Cost Benefit Analysis of Food Waste Processing in Massachusetts

A Cost-Benefit Analysis of Food Waste Processing in Massachusetts

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Abstract

This thesis aims to compare food waste processing technologies to understand which have higher socio-economic benefits. Each year, approximately 1.3 billion tons of food produced for human consumption is wasted globally which puts stress on the environment and undermines efforts to combat world hunger (van Otterdijk & Alexandre, 2011). As food waste diversion systems are being developed across the world, strong food waste management planning should be evaluated to reduce its negative impacts and optimize its benefits. In order to suggest sustainable ways of developing a food waste management infrastructure, this study will compare the socio-economic costs and benefits for leading commercial food waste processing technologies in Massachusetts.

Data were collected by surveying 10 of 30 windrow aerobic composting (AC) facilities and four of five on-farm anaerobic digestion (AD) facilities. The data used were collected through interviews, added from comparable studies to close gaps, and calculated cost and benefit variables. By discounting these variables over a lifespan of 15 years, the net present value (NPV) was derived for each food waste processing methodology. The analysis yielded a NPV of $10 per short ton of food waste for windrow AC and -$12 for on-farm AD. A sensitivity analysis highlighted that the driving factors for the NPVs are transportation, diesel price, and the tipping fees (facility's waste acceptance fee). AD is furthermore sensitive to electricity prices and the cost of construction and equipment while the price of compost is a determining factor for the feasibility of AC. Differences in tipping fees and distance to food waste generating

sources best explain the differences in the NPV between AC and AD in Massachusetts. Since both variables are not necessarily linked to either food waste treatment methodology, the gap in NPV is significantly closed. With variables like the marketability of digestate and differences in opinions to the cost of carbon, it cannot be inferred from the CBA results that one is in fact superior to the other. Because of the difference in costs and benefits, as well as opportunities and limitations, the continued support for the development of both technologies is best advised for optimizing food waste diversion efforts.

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Chapter I

Introduction

Approximately one-third of all food produced for human consumption is wasted globally (van Otterdijk & Alexandre, 2011). This is equivalent to about 1.3 billion tons of food waste per year. Food that goes into landfills creates unnecessary greenhouse gas emissions, both from its production and landfilling. It wastes the resources of its production, and loses the economic value of the food produced for both the farmer and the consumer.

Industrialized countries waste about 95-115 kg per consumer per year, which is significantly more than in developing countries (van Otterdijk & Alexandre, 2011). With the industrialization of developing countries, this issue is a global problem that will only worsen with time. Food loss is an important issue in the world today in the efforts to combat hunger, raise income and improve food security in the world's poorest countries. Ideally food waste is consumed within the food chain, but in places where this is not feasible, strong food waste diversion planning should be understood in order to reduce the environmental impacts and develop a sustainable infrastructure.

As more private and public entities are taking action to divert food waste from their waste streams, an opportunity presents itself to develop this sector efficiently, effectively, economically and sustainably. A thorough investigation into the costs and benefits of different methodologies and infrastructures related to food waste diversion is the first step in understanding how best to do this.

Research Significance and Objectives

The state of Massachusetts is a frontrunner when it comes to policies aimed at reducing the burden of waste disposal. In 2014, it was the first state in the U.S. to ban commercial food waste from landfilling. Any business or institution that disposes of one ton or more of food waste per week must divert the food waste from disposal to either composting, conversion, recycling or reuse (MassDEP, 2016). These types of early regulatory pressure can be highly beneficial since it increases the potential to capture more of the benefits, and to reduce costs and environmental impacts. In addition it has the potential to nurture efficient infrastructure development that will effectively sustainably reduce those long-term impacts. Yet, we need additional scientific analysis to capture the full socio-economic potential of such policies; however, research on this topic, especially that which compares the costs and benefits of the different food waste processing methodologies, is still limited. As such, waste management developers lack guidance and are left to their own devices.

My thesis aims to close this knowledge gap. I intend on conducting a comparative study of two different food waste processing technologies that are widespread in the State of Massachusetts.

My objectives are:

- To compare the two primarily used food waste processing technologies in Massachusetts to understand which has a higher socio-economic benefit
- To perform a cost-benefit analysis for food waste processing technologies that incorporates GHG accounting

- To provide key decision makers with a methodology for the economic assessment and selection of different food waste processing systems

Background

After a decade of prolonged decline in the number of malnourished people, world hunger is on the rise again (FAO, IFAD, UNICEF, WFP & WHO, 2017). At the same time, however, one-third of food produced is wasted, meaning that one-third of resources are unnecessarily misused and degraded. In addition, the excess food production has a substantial carbon footprint estimated around 3.3 Gtonnes of CO_2 equivalence. In light of an expanding world population, worsening effects from climate change, increased food production and stronger competition for land use, such a practice portends a ton of potential for conflict (FAO, 2015).

The best way to reduce food waste after avoidance is to donate or resell it, but opportunities for consumption have limitations. The most effective way to mitigate the effects of food produced but not eaten is to recycle it through composting and to use the compost to bring nutrients back into the soil (FAO, 2015). In order to do that, the developing food waste processing sector is already adapting techniques, most notably aerobic composting (AC) and anaerobic digestion (AD). These techniques also introduce opportunities to accommodate the processing of other organic waste streams like manure, yard waste and wastewater sludge. A shared commonality is that both AC and AD allow the turning of organic material, such as food waste, into a soil enrichment amendment (FAO, 2015). Waste is thereby diverted from landfill, groundwater contamination is mitigated, and air pollution and greenhouse gas emissions are reduced (Adhikari, Barrington, Martinez, & King, 2008). Despite their similarities, they use different approaches with a unique set of advantages and disadvantages.

Approaches to Food Waste Management

Food waste diversion can happen in many different ways. Initiating the collection and processing of food waste can happen from the bottom up, through initiatives from individual households or within organizations. They can also happen in top down measures, like a legislative ban on its disposal. Major advances in food waste bans have developed in recent years. In 2016, France was the first country in the world to ban supermarkets from throwing away or destroying unsold food, forcing them instead to donate it to charities and food banks (Chrisafis, 2016). Major efforts have also happened in the United States. Recently, five states in the U.S. have implemented state-level waste bans, prohibiting certain entities from disposing of organics. Some states and localities have implemented mandatory organic waste recycling laws, requiring certain producers of organic waste to recycle the organics through specific methods, like composting. Connecticut, Massachusetts, Rhode Island and Vermont structured their laws as organic waste bans, while California instituted a waste recycling law requiring commercial generators of organic wastes to either compost or conduct anaerobic digestion. Each state has structural similarities, but differ in important details. These in turn have significant impacts on the reach of these laws, and thus the amount of food waste diverted from landfills. Areas of differences include types of generators covered, quantity thresholds, and exemptions. By 2020, Vermont's law will cover anyone who generates any amount of food waste, while other states' bans only include commercial producers. The amount of food waste that qualifies a generator to be covered by the ban varies, with Massachusetts having the most aggressive restriction of one ton or more of food waste per week. Massachusetts is also the most aggressive in exemptions, as it is the only state that does not provide any. Other states allow some exemptions, like the proximity of a compost facility (Broad Lieb, Rice, & Mahoney, 2016).

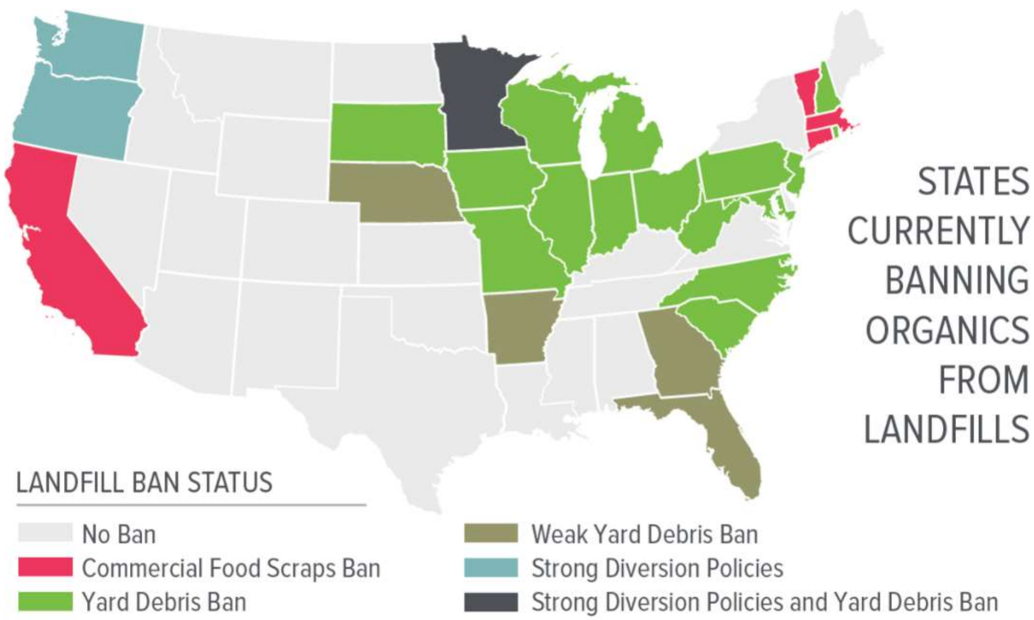


Figure 1. U.S. states currently banning organics from landfill (Bailey, 2017).

Case Study: Food Waste Processing in Massachusetts

Food waste makes up roughly 25 percent of the total waste stream after recycling in Massachusetts. This is equivalent to one million tons per year according to the Massachusetts Department of Environmental Protection (MassDEP). The main food waste generators are food and beverage producers followed by restaurants and supermarkets (Figure 2).

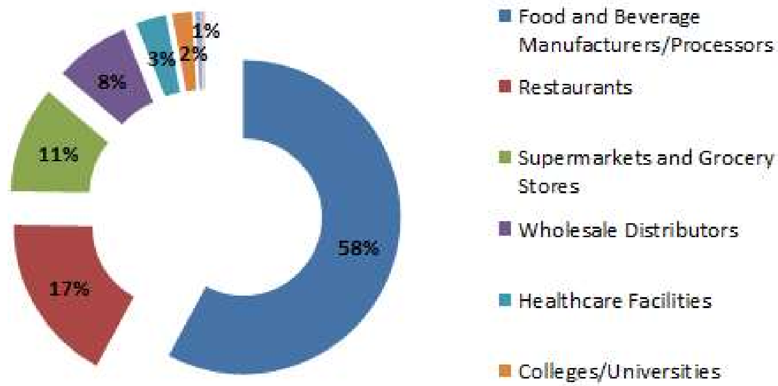


Figure 2. Food waste generation in Massachusetts per source (EPA, 2011).

Despite being such a substantial source of waste, less than 10 percent of food waste was diverted as of 2015. As part of the Massachusetts 2010-2020 Solid Waste Master Plan, MassDEP introduced the goal to divert at least 35 percent of organic waste by 2020. In support of that it added commercial organic material to the blacklist of banned materials from disposal in 2014. Since then, businesses and institutions that generate over one ton per week of organic materials (Figure 3) have not been allowed to dispose of it in the trash. In order to comply with the ban, affected institutions can donate food, send it to animal feed, aerobically compost it or apply anaerobic digestion (MassDEP, 2015). There are a number of sites across Massachusetts that are permitted to accept the diverted organic materials (Figure 4).

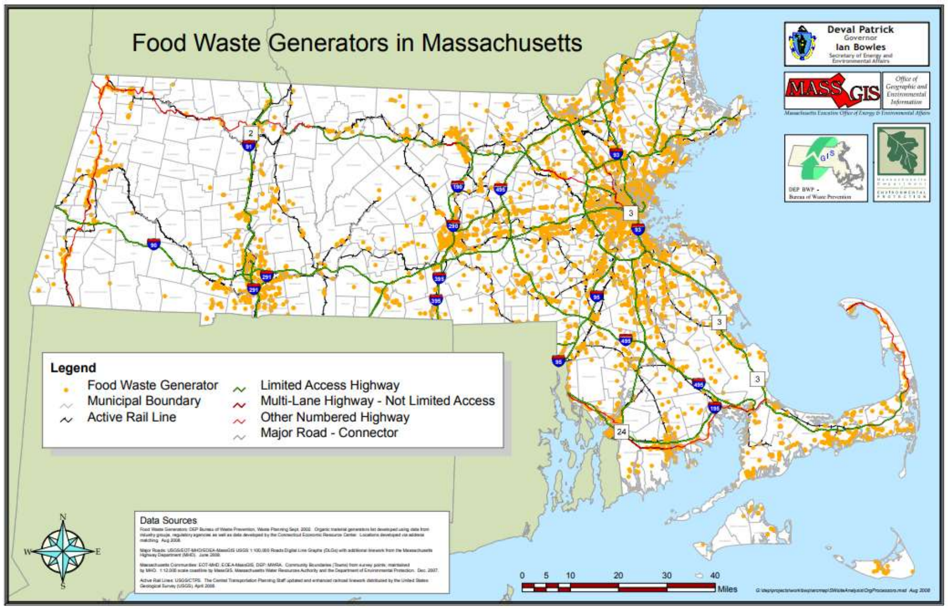


Figure 3. Food waste generators in Massachusetts (MassDEP, 2017).

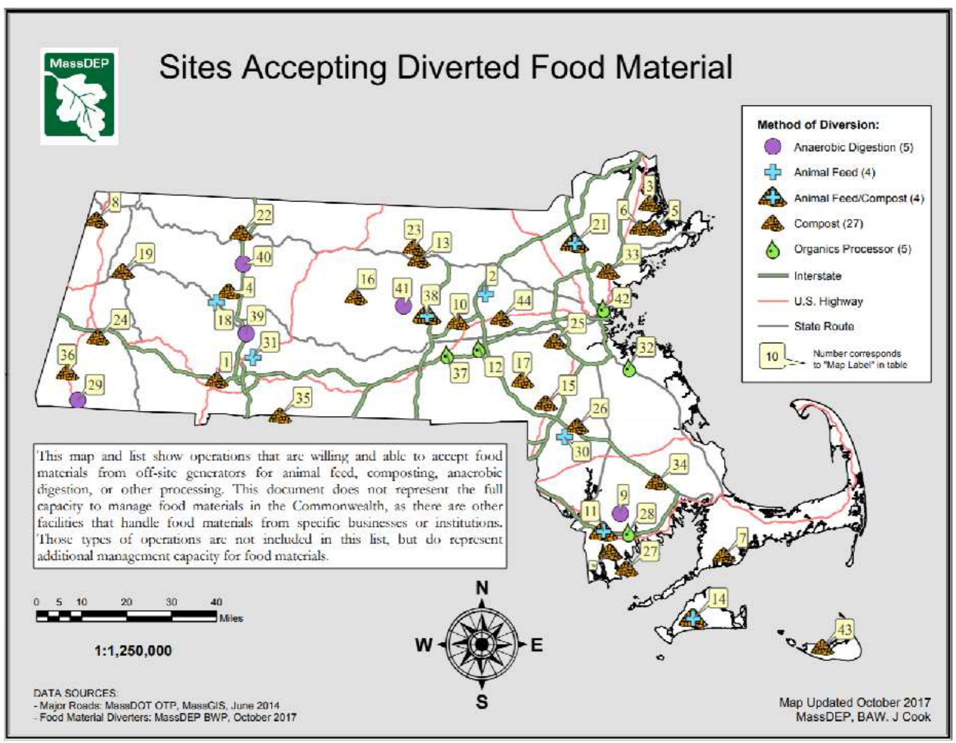


Figure 4. Sites allowed to accept diverted food waste in Massachusetts (MassDEP, 2017).

My study was mainly concerned with the primary food waste processing methodologies, aerobic composting (AC) and anaerobic digestion (AD). At the moment, 30 AC facilities and seven AD facilities are distributed across Massachusetts with a combined capacity of at least 150,000 tons per year; however, meeting the 2020 diversion requires more than doubling that capacity. MassDEP is determined to support the development of the necessary AC and AD infrastructure (MassDEP, 2015). This will drastically change the organic food waste landscape. ICF (2016) published a study for MassDEP which confirms strong growth since implementation of the ban, creating jobs and stepping up investments with more positive economic and ecological effects envisioned to come. Yet, how much and in what form society and the environment will benefit also depends on how food waste disposal capacity is created and which technologies are applied. AC and AD are likely to have different socio-economic impacts. By providing incentives for key stakeholders in food waste management, more beneficial technologies may help to shape the industry in a way that make the most out of this opportunity.

An Introduction to Food Waste

As outlined above, food waste represents a significant part of total waste. It is unique among organic waste types because of its low carbon to nitrogen (C/N) ratio, high nitrogen, oil and salt content, high organic-to-ash ratio and its loose physical structure (Chang & Hsu, 2008; Kumar, Ou, & Lin, 2010). It is usually rich in starch, lignin, cellulose and monosaccharides that are all easily degradable organic substances (Hedge, Lodge, & Trabold, 2018).

Food Waste Processing via AC and AD

Aerobic composting (AC) and anaerobic digestion (AD) are both suitable tools to divert food waste from landfills and to create nutrient rich compost. AC is the natural process of decomposing organic matter in an aerobic environment (FAO, 2015). The basic inputs to composting are organic matter, water and air while outputs are nutrient rich compost, CO_2 and the residuals that remain after screening (Figure 5).

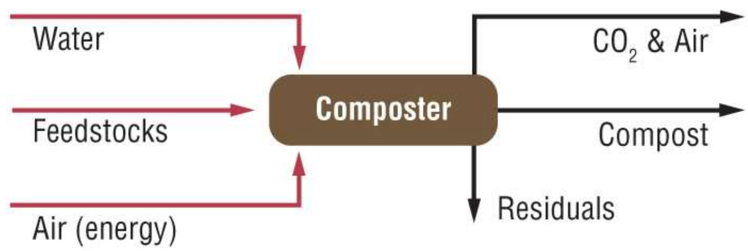


Figure 5. Aerobic composting inputs and outputs (Kraemer & Gamble, 2014).

Compost is a fairly stable humus-like substance that can be used as organic fertilizer, and to amend or enhance soil. The most important factors influencing food waste composting are temperature, moisture content, aeration rate, C/N ratio, particle size and nutrient content (Adhikari, Barrington, Martinez, & King, 2008). These factors change frequently during the decomposition process and substantially influence the final compost. C/N ratio, pH levels and aeration determine bacterial growth and gas emissions. Moisture content affects the chemical and physical properties of the materials, and temperature influences the pathogen reduction (Tiquia, 2010).

There are basically two approaches to AC, namely in-vessel systems and windrow systems. The in-vessel system composts organic materials in a vessel, container or building (Cekmeceloiglu, Demirci, Graves, & Davitt, 2005). It requires less space and is thus more common in urban areas. The initial investment is higher as is energy consumption. In addition, the organic material subject to composting has to be pretreated.

Windrow systems are placed outdoors. The feedstock is laid out in long windrows in lengths anywhere from 15 m to 115 m, and averages two meters in height and five meters in width (Zhu-Barker, Bailey, Tha Paw U, Burger, & Horwath, 2017). Front-loaders or windrow turners are used to mix piles for even composting of materials and the introduction of oxygen. Windrow systems require more space and reach higher temperatures.

Contrary to AC is AD, which takes place in an oxygen-deprived environment and yields biogas. Inputs are feedstock like food waste, manure, yard waste and sewage, energy and depending on the type of digester, water. Thermal energy is used to heat the digestion tank and electricity for pumping. Outputs are the production of biogas that typically exceeds the energy requirements of the digestion process, effluents and digestate (Figure 6).

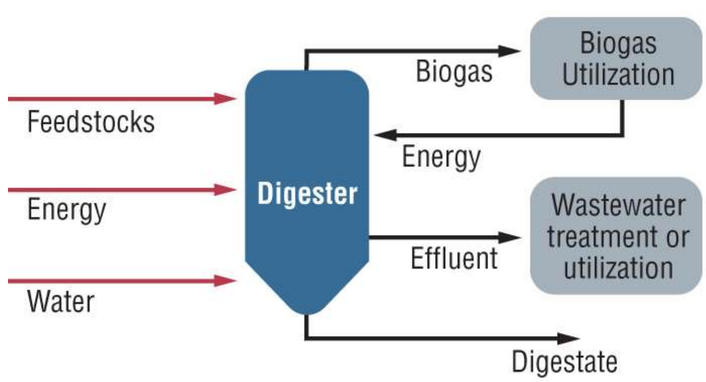


Figure 6. Anaerobic digestion inputs and outputs (Kraemer & Gamble, 2014).

AD is either tailored for low or high solid content. The technology used for the former is called wet and the one for the latter is dry digestion. Low solid content refers to solids representing between 3 percent and 10 percent, and high solid >= 15 percent of total organic waste content. Solid waste is reduced to < 10 percent by adding water in case wet digestion technology is used.

AD systems may also differ in terms of temperature. Mesophilic digesters use temperatures in the range of 95°F to 105°F while thermophilic digesters operate between 125° and 140°F. Dry digestion is usually, but not necessarily, undertaken with thermophilic digesters and wet digestion with mesophilic ones. The length of time necessary to complete the degradation of food waste, also called residence time, is shorter in the high temperature environment. Thermophilic technology also yields more biogas for the same amount of organic waste and causes a substantially lower amount of effluent. Nonetheless, mesophilic wet systems are the dominating technology in the U.S. due to lower investment costs (National Renerable Energy Laboratory, 2013).

In Massachusetts, a common AD technology is wet on-farm digesters. These help farmers manage nutrients, reduce odors, generate additional farm revenue, and often accept outside food waste as a feedstock (US EPA, 2016). The biogas produced by the AD system is often used to then generate electricity to fuel boilers or furnaces, or to provide combined heat and power.

Cost-Benefit Analysis

It is easy to see that AD can gain major profits through biogas sales, or that it is a major investment compared to that of an AC facility; however, the underlying logic of a pure financial analysis of AC and AD investment and sales fails to capture the true economic implications of the projects as a whole. Those that reap the lion's share of the profits might be better off, while the costs of a depleted common good such as climate change, higher crop yields, or carbon sequestration of soil compost are borne by all. It is, therefore, critical to extend the pure financial analysis of food waste processing systems to include the value of less tangible services for informed decision-making.

Cost-Benefit Analysis (CBA) is an important socioeconomic valuation tool for public investment decision making. It compares costs with benefits for the whole society and only when the latter exceeds the former should the proposed action be undertaken. Basically, benefits increase human well-being, while costs decrease it. Cost and benefits will vary from one social group to another, which is why both need to be assessed for each group separately and the numbers then aggregated. It might even be that benefit to low-income or disadvantaged groups may receive a higher weighting than privileged groups. Since the occurrence of costs and benefits can differ in timing, they are discounted to present value so that figures become comparable (OECD, 2006).

CBA has been applied to AC and AD on several occasions. Depending on the number of variables considered, a large range of net present values (NPV) has been calculated. Many analyses only consider marketable values, such as compost or biogas production, but lack full ecosystem services and regulatory functions (i.e. greenhouse gas emissions, soil productivity).

Cost-Benefit Analyses of Aerobic Composting

Rynk et al. (1992) created an on-farm composting handbook in which economics are thoroughly discussed. They report that at that time, compost can be sold from $10 to $50 per cubic yard depending on its consistency, overall quality, promotion, packaging, and associated services like bulk delivery. Agricultural composters can be large commercial enterprises while others are small hobby farms. Some use much of the compost on farm, while some market the compost as an agricultural product. Many use existing on-farm technology to manage the compost piles, while others invest in composting production equipment. AC farms can charge tipping (gate) fees and get revenue from sales, but they can also have unexpected costs like legal fees and odor control systems which can quickly eliminate the anticipated profits. Many farmers have the potential to compost up to several thousand cubic yards of material each year without significant added costs. Larger volumes require greater commitments of land, labor, and/or capital investments.

Rynk et al. (1992) further explain that the cost of an AC operation depends on a large number of variables that differ from farm to farm. Variables include the local costs of labor and fuel, the value of land, and the cost of purchasing and maintaining equipment. Several location factors can have strong influences on costs, including proximity to neighbors and transportation. Large equipment can handle more material and decrease processing time, taking initial costs from a few hundred dollars to hundreds of thousands of dollars (Dreyfus, 1990; Gresham, Janke, & Moyer, 1990; Richard, 1990).

Rynk (2001) provides insight into the economics of on-farm composting via case studies of seven on-farm composters located within or near the Pacific Northwest of North America. Expenses that were looked at included business and site development, feedstocks, equipment, labor, marketing and/or compost use, and management. Rynk noted that savings on a farm can come from less costly manure handling, elimination or reduction of handling and disposal costs for crop residues, benefits from fewer weed seeds in compost rather than manure, and reduced pesticides and other costs for fly control. In addition, intangible benefits that are difficult to put a value on, include improved neighbor relations due to fewer odors and flies, improved animal health resulting in lower veterinary costs and/or better productivity, a smaller risk of dispersing pathogens and lower environmental impacts like runoff or leaching.

Rahmani, Hodges and Kiker (1999) conducted a CBA at four AC facilities in Florida. Statistics were compiled on facility ownership, feedstocks used, parameters of finished material, major customers, cost of making compost and income generated. Data were obtained on the type of compost used, soils, application rates, crops, cost per ton of compost, purchased transportation and spreading methods, effects on the yield, quality, and changes in the fertilizer of the applied compost, impact of feedstock quality, application rates, yield increases and fertilizer usage. The costs associated with applied composting included compost cost, hauling cost, and cost of application. Benefits associated with applied compost included yield increases, irrigation savings and savings in fertilizers, pesticides and herbicides.

Cost-Benefit Analyses of Anaerobic Digestion

Duffy (2017) performed a CBA of AD of manure for a farm. The benefits that were taken into consideration included the potential sale of either the biogas itself or the use of biogas to generate electricity which could be sold back to the grid, the resale of digested fiber as compost or liquid digestate as high-quality fertilizer, and the heat generated by the system in the form of hot water circulated by a CHP system. Capital costs considered included lift station pumps, mixing tanks, the digester tank itself, piping for gas and hot water, gas pumps, flow meters, safety features, generators, electrical wiring and controls as well as power transmission lines, design engineering, and onsite buildings for generators, maintenance, operations, etc.

Navaratnasamy, Edeogu, & Papworth (2008) provided a high level, theoretical approach to exploring the costs of AD. Datasets on the assumptions available in the literature were presented on the ranges for total solids, volatile solids and biogas yield (m3/tonne) and estimated total annual biomass production (tonnes) and energy potential (PJ). With the calculation of total energy production, a methodology for calculating the total capital costs was provided. Moser, Mattocks, Gettier, & Roos (1998) analyzed seven agricultural AD systems. Variables that were considered for the calculation of the annual benefits included electricity sales, digested fiber sales, reductions in propane use, and hot water. Total benefits were as high as $55,400. The cost variables considered included constructions cost of the digester system, and ranged from $125,000 to $289,474.

Climate and Energy Benefits

Many have done assessments to calculate the climate and energy impacts of food waste processing. Morris, Brown, Cotton and Matthew (2017) performed a harmonization of life-cycle assessments (LCA) and a soil science ranking of food waste management methods. Twenty-eight life cycle studies were used to harmonize methods of estimating climate and energy impacts from food waste processing, and 80 scientific soil productivity studies were assessed to rank each processing method's soil benefits. AC and AD were among the methods reviewed. It was determined that the harmonized climate impacts per kg of food waste for AC was -0.10 kg of CO_2e and -0.20 kg of CO_2e for AD (

Table 1). Harmonized energy impacts for AC was 1.14 MJ/kg and 0.27 MJ/kg for AD. Qualitative rankings of AD and AC indicate AC is better for carbon storage and water conservation, AD better for fertilizer replacement, and tie AC and AD are similar for plant yield increase. To harmonize climate and energy impacts, all LCAs were adjusted to use 2007 Intergovernmental Panel on Climate Change (IPCC) 100 year global warming potentials, and to use the energetic value of electricity of 3.6MJ/kWh.

Table 1. General harmonization results for climate and energy impacts (Morris, Brown, Cotton, & Matthew, 2017; State of Oregon Department of Environmental Quality (DEQ), 2014).

	climate impact (kg CO_2e/kg food waste)		energy impact (MJ/kg food waste)	
activity	aerobic composting	anaerobic digestion	aerobic composting	anaerobic digestion
LCA sample size	(25)	(10)	(10)	(1)
collection and transport	0.04	0.02	0.68	0.68
processing	0.11	0.09	0.66	0.58
carbon storage	−0.12	−0.08		
fertilizer displacement	−0.05	−0.02	−0.14	−0.08
peat displacement	−0.07	−0.01	−0.06	−0.09
electricity displacement		−0.19		−0.83
total impact (net)	**-0.10**	**-0.20**	**1.14**	**0.27**

Morris, Brown, Cotton, and Matthew's (2017) LCAs for harmonization of food waste processing also estimated values for soil carbon storage, fertilizer displacement, peat displacement, and electricity displacement impacts (Table 1). Soil carbon storage occurs when stable soil carbon content increases following the application of AC compost or AD digestate. Synthetic nitrogen (N) requires significant quantities of energy to transform gaseous N to mineral N, and phosphate has to be processed from phosphate rock into a form that is plant available. Displacement of peat in growth media and grid electricity were additional variables that were harmonized for the carbon and energy impacts of AC and AD.

Morris et al. (2017) also looked at qualitative studies that reviewed the climate and energy impacts of AC vs. AD on plant and soil productivity. A qualitative approach was taken because the response of the different amendment will be inherently variable depending on soil type, cropping system and the characteristics of the amendments. AC ranked higher than AD in soil carbon sequestration and water conservation, while AD ranked higher in fertilizer replacement and yield increase (Table 2). Climate and energy impacts of facility construction and equipment manufacturing were not included due to the highly uncertain nature of the assessments and are typically found to be *de minimus*. Also not included were the production of vehicles, roads or waste water conveyance pipes.

Table 2. Ranking from harmonization and qualitative assessments of food waste treatments (Morris, Brown, Cotton, & Matthew, 2017).

treatment	climate	energy	soil carbon	fertilizer replacement	water conservation	yeild increase
AC	2	2	1	2	1	1
AD	1	1	2	1	2	1

Research Questions, Hypotheses and Specific Aims

The main objective of this thesis was to compare food waste processing technologies to understand which have higher socio-economic benefits. This comparative study would suggest sustainable ways for developing a food waste management infrastructure. The main research question I investigated were: Which food waste processing strategy has higher net benefits? I hypothesized that the net socio-economic benefits of AC are higher than those associated with AD.

Another research question I examined is: Which variables drive the economics of food waste processing methodologies the most? I hypothesized that transportation, changes in output product prices (digestate, biogas and compost), and the social cost of carbon would be the biggest drivers. In addition, I hypothesized that the driving variables are the same for AC and AD.

Specific Aims

To accomplish this research, I:

1. Extracted data from the literature to estimate the economic costs and to identify the cost and benefit variables
2. Interviewed AC and AD facilities in Massachusetts
3. Developed a CBA model for the NPV of the two methodologies
4. Analyzed the results
5. Performed a sensitivity analysis to highlight the driving factors for the NPV

Chapter II

Methods

I used interviews with key representatives of a large number of AC and AD facilities in Massachusetts to produce comprehensive datasets on food waste management in this state. Literature research helped to fill data gaps and verify collected data. Detailed information on all aspects of windrow AC and on-farm AD were then used to undertake a cost-benefit analysis comparing the two food waste processing approaches. Finally, I carried out sensitivity analyses to gain an understanding about each variable's impact and about the robustness of the CBA results.

Data Handling

As the first state in the United States to ban food waste, I conducted my study in the State of Massachusetts in the region of New England. To obtain an understanding of the operational logistics of food waste processing in Massachusetts, I had meetings with the Massachusetts Department of Environmental Protection (MassDEP) and other food processing experts in Massachusetts. I also attended a Massachusetts based composting conference and visited food waste processing facilities. From these meetings, I identified the state's primary food waste processing methodologies that would be the basis of this study. The facilities possible for review for data on windrow composting were 30 AC facilities, and five on-farm AD facilities. During the months of January and February, 2018, I called them all to solicit data on their facility. Facility managers were informed that the data was for a CBA of food waste management in Massachusetts, and that their facility would be kept confidential, which was a key request of many of the processors. Finally, 10 windrow AC facilities and four on-farm AD facilities were willing to share their data with me.

Survey questions were developed before the interviews to standardize the approach. Some questions were derived from previous CBA in the literature that focused on financial data of AC and AD facilities. The question catalogue was continuously updated and extended as new facts were learned during the interviews. In some cases, several rounds of discussions were necessary until the different datasets were comprehensive and comparable. Data estimations were requested for an annual average, and for only the AC or AD operations, as some facilities had additional operations. Questions were raised to gain an understanding of the food waste processing methodology used, the size of the facility, financial parameters and the facilities' views on broader food waste topics (Table 3).

Although the interviews yielded very comprehensive datasets, differences in the data and the existence of data gaps made it essential to access literature as well. I used peer reviewed journals and other information from trusted sources to check data for plausibility. This was especially important for data points that varied strongly among interview partners. In addition, not everyone was able to provide me with a full set of answers. The resulting mosaic of very valuable data was extended by the third party literature wherever needed to arrive at a complete table of variables that could be used for the economic appraisal.

Table 3. Question catalogue for Massachusetts food waste processors surveys.

General
What methodology of food waste processing do you use?
What are the feedstock inputs to your operation?
Please describe each step of your food waste process.
Do you perform other operations in addition to food waste processing at your facility?
How long has your facility been in operation?
Size
How much food waste goes into your process?
What are the quantities of feedstocks inputs, or, what is the volumetric percentage of each input feedstock?
Upfront costs and immovable assets
Can you estimate your startup costs of entering this business?
What were your construction costs?
Did you have any preexisting infrastructure that supports your operations?
Movable assets and operating costs
Please list all equipment that supports your operation.
For each piece of equipment please provide the make, model, age, price paid, estimated current price new, percent usage for the food waste operations, number of operating hours, number of labor hours, maintenance costs and fuel consumption.
Please estimate your annual equipment maintenance costs.
How many labor hours are invested in the food waste operation each week?
Can you think of other operating expenses you incur?
Benefits
What are your tipping fees?
What products do you produce and how much do you sell them for?
How much is sold externally and how much is applied to your own land?
Ancillary questions
What do you think are the biggest issues or opportunities with food waste management in MA?
What do you think are the intangible costs or benefits associated with food waste management?
What do you think can be done better to improve food waste management in MA?

Establishing Comparability between Datasets

Food waste processing facilities vary greatly in size. To make data comparable, I needed to restate numbers from different facilities on a per short ton (2,000 lb, or 907.19 kg) of food waste basis. In addition, the amount of food waste processed per year was reported in different units. I converted volumetric food waste estimates to weight-based estimates by applying an EPA density estimation (US EPA, 2006).

Apart from facility size differences, there were also differences in how a facility is run. Most facilities process waste other than food waste and/or run a farm partly using the same equipment that is used for treating food waste. Where applicable, I adjusted costs and benefits for their actual share in treating food waste (for example, if a front loader is used only 20 percent of the time for composting and 80 percent for other farm related work, only 20 percent of the front loader's maintenance costs were considered). The weight-based percentage of food waste was also applied to equipment costs, equipment maintenance costs, land costs, employment payments, savings in unemployment costs, and sales of finished compost or digestate. The weight-based percentage of food waste was, however, not applied to transportation, tipping fees, or climate and energy benefits of food waste processing, as these calculated values were only associated with the food waste portion of the input feedstocks.

CBA Variables

The variables used for the economic appraisal include both actual costs and benefits associated with setting up and running AC and AD facilities in Massachusetts. The types of costs and benefits are similar for both food waste treatment methods with differences stemming mainly from the output products and the necessity of having buildings in place to run operations (Table 4). For comparability, all cost and benefit variables were converted into dollars per short ton of food waste.

Table 4. Overview costs and benefits.

	Aerobic Composting	Anaerobic Digestion
Costs		
Land	✓	✓
Buildings		✓
Equipment and maintenance	✓	✓
Operating costs including labor	✓	✓
Transportation	✓	✓
Benefits		
Labor benefits to society	✓	✓
Tipping fees	✓	✓
Compost sales	✓	
Electricity sales from biogas		✓
Digestate sales		✓
Heat production from biogas		✓
Energy from fertilizer replacement	✓	✓
Energy from peat replacement	✓	✓
Social cost of climate	✓	✓

AC equipment and equipment maintenance costs. The type of machinery used in AC depends on the composting system and on the quantity of organic waste treated at the facility. All composting sites interviewed in Massachusetts were windrow composting sites, which are also the simplest and cheapest form of composting. This system requires machines that mix and turn windrows on a regular basis. This can be done with front-end loaders, backhoe loaders, equipped tractors or windrow turning machines (RSS, 2017). Of the facilities surveyed, only a few AC facilities in Massachusetts use a windrow turner or tractor while all AC facilities use front-end loaders. This is also explained by the fact that farms often need front-end loaders for other activities on the farm which means that no additional capital investments have to be made for composting (Fabian, Richard , & Kay, 1993).

AC processors were asked to list each piece of equipment that supports their composting operations. For each piece of AC equipment, data were collected on the equipment type, make and model, age, purchase price, percent of usage dedicated to composting operations, number of operating hours, number of associated labor hours, maintenance costs, and fuel consumption. All ten AC facilities used at least one front-end loader and most used a trommel screener. Research into the specifications of each piece of equipment was performed online and data of significance, like a tractor's horsepower or a front-end loader's bucket size, was collected. These details were important in order to compare machinery across brands.

The respondents' estimates of capital and maintenance costs of equipment varied widely. In addition, many facilities do not track maintenance costs. Because of that, I was not able to directly plug the answers into the CBA; however, knowing the type of machinery made it possible to indirectly calculate equipment costs. The U.S. Army Corps of Engineers (USACE) provides estimates for construction equipment ownership and operating expense rates for the region of New England. Data from this resource covers inter alia machinery used for food waste processing, such as front-end loaders, tractors, excavators, and backhoes. USACE (2016) provides average hourly equipment rates of equipment ownership and operation per type of machinery which I was able to use for my analysis.

The ownership portion of the rate consists of an allowance for depreciation (DEPR) and a facilities capital cost of monies (FCCM). For the DEPR rate, a straight line method is used and calculated by dividing the depreciable value by the expected economic life of the unit of equipment in hours. The FCCM rate is computed by multiplying a discounted cost of money rate by the average value of equipment and prorating the result over the annual operating hours. The operating portion of the rates of equipment include fuel (FUEL), filters, oil, grease (FOG), repairs (REPAIRS), tire wear (TIRE WEAR) and tire repair (TIRE REPAIR). The total equipment value (TEV) and the economic life (LIFE) of each piece of equipment is also provided by USACE. Equipment that was not listed in the USACE resource are grinders, manure spreaders, trommel screeners, trucks and windrow turners.

For each reported piece of equipment, reported equipment data were entered into an AC equipment calculation spreadsheet, and where available, USACE equipment rates for DEPR, FCCM, FUEL, FOG, REPAIRS, TIRE WEAR and TIRE REPAIR, as well as, the USACE values for TEV and LIFE. To integrate USACE rates into the CBA, several adjustments were made. First, rates were adjusted from 2013 values to a 2017 value, by applying inflation rates as reported by The World Bank (2018). Second, the diesel fuel rates were adjusted for 2017 fuel rates in Massachusetts. The average price for one gallon of diesel in Massachusetts in 2017 was $2.573 including taxes (Commonwealth of Massachusetts, 2017). Facilities reported current diesel fuel costs between $2.75 and $3.00 per gallon which match the diesel rates for 2018 as reported by the Commonwealth of Massachusetts. As data was collected for historical costs, FUEL was adjusted to the 2017 Massachusetts average diesel fuel price of $2.573.

In the AC equipment calculations spreadsheet, annual equipment costs and operating costs were calculated for each reported piece of equipment. Facilities will buy equipment that is new or used. For standardization, the cost of each piece of equipment when it was new was calculated. The annual equipment costs were estimated in two ways. As shown in Equation 1, they were first calculated with the processors' estimated cost of their equipment if purchased new and then calculated as in Equation 2 using the USACE DEPR rate. These numbers were compared for similarity, and it was observed that the reported costs closely matched the USACE calculation of equipment costs. To better represent the state of Massachusetts, the calculation of the reported estimations of equipment costs new was input into the CBA model. If this was not available, the USACE estimation was then used. The economic life was estimated as reported in the USACE resource. Where data were not available, the estimate by Bennet & Ward (2010) was used, that farm equipment and machinery has an asset recovery period of ten years.

$$EQUIPMENT_{REPORTED} = \frac{VALUE_{NEW} \times USA\quad_{COMPOST}}{\left(\frac{LIFE}{HOURS_{COMPOST}}\right)} \qquad (1)$$

Where:

$VALUE_{NEW}$ is the reported new cost estimate of a piece of equipment
$USAGE_{COMPOST}$ is the annual usage hours for composting operations
LIFE is the economic life
$HOURS_{COMPOST}$ is the reported number of hours the equipment was used for composting operations

$$EQUIPMENT_{USACE} = DEPR \times HOURS_{COMPOST} \qquad (2)$$

Where:,

DEPR is the allowance for depreciation
$HOURS_{COMPOST}$ is the reported number of hours the equipment was used for composting operations

Annual operating costs were similarly estimated two ways using the AD or AC processor's reported data and calculations from USACE estimations (Equation 3). The reported operating costs were extremely variable as they were dependent on the age of the equipment and the variance in repairs year-to-year. To reduce variability, fill data gaps and stay consistent with the straight line method of depreciation calculations, the USACE estimations were used to estimate annual operational costs for front-end loaders, tractors, backhoes, and excavators. For equipment not included in the USACE resource, the reported annual maintenance cost (Equation 3) was used. Annual fuel consumption was calculated for both the reported consumption and the USACE estimated consumption to gain insight into the reliability of the maintenance calculations. The observed comparison of the values showed both strong correlations and variation. If any data needed for the aforementioned calculations was not reported or available through USACE estimates, the costs reported by another facility were then used.

$$MAINTENANCE_{USACE} = (FUEL + FOG + TIRE\ WEAR + TIRE\ REPAIR + REPAIR) \times HOURS_{COMPOST} \quad (3)$$

Where:

FUEL is the hourly fuel rate
FOG is the hourly filters, oil, grease rate
REPAIRS is the hourly repair rate
TIRE WEAR is the hourly tire wear rate
TIRE REPAIR is the hourly tire repair rate
$HOURS_{COMPOST}$ is the reported number of hours the equipment was used for composting operations

AC equipment and equipment maintenance costs. AC processors were also requested to describe any construction work that was needed to support their operations and to provide estimations of the costs. Investments in construction were variable. Most processors did not use any infrastructure to house their equipment. A few facilities made initial investments in excavating, grading and laying down stone at their composting facility. One facility built an office while another used existing infrastructure for an office. A few facilities made investments in odor control techniques like a leachate lagoon, a grinder for the preprocessing of food waste, and a compost pile treatment and perimeter vapor system. In general, buildings are not a crucial component of a windrow composting facility. As such, AC construction costs were not included in the CBA.

AD construction, capital, and operating costs. Contrary to AC, AD takes place in-doors and construction expenses are a considerable cost factor. AD processors were asked to provide estimates of their construction or capital costs, and their annual maintenance costs. Construction costs and any upgrades were provided, for which a ten year lifespan was assumed (USDA, 2007). The World Bank (2018) inflation rates were applied, adjusting costs from the year of initial construction. Maintenance costs provided by the processors was entered into the CBA model. If maintenance costs were not provided, three percent of the total capital costs was then estimated as the cost of maintenance as recommended by USDA (2007) for AD. Operating costs are mainly labor costs and electricity consumption. Labor costs are discussed later but other operating costs incurred were mostly due to the consumption of energy to keep the digesters running. It was not possible to get detailed figures on the energy consumption of AD processing from my interview partners, so I used third party literature (i.e. Morris et. al., 2016) to fill this data gap.

Land. The number of acres used for the processing operations was solicited from the processors. AD facility owners reported their rental costs, which were entered into the model. In AC operations, most land was already owned and the land value was not known. To estimate the value of the compost land, a study on the cost of renting agricultural land for biomass production in Massachusetts was used (Timmons, 2014). A geographic information system model identified a landowner population. A contingent valuation survey revealed that landowners were willing to accept a median payment of $321 per hectare for growing biomass crops. To estimate the annual cost of food waste processing land for AC sites, I multiplied the total number of acres by the adjusted land rate of $792.87 per acre.

Transportation. These expenses reflect the costs of transporting food waste to the facilities. For all food waste generators (Figure 3), for which the Massachusetts food waste ban applies, location coordinates are provided by the MassDEP (Mass DEP, 2011). The average of all coordinates was calculated to find the average location of the food waste generation in Massachusetts. The coordinates of this average location of all Massachusetts food waste generators was calculated as 42.253, -71.303. The distance from this location to each processor's facility considered in this study was then calculated using google maps. A 3:00 AM EST departure time was used to eliminate any variability from traffic. Waste management companies in Massachusetts were called to get their estimated cost associated with the transportation of food waste. One waste management company estimated that a round trip delivery of food waste from their facility to a processor facility costs $0.50 per ton of food waste for every mile travelled. To get the cost associated with the transportation to each processor's facility, the distance was multiplied by the transportation cost factor.

Cost of employment. I have interviewed AC and AD facility owners to gather information on labor intensity and costs. In addition, I used third party material to verify the numbers. AC requires workers to operate machines, such as front loaders and tractors. Estimations of labor hours for operating machinery are typically 10-20% longer than the field time because of travel and the time required to lubricate and service machines (Edwards, 2015). Machinery operation hours were multiplied by 1.15 to calculate the labor hours associated with each reported piece of equipment. For equipment that was reported as not needing any operation other than maintenance and setup, like a trommel screener or a manure spreader, the multiplier was 0.15 in calculating the associated labor hours. On-farm AD requires workers to operate the digester. The number of labor hours needed to support the operation of the on-farm AD systems was provided by the AD processors. Where information on the engineering support group for AD was not provided, an estimate of 15% additional labor hours was similarly applied to the total operating labor hours.

According to the United States Department of Labor (2016), operators of such machinery make on average $14.60 per hour (United States Department of Labor, 2016). This value was in line with the estimates of interviewees from both AC and AD facilities. To calculate the annual value of employment, the reported working hours were multiplied by the estimated cost of labor for machinery operations from the United States Department of Labor.

Benefits of employment to society. While employment is a financial cost for AC and AD operators, it is a benefit to society. Employees pay income tax to the government and use their salary/wages to buy products and services, thereby paying value-added taxes and increasing corporate taxes paid by companies. In turn, increased unemployment rates increases government spending on unemployment benefits. This may also require the government to borrow money, on which it pays interest. Studies suggest that the costs of one unemployed person may add up to as much as $100,000 per year (Masur & Posner, 2012). The labor intensiveness between AC and AD is indeed different. With AC, workers have to operate machines to frequently turn the compost, while AD plants are mostly operated automatically with one person supervising. Labor hours, in full year equivalents, were multiplied by $100,000 per person and added into the CBA as a benefit.

Tipping fee. Information on tipping (or gate) fees were collected from each facility. Some facilities charged different tipping fees depending on the frequency of the deliveries and the type of organic material being delivered. Some facilities did not have revenues from a tipping fee because they had their own food waste transportation operation or are a new facility that has not yet begun to collect food waste. Revenues from tipping fees were added to the CBA as a benefit.

AC compost. Each facility was asked what input feedstocks made up their compost, and their correlating volumetric percentage. The EPA density value for each feedstock was applied to calculate the percentages of each feedstock by weight. Each facility was also asked how much compost they produced each year and what their average selling price was. The compost produced was either sold or applied to fields owned by the processors. Independent of whether the compost was sold or applied to land, the selling price of the compost was multiplied by the total compost produced and applied to the CBA as a benefit.

AD biogas and the production of electricity and heat. Production of biogas from Massachusetts AD facilities is used to generate electricity and heat. Electricity is sold to the grid, and heat is generated and provided back to the farm at no cost. The amount of electricity produced at each facility surveyed was collected, as well as the current selling price of the electricity. The estimated selling price of electricity matched the 2018 values as reported by the US Energy Information Administration (2018). Revenues from electricity production were added into the CBA model using a Massachusetts 2017 value of $0.15/kWh (US Energy Information Administration, 2018). In addition to the revenues from the selling price of the biogas, carbon credits were purchased for the use of biogas, providing additional revenues. Heat costs were estimated using source data. One of the AD facility owners reported that their facility was saving the farmer between $25,000 and $30,000 a year on heat costs. Farmers of on-farm AD facilities were also asked for the solicitation of this data. One of the farmers estimated that they had an annual heat cost saving between $25,000 and $35,000 a year. An average of these estimates was applied to all the farms from which I was not able to obtain source data.

AD digestate. The quantity of liquid digestate produced from AD was calculated using information provided by the facility. Through this process, one facility reported that the feedstock quantity was reduced by 10% as a result of the biogas production. The quantity of the digestate was calculated at 90% of the feedstock. One farmer, who has an AD facility on his farm, reporting selling a tank of 5,000 gallons for $100 to $120, not including the cost of transportation fuel. This is equivalent to $0.02 per gallon of digestate. Dr. Ruihong Zhang, a professor of Biological and Agricultural Engineering at the University of California Davis, mentions that digestate has been sold to farms and agricultural material facilities at a cost of $0.10 per gallon (Zhang, 2017). However, the source-provided estimate price of $0.02 per gallon of digestate was applied to all AD facilities in the CBA.

Peat and fertilizer savings in energy. Morris, Brown, Cotton, & Matthew (2017) provide rates for the energy savings from peat and fertilizer production of compost and digestate. Synthetic nitrogen (N) requires significant quantities of energy to transform gaseous N to mineral N, and phosphate has to be processed from phosphate rock into a form that is plant available. Benefits from the displacement of peat in growth media and grid electricity were added into the CBA. These energy rates were converted for an energetic value of electricity of 3.6MJ/kWh.

Climate benefits. Mapping the impact on climate of all food waste management processes would go beyond this thesis and requires different tools, such as life-cycle assessments (LCA). Nonetheless, CO_2 and methane generation may very well be significant variables and leaving them out entirely might distort the final result. As such, I opted to access literature to find estimates on the carbon footprint of AC and AD. The analysis of 28 LCAs by Morris, Brown, Cotton, & Matthew (2017) calculated the release of CO2e for each methodology per kg of food waste. This number considers greenhouse gases generated while transporting food waste and processing it, but also takes into account the CO2e savings from carbon sequestration and producing renewable energy, peat and organic fertilizers. I converted this number to the unit of short ton of food waste and added it to the CBA by multiplying the CO2e savings by a factor for the social cost of carbon. The USEPA and other governmental agencies use estimates of the social cost of greenhouse gases to value the climate impacts of rulemakings. The social cost of carbon is meant to be a comprehensive estimate of climate change damages and includes changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. Table 5 shows the summary of their findings. At a recommended discount rate of 3%, the 2017 social cost of CO2e is $38.40 (US EPA, 2018).

Table 5. Social Cost of CO_2, 2010-2050 (in 2007 dollars per metric ton of CO2e) (US EPA, 2018).

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

CBA & Sensitivity Analysis

The costs and benefits identified so far were then expanded over a time horizon of 15 years, which is a fairly typical expected life span of food waste processing investments. I applied a discount rate of 2.50 % to discount future costs and benefits. This rate is the most updated discount rate required by the US Office of Management & Budget for CBAs in relation to federal project spending (OMB, 2016). I also applied the ten year lifespan estimate for the cost of agricultural equipment and AD facilities, making this cost drop to zero for years 11 through 15. I then compared the net present value (NPV) of AC with AD. The food waste methodology that exhibits a higher NPV is the more beneficial one for society.

After determining the NPV, I carried out a sensitivity analysis to find out which variables exerted the strongest influence on the CBA results. I changed each variable separately by the same degree and observed the resulting change in NPV. I then ranked the variables from highest to lowest impact on NPV. Finally, I produced graphs that make it easier to understand each variable’s impact on NPVs across a wider range of assumptions.

Chapter III

Results

A Cost-Benefit Analysis (CBA) was used to compare the economics of AC and AD to the society in Massachusetts. With the help of a sensitivity analyses, I identified the driving variables of the model.

Cost-Benefit Analysis

Discounting costs and benefits of AC over a lifespan of 15 years produced a positive net present value of $10 per short ton of food waste. The biggest benefit generators are revenues from tipping fees ($18) followed by the selling of compost ($12). In addition, AC generates tangible benefits to a society by creating jobs ($10). This avoids direct costs like unemployment payments, but also supports the economy since employed people typically consume more. The biggest cost factor, by far, is the transportation of food waste to the AC operators ($23 per short ton of food waste). Discounted expenditures related to running AC equipment, such as front-end loaders, amount to $4, while salaries equal $3 per short ton of food waste. Since compost effectively avoids the need to produce fertilizers elsewhere, benefits are generated for forgone energy consumption and CO2e release, as well (Table 6).

The NPV for AD is negative and sums up to -$12 per short ton of food waste. For AD, the biggest cost driver is the transportation of food waste to the facilities ($33). In Massachusetts, on-farm AD facilities are generally farther away from food waste sources,

Table 6. CBA results of aerobic composting.

Aerobic Composting	2017	2018	2019	...	2029	2030	2031	Total	NPV
Construction and Equipment	($9)	($9)	($9)		$0	$0	$0	($88)	($4)
Maintenance	($11)	($11)	($11)		($11)	($11)	($11)	($160)	($4)
Land	($1)	($1)	($1)		($1)	($1)	($1)	($9)	($0)
Transportation	($58)	($58)	($58)		($58)	($58)	($58)	($867)	($23)
Labor	($8)	($8)	($8)		($8)	($8)	($8)	($113)	($3)
Unemployment Savings	$25	$25	$25		$25	$25	$25	$371	$10
Tipping Fee Revenues	$45	$45	$45		$45	$45	$45	$675	$18
Compost Amendment Revenues	$29	$29	$29		$29	$29	$29	$436	$12
Fertilizer Displacement Energy	$5	$5	$5		$5	$5	$5	$81	$2
Peat Displacement Energy	$2	$2	$2		$2	$2	$2	$35	$1
Climate Benefits	$3	$3	$3		$3	$3	$3	$52	$1
						Aerobic Composting			$10

which increased transportation costs by $10 compared to AC facilities. Unlike AC, AD is affected by substantial cost drivers, such as construction costs and the energy needed to run the digesters. The biggest benefit generators for AD are electricity sales from biogas production ($19) and tipping fees ($12), even though AD facilities seem to collect lower fees (-$6) than their AC peers. Since AD facilities are more automated and require less manpower, the benefits to society of creating jobs is also smaller (Table 7).

Table 7. CBA results of anaerobic digestion.

Anaerobic Digestion	2017	2018	2019	...	2029	2030	2031	Total	NPV
Construction and Equipment	($27)	($27)	($27)		$0	$0	$0	($266)	($11)
Maintenance	($1)	($1)	($1)		($1)	($1)	($1)	($14)	($0)
Land	($0)	($0)	($0)		($0)	($0)	($0)	($5)	($0)
Transportation	($82)	($82)	($82)		($82)	($82)	($82)	($1,233)	($33)
Labor	($2)	($2)	($2)		($2)	($2)	($2)	($31)	($1)
Processing Energy	($22)	($22)	($22)		($22)	($22)	($22)	($335)	($9)
Unemployment Savings	$5	$5	$5		$5	$5	$5	$78	$2
Tipping Fee Revenues	$30	$30	$30		$30	$30	$30	$450	$12
Electricity Revenues	$48	$48	$48		$48	$48	$48	$727	$19
Heat Cost Savings	$1	$1	$1		$1	$1	$1	$20	$1
Digestate Revenue	$6	$6	$6		$6	$6	$6	$87	$2
Fertilizer Displacement Energy Savings	$3	$3	$3		$3	$3	$3	$46	$1
Peat Displacement Energy Savings	$3	$3	$3		$3	$3	$3	$52	$1
Climate Benefits	$7	$7	$7		$7	$7	$7	$109	$3
						Anaerobic Digestion			($12)

Sensitivity Analysis

Running sensitivity analyses revealed which variables disproportionally impact the NPVs of the cost-benefit models, meaning that some variables have a stronger influence on the feasibility of the respective food waste methodology than others. The NPVs of AC and AD are most sensitive to changes in the distance of the facilities to the sources of food waste and the price of diesel (Figure 7). A 20% change in distance would lead to a 39% change in AC and 85% change in AD NPV. Tipping fees impact the economics of AC more than the market price of compost (30% vs. 24% for a 20% change in each variable). In turn, equipment costs, labor costs and the price of CO2e have an under proportional effect, meaning that changes in those variables lead to a smaller change in AC NPV (Figure 7, top). The AD NPV is more impacted by changes in the price of electricity, which directly affects the value of its biogas than by tipping fees. Construction and equipment costs also have an over proportional effect (Figure 7, bottom).

Each variable's impact can be positive or negative for NPV values, as highlighted by Figure 8 below. Lines drawn from the upper left to the lower right of the graphs show variables that decrease the NPV with increasing variable size (i.e., costs). Lines from the lower left to the upper right have the opposite effect with increasing NPVs and represent increasing benefits. The steeper the slope of the line, the stronger the variable's impact is on NPV. While transportation, diesel and tipping fees are steep, labor and CO2e costs are relatively flat.

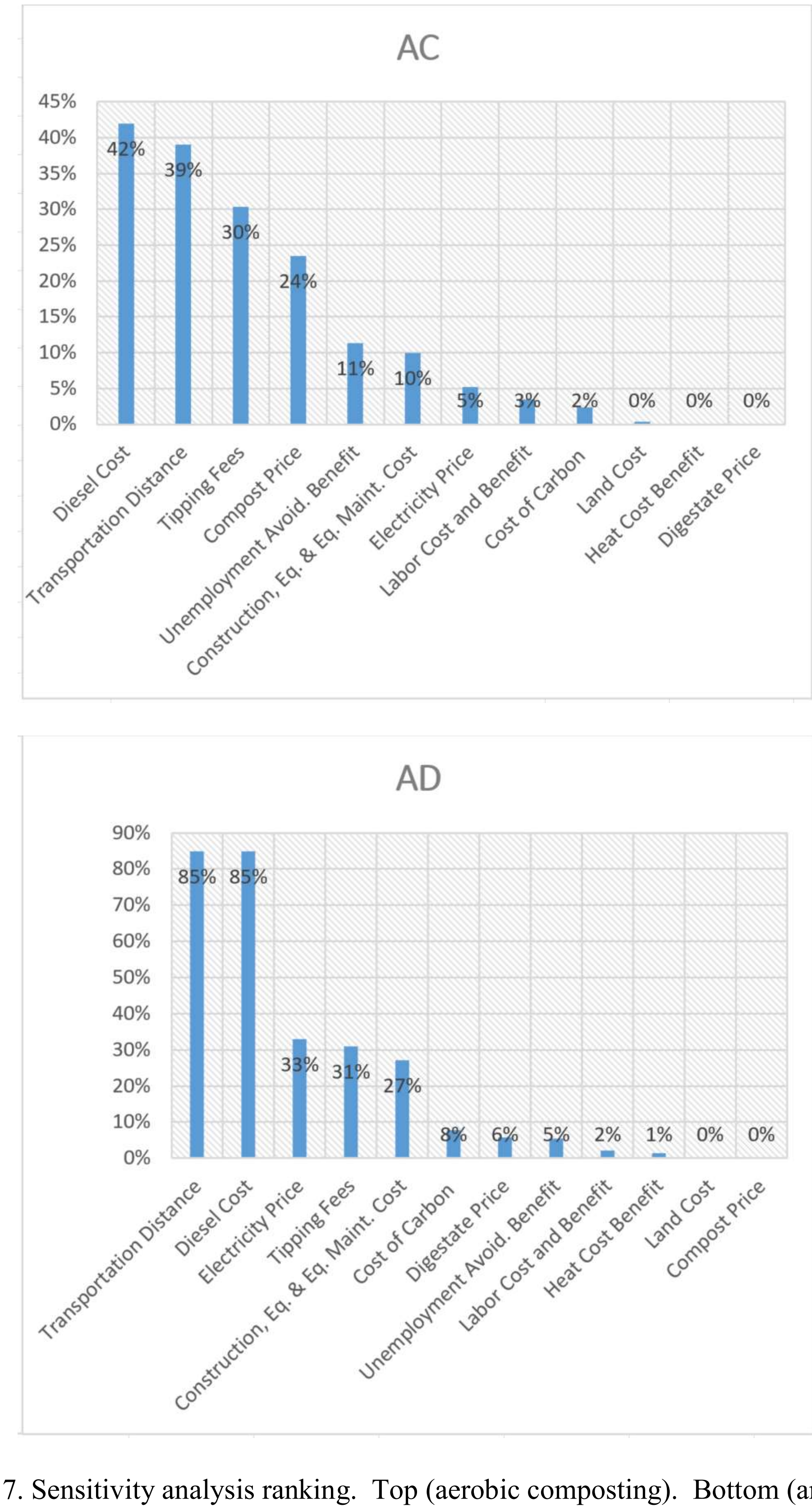
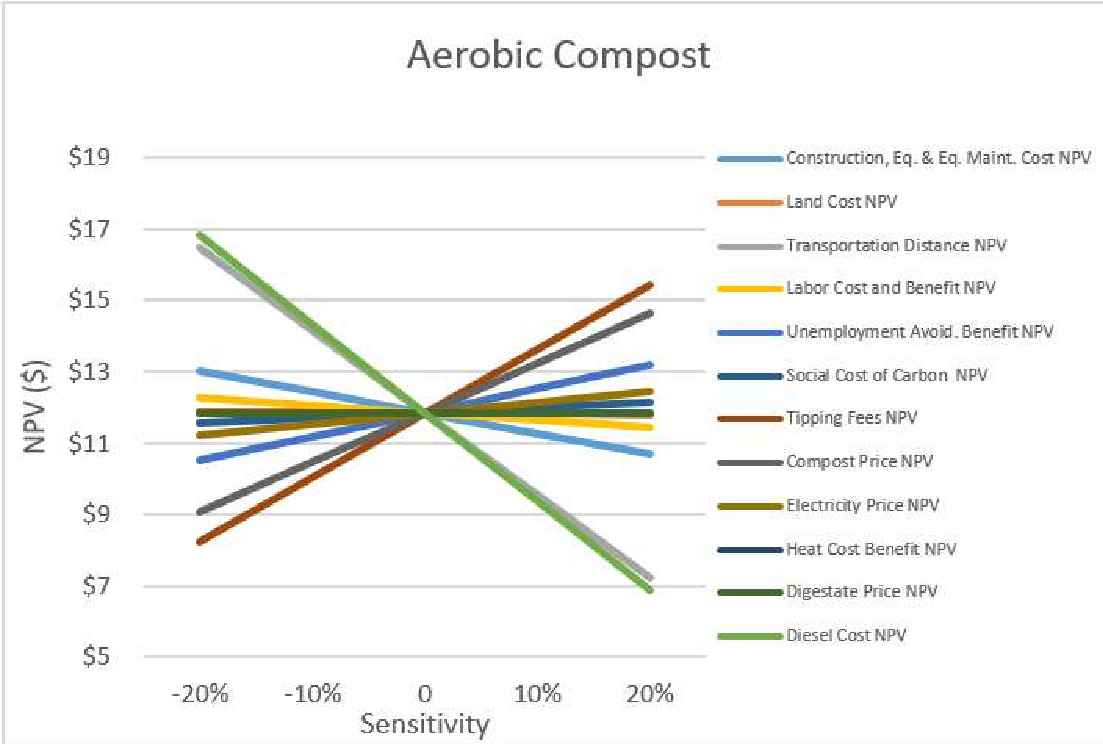


Figure 7. Sensitivity analysis ranking. Top (aerobic composting). Bottom (anaerobic digestion).



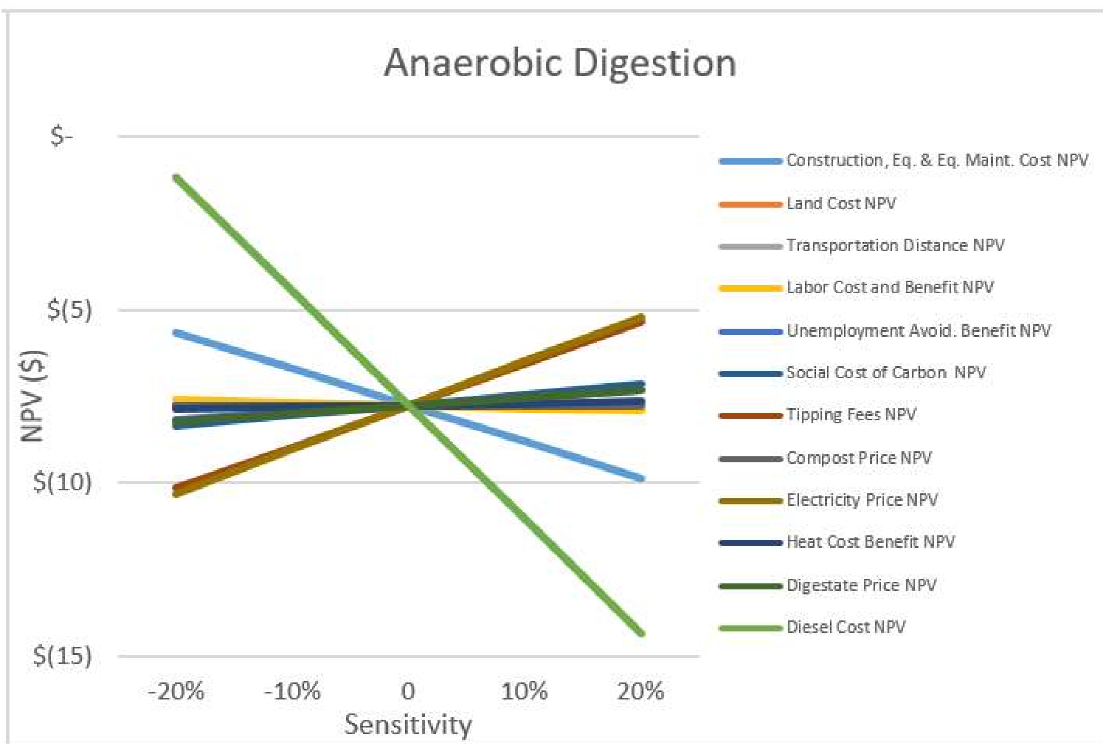


Figure 8. Sensitivity analysis values across NPV ranges. Top (aerobic composting). Bottom (anaerobic digestion).

Chapter IV

Discussion

Model outputs and sensitivities highlight the significance that food waste processing methodologies and variables have for providing ecosystem services. This valuation of food waste processing is not meant to be comprehensive but to elucidate the net benefits of its variables. A review of the results of the CBA of food waste processing variables will provide this insight.

Interpretation of Cost-Benefit Analysis

My primary hypothesis was that the net socio-economic benefits of AC are higher than those associated with AD. The results suggest that AC would have higher net socio-economic benefits than AD by $22 per ton of food waste, thereby supporting this hypothesis. The major contributing factors to these results were construction and equipment, transportation, tipping fees, employment and the revenues from biogas and compost. Equipment costs are fairly set for AD, but the costs for AC would probably be even lower than the estimates made herein, as many facilities buy used equipment and even do their own maintenance to keep these costs down. The revenues from AD and AC are set by market demands. Changes in these demands can be influenced by marketing, and a CBA presents a new marketing opportunity. It is my opinion that more marketing about the true socio-economic value of food waste processing might not only increase demand for its products, but also provide more tolerance among local populations to the issues that these technologies bring, like odors or visual disturbances.

The NPV of transportation was $10 less for AC when compared to AD. The estimation of transportation costs from the food waste generation location to the facility site was largely generalized by factoring in location and diesel fuel costs as variables. Collection of actual transportation costs were outside the scope of this project, as this enormous dataset would be very difficult to acquire and analyze. Future research would benefit from a separate analysis that focuses on the efficiencies of food waste transportation. The inclusion of transportation of food waste in a CBA depends largely on what is being compared. For this analysis, two different technologies were being compared in a case study for which locations were known, so it made sense to include this estimate. On the other hand, an analysis to determine if an AC or AD facility should be added to a farm operation would not be dependent on location.

Several factors influence the location selection of AC and AD facilities in Massachusetts. Typically, AC facilities are additions to existing farming operations, and are often also located on farms which tend to be located farther away from densely populated areas where food waste is generated. Both AC and AD facilities tend to also be located in places of low population because odor can be a problem for neighbors. Investments in odor control have the potential to mitigate this limitation, which affects both AC and AD facilities. A second factor that influences facility location for AD is the lack of a market for digestate in Massachusetts. Most of the digestate from AD will be applied to the farm on which it operates. In order to reduce the risk of effluent amounts of nutrients on farm land, AD facilities need to be located on farms with lots of agricultural land, thus limiting on-farm AD location options. Marketing of digestate would relieve this restriction, but would have to overcome two key barriers- the low perceived value of digestate and the high costs for transportation and handling (Mouat, Barclay, Mistry, & Webb, 2010). Further research should be performed on investments for AC and AD odor control technology, as well as the market for digestate.

Tipping fees differ by a NPV of $6, with current AC tipping fees charging $15 more than AD. Closing this gap would also close the gap on the difference in the financial assessment of the two facilities, making each technology similarly profitable. A financial assessment of the data for each technology could be taken as the sum of the processing facilities costs and their direct revenues. The results of a strictly financial assessment of the data collected results in an NPV profit for AC of $19 per ton of food waste and $10 for AD. Matched tipping fees between the two technologies would not only accomplish a similarity in the profitability of each technology, but would eliminate this competitive advantage.

A food waste generator or food waste management company will look at both the tipping fee cost and the cost of transportation when selecting a food waste processing facility. Eliminating differences in tipping fees between facilities would likely result in the selection of the closer facility, increasing the likelihood that the facility with a more efficient transportation route is selected. Tipping fees are determined by supply and demand. Opportunities to close the gap in tipping fees, lie in either greater transparency of the tipping fee prices or government interventions. Another argument in support of the development of a government control on the tipping fee would be that it would ensure food waste processing facilities remain profitable. In response to the addition of food waste processing at a waste water treatment plant in Massachusetts that used AD, concerns were reported by several AC facilities about the need to drop tipping fees to stay competitive in the industry.

Job creation from AC is about 1.5 times more per ton of food waste than AD. From a government point of view, this socio-economic factor alone is important in reducing unemployment rates. AC and on-farm AD also support many farms by providing an additional source of income so these technologies can also support employment rates by securing agricultural and animal husbandry operations in Massachusetts.

The case study for this project was designed to focus on the biggest food waste processing technologies used in Massachusetts, but incorporation of all technologies would be very useful in making future decisions on the development of food waste processing. Future analysis should incorporate secondary technologies, like AD facilities located at wastewater treatment plants or landfill sites, as well as landfilling of food waste. Because of the large quantities of food waste these secondary food waste processing facilities take in, their role in the economic landscape of food waste processing in Massachusetts is significant, and would be highlighted with their incorporation into the CBA. They would also be an interesting addition, as these technologies would have very different socio-economic results when compared to on–farm AD. Through the various discussions I have had with various industry experts and stakeholders, the addition of food waste processing at wastewater treatment plants or landfill sites would provide the benefit of greatly reducing transportation costs in Massachusetts, but would have less socio-economic benefits when compared to on-farm

AD or AC (Mass.gov, 2018). The addition of landfilling food waste into the CBA would also provide additional insight into the value of food waste collection and processing and would be a valuable element in the promotion of the food waste collection program.

When taking the aforementioned interpretations into consideration, a discussion presents itself around a scenario in which transportation costs are removed from the analysis and the closing of the tipping fee gap. Tipping fees are set by the facility and it is not clear from this analysis why there is a difference between AC and AD prices. If these two variables were matched for AD and AC composting, then the socio-economic benefits of AC and on-farm AD would be more closely matched ($6 per short ton of food waste). If it is assumed that digestate is undervalued and there is a market for this resource, then this would result in a rejection of the hypothesis due to the indifference between the socio-economic benefit of AC and AD.

Interpretation of Sensitivity Analysis

My second hypothesis stated that transportation factors, changes in output product prices (digestate, biogas and compost) and the social cost of carbon will be the biggest drivers of NPV, and that the driving variables would be the same for AC and AD. I reject both of these hypothesis, as the driving variables were not as hypothesized and were not matched for AC and AD. AD-only drivers included electricity price and construction and equipment costs. The only driver for AC was the price of compost. Drivers that impacted both AC and AD were transportation, diesel price, and tipping fees.

The result of the sensitivity analysis confirmed the importance of further research into reducing factors that limit location options for windrow AC and on-farm AD, as well as the optimization of transportation and its associated costs. It also indicated the importance of tipping fee prices and the need for further evaluation of its optimization options. Finally, it confirmed the value of developing marketing for food waste products and increasing awareness around the value of AD electricity and AC compost.

Data Collection, Research Limitations and Caveats

There are several caveats and limitations to the data collection. Since results are only as good as the input data, several potential factors of this study may have negatively influenced the accuracy of the data. Due to the infancy of food waste processing, limitations of data availability was a major restriction in data accuracy. The small number of AD processors in Massachusetts significantly limits the size of this dataset. Similarly, AC processing would have been better represented by a larger dataset. Although there are significantly more AC facilities than AD facilities and a much higher number of datasets were collected, many things are optional in AC processing (i.e. trommel screener, turn rates, feedstocks) so there are many variables that differed between facilities.

Data collection was voluntary and time availability for the processors was varied and limited. I connected with many processors that provided data they had readily available. For data not readily available, some processors were not able to invest the additional time required to collect this data from their historical records. Also, some processors were not able to make all estimations, particularly if there were multiple operations at the facility. Another major variable was the level of knowledge of ones financials. AC facilities provided more estimations of their financials, while AD operations and some larger AC operations tend to run more like companies and have a more comprehensive understanding of their financials. Transparency and competition concerns were also contributing factors, affecting the willingness of a facility to share its data. Lastly, the voluntary nature of the data collection also made it challenging to pursue data accuracy details. It should be noted and recognized that most facility managers made major efforts to work with me and to provide the most accurate estimations of the data requested. Future analysis should pursue opportunities to mandate participation and to use the opportunity to request a detailed account that would optimize the data accuracy. I would also recommend that future survey questionnaires be developed with representatives of each technology as much of the process details were learned while going through the survey process.

The data accuracy of operational costs were also dependent on a number of variables that differed between technologies and from facility to facility. Major variables included the operational process used, the cost of purchasing and maintaining equipment, the set price of the revenue products, and the types, availability and quantities of feedstocks. In developing the model, I attempted to assimilate these variables by normalizing data, taking median values of estimates, and isolating costs for the food waste portion of the operation. The drawback of these procedures is that they could potentially introduce additional inaccuracies to the calculations. There are many possible approaches to eliminating these sources of variability. Future analysis might include having a problem-solving meeting with key stakeholders to collaborate on the development of methodologies for data accuracy optimization.

Another limiting factor was the input feedstocks that are needed for the AC or AD processing of food waste. Yard waste, for example, is a critical input in food waste compost because of the carbon demands. Yard waste availability is limited and mostly seasonal, unlike commercial food waste generation which is ongoing. Future analysis may want to evaluate the impact on ecosystem services of the seasonality and limitations of various food waste feedstocks. Another limiting factor of the feedstocks lies in the sensitivity AC and AD have to the contamination of food waste feedstocks. Many processors reject contaminated food waste feedstock or incur additional costs and penalties in its processing. This suggests that more effort in food waste contamination reduction is needed and would ensure that food waste collected is getting repurposed.

A final limiting factor of this analysis was the availability of quantitative data. Some cost and benefits could not be included, as a complete analysis into the differences between AC and AD does not currently exist. As the research develops, rates for the costs and benefits of yield increases and water conservation should be included in the CBA analysis. Other quantitative factors that could not be included were cost and the benefits associated with the final destination of output products. Food waste that is composted in Massachusetts is going to where soil fertility improvements are needed, as this product is enters the market and is dispersed across Massachusetts. Food waste that is digested is generally only being applied to a few farms and remains restricted to these farms year after year.

Additional Considerations Warranting Discussion

The cost of carbon was not highlighted by the sensitivity analysis, but major discrepancies exist in the literature on how to value the cost of carbon. The EPA estimation of $38.40 per ton is currently most widely accepted, but other studies have concluded that the actual cost, as estimated in 2015, can be somewhere closer to $220 per ton. This could significantly increase the NPV of climate benefits of AC and AD by $7 and $14, respectively. Also, this would close the gap between AC and AD from $22 to only $14. Such an impact would really change the numbers and so keeping an updated CBA would ensure that decisions stay updated with the evolution of scientific research.

Food waste diversion supports our move from a linear global food system that creates the food waste and degrades soil to a circular global food system that reduces these impacts and provides us with an opportunity to address many of our global sustainability issues. Food waste is a precious resource that presents us with an opportunity to address several major global issues, like soil degradation, atmospheric carbon, hunger, and poverty. Soil degradation is a result of conventional agriculture and linear food systems (Project Drawdown, 2017). Without returning the carbon back to the soil, the soil becomes severely depleted, causing issues of food security, water security, energy sustainability, climate stability, biodiversity, ecosystem service delivery, lower yields, land abandonment and unsustainable agricultural practices (McBrathney, Field, & Koch, 2013). Future research should continue to build-in variables that are comprehensive of the potential food waste has on restoring our depleting soils (FAO, 2006, 2011).

Conclusions

Both, windrow AC and on-farm AD have high socio-economic benefit potential. Major opportunities exist for the further development of both these processes to increase the net socio-economic benefit of food waste processing and to ensure they are both major players in the industry. They have different costs and benefits, as well as opportunities and limitations, so the continued support for the development of both technologies is best advised for optimizing food waste diversion efforts. These benefits from AC include continued support of small farm operations and jobs, and the composting of additional organic materials, like yard waste, which produce a very high quality compost. On-farm AD supports large farm operations without taking away from the farmer's labor hours. It also produces a product that reduces our reliance on non-renewable sources of energy. Both of these food waste recycling methodologies also support soil restoration and limit soil contamination when compared to AD facilities on wastewater treatment plants and landfill sites.

One of the greatest opportunities for improving the socio-economic benefits of AC and AD are the investments in the development of AC and AD technologies to be less sensitive to location restrictions. Development opportunities lie in investments for odor control technology, development of an AD digestate market, development of more efficient transportation systems, and reducing costs associated with its transportation (i.e. using the empty food waste delivery trucks and more efficient modes of transportation).

Another major opportunity is the control of tipping fees through incentives or subsidies. Tipping fees are major sources of revenue in food waste processing and control of this source of income will ensure that our facilities remain operational and profitable. This would also support improvements in transportation efficiencies.

Additional considerations in the development of food waste processing include marketing and the cost of carbon. Improvements in the marketing of food waste processing would increase tolerance, as well as match the market value of its products to their socio-economic value. More specifically, the development of a market for digestate would help close the socio-economic gap between AC and AD. This gap can also significantly change with developments in estimations for the cost of carbon.

Further development of CBA and its sustained use in decision-making of food waste management development will provide the opportunity to increase the socio-economic benefit of food waste processing. As technology, infrastructure and regulations change, the results of a CBA will continuously change and provide guidance for decision makers. Developing and sustaining a comprehensive CBA for food waste processing will enhance the likelihood that the most sustainable, efficient and effective decisions will always be made.

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