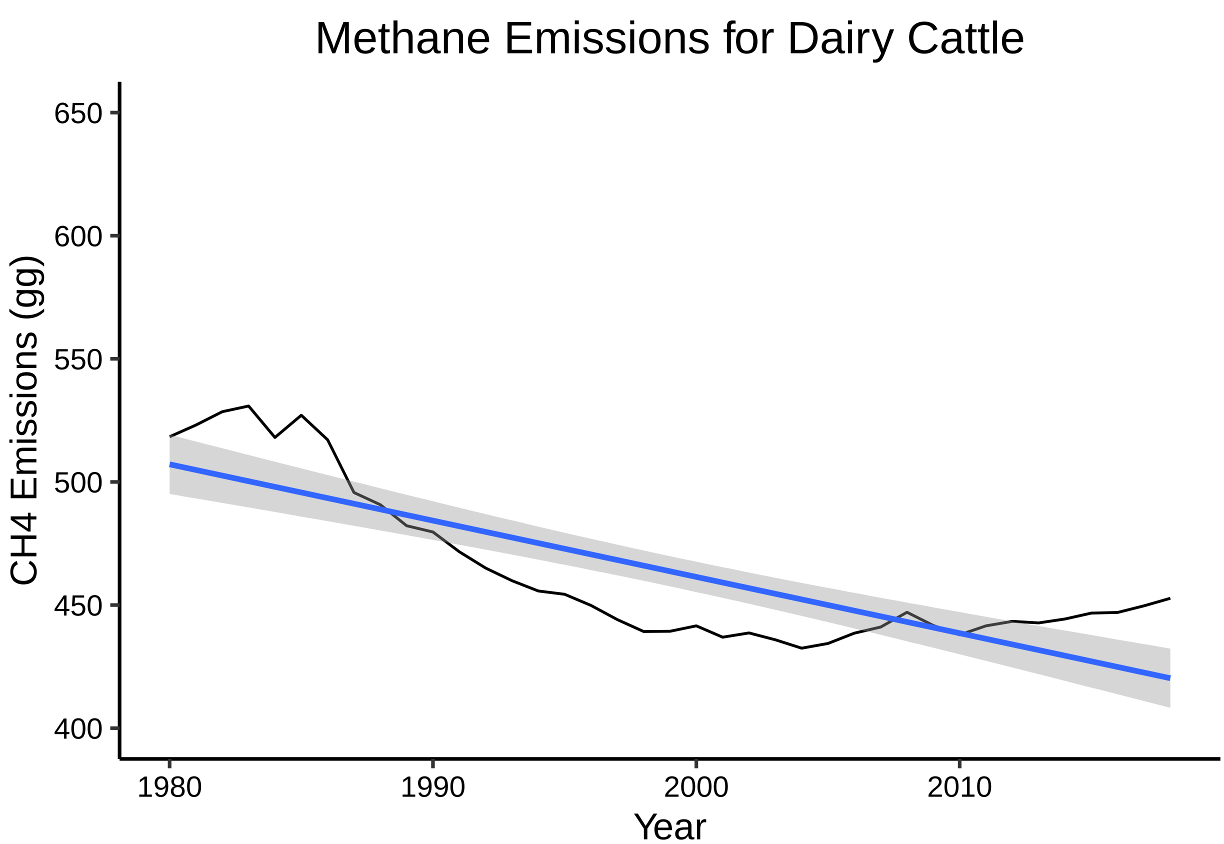

Figure 6: Methane Emissions of Dairy Cattle

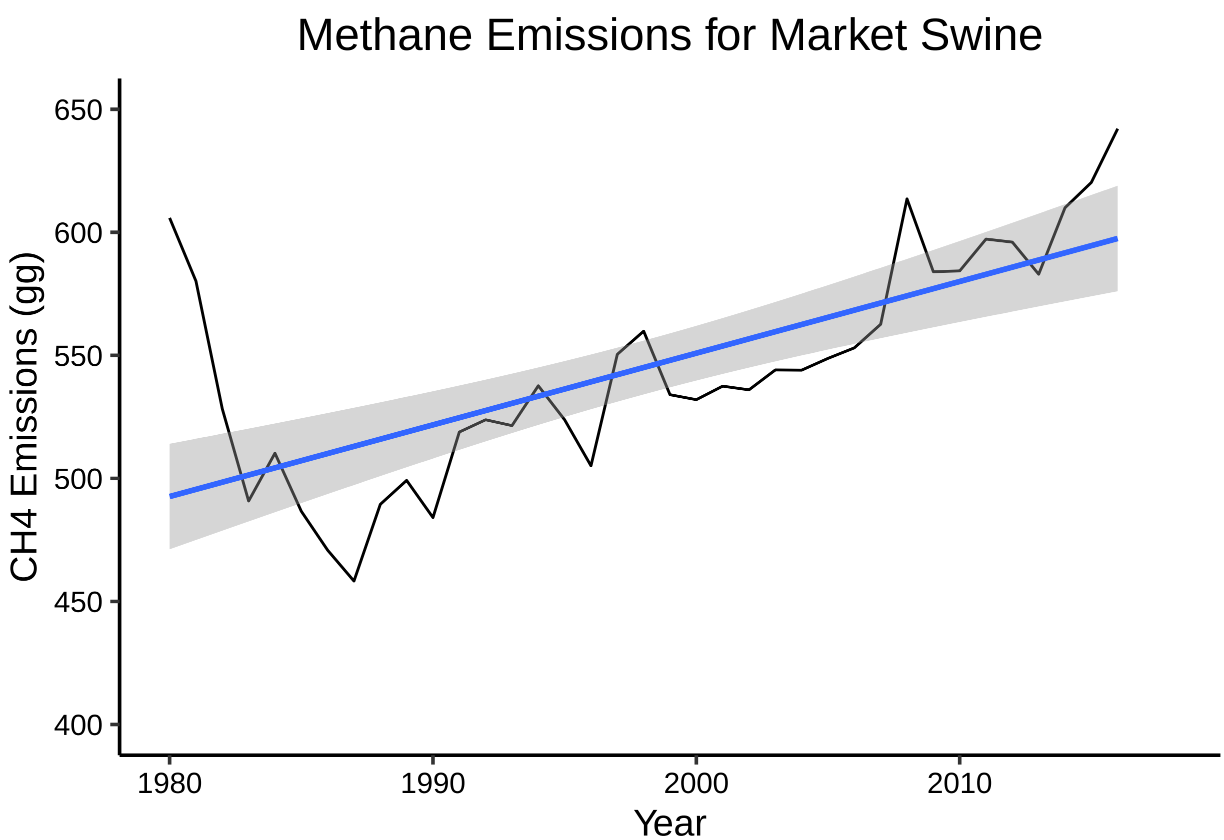

Figure 7: Methane Emissions of Market Swine

4.2 Research Question 2

To answer the second research question, a one-way ANOVA test was conducted to evaluate whether the different animals, on average, have different emission rates. To begin this process, the emission rates were checked for normality. The important assumption for generalized linear models is the normality of residuals. The Shapiro-Wilk test showed that, of the 13 livestock, only ducks, breeding swine, and market swine were normally distributed. When viewing a Q-Q plot, once can see the data does not follow a normal distribution (Figure 8). Lastly, Bartlett's test for homogeneity of variances was run, which revealed that the variances were not equal ($p < 0.001$). Even though all of the tests for normality failed, we proceeded on with the analysis.

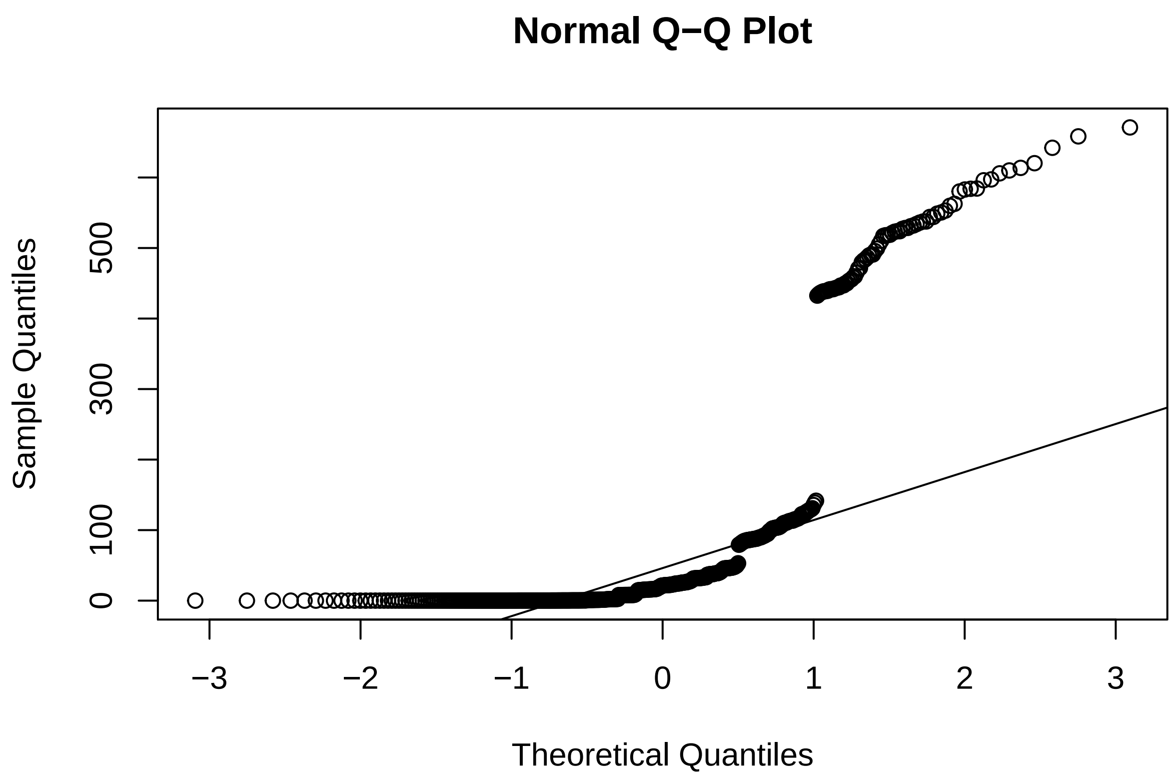

Figure 8: QQ plot

Analysis then revealed that there was a significant difference in mean emissions among animals (ANOVA; F: 4394 on 12 and 494 DF,$p<0.05$). But which animals had different means? A Tukey's HSD test showed which means were different between the animals. Groupings for pair-wise relationships were extracted, where the letters in Figure 9 represent the different groupings. Thus, asses, ducks, goats, mules, and sheep all had statistically similar emission rates (Figure 9). Most of the other animals, such as market swine and dairy cattle, have their own grouping.

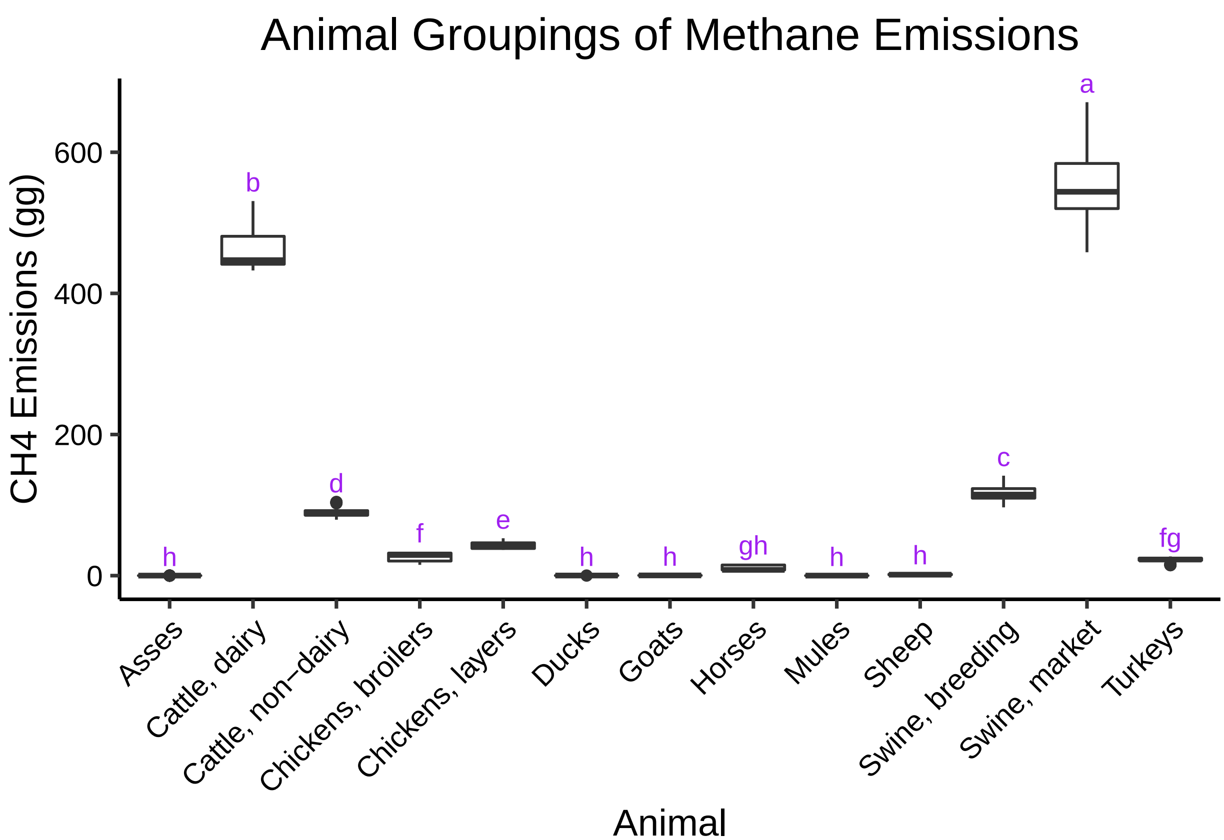

Figure 9: Animal Groupings of Methane Emissions

5 Summary and Conclusions

With approximately a tenth of all methane emissions coming from manure collections ponds, amounts of manure must be considered and properly managed (Horn, 2018). To summarize, this project investigated how methane emissions changed over time and how they differed between livestock. Analysis revealed a significant upward trend in emissions over time across all selected livestock in the USA. The animals with the highest emissions, dairy cattle and market swine, exhibited significant trends with dairy cattle decreasing and market swine increasing from 1980-2018. A one-way ANOVA test confirmed that there were significant differences in methane emission rates between animals. The Tukey's HSD test resulted in 8 groups, with asses, ducks, goats, mules, and sheep being paired in the lowest emitting group. Dairy cattle and market swine had their own groups and were the highest emitters.

Further analysis could include researching the reasons behind the decrease in total methane emissions between ~1980-1985. Within this dataset, additional research avenues include assessing trends in other green house gases, including nitrous oxide and carbon dioxide emissions. Our research did not include methane emissions from non-manure sources, such as cattle burping. However, recent strides in methane reduction research include innovative solutions to limiting methane produced and emitted by livestock. Such methods include burp backpacks and vaccinations for reducing methane producing microbes (Bustamante, 2008).

6 References

Bustamante, J. (2008, July 8). Cow burps help Argentines study climate change. Reuters. https://www.reuters.com/article/us-argentina-cows/cow-burps-help-argentines-study-climate-change-idUSN0830630220080709.

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