**Project check-in # 1: Preliminary findings Report**

# 1. Preliminary Analysis

**Data Description:** The dataset is of the chemical characterization of 88 food waste substrates with specific importance on the principle nutrient components of the substrate i.e. carbohydrates, proteins, and lipids (fats). A snapshot of the dataset is shown below. Each food waste item, heretofore referred to as ‘substrate’, is assigned to a group based on rough commonalities of the substrate’s characteristics or what would be generally considered a food group in modern society i.e. products containing milk are all assigned to the group ‘Dairy Products’ while products containing animal flesh (non-fish) are assigned the group ‘Meat Products’. There are 15 groups across the 88 food substrates.

In the proposed analysis we will utilize the MATLAB based Anaerobic Digestion Model #1 (ADM1) to estimate the amount of biogas (methane) that can be produced from each food substrate. The model requires that the mass of the principal nutrients be provided, which can be determined by the characteristics listed in the table. Briefly: the amount of substrate material is determined by ‘TS.Perc’ or total solid percentage i.e. the mass of material that is not water, from the total solid percentage we then take the volatile solids percentage (VS.Perc) which is the fraction that can engage in anerobic digestion. Within the volatile solids we can then fraction out the principal nutrients (carbohydrates, proteins, and fats) by their listed percentages. The final mass of each of these will be what is fed into the model.

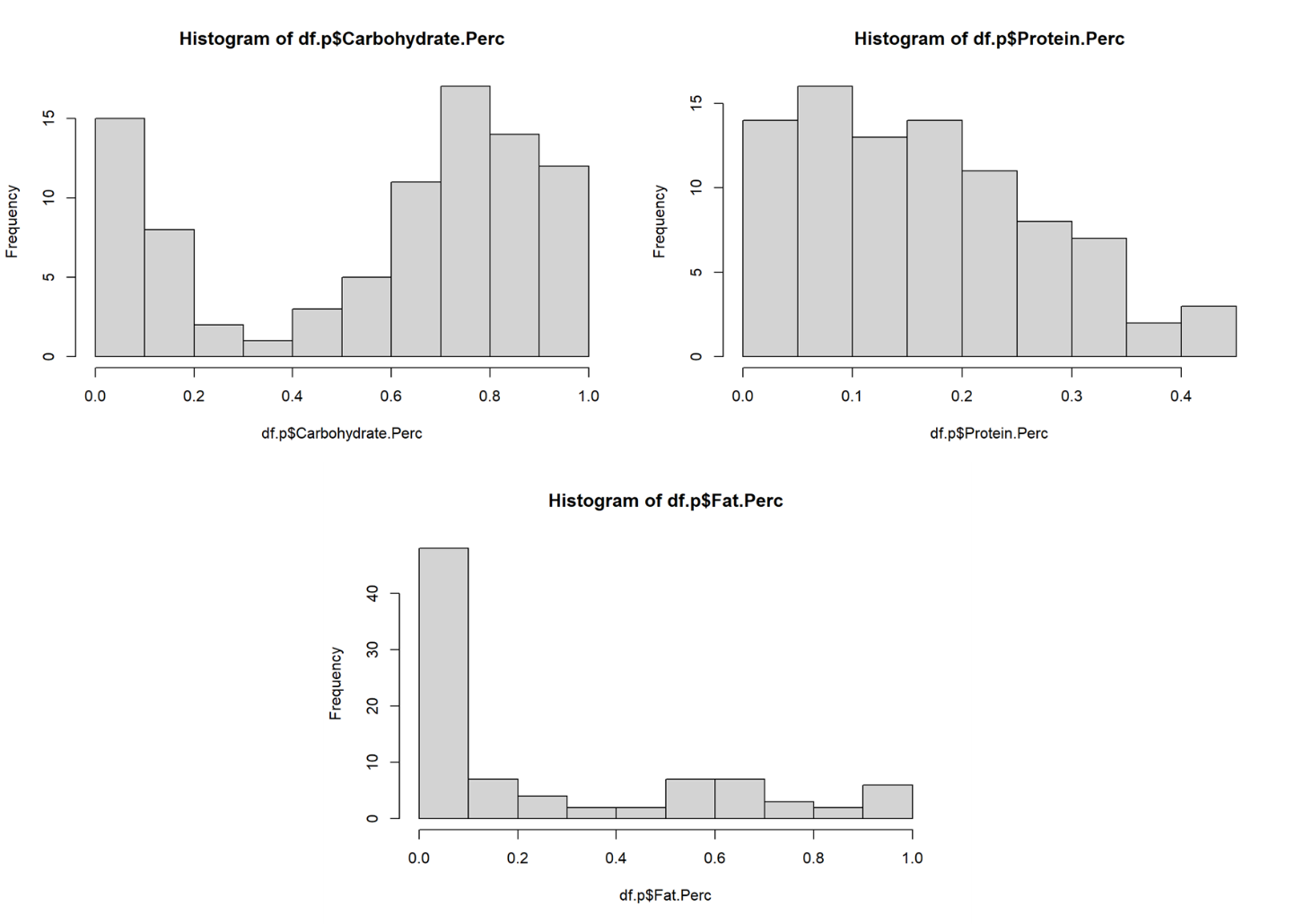
A screenshot of a computer program

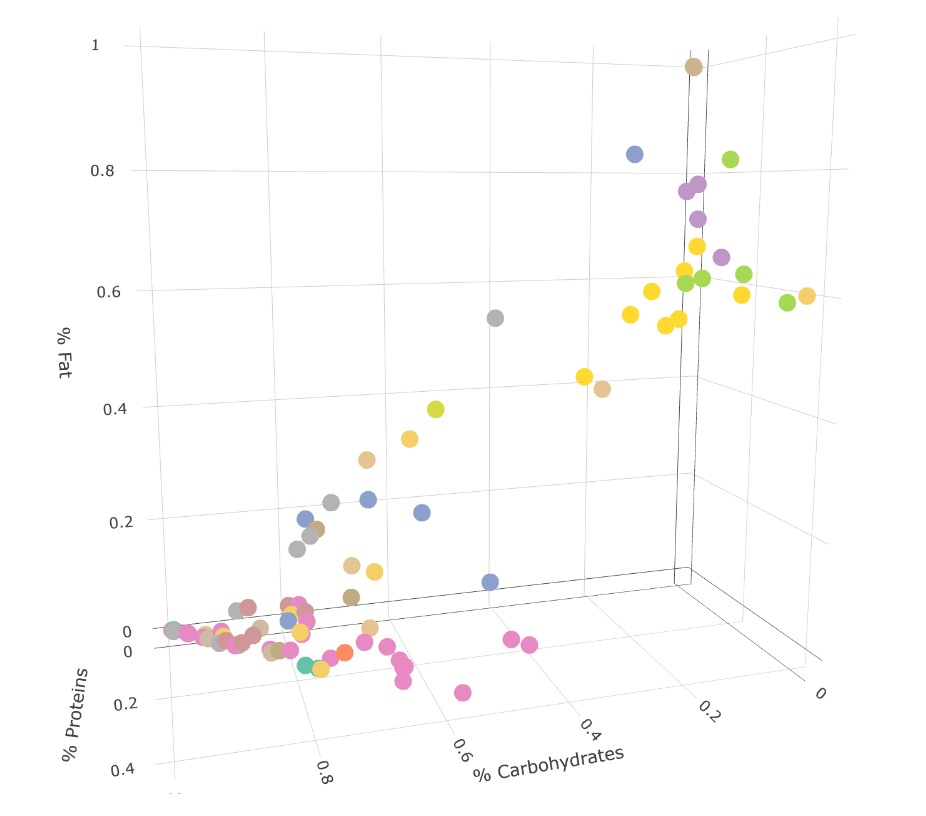
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**Initial Analysis:**

**Carbohydrate, Proteins, Fats Percentages**

To better understand the variability of each of the principal nutrients in the dataset, we developed histograms based on their percentages. We see that carbohydrates generally dominate the overall mass of the substrates with the majority of foods being >40% carbohydrates (by mass of VS). Proteins in general occupy a smaller percentage of the VS mass with the majority of foods having <20% proteins. In comparison, more than half the food substrates have 0-10% fats marking them as the lowest represented nutrient by mass with notable exceptions that are fat dominant such as oils, grease, and fatty dairy products.



To obtain more resolution on the overall fractionation of each of the principal nutrients we also plotted them in 3D space with each axis representing a % of the three nutrients as seen below. Due to the limitations of the program’s color palette it is difficult to infer distinctive groupings of the foods however we can see that the greatest percentage of food substrates is in the bottom left quadrant (blue circle, non-statistically based) i.e. possessing high carbohydrates, mid proteins, and low fats which corresponds to the observations of the histograms. A secondary cluster in the upper right (red circle, non-statistically based) describing low carbohydrates, mid proteins, and high fats is also in the spread.

**Mono-feed Biogas Output**

The primary output that will address our research questions is the production of methane biogas; and we are interested in both the rate and the overall quantity produced. Using the default parameters of the ADM1 model we ran an initial test under a batch feed (sequential i.e. a feed every n days) and a continuous feed regime. The model outputs the biogas as a rate (liters of biogas/day) over the reactor time (measured in days). The output for the two studies is below grouped by food category (table below).

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| Food Classification | Symbol Used |
| Dairy Product | DP |
| Fats, oils, and grease | FOG |
| Ice Cream | IC |
| Fruit and Vegetable | FAV |
| Confectionary (canned good) | CCG |
| Cereals and Cereals Products | CP |
| Bakery Wares | BW |
| Meat and Meat Products | MP |
| Fish and Fish Products | FP |
| Eggs and Egg Products | EP |
| Sweeteners and Sweet Goods | SSG |
| Sauces, Spices, and Soups | SS |
| Beverages | BEV |
| Ready to eat food or restaurant waste | REWE |
| Other Expired Food | OT |

**Batch Feeding**

Briefly the batch feeding consisted of feeds of 1000 grams of total mass for all substrates. The results are output as a rate (q\_gas Liters/day) each day of the 100 day reactor. The output of the batch feeding (occurring day 0, 10, 30, 50, and 70) shows a consistent pattern across all food substrates but the magnitude varies both within and across food groups. The most consistently highly productive food groups are cereal products (CP) and bakery wares (BW) likely owing to their high percentage of carbohydrates. Meat products (MP), sweeteners and sweet goods (SSG), and ready to eat foods (REWE) are also highly productive but have greater variability across the foods within that category. Future analysis will investigate the chemical differences between foods within each group to identify possible associations explaining higher or lower production. An important aspect to remember for this analysis is that it utilized a base total mass (includes water and inerts) for each food item, which while more realistic in that food waste is typically presented as a bulk without consideration to the volatile solids, this does present great variability in the relative amounts of available material. For example, 1000 grams of bread has little water or inerts thus the overall VS amount is higher than butter which contains a larger amount of moisture. Normalizing the batch feed will be another aspect of consideration for future analysis.

A graph of different colored lines

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**Continuous Feed**

For the continuous feed analysis, the mass of feed was normalized to be a consistent total volatile solid amount of 300 grams and presented to the model as a constant daily rate of 300 grams of VS per Liter per day. This was done over the 100-day reactor timeline. The results are output as a rate (q\_gas Liters/day) each day of the 100-day reactor. Unlike the batch feed the reactors output an exponential growth pattern with a plateau. This can be thought of as the maximum rate of production for each food substrate under the given conditions. There appears to be lower variability between and across food groups than was observed in the batch reactor, which may be due to the fact that the substrate is not limited as it is in the batch reactors. The general range for production rate for all food substrates is between 700-1250 Liters of biogas/ day which may be lower than the batch feed but does incorporate a lower amount of substrate and shows stability which could be more desirable overall in a real world scenario.

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**Data Issues**

We currently have no issues with the data itself, our primary considerations that will require rectification are in how we treat the data specifically how we normalize it or scale to allow us to make direct comparisons. For example, in our preliminary batch and continuous feed analysis we utilized a bulk feed based on total mass for the batch analysis and a feed rate based on total VS in the continuous analysis. Neither method is necessarily incorrect they simply represent different scenarios and address different questions. However for the future of the analysis it would be useful to be able to compare the batch and continuous feed scenarios directly, requiring a common unit.

One way we may address this is to work from a total system mass, which is to say that over the 100 day period the same total mass of VS is introduced into the system whether it is done in pulses in the batch or over time in the continuous feed.

# 2. Approach

# 3. Next Steps

# 4. Literature Review

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| **Citation:**  De Jonge, N., Davidsson, Å., la Cour Jansen, J., & Nielsen, J. L. (2020). Characterisation of microbial communities for improved management of anaerobic digestion of food waste. *Waste Management*, *117*, 124-135.  **Summary:** Unlike other conventional waste streams such as wastewater or manure, food waste streams are physiochemically variable and complex, potentially resulting in a diverse microbial community that is unique to each food waste stream. This would make predicting and modelling anaerobic digestion difficult. This paper researched 18 food waste based reactors under different operational parameters and investigated the microbial communities. They found that indeed, no one microbial community was consistent in food waste however, food waste was more plentiful in key microbial members that aid in anaerobic digestion such as syntrophic acetate oxidizing microbes.  **Relevance:** Microbes are the primary driver of anaerobic digestion in a bioreactor and their activity defines the production of biogas. Most models utilize a general collection of microbial processes to estimate biogas production which is applicable to waste streams that are consistent. However, food waste streams are highly variable thus understanding the microbial composition is integral to accurately predicting biogas production and yet understudied. As this study shows, there actually may be highly beneficial (in regards to anerobic digestion) microbes contained in certain food wastes that could be optimized for better biogas production  **Further References:**  Lee, J., Kim, E., Han, G., Tongco, J.V., Shin, S.G., Hwang, S., 2018. Microbial communities underpinning mesophilic anaerobic digesters treating food wastewater or sewage sludge: A full-scale study. Bioresour. Technol. 259, 388–397. https://doi.org/10.1016/j.biortech.2018.03.052. Lee, J., Shin, S.G., Han, G., Koo, T., Hwang, S., 2017. Bacteria and archaea communities in full-scale thermophilic and mesophilic anaerobic digesters treating food wastewater: Key process parameters and microbial indicators of process instability. Bioresour. Technol. 245, 689–697. https://doi.org/10.1016/j. biortech.2017.09.015. |
| **Citation:**  Dhar, H., Kumar, P., Kumar, S., Mukherjee, S., & Vaidya, A. N. (2016). Effect of organic loading rate during anaerobic digestion of municipal solid waste. *Bioresource Technology*, *217*, 56-61.  **Summary:** The organic loading rate (rate of VS introduced into a reactor) is highly determinant of the overall reactor function and can be optimized on a per reactor and per substrate bases to achieve optimum biogas production. In this paper different loading rates of the organic fraction of municipal solid waste were trialed in a laboratory-scale digester. They found that increased loading rate resulted in increased biogas production however the increases in rate quickly decreased as loading rate increased demonstrating the system maximum.  **Relevance:** Loading rate is a key parameter in reactor production and can easily be over or under estimated especially when the substrate is less known. Having empirically defined benchmark values will aid us by providing benchmarked realistic values that can be trailed in the ADM1 model to give us more realistic results  **Further References:**  Chen, Y., Cheng, J. J., & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: a review. *Bioresource technology*, *99*(10), 4044-4064.  Razaviarani, V., & Buchanan, I. D. (2014). Reactor performance and microbial community dynamics during anaerobic co-digestion of municipal wastewater sludge with restaurant grease waste at steady state and overloading stages. *Bioresource technology*, *172*, 232-240. |
| **Citation:**  Agency USEP (2014) Food Waste Management in the United States. Office of Resource Conservation and Recovery. Available at [https://www.epa.gov/sites/production/files/2016-12/documents/food\_waste\_management\_2014\_12082016\_508.pdf. Accessed 21st Jan 2021](https://www.epa.gov/sites/production/files/2016-12/documents/food_waste_management_2014_12082016_508.pdf.%20Accessed%2021st%20Jan%202021)  **Summary:** This report is a summary of the food waste management practices in the United States circa 2014. It outlines the mechanisms of food waste reduction from donation to composting by state and by year from 2004-2014. It also touches upon policies that have impacting food waste management in the decade of analysis.  **Relevance:** While a decade old it still touches on the fundamentals of the purpose of this research which is to reduce the amount of terminal food waste (transported to landfill without additional purpose). Thinking about this research and analysis in a larger context is valuable in understanding the impact that alternative food waste protocols can have in the overall waste stream and can also identify specific states or locals where outcomes of this research may be most valuable.  **Further References:**  U.S. EPA Region 1. 2013. Anaerobic Digestion of Food Waste in New England Summer 2013 Report. Revised 2-9-2015. <http://www.ct.gov/deep/lib/deep/compost/compost_pdf/ad_of_food_waste_in_new_england.pdf>  Platt, B.; Goldstein, N. 2014. State of Composting in the U.S. BioCycle 55(6): 19. http://www.biocycle.net/2014/07/16/state-of-composting-in-the-u-s/. Accessed March 2016 |
| **Citation:**  Meegoda, J. N., Li, B., Patel, K., & Wang, L. B. (2018). A review of the processes, parameters, and optimization of anaerobic digestion. *International journal of environmental research and public health*, *15*(10), 2224.  **Summary:** There are a multitude of processes, parameters, and design considerations that must be taken into account to achieve optimal production of biogas for any anaerobic digestion bioreactor. Some example parameters are temperature, pH, loading rate, total solids, and carbon/nitrogen ratio. This paper walks through each of the typical parameters and assess the impact of the changes one could make and methods for choosing an optimal setting.  **Relevance:** The ADM1 Model utilized in our analysis is an effort to reduce the number of parameters that have to be optimized in order to allow the user to achieve realistic estimations of biogas production quickly. However, it is important to understand what each parameter contributes to the production rate and how changes will impact said rate. Establishing a baseline rate and then adjusting parameters to understand the limit is a fundamental aspect of reactor design that, time willing, will be implemented in future analysis.  **Further References:**  Wang, X.; Yang, G.; Feng, Y.; Ren, G.; Han, X. Optimizing feeding composition and carbon–nitrogen ratios for improved methane yield during anaerobic co-digestion of dairy, chicken manure and wheat straw. Bioresour. Technol. 2012, 120, 78–83  Ferguson, R.M.W.; Coulon, F.; Villa, R. Organic loading rate: A promising microbial management tool in anaerobic digestion. Water Res. 2016, 100, 348–356. |
| **Citation:**  Menzel, T., Neubauer, P., & Junne, S. (2020). Role of microbial hydrolysis in anaerobic digestion. *Energies*, *13*(21), 5555.  **Summary:** Hydrolysis is the first rate-limiting step for any anaerobic digestion reactor as it breaks down the principal nutrients into the more degradable products. The microbes responsible for hydrolysis will therefore determine the rate of downstream processes depending on their ability to interact with the substrate. This paper investigates improving microbial hydrolysis efficiency through parameter and process manipulation, staging, substrate pretreatment, and reactor design adjustments.  **Relevance:** For complex substrates like food waste the process of microbial hydrolysis will be variable corresponding to the diversity of foods in the waste stream. Understanding mechanisms to improve overall hydrolysis will be important in understanding rate-limiting parameters to achieving higher biogas production  **Further References:**  Shrestha, S.; Fonoll, X.; Khanal, S.K.; Raskin, L. Biological Strategies for Enhanced Hydrolysis of Lignocellulosic Biomass during Anaerobic Digestion: Current Status and Future Perspectives. Bioresour. Technol. 2017, 245, 1245–1257  Gottardo, M.; Micolucci, F.; Bolzonella, D.; Uellendahl, H.; Pavan, P. Pilot Scale Fermentation Coupled with Anaerobic Digestion of Food Waste—Effect of Dynamic Digestate Recirculation. Renew. Energy 2017, 114, 455–463. |