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Modernizing Organics Collection Using Food Waste Disposals

Howard Feng, Hongjiang Ye, Emma Keogan

Abstract

Residential in-sink food waste disposals (FWDs) have been legal in New York City since 1997. These disposals could offer a more cost-effective solution to organic waste management. FWDs are more accessible to use than composting in apartments. Our goal was to create a life-cycle cost-benefit analysis model to determine if there would be a net gain or a net loss from the policy to increase residential FWD penetration, and quantify that amount. Our model considers negative effects of added food waste in the sewer system, such as increases in fats, and the added cost of installing nitrogen removal equipment in wastewater treatment plants. This is compared to the added benefits of reduced trucking and processing costs from the organic pick-up program, and the heat and electricity gained during cogeneration. In the end, we found that if half of New York City households used a FWD, there would be yearly savings of $32,153,345.

INTRODUCTION

1.1 Introduction

The question of organic waste management in New York City has been reignited over the past few years. New York City has set a goal for city-wide composting through the Department of Sanitation (DSNY), but the pandemic shutdown and lack of government funding have stifled its participation, and further expansion.

Organic waste makes up just over 30% of the residential waste stream. (Department of Sanitation [DSNY], 2019) Diverting organics would not only be beneficial on a large scale, but is necessary for a sustainable city. Organic waste produces methane when decomposing, a greenhouse gas 25 times more potent than carbon dioxide. While landfills are able to manage some of this gas, they still produce a substantial amount of emissions in the United

States.(Environmental Protection Agency [EPA], 2022) NYC also delivers most of its waste into landfills outside the city, creating additional emissions from trucks.

In-sink food waste disposals (FWDs) could provide a more cost-effective solution compared to a pick-up organics and compost system. Since food waste is mostly water, it can easily be carried into the sewer system, where it can be treated and repurposed into byproducts such as biogas and biosolids. However, there is no estimate on how much it would cost to rely on FWDs as a means of diverting organic waste. Already, the sewer system is in need of upgrades, and adding additional waste to this system may increase the number of overflows that are present today. Since 60% of NYC relies on a combined sewer system (Department of Environmental Protection [DEP]), which combines wastewater and stormwater runoff, heavy rainfall can overwhelm the system. This can create combined sewer overflows (CSOs) in which the combined stormwater and wastewater bypass wastewater resource recovery facilities (WRRFs) with insufficient holding tank capacity, and flows into the water untreated. Many NYC officials worry that FWDs disposals can cause the system to be overwhelmed, by increasing water use in residential areas, or causing fat, oils, and grease (FOG) to build up in the system. Both of these concerns could raise the average water level in the system, which means it will take less for the system to overflow at certain pressure points.

1.2 Problem Statement

While we know how much composting currently costs, we don't have an estimate on how much it would cost to switch to a sewer-based organics waste management system. There are unknowns, including growth in the installation of FWDs and the impact of a potential change in organic material within NYC's sewer system. There is no previous research on whether this change is great enough to require capital investment in NYC. Our aim is to answer these questions and find if there is a cost reduction to using in-sink FWDs to recycle organic waste instead of implementing a mandatory pick-up compost program.

1.3 Literature Review

NYC first considered using FWDs for diverting organic waste from landfills in 1993. Commissioner Llyod (1993) of the DSNY proposed the idea, citing that if "10% of the City's 3,170,000 households had disposals, DOS projects that between 25,000 tons and 42,000 tons of food waste would be sent through disposals." (p. 2). This prompted Commissioner Appleton of the DEP to respond, initiating an 18-month study to determine if there would be negative impacts on the surrounding sewer system (Appleton 1993).

The study conducted by the NYC DEP (1997) installed FWDs into sample groups of apartments which were then compared to the neighboring control group. Overall, the study declared that FWDs had a negligible effect on the sewer system. Little to no difference was found in water usage, and the increase of suspended solids were negligible. This study allowed FWDs to be installed city wide for the first time since the 1970s.

While the 1997 study focused on residential buildings, another study conducted by the DEP in 2008 found that commercial establishments posed a greater problem when using FWDs. The study focused on the potential effects of food service establishments using FWDs, to determine if they could alleviate food waste without the use of trucks. However, they concluded that the infrastructure cost needed to support the wastewater pollution control plants would not outweigh the reduced cost of trucking organic waste.

Research has been done in other cities, which can help predict the severity of wide-spread residential use in New York City. Mattsson et al. (2015) has run an extensive literature review that shows the most common effects of FWDs across studies. The results found that, like in the original 1997 study, the change in water use is minimal. Results were split on the size of particulate matter from FWDs, but some studies found that 98% of particles produced were able to fit through a 2mm sieve. Since the 1993 study found that there was little change in suspended solids, we can conclude that FWDs in a NYC context are also negligible. One caveat is that higher density particles, like eggshells or small animal bones, cause deposits to build and should not be encouraged when using a FWD.

FOG still remains a point of concern across all points of research. Mattsson et al. found that all three studies on the matter found an increase in FOG. A case study in Malmö, Sweden by Bernstad et al. (2013) provides the most in depth look at FOG increase, finding a 40% increase within the tank-based system. They also found that effluent within the system exceeded the municipal limits. Our model utilizes this 40% increase in FOG in residential use.

DATA

2.1 Phase 1 Data Acquisition

Data Acquisition was split into two parts, Phase 1 and Phase 2. The approach for Phase 1 was to find granular data for Downtown Brooklyn and Long Island City Queens. These areas were rezoned in 1999 and could provide a baseline FWD penetration rate without the ban. However this approach led to several roadblocks, as district-level data either doesn't exist, or is not publicly available. While the NYC Department of Buildings (DOB) takes permit information for installing FWDs, this information is not digitized, and was inaccessible as a result. Real estate websites do not list FWDs as appliances, and only 3 out of the over 700 buildings we looked at either confirmed or denied having a FWD.

Proxies were used to estimate information we were unable to access. For example, while the Department of Environmental Protection tracks data on sewer water composition (Aufrichtig & Anthes, 2022), it does not make this data public. Instead increasing the amount of FOG by 40% in our model, we used cleanup cost as a proxy, and increased that amount by 40% to determine total cost.

2.2 Phase 2 Data Acquisition

Phase 2 data was collected from a number of city and federal government sources, as well as economic databases. The amount of organic waste produced in NYC was calculated based off data from datasets available on the NYC Open Data Portal, particularly the "DSNY Waste Characterization: Mainsort" and "DSNY Monthly Tonnage Data". The percentage of households with a FWD was given by the 2013 American Housing Survey (2015), and was used to estimate the penetration rate. NYC's Independent Budget Office (IBO) fiscal brief (2021) was used to determine organic waste processing cost and trucking costs for the compost program. The government electricity rate, which differs from consumer costs, was given by the NYC Department of Citywide Administrative Services (Olowu, 2022). Assumptions for capital investments and related variables were provided by Town+Gown.

Summary data was also collected from David Duest, Director of the Deer Island wastewater treatment plant (WWTP). Deer Island is part of the Massachusetts Water Resources Authority (MWRA), which oversees the water quality of the state. Deer Island itself serves around 34% of the population, specifically around the Boston metropolitan area. (Duest, 2022). The WWTP uses cogeneration technology to create heat and energy from the organics found within the wastewater, a technology that the North River WWTP in NYC uses. Since the Deer Island plant was able to produce energy to cover 95% of the heating cost, and 22% of the electricity cost, we assumed this was the baseline for the North River plant as well.

METHODOLOGY

3.1 City-Level Model

Our group used a Life Cycle Cost Benefit Analysis (LCCBA) model to calculate the cost and benefits of transferring organic waste using FWDs year over year. Our independent variables include the FWD penetration rate, estimated to be around 12% for 2023. The growth rate is assumed to be linear based on the 7% rate given by the American Housing Survey (2015) and the assumption of a 0% penetration rate when the FWD ban was just lifted in 1997. This would be a natural growth rate of about 0.43% of households installing a FWD per year.

The flow chart in Figure 1 illustrates the life cycle of organic waste from the point where it's produced to its end point of a landfill, electricity and gas, or compost. When organic waste is produced, it's split between households with and without FWDs. The FWD penetration rate determines how much organic waste will arrive at households with FWDs.

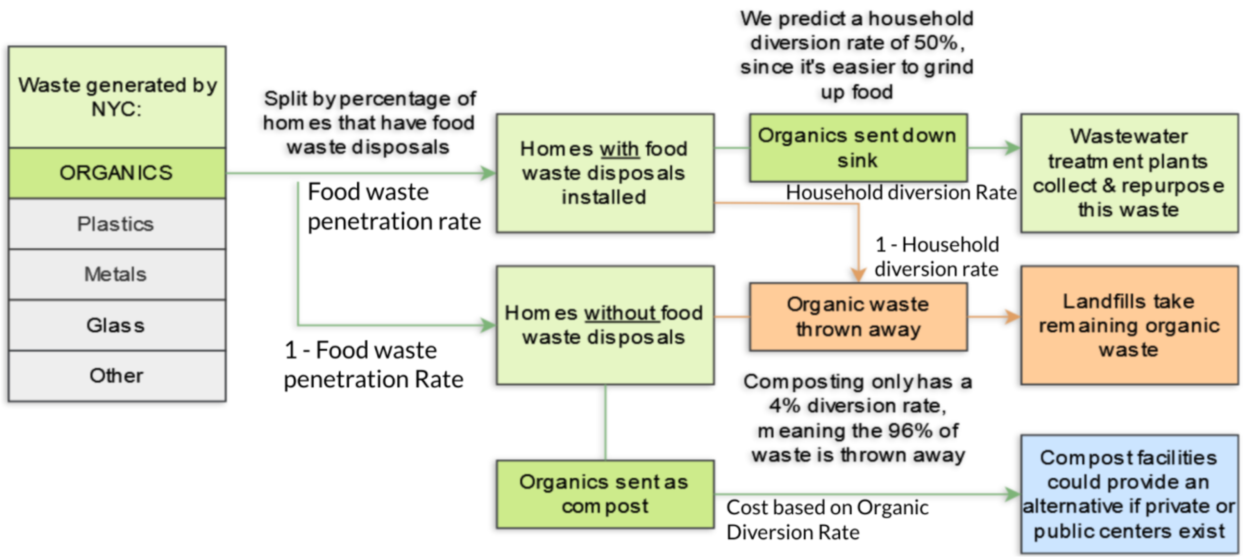

Figure 1. Diversion Rate Flow Chart

In houses with FWDs, only part of the organic waste will be put down the sink. Discouraged waste like eggshells and small bones would be put into the main waste stream. Additionally users who find FWDs time consuming may not use it for all of their remaining organic waste. We've used the Household Diversion Rate (HDR) in our model to demonstrate this.

For organic waste sent from households without FWDs, we assume they are thrown into the main waste stream, or are sent to a compost processing facility. Both of these streams are collected by trucks run by the DSNY. As more households use FWDs, less trucking will be needed for both streams, and money will be saved on trucking costs. Trucking costs were taken from the DSNY Preliminary Fiscal 2022 Management Report (Mayor's Office of Operations). Likewise, the cost of processing organic waste in a landfill will decrease as the waste is diverted. These processing costs were taken from the same source.

The 40% increase in FOG found in previous literature was multiplied by the increase in FWD penetration since 2024, and then multiplied with the cost of city-wide contract inspection and cleaning, which was estimated to be $3,169,710. (DEP, 2019). In order to find the cost of cogeneration, we took the 30.5 GWh of electricity and 121 GWh of heat it takes to power Deer Island, and multiplied it by the capacity of North River. This was then converted into dollar amounts, and the amount of savings was estimated off of the 95% and 22% able to be generated at Deer Island.

3.2 Assumptions Made

Various assumptions were made in our model, as little research has been done on the effects of FWDs. For many of our variables, we relied on a linear growth model to determine their change in value over time. This was due to a lack of data, such as the total number of FWDs present in NYC. Since we only had two data points, we had to assume that growth was a constant rate.

We also didn't account for bias in FWD installation. Income could possibly play a role in the penetration rate, as lower-income households could be more hesitant in paying for in-sink disposal. There may also be a correlation between high-income households and the amount of organic waste they produce. These homes would likely divert a greater amount of waste, as well as be more likely to install an FWD. However, we don't have the data to measure this, and it may not create a large enough difference to significantly affect savings.

RESULT

4.1 Variable Visualization

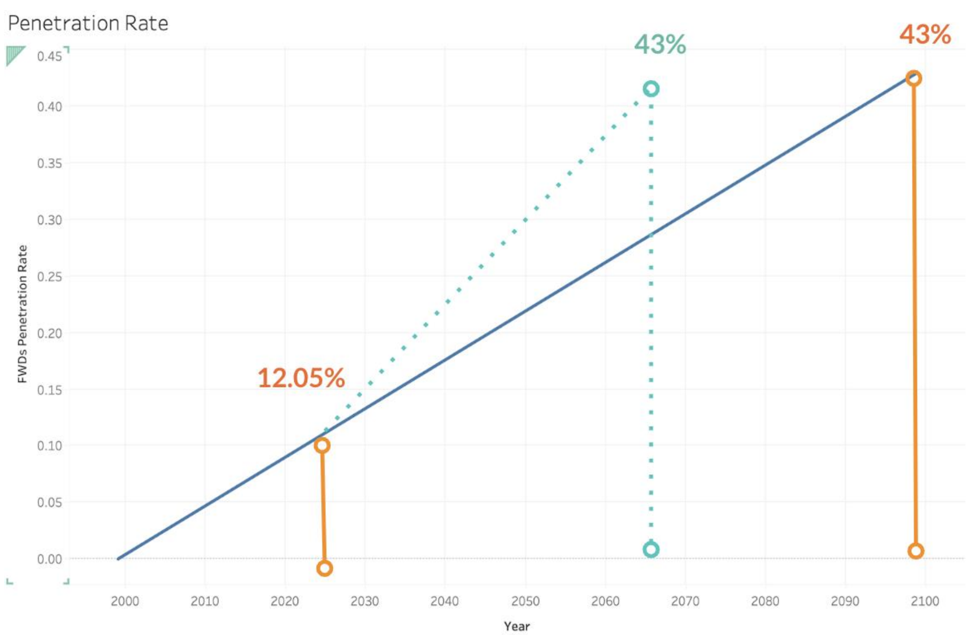

Figure 2. Penetration Rate

Using the LCCBA model to project long-term benefits and expenditures over the next 75 years, Figure 2 shows that, without policy intervention, the city's FWD penetration rate would reach 44% after 75 years through a natural growth rate of 0.43%. However, with policy intervention, such as mandatory FWD installation in new residential construction, the same rate would be reached within 44 years, or a 41% reduction year over year. This is assuming the natural growth rate is combined with the new building growth rate, creating a 0.75% year over year increase in FWD installation.

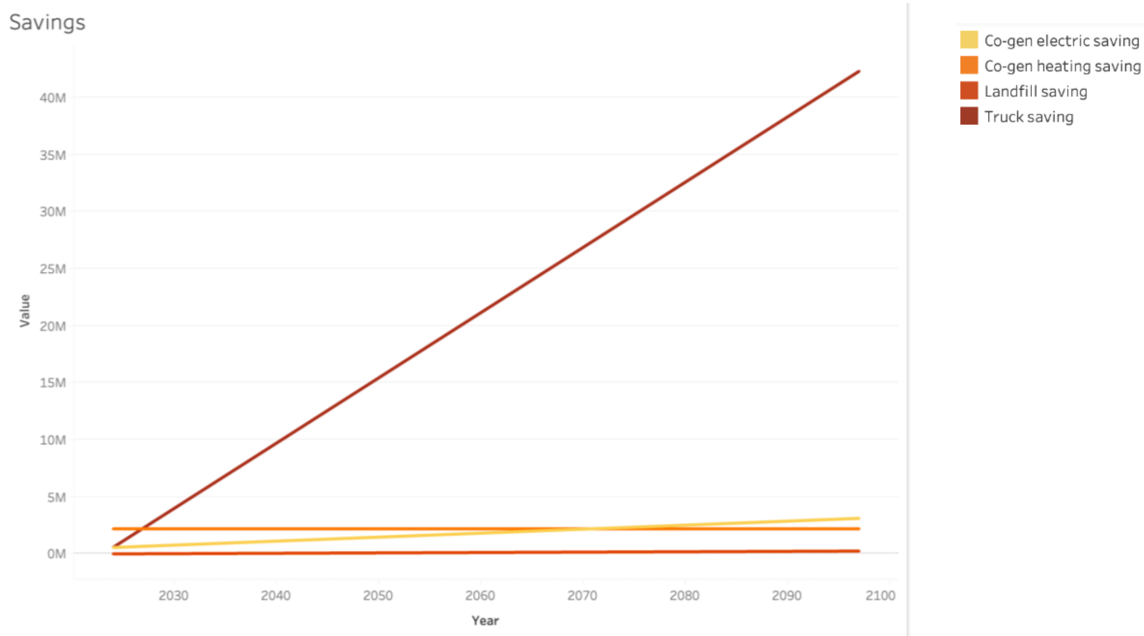

Figure 3. Savings

All the savings, e.g., co-generation, savings from reduced landfill processing, and savings from reduced trucking, are shown in Figure 3. Since benefits are dependent variables, the benefits growth rate is proportional to the FWD penetration rate and a linear relationship.

Savings from reduced trucking is the main source of benefits, providing 83.7% of savings, calculated as freight per ton of waste ($314) * organic waste reduced from landfill by adopting FWDs. Since only the North River wastewater resource recovery facility (WRRF) has a cogeneration device among all WRRFs in NYC, the overall benefits from the cogeneration system are very limited, averaging $4,042,074 per year, or 15.7% of the total benefit.

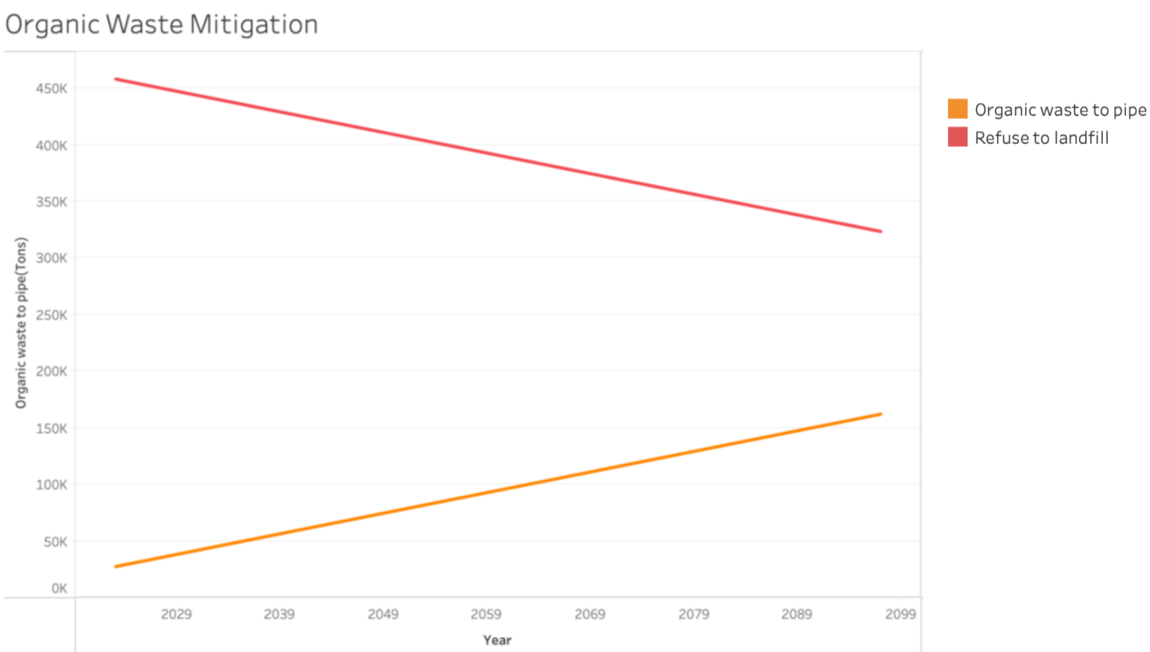

Figure 4. Organic Waste Mitigation

The mitigation of organic waste is shown in Figure 4. After 75 years, the amount of the city's daily refuse would drop by 134,768, or 29.4%. Meanwhile, the amount of organic waste entering the WRRF has increased by 491%.

4.2 75-Years Estimation Result

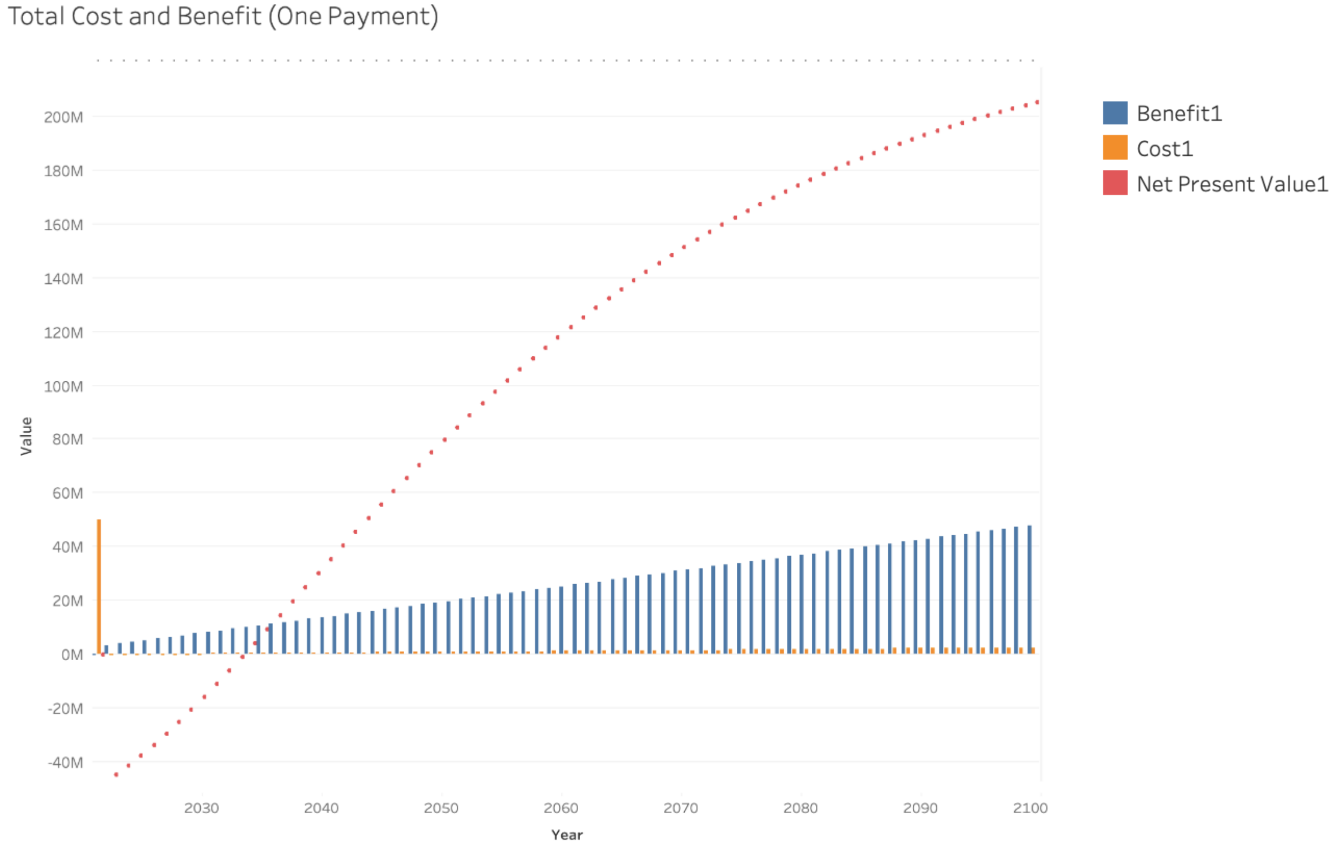

Figure 5. Total Cost and Benefit (One Payment)

In Figures 5 and 6, the overall accumulated savings is indicated in red. Figure 5 shows an expense fund investment of $50 million for the construction of nitrogen removal equipment at one WRRF to cope with the increasing nitrogen levels in the wastewater. In this case, the total cost over benefits is negative in the first 13 years, and benefits exceed costs starting in the 14th year. Also, the highest single year benefits over costs of $47,885,766 is reached by year 75, and the total benefits within the 75-year span is $205,513,085.

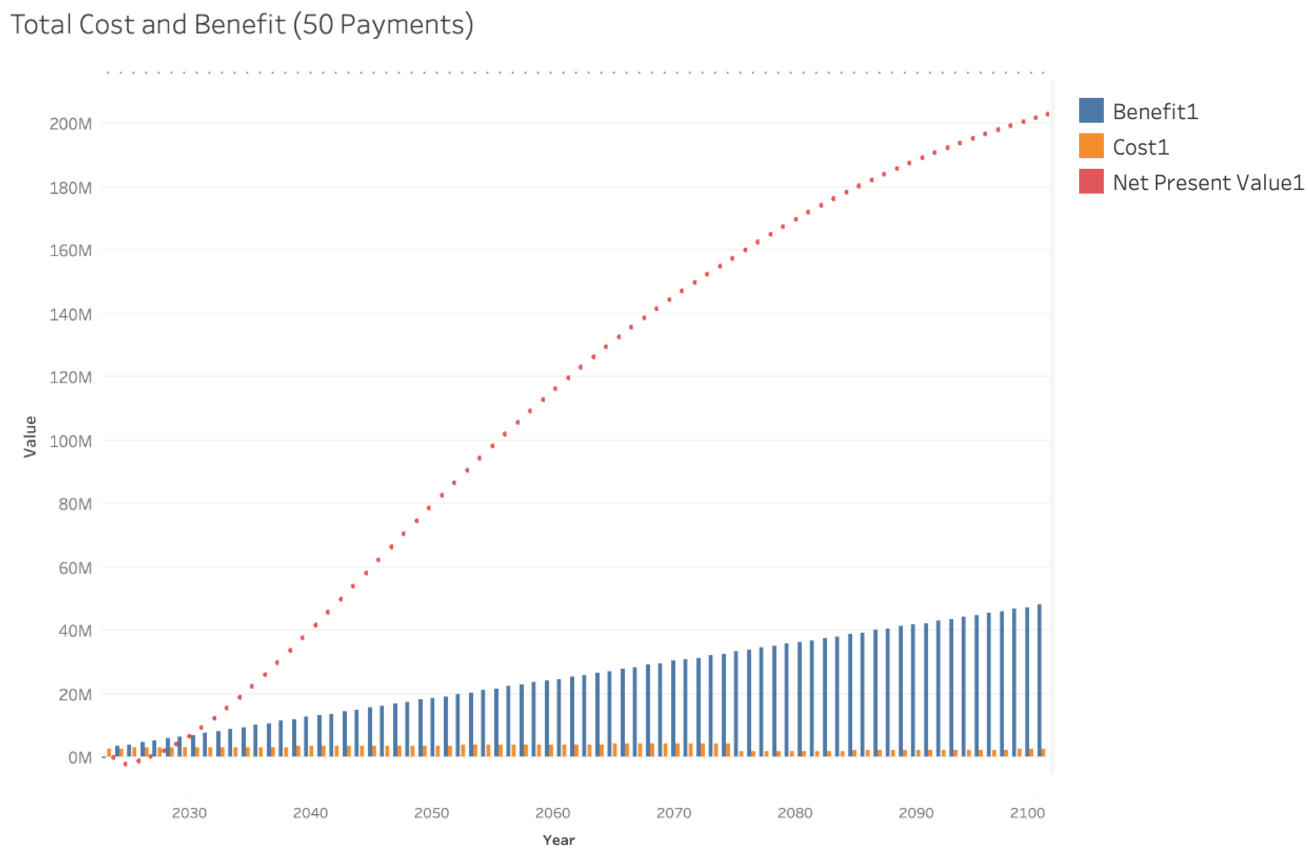

Figure 6. Total Cost and Benefits (50 payments)

The second scenario is a capital investment with a 50-year maturity to build a nitrogen removal facility at one WRRF with an annual repayment of $2,738,837 at a 5% interest rate, which the benefits in excess of costs starting in the third year. In the 75th year, the total benefit would be $205,513,085.

CONCLUSION

Overall, FWDs could offer a way to capture a greater amount of organic waste, without the hurdle of creating difficult policies and investments for composting. Critics may argue that composting has the potential to save money, however it requires a high participation rate from citizens, and the early backing needed to invest in the program. FWDs have the potential to save the city $205,513,085 during the next 75 years. Further research could be done using Philadelphia as a model, which has recently required the use of FWDs in residential buildings (Bliss 2016). Since this program is still new, there hasn't been official studies on the effects of FWDs on the infrastructure, but a case study could definitively help support this study analysis that benefits outweigh the costs.

APPENDIX A: MODEL TABLES

TOTAL ORGANICS (Ton / year)			**Co-gen Based on Deer Island WW**	Electricity	Heating
			Potential Saving(GWh / yr)	4.0	$16
Yard Waste Excluded	485650		Potential Saving(KWh/ yr)	$3,965,000	$15,730,000
			Potential Saving($ / year)	$527,345	$2,092,090
			Potential Bill	$2,397,023	$2,202,200
Base line: (ODR1=1.4%, ODR2=50%, Organic Process cost = 132, FWD-PR=11%)					
Current Lanfill cost($)	$846,773.51	Landfill(Tons)	629992		
Current Organic to Pipe in Ton	27439.225	Current Sewer Cleaning Cost	$3,169,710.00		
land fill in ton	458210.775	BNR II Cost per year:	2566080		
Independent Varibles:		(Potential Range of Variable)	**Dependent Variable**		
ORGANICS DIVERSION RATES:	(ODR)		Organic Waste into the pipe(Tons)	29260	
ODR 1 (from refuse)	1.4%	(1.4% - 35%)	Refuse to landfill(Tons)	456390	
ODR 2 (for FWD)	50%	(10% - 90%)	Lanfill Saving($)	$3,366	
FWDs Penetration Rate	12%	(11% - 100%)	Truck saving($)	$571,853	
			Co-gen: Electric	$35,001	
Organic processing cost	132	(based on ODR1)	Co-gen: heating	$2,202,200	
Inflation rate	0.05		Co-gen: Fertilizer	0	
increase DEP-side process cost			FOG Cleaning Cost	$33,281.96	
This is a no Nitrogen removal version					
Total cost = DSNY Cost + DEP Cost + Composting + Electricity Bill + Heat bill					
Total saving = Co-gens saving+ Landfill saving + truck saving - FOG cleaning					

Table A.1: Lifecycle Cost Benefit Model

Debt for BNR II	Principal :	50,000,000	
	Interest Rate:	0.05	
	PPU:	50	
1	$238,836.77	$2,500,000.00	$2,738,836.77
2	$250,778.61	$2,488,058.16	$2,738,836.77
3	$263,317.54	$2,475,519.23	$2,738,836.77
4	$276,483.42	$2,462,353.35	$2,738,836.77
5	$290,307.59	$2,448,529.18	$2,738,836.77
6	$304,822.97	$2,434,013.80	$2,738,836.77
7	$320,064.12	$2,418,772.65	$2,738,836.77
8	$336,067.33	$2,402,769.45	$2,738,836.77
9	$352,870.69	$2,385,966.08	$2,738,836.77
10	$370,514.23	$2,368,322.55	$2,738,836.77
11	$389,039.94	$2,349,796.84	$2,738,836.77
12	$408,491.94	$2,330,344.84	$2,738,836.77
13	$428,916.53	$2,309,920.24	$2,738,836.77

14	$450,362.36	$2,288,474.42	$2,738,836.77
15	$472,880.48	$2,265,956.30	$2,738,836.77
16	$496,524.50	$2,242,312.27	$2,738,836.77
17	$521,350.73	$2,217,486.05	$2,738,836.77
18	$547,418.26	$2,191,418.51	$2,738,836.77
19	$574,789.17	$2,164,047.60	$2,738,836.77
20	$603,528.63	$2,135,308.14	$2,738,836.77
21	$633,705.07	$2,105,131.71	$2,738,836.77
22	$665,390.32	$2,073,446.46	$2,738,836.77
23	$698,659.83	$2,040,176.94	$2,738,836.77
24	$733,592.83	$2,005,243.95	$2,738,836.77
25	$770,272.47	$1,968,564.31	$2,738,836.77
26	$808,786.09	$1,930,050.68	$2,738,836.77
27	$849,225.40	$1,889,611.38	$2,738,836.77
28	$891,686.66	$1,847,150.11	$2,738,836.77
29	$936,271.00	$1,802,565.78	$2,738,836.77
30	$983,084.55	$1,755,752.23	$2,738,836.77
31	$1,032,238.78	$1,706,598.00	$2,738,836.77
32	$1,083,850.71	$1,654,986.06	$2,738,836.77
33	$1,138,043.25	$1,600,793.52	$2,738,836.77
34	$1,194,945.41	$1,543,891.36	$2,738,836.77
35	$1,254,692.68	$1,484,144.09	$2,738,836.77
36	$1,317,427.32	$1,421,409.46	$2,738,836.77
37	$1,383,298.68	$1,355,538.09	$2,738,836.77
38	$1,452,463.62	$1,286,373.16	$2,738,836.77
39	$1,525,086.80	$1,213,749.98	$2,738,836.77
40	$1,601,341.14	$1,137,495.64	$2,738,836.77
41	$1,681,408.20	$1,057,428.58	$2,738,836.77
42	$1,765,478.60	$973,358.17	$2,738,836.77
43	$1,853,752.54	$885,084.24	$2,738,836.77
44	$1,946,440.16	$792,396.61	$2,738,836.77
45	$2,043,762.17	$695,074.60	$2,738,836.77
46	$2,145,950.28	$592,886.50	$2,738,836.77
47	$2,253,247.79	$485,588.98	$2,738,836.77
48	$2,365,910.18	$372,926.59	$2,738,836.77
49	$2,484,205.69	$254,631.08	$2,738,836.77
50	$2,608,415.98	$130,420.80	$2,738,836.77

Total:	$50,000,000	86941888.76	
Grand Total:	$136,941,889		

Table A.2: Year by year breakdown of BNR II debt.

REFERENCES

Appleton, A. (1993, December 29). *Lloyd-Appleton Letters* [Letter to Emily Llyod].

Aufrichtig, A., & Anthes, E. (2022). How Wastewater Can Help Track Viruses Like Covid and Polio. *The New York Times*, 26.

Barnard, A. (2022, February 18). New York Was Set to Expand Composting. Now It's on the Chopping Block. *The New York Times*. https://www.nytimes.com/2022/02/17/nyregion/nyc-budget-composting-adams.html

Bernstad, A., Davidsson, A., Tsai, J., Persson, E., Bissmont, M., & la Cour Jansen, J. (2013). Tank-connected food waste disposer systems – Current status and potential improvements. *Waste Management*, *33*(1), 193–203. https://doi.org/10.1016/j.wasman.2012.09.022

Bliss, L. (2016, January 12). Philadelphia Goes All In on Garbage Disposals. *Bloomberg.Com*. https://www.bloomberg.com/news/articles/2016-01-12/philadelphia-building-code-now-requires-garbage-disposals-in-new-construction

Cecchi, F., & Cavinato, C. (2019). Smart Approaches to Food Waste Final Disposal. *International Journal of Environmental Research and Public Health*, *16*(16). https://doi.org/10.3390/ijerph16162860

Construction Inflation 2022 – update 5-3-22. (2022, February 11). *Construction Analytics*. https://edzarenski.com/2022/02/11/construction-inflation-2022/

Duest, D. (2022, June 24). *MWRA Student Interview* (E. Keogan, H. Feng, & H. Ye, Interviewers) [Personal communication].

Duest, D. (2022, July 5). *Follow up with last meeting w/ question* [Letter to Howard Feng]. https://mail.google.com/mail/u/1/#search/dave.duest%40mwra.com/FMfcgzGpGnGxQXqxtrnNcbWlvjtTtgjs

Galil, N., & Shpiner, R. (2001). Additional Pollutants and Deposition Potential from Garbage Disposers. *Water and Environment Journal*, *15*(1), 34–39. https://doi.org/10.1111/j.1747-6593.2001.tb00301.x

Kalmykova, Y., Harder, R., Borgestedt, H., & Svanäng, I. (2012). Pathways and Management of Phosphorus in Urban Areas. *Journal of Industrial Ecology*, *16*(6), 928–939. https://doi.org/10.1111/j.1530-9290.2012.00541.x

Llyod, E. (1993, December 3). *Lloyd-Appleton Letters* [Letter to Albert Appleton].

Mattsson, J., Hedström, A., Ashley, R. M., & Viklander, M. (2015). Impacts and managerial implications for sewer systems due to recent changes to inputs in domestic wastewater – A review. *Journal of Environmental Management*, *161*, 188–197. https://doi.org/10.1016/j.jenvman.2015.06.043

New York City Department of Buildings. (n.d.). *DOB New Building Permits*. New York City Department of Buildings.

New York City Department of Environmental Protection. (n.d.). *Sewer System—NYC DEP*. NYC Environmental Protection. Retrieved August 19, 2022, from https://www1.nyc.gov/site/dep/water/sewer-system.page

New York City Department of Environmental Protection. (1997). *The Impact of Food Waste Disposers in Combined Sewer Areas of New York City* (p. 12). New York City Department of Environmental Protection.

New York City Department of Environmental Protection. (2008). *Commercial Food Waste Disposal Study*. New York City Department of Environmental Protection.

New York City Department of Environmental Protection. (2019). *14 Wastewater Resource Recovery Facilities' SPDES Permits Combined Sewer Overflows Best Management Practices Annual Report* (p. 335). New York City Department of Environmental Protection.

New York City Department of Environmental Protection. (2022). *Wastewater Treatment Plant Performance Data* [Dataset]. NYC Open Data. https://data.cityofnewyork.us/Environment/Wastewater-Treatment-Plant-Performance-Data/hgue-hj96

New York City Department of Sanitation. (2019). *DSNY Waste Characterization: Mainsort | NYC Open Data* [Dataset]. NYC Open Data. https://data.cityofnewyork.us/City-Government/DSNY-Waste-Characterization-Mainsort/k3ks-jzek

New York City Department of Sanitation. (2022). *DSNY Monthly Tonnage Data | NYC Open Data* [Dataset]. NYC Open Data. https://data.cityofnewyork.us/City-Government/DSNY-Monthly-Tonnage-Data/ebb7-mvp5

New York City Independent Budget Office. (2021). *Going Green: Can The Organics Collection Program Be Fiscally & Environmentally Sustainable?* (p. 13) [Fiscal Brief]. New York City Independent Budget Office.

New York City Mayor's Office of Operations. (2022). *Preliminary Fiscal 2022 Mayor's Management Report—Department of Sanitation* (pp. 95–100) [Management Report]. New York City Mayor's Office of Operations. https://www1.nyc.gov/assets/operations/downloads/pdf/pmmr2022/dsny.pdf

Olowu, L. (2022, July 7). *FW: NYPA electricity rate for City agencies* [Letter to Terri Matthews]. https://mail.google.com/mail/u/1/#search/electricity+rate/FMfcgzGpGnNrbKpHCVnKWPQJMpXDSVzk

Perriam. (2007). *Food Waste Disposers (Garbage Grinders, Macerators, etc.)—The Case against, WRc Host CIWEM Debate on Food Waste Disposal and Macerators*. https://www-sciencedirect-com.proxy.library.nyu.edu/science/article/pii/S030147971530133X

State of the Sewers 2021—Performance metrics (p. 14). (2021). [Performance Metrics]. NYC Department of Environmental Protection.

Truini, J. (2004). NYC to invest $2.2 billion in wastewater system. *Waste News*, *10*(11), 10–10.

United States Environmental Protection Agency. (2022, April 21). *Basic Information about Landfill Gas* [Overviews and Factsheets]. Landfill Methane Outreach Program (LMOP). http://www.epa.gov/lmop/basic-information-about-landfill-gas

US Census Bureau. (2015). *AHS 2013 Metropolitan Summary Tables* [Dataset]. United States Census Bureau. https://www.census.gov/programs-surveys/ahs/data/2013/ahs-2013-summary-tables/metropolitan-summary-tables---ahs-2013.html

Wei, T., Wu, J., & Chen, S. (2021). Keeping Track of Greenhouse Gas Emission Reduction Progress and Targets in 167 Cities Worldwide. *Frontiers in Sustainable Cities*, *3*. https://www.frontiersin.org/articles/10.3389/frsc.2021.696381

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