Trash or Treasure: An Analysis of Airline Catering Food Waste

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ABSTRACT

With air passenger traffic projected to increase significantly over the following decades, the airline catering industry urgently needs to explore the underlying causes of food waste produced in their kitchens and develop concrete strategies to manage it better going forward. Spanning over 60+ countries, operating 200+ catering units, and serving more than 700 million passengers every year, the sponsoring company for this capstone project, a leading airline catering company, is uniquely positioned to make a sizeable impact on this global issue. Considering that the in-flight catering services industry was valued at $17.7 billion in 2018, airline catering food waste was reckoned with millions of worth. In this report, we proposed innovative solutions to reduce the food waste in their catering kitchens, considering the potential financial and environmental impacts of improved food waste management. We combined data analytics and machine learning algorithms with system dynamics frameworks to minimize cost and maximize the utilization and preservation of resources. We modeled the system with a 91.12% accuracy and evaluated eight different waste management alternatives regarding the cost and environmental impact. Through our study, we provided the sponsoring company with actionable, data-driven recommendations to aid in developing their first attempt to create a global organic waste management strategy..

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Last but not least, to ourselves. “To all the voices in our mind. We made it.” ---- C. Minas

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1 Introduction

In 2011, the Food and Agriculture Organization estimated that around one-third of the world's food, estimated at 1.3 billion tonnes, was either lost or wasted every year (UNEP, 2014). In addition, millions of people worldwide are suffering from hunger, and the global pandemic has only contributed to it with more extended food insecurity issues (UNEP, 2014). To address arising world hunger, Target 12.3 of the Sustainable Development Goal (SDG) of the UN Environment Programme calls for "halving per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses by 2030" (UNEP, 2014). Developing countries often experience food losses in the initial stages of the food supply chain (e.g., harvesting, processing, storing, transporting). In contrast, more developed countries see food waste primarily produced at the retail and consumer level (Fox, 2013). It has been estimated that between 30% and 50% of the food purchased by an individual in a developed country will end up in the kitchen trash bin (Fox, 2013).

Although food waste management practices vary across food service industries, the story is not significantly different (Dhir et al., 2020). Food waste has been investigated in hospitals, restaurants, college dining facilities, and school cafeterias. They all point to at least one-fifth of their total food not being consumed by their customers and being wasted (Ross, 2014). One industry that stands out for its global reach and its ability to serve over a billion customers every year is the airline catering industry. Even though it is one of the lesser researched of the industries above, it has a unique potential to impact food waste production and management (Ross, 2014). With air passenger traffic projected to double over the next two decades, the airline catering industry urgently needs to explore the underlying causes of food waste produced in their catering kitchens and develop concrete strategies to manage it better going forward (ICAO, 2014).

Bearing the growing demand for air travel in mind, the sponsoring company for this capstone project, a global leader in the airline catering industry, is looking to find innovative and disruptive solutions to address their global food waste. Spanning across 60+ countries, operating 200+ catering kitchens, and serving more than 700 million passengers every year (2019), the sponsoring company is uniquely positioned to have a sizeable impact on this global issue. Considering that the in-flight catering services market was worth about US$17.7 billion in 2018, airline catering food waste was reckoned at millions of worth.

From the industrial perspective, food waste in the airline catering industry is heavily regulated and strictly enforced due to the many health risks of mishandling organic products moving across borders (Regulation of the European Parliament, 2009). Most airline catering kitchens do not segregate kitchen waste from cabin waste, nor organic waste from non-organic waste. As a result, most of the food waste generated by these kitchens is often compacted, incinerated, or disposed of in landfills (Blanca-Alcubilla et al., 2019). In the case of the sponsoring company, it has increased its efforts around proper food waste disposal; however, these efforts are usually fragmented and lack a comprehensive approach.

1.1 Problem Description and Scope

Our research project focuses on addressing organic waste management and proposing innovative solutions that the sponsoring company can leverage to reduce or repurpose the food waste generated in their catering kitchens. We will take a systematic review of innovative solutions and potential impacts (e.g., economic, operational, and environmental) of improved food waste management and propose strategies that can be implemented globally to leverage the sponsoring company's international reach. We will investigate system dynamics frameworks and machine learning with two research goals among those potential strategies. First, we aim to identify food waste's prominent locations and drivers during production in the sponsoring company's catering kitchens. Second, we seek to explore what solutions can be applied to improve waste management and the overall company performance. While these models are not new, much remains to be done regarding their application in the food industry, especially on how they may relate to the airline catering industry.

1.2 Report Structure

The report is structured as follows: First, we review previous research on food waste management in terms of motivations, innovative solutions, and application of system dynamics to gain a holistic overview of the topic we investigate. This helps us reveal gaps that exist in the current literature body and identify the most relevant research questions to tackle. This is followed by a detailed clarification of how we developed Machine Learning and System Dynamics model methodologies. We report on Machine Learning and System Dynamics simulation results, sensitivity analysis, and scenario testing in response to the two research goals by feeding the methods with industry-based data. The report concludes with insightful implications of strategic and operational recommendations for the sponsoring company to implement across their global catering units.

2 Literature Review

Food waste is not a new issue, but it has gained a lot of interest in the last decades. In a world that still struggles to end world hunger and feed an ever-growing population, this issue must be addressed and actively managed in the coming years (UNEP, 2014). In this section of the report, we will explore what exactly food waste is, what are some factors contribute to its management or lack thereof, some of the technologies and concepts that have gained a lot of traction over the last years that have a vast potential to create a significant dent in this global problem as well as how System Dynamics models have been applied within the food waste management domain

2.1 Food Loss & Food Waste

Food loss and food waste are often used interchangeably across academic and industry reports, but they represent different concepts in the food supply chain. Food loss relates to the early stages of the food supply chain "where there is a decrease in food quantity or quality, which makes it unfit for human consumption." (Parfitt et al., 2010). On the other hand, food waste relates to the later stages of the food supply chain, where it is entirely dependent on retail and end consumer behaviors (Parfitt et al., 2010). As we evaluate the airline catering industry, it is crucial to distinguish between food loss and food waste since this capstone project intends to assess the sponsoring company's food production processes and not the management of the earlier stages of the food supply chain. Food waste is defined as all food volumes disposed of at the catering kitchens manufacturing processes "intended for human consumption" (Gustavsson et al.,, 2011).

2.2 Motivators & Barriers in Food Waste Management

Corporate social and environmental responsibility (CSER) is a term that has become important across industry and academia (Lynes & Andrachuk, 2008). However, its scope was limited. It was often viewed as a peripheral objective and an "irresponsible use of shareholder's money" rather than an active part of the core corporate business strategy (Porter & Kramer, 2011). CSER has changed since the introduction of the concept of "shared value" as an alternative in 2011. This concept "involves creating economic value such that the society also gains value by addressing its needs and challenges." (Porter & Kramer, 2011). Having social impact, helping develop local communities, investing in education, minimizing overproduction and waste, utilizing materials in their entirety, and implementing responsible recycling practices, are now considered critical in corporate strategies (Henningsson et al., 2004).

However, implementing these changes poses a big challenge for corporations worldwide, especially for organic waste management. Some factors that contribute to this are, for example, food overproduction, poor storage practices, demand fluctuations, and temperature swings within operations to name a few. Additionally, the composition of food waste depends heavily on its source and even common widespread strategies are often infeasible even amongst neighboring areas (Sindhu et al., 2019). These factors often drive corporations to opt for traditional practices such as landfill disposal or incineration, further separating themselves from a shared value approach.

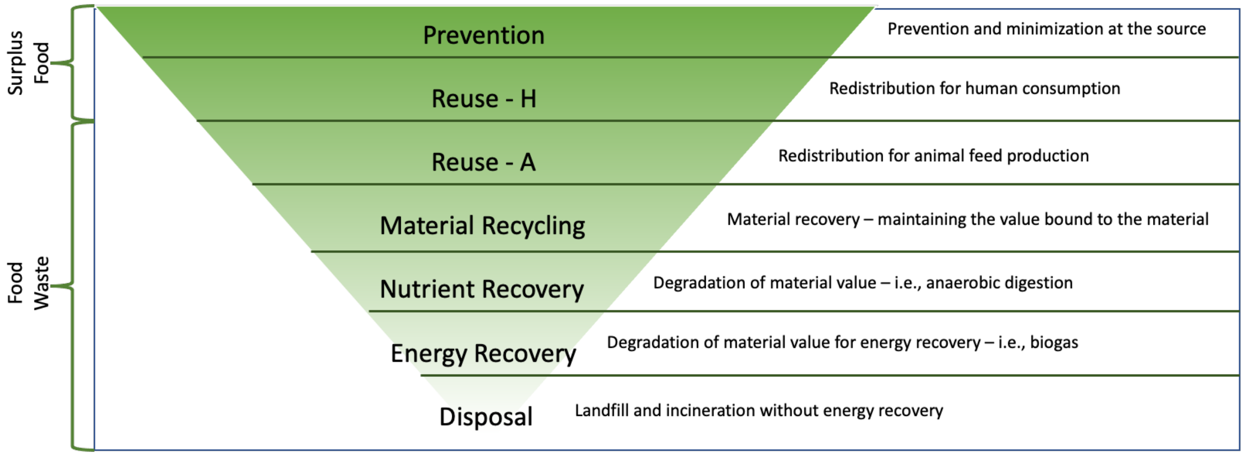
At this time, the sponsoring company for this project is still driving traditional waste management practices. However, it has a vested interest in developing a shared value approach that can be implemented across its global network of catering kitchens. Given that their largest units currently handle over 16 metric tonnes of organic waste per month (2019), the potential impact they could have on the environment, local community and financial performance of the unit itself by adopting a shared value approach is quite sizeable.

2.3 Innovative Strategies for Food Waste Management

The efficiency of organic waste management may be improved with a guideline to treat different waste streams. Teigiserova et al. (2020) proposed a food waste hierarchy where users can categorize food waste into six buckets based on edibility and degrees of priority for re-utilization, namely i) edible, ii) naturally inedible (e.g., pits), iii) industrial residue, iv) inedible due to natural causes (e.g., pests), v) inedible due to ineffective management and vi) not accounted. It suggests prevention and reuse for human consumption at the top of the pyramid, where the most significant efforts shall be invested (Figure 1). When prevention fails, it enters the food waste management phase, where reuse for animal feed is prioritized over material recycling, followed by nutrient and energy recovery. This expanded waste hierarchy builds on a collection of European legislation and policy (European Commission 1977, European Parliament Council 1975, 1989, 2008) and provides an environmentally efficient perspective to decision making.

Figure 1

Waste Hierarchy



Note. Adapted from Teigiserova, D. A., Hamelin, L., & Thomsen, M. (2020).

On top of the food waste hierarchy, academic researchers have developed and proposed several frameworks around food surplus, waste, and loss (FSWL). Two have gained the most traction over time, circular economy and bio-economy. The circular economy emphasizes closing the material loops through recycling and reusing products based on fossil-based production environments. At the same time, the bio-economy focuses on replacing fossil carbon with renewable biomass (European Commission, 2015). Although these two frameworks' approaches differ, they share the same objectives of reducing waste generation through a closed loop approach, which enhances resource utilization efficiency and conserves resources in the economy for a more extended time. As such, since 2016, a new and more comprehensive term, "Circular Bio-economy" (CBE), that combines the advantages of these two strategies has been put forward (Schoenmakere et al., 2018; Stegmann et al., 2020). This model adopts an integrated, multi-output production approach, prioritizes biomass resource-efficient valorization, and considers economic, environmental, and social aspects.

To advocate CBE, Mahro and Timm (2007) summarized three main possibilities of using food processing residues, namely 1) biomaterials, 2) chemical feedstock, and 3) energy resources. Table 1 lists more examples of how biowaste can add value under the aforementioned approaches. In terms of biomaterials, waste can be either turned into traditional by-products with a monetary value, such as skins, clothing, or brushes, or sold as animal feed due to their nutritional value. However, due to potential diseases, most of the animal feed volumes are regulated as plant-borne residues instead of animal-borne (EU regulation 1774,[25]). Chemically, biowaste can be either used to extract unique compounds that feed the production of detergents, gelling agents, cosmetic additives, etc., or used as a fermentation medium in biotechnological processes. Energy-wise, two standard practices are thermal energy production and energy carriers' generation like biogas, ethanol, or hydrogen.

Table 1

Detailed use of food processing residues as biomaterials, chemical feedstock, and energy resources

Biowaste Approach	*End Products*
Biomaterials	• Sausage skins • Leather clothing • Duvet feathers • Bristle brushes • Adsorbents in water treatment • Insulating material • Animal feedstock for farm animals that go into the human food chain • Pet food
Chemical Feedstock	• Chemical compounds, e.g., collagen, gelatin, antioxidants, tannin, essential oil, vitamins • Fermentation medium in biotechnological processes
Energy Resources	• Thermal energy production • Energy carriers, e.g. biogas, ethanol or hydrogen

Note. Mahro, B., & Timm, M. (2007).

2.4 Application of System Dynamics in Food Waste Management

In the face of complex and dynamic problems, system dynamics can be used to describe non-linear cause-effect relationships among variables, e.g., stocks and flows. Despite the importance of quantifying food waste, there are scarce scholarly publications on food waste management through the system dynamics approach and even fewer in the hospitality and airline businesses. Waste production and especially organic waste production is heavily dependent on human behavior and preferences so applying a linear approach is often unfeasible (Parfitt et al., 2010). System dynamics allows for the introduction of complex relationships that capture the underlying trends and behaviors of the system.

In Hong Kong, Lee et al. (2018) applied system dynamics (SD) modeling to investigate the current landfill situation and the effectiveness of municipal food waste policies. Authors found that education initiatives such as advertising, school programs, training, and competitions help prevent waste by raising waste producers' awareness of the impact of different food waste disposal methods on the environment.

Similarly, through a system dynamics simulation model in Iran, Mobaseri et al. (2021) found that a 1% reduction in food waste results in a 0.95% and 0.83% reduction in energy demand and pollution emissions, respectively. In Phnom Penh, Cambodia, Chinda and Thay (2020) also used the system dynamics model. They revealed that household and retailer vegetable waste is mainly driven by poor preparation processes and inappropriate packing sizes.

In Indonesia, Oktaviasari et al. (2021) ran a system dynamics simulation to test the best scenario for reducing food waste in the restaurant sector. The simulation result shows that cooperation with food banks contributes to the most significant food recovery, reducing food waste by 25.10% per day compared to other options of increasing the frequency of purchases and increasing consumer awareness of food waste through a proper policy.

Although system dynamics has drawn the attention of food industry researchers over the last five years, the number of applications in this sector is still limited compared to its economic size and impact. Therefore, it is recommended that academics put in more research efforts on the use of SD modeling in the HoReCa (i.e., hotel, restaurant, catering) industry. The latter will promote a holistic understanding of its complex issues and assist decision-makers and regulators in developing more effective policies.

2.5 Gaps and Contributions

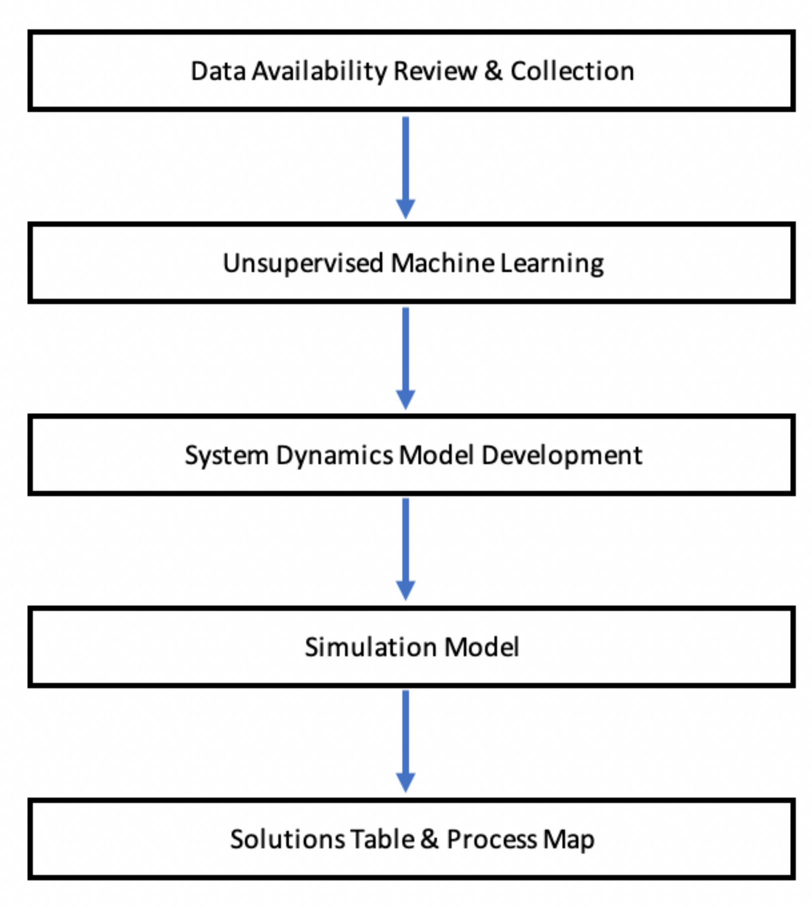
There is growing academic and industry research on waste management in the airline catering industry (Ross, 2014; Blanca-Alcubilla et al., 2019; Baxter, 2020; Sambo, 2018; Megodawickrama, 2018; IATA, 2019). However, there is a lack of research focused on biowaste management in the airline catering industry and the application of the system dynamics framework to this problem (Appendix A). In this light, the underlying objective of this contribution is to propose a global framework of food waste management by utilizing system dynamics and machine learning algorithms to address this issue for a leading airline catering company.

3 Research Methods

The focus of this section falls on describing the steps taken to collect and analyze data from the sponsoring company's catering kitchens. All these efforts are in line with understanding how data can be used to outline solutions to reduce or repurpose the organic waste generated in the catering kitchens' processes. This section will describe the initial data from the sponsoring company, the gaps we found across the organization, how we collected data via quantitative and qualitative approaches, and how we analyzed this data using system dynamics, simulation, and machine learning techniques. The flowchart in Figure 2 will be referenced throughout this report section.

Figure 2

Methodology Process Map



3.1 Data Availability

The first approach involved understanding what data was already available in the company's systems. Given that the sponsoring company is the result of various mergers and acquisitions over the years, they handle multiple systems and tracking mechanisms to run their operations. The lack of standardization across the different units made it especially complex to isolate waste management data for analysis. For this reason, we decided first to take a look at the financial data across the company. Then, we understood how recycling and waste management contribute to the overall operational cost for each unit. We used data sets from 2018 and 2019 to represent regular operating conditions (i.e., pre-pandemic). We end up analyzing 162 units across the globe. The data included operational costs across various categories, including:

- Administrative costs
- Advertising
- Insurance
- Laboratory Services
- Facility Maintenance
- Recycling and Waste Management

Recycling and waste management costs were compared with their established waste management budget, the overall cost budget for the unit, and the overall budget for the region. Descriptive statistics such as the mean, median, range, and standard deviation were computed to evaluate further the impact of waste management at each of the 162 units. These findings and trends will be further described in a later subsection.

Aside from financial cost data, the local teams were able to provide more details about their waste management practices in some isolated cases. For example, in the case of the unit in Zurich, Switzerland, the local teams were able to provide organic, cardboard, plastic, and glass waste volumes in kilograms. This data set contained the waste volumes per month and allowed the team to understand the potential waste configurations at each of the sponsoring company's catering kitchens. Similar data were secured from Munich, Bogota, Frankfurt, and Lima sites.

Finally, to bridge the gaps in the data and get a better understanding of the approximate waste composition at each of the 162 sites analyzed, the sponsoring company provided the capability and capacity data for each of the units. These data included:

Table 2

Breakdown of catering unit characteristics

Variable	Unit of Measure
Number of Employees	Full-time Employees
Unit Size	Square Meters
Flights Catered per Day	Flights per Day
Meal Production Capacity	Meals per Day
Average Meals Produced	Meals per Day
Max Storage Capacity	Square Meters
Percent Domestic Flights	Percentage
Percent International Flights	Percentage
Number of Airline Customers	Customers
Number of External Customers	Customers

These unit characteristics will later be used to validate approximations made for waste management composition at the catering kitchens. Details of that review are elaborated in a later subsection of this report.

3.2 Data Collection

Quantitative Data

We gathered quantitative data from various units to further understand the organic waste at the sponsoring company's catering kitchens. There are multiple Enterprise Resource Planning (ERP) systems, namely BACS, Prodige, SAP Logistics, SACS 5.1, and SACS 6.0. Therefore, no universal standard waste reports enabled us to compare figures from the same period using the same logic.

To overcome this data availability challenge, we retrieved financial data from the Annual Zero-based-budgeting (ZBB) report from January to December 2019, which covers a large number of catering units as well as their recycling and waste management costs. Unfortunately, the ZBB recycling and waste management costs cover both organic and non-organic waste recycling costs. Hence, we requested additional organic waste recycling invoices that showcase weight in kilograms and value in local currencies and received datasets from five units, namely Zurich, Frankfurt, Munich, Bogota, and Lima. Unfortunately, we could not find more units that shared the same reporting structure and had the same level of detail as the one listed. Thus, we were bound to analyze these five units as our primary data sources.

On the one hand, the ZBB recycling and waste management cost allowed us to understand at a macro level where the largest opportunity may be financially. On the other hand, the waste invoices supplement the lack of waste details for a small number of units, which will be later leveraged as proxy data for inference on sites of similar characteristics.

As for secondary data, we retrieved data not directly related to food waste to outline major causes of waste. In terms of supply and demand, we refer to the passenger forecast report, which discloses forecasted versus actual passenger numbers per flight. We refer to the material management report for manufacturing processes where different waste reason codes, waste locations, quantities, and financial value are captured. To validate the accuracy and reliability of the internal dataset, we also examine external data sources from academic papers on the tourism and foodservice industries to inform our analysis. This additional information helps respond the first research question on why waste is being generated, where it is being generated, and an approximation of how much waste might be in scope for us to tackle. This will help further understand the processes at these catering kitchens and map out what external actors will be needed to reuse or repurpose this waste.

Once all these data were gathered from both the local units and the sponsoring company's headquarters team, the team decided to perform a scope reduction exercise to focus on the units with the most significant environmental and operational impact. The following subsection of this report describes a description of the analysis and the scope consensus.

Identification of Catering Units in Scope

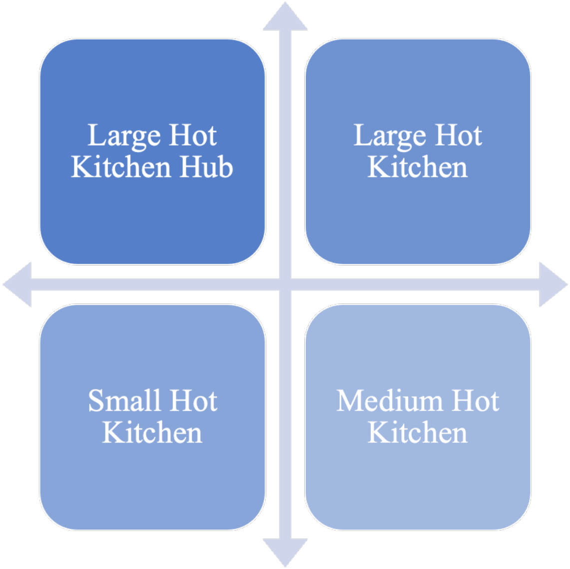
There are hot kitchens and assembly kitchens among the sponsoring company's production units. Given that organic waste is mostly created in hot kitchens where raw material preparation and large-scale production are involved, the team decided to focus on hot kitchens only for our research.

Secondly, we kept only hot kitchens that were captured in the ZBB recycling and waste management costs to ensure units in scope had either operational or financial impact on the sponsoring company. Additionally, the team also considered units identified as "Competence Centers" as they facilitate the implementation of the waste management solutions that will be derived from this capstone project. The global Operational Excellence team defines " Competence Centers " as units that have fully implemented the sponsoring company's core processes and act as the golden standard for their respective region.

Lastly, the team reduced the final list of catering units for our research to 72 units (44% of total units), covering all the sponsoring company's brands, regions, production unit sizes, and global competence centers. This will provide the team with an adequate sample to run all evaluations in scope and simplify the amount of data still required to be collected from all these units. In the following subsection, we will describe how the team collected additional data from this reduced set of units and how it will complement the quantitative data already described above.

Figure 3

Sponsoring Company's Standard Production Type



Note. *Adapted from sponsoring company internal document. Copyright 2018 by the sponsoring company.*

Qualitative Data

To complement the quantitative data and give the team first-hand experience in the operations at these catering kitchens, the team performed various site visits to units around the world: Switzerland, Netherlands, Germany, Mexico, Brazil, Ecuador, and the United States. Before the visits, the team prepared a semi-structured interview and a questionnaire (see Appendix A) to have a standardized way of comparing these units and their practices. The questionnaire was divided into three sections: general questions about the unit, production questions, and waste management questions. The general questions aimed at validating the data the team could secure from the headquarters' office around full-time employees and unit size. Production questions were meant to validate capacity and average daily production volumes. Finally, the waste management questions were designed to understand practices, waste generation, waste tracking mechanisms, and supporting actors or resources involved in waste management processes (e.g., environmental agents, certifications, local partnerships, etc.). The questions were also adapted to a digital version to cover any units not visited but still in scope for our project. Additionally, the team was encouraged to ask supplementary questions throughout the process, and all the observations were documented.

After the team completed the quantitative review, the scoping of the project, and the supplementary qualitative data collection, we were ready to start the analysis portion to break the data further down. The following subsection of this report goes over the initial approaches taken to study these different data sources and all the steps taken. First, the System Dynamics model development and simulation are reviewed. Second, we approach the detailed application of unsupervised machine learning for clustering.

3.3 Unsupervised Machine Learning

Once the team had secured the data and developed the model based on its intricacies, limitations, and relationships, the team decided to apply machine learning methods to uncover underlying patterns and insights that will help approximate the results from the Zurich kitchen to other units around the globe. The approach taken was based on an unsupervised clustering method called K-means clustering. This machine-learning algorithm was selected to understand how the characteristics or features of the data influence how we group and analyze the sponsoring company's catering units. Since this is an unsupervised learning method, the team did not define any labels for the data. It allowed the algorithm to make its groupings based on how well the features we selected explain the overall variation of the data. This exercise aimed to understand if there were any other valuable ways to cluster the catering units to provide the team with new insights on their waste management practices. Traditionally, the sponsoring company has limited its unit analysis to regional clusters, so this exercise was performed to uncover previously unseen ways to relate the catering units. Figure 4 represents a high-level process of what was involved in this analysis.

Figure 4

High-level K-means clustering process

There are three main components to the analysis. First, there is feature selection, where the team analyzed the available data and decided on what characteristics were the most complete and informative to use in this analysis. Second, we performed a dimensionality reduction through principal component analysis (PCA) to transform the features into useful normalized data that captures the highest percentage of the overall variance in the data. Finally, a selection of the appropriate number of clusters to break down the data into helpful categories. All these efforts were carried out in Orange Machine Learning software and Python libraries to validate the results. Results from applying this unsupervised learning method will be examined in the results section of this report.

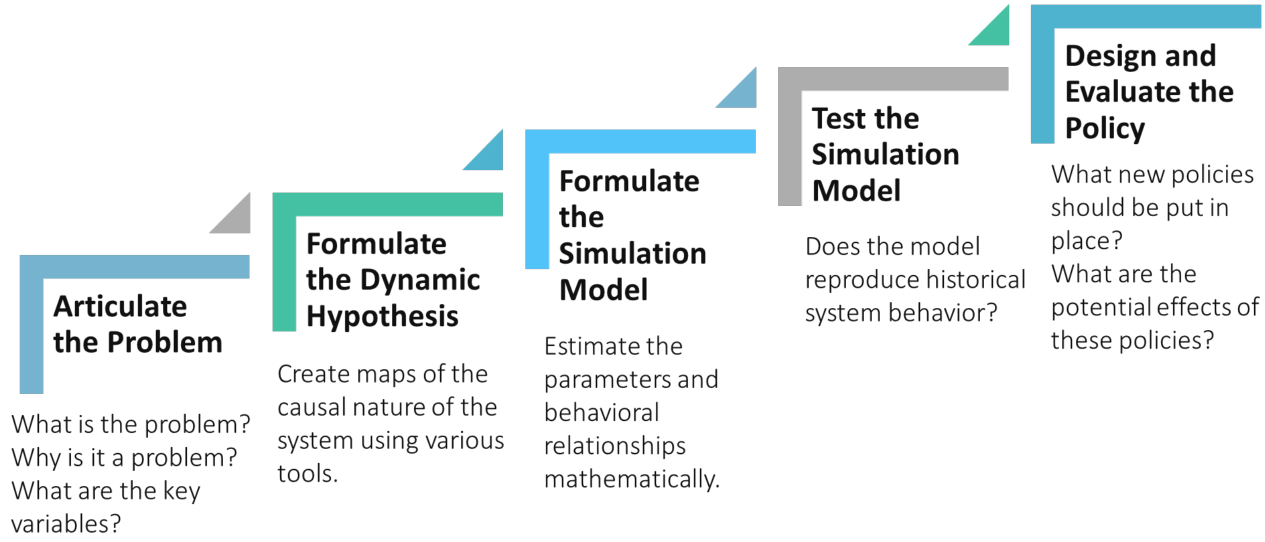
3.4 System Dynamics Model Development

The airline catering food system is complex in that airline caterers are required to accommodate conflicting interests among multiple players, i.e., suppliers, airline customers, and aviation regulatory bodies. Given the complexity of the problem and the combination of qualitative and quantitative data obtained, the team decided to use System Dynamics (SD) approach to perform the project and learn more about non-linear behaviors within the complex food waste systems. Vensim® software was used to design and test the dynamic model.

Following the 5-step SD modeling process (Figure 5), the team first mapped out the significant variables affecting food waste management at the airline catering kitchens. Then they identified a causal loop diagram based on these variables and relationships. Once the causal loop diagram captured most of the intricate relationships between the variables, the team converted it into a stock and flow diagram that encapsulates the stock - "state of the system" and flow - "rate of change." Based on the stock and flow diagram, the team narrowed it down to the driving loops based on the level of interest and data availability. It formulated simulation models that mathematically estimate the parameters and behavioral relationships. Next, the team inserted historical data into the simulation models to test and verify whether the model accurately reflected the catering unit processes. Based on the simulation results, the team suggested appropriate policies and solutions to the sponsoring company to prevent and reduce food waste in the catering kitchens.

Figure 5

Five-Step System Dynamics Modelling Process



Note. Sterman (2000).

Causal Loop Diagram

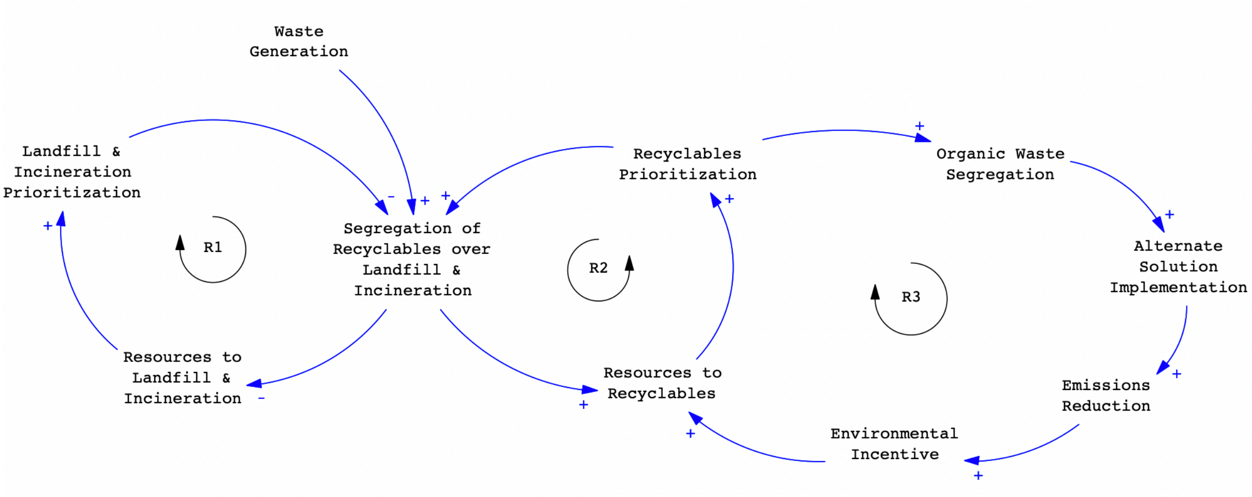
A causal loop diagram (CLD) visualizes problem-related variables and their interrelations. It consists of three key components, links, loops, and lags. Causal links capture the relationship between two variables and must have positive (+) or negative (-) polarity. For positive polarity, an increase in one variable causes an increase in the other variable (i.e., grow in the same direction). On the contrary, variables move or change in the opposite direction for negative polarity. For instance, an increase in one variable causes a decrease in the other variable.

By developing causal links between variables, we build loops, of which some are reinforcing loops (R), and others are balancing loops (B). Reinforcing loops are a collection of links that form a loop that provides positive feedback, whereas balancing loops are a collection of links that include a loop that provides negative feedback. Reinforcing loops consist of an even number of negative links and results typically in exponential growth (or decline) over time. Balancing loops consist of an odd number of negative links and often result in equilibrium or a state of balance over time. The last component in the causal loop diagram is a delay, indicated by double bars on a causal link. If the system has delays, meaning the feedback of one variable to another has time lags, such as a decrease in customer satisfaction, is not going to result in an immediate drop in revenues but a drop over time, the system might fluctuate and have unintended consequences (Sterman, 2000).

Figure 6 shows a representation of the system where we leverage these causal relationships to explain the system's behavior. Our model primarily sees reinforcing loops that indicate positive feedback between the variables and eventually an increase or decrease over time. The primary relationships we observe point to our model following one of the well studied systems archetypes called, success to the successful. This archetype represents the relationship between two competing efforts where the resources are allocated to the one with the highest perceived propability to succeed or the one with more immediate success. In this case we see this competition between utilizing landfill and incineration as a primary waste management solution versus using alternate and more environmentally friendly solutions. The battle between the convenience of landfill and incineration and the benefit of more complex environmentaly conscious solutions is what the team captured through this exercise. All the loops in the diagram are of a reinforcing nature as they support these competing efforts and try to utilize as many resources as possible. These relationships will be further explored in section 6.1 of this report.

Figure 6

Airline Catering Kitchen Food Waste Causal Loop Diagram



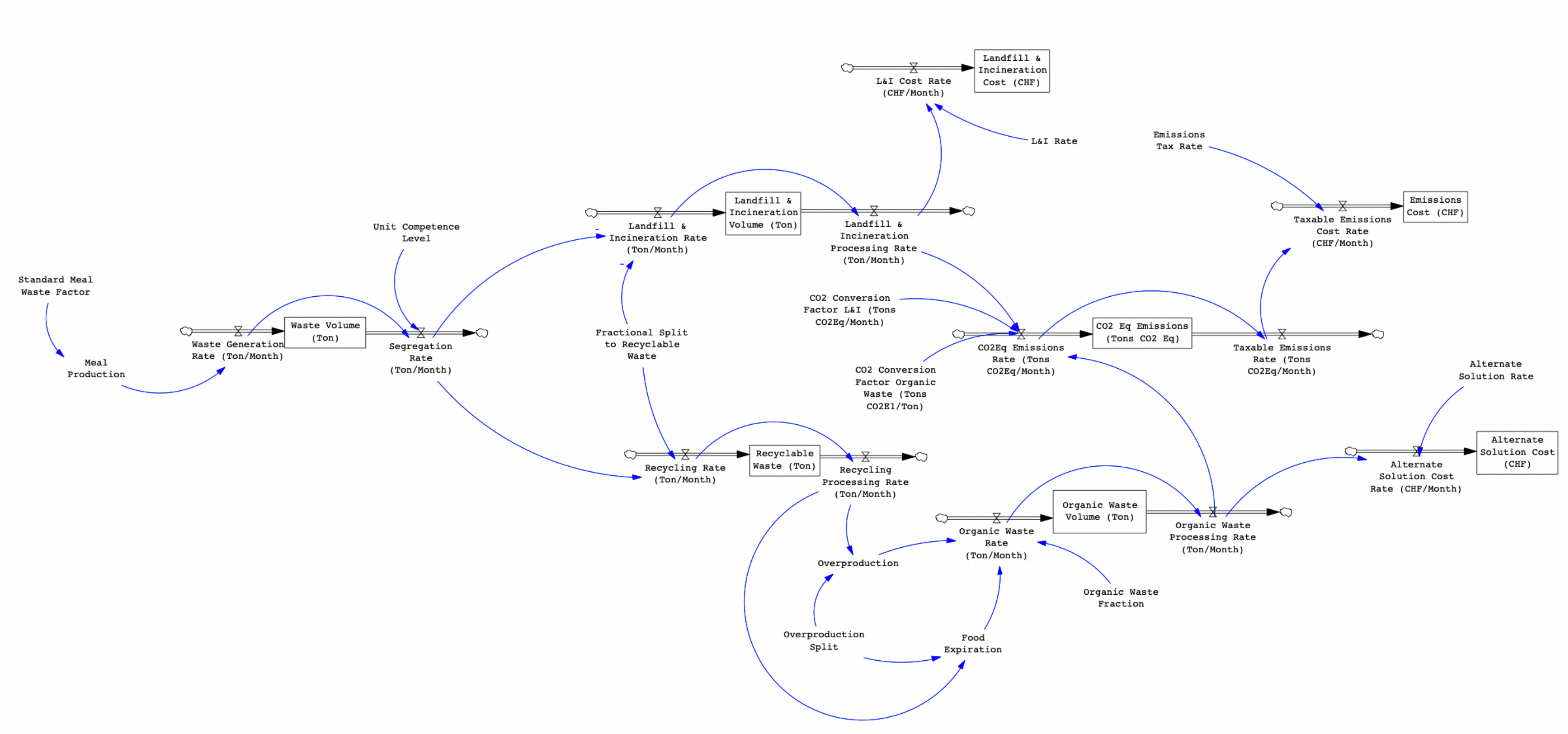
Stock & Flow Diagram

The stock and flow diagram consists of three main elements: stock, flow, and flow rate. The stock indicates the "state" of the system and accumulates over time (i.e., waste volumes, inventory, etc.). They are typically referred to as the elements you could generally see or capture in a photo. Inflows and outflows determine the level of a stock variable. These flows are critical in the diagram, and they are described as rates or elements that cannot be seen or captured in a photo. Additionally, the flow rate includes auxiliary variables that affect the behavior of the flow.

Figure 7 shows the stock and flow diagram we created to explain the system and model the dynamic relationships between the variables. Eight different sections represent all essential stocks and flows that define the system and are critical to accurately representing the behaviors at the sponsoring company's catering kitchens.

Figure 7

Airline Catering Kitchen Waste Stock & Flow Diagram



3.5 Simulation Model

Having developed the causal loop diagram and the stock and flow model, we were ready to simulate the system and perform some scenario testing that would allow us to explore the model in more detail. To do this, we again leveraged Vensim® software. The first objective was to find the relationships among all the variables at the current state. The latter would allow us to get similar results to what the company experienced in 2019. To do this, we decided to start with a model that would represent the operations of the Zurich catering kitchen as it had the most data available on their waste operations. We broke down the process into eight sections that would capture the key indicators the sponsoring company was interested in improving. The sections are the following: total waste generation, non-recyclable waste generation, non-recyclable waste cost, recyclable waste generation, organic waste generation, organic waste cost, CO_2 Eq emissions generation, and emissions cost. These are represented in the stock and flow diagram presented in Figure 6.

These flows allowed us to understand the different sections of the process and evaluate their intricacies between them. The final variables the sponsoring company was most interested in exploring were the "Alternate Solution Cost," the "Landfill & Incineration Cost," the "Total CO_2 Eq Emissions", and the "Emissions Cost." As we evaluated different potential organic waste management solutions to be applied to the Zurich catering unit, we introduced different rates and factors into the model to see how these costs and emissions would be affected. Then we were able to test which of the organic waste solutions we proposed were the most effective, cost-friendly, and environmentally conscious. To further illustrate the relationships between our stock and flow model variables, we have included them in the breakdown shown in Table 3.

Table 3

Airline Catering Kitchen Waste Stock & Flow Variables & Constants

	Name	**Abbreviation**
Variable 1	$Waste\ Generation\ Rate$	WGr
Variable 2	$Food\ Expiration\ Rate$	FEr
Variable 3	$Overproduction\ Rate$	OVr
Variable 4	$Meal\ Production$	MP
Variable 5	$Waste\ Volume$	WV
Variable 6	$Segregation\ Rate$	SGr
Variable 7	$Unit\ Competence\ Level$	CL
Variable 8	$Landfill\ \&\ Incineration\ Rate$	LIr
Variable 9	$Landfill\ \&\ Incineration\ Volume$	LIV

Variable 10	Landfill & Incineration Cost	LICr
Variable 11	Landfill & Incineration Cost	LIC
Variable 12	Landfill & Incineration Cost Rate	LIR
Variable 13	Recyclable Waste Rate	Rr
Variable 14	Recyclable Waste Volume	RWV
Variable 15	Fractional Split Recyclable Waste	FS
Variable 16	Organic Waste Rate	OWr
Variable 17	Organic Waste Volume	OWV
Variable 18	Organic Waste Processing Rate	OWPr
Variable 19	Alternate Solution Cost Rate	ASCr
Variable 20	Alternate Solution Cost	ASC
Variable 21	Alternate Solution Rate	ASR
Variable 22	CO_2 Eq Emissions Rate	Er
Variable 23	CO_2 Eq Emissions	E
Variable 24	Taxable Emissions Cost Rate	TXCr
Variable 25	Emissions Cost	EC
Constant 1	Recyclable Waste Processing Rate	RPr
Constant 2	Landfill & Incineration Processing Rate	LIPr
Constant 3	Organic Waste Fraction	OWF
Constant 4	Emissions Tax Rate	ETXr
Constant 5	CO_2 Eq Conversion Factor L&I	ELI
Constant 6	CO_2 Eq Conversion Factor Organic Waste	EO
Constant 7	Taxable Emissions Rate	TXr
Constant 8	Standard Meal Waste	SMW
Constant 9	$Biogas\ Flat\ Rate\ (Zurich) =\ 2500\ CHF$	BFR

For the convenience of readers understanding, Figure 6 from left to right, the team broke down the stock and flow model into 8 subsections, namely Waste Generation, Recyclable Waste, Organic Waste, Alternate Solution Cost, Landfill & Incineration, Landfill & Incineration Cost, CO2 Eq Emissions and Emissions Cost. Within Waste Generation subsection, segregation rate (SGr) was generated through random triangular distribution that takes into account waste generation rate (WGr) and waste volume (WV) and whether it is a competence center or not, as seen in equation (3). As for Recyclable Waste subsection, recyclable waste processing rate (RPr) followed the same random triangular distribution that relies on recyclable waste rate (Rr) and recyclable waste volume (RWV), as seen in equation (6). In terms of Organic Waste subsection, equation (9) shows that organic waste processing rate (OWPr) follows the random uniform distribution that is dependent on two inputs from organic waste rate (OWr) and organic waste volume (OWV). When it comes to Landfill & Incineration Cost as seen in equation (14), the landfill & incineration processing rate (LIPr) followed the random uniform distribution function based on landfill & incineration rate (LIr) and landfill & incineration volume (LIV).

Variable Relationships:

1. **Waste Generation:**

$$MP = SMW * RANDOM\ PINK\ NOISE(Avg\ Meals\ 2019, Std\ Dev\ Meals\ 2019, 3\ months)$$

$$WGr = MP \tag{1}$$

$$WV = WGr - SGr \tag{2}$$

$$SGr = RAND\ TRIANGULAR(Min\ WV, Max\ WV, WGr, Max\ WV, WV\ Dec\ '19) * CL \tag{3}$$

2. **Recyclable Waste:**

$$Rr = FS * \ SGr \tag{4}$$

$$RWV = Rr - RPr \tag{5}$$

$$RPr = RAND\ TRIANGULAR(Min\ RWV, Max\ RWV, RWV\ Jan\ \ '19, Max\ RWVMin\ RWV, Rr) \tag{6}$$

3. **Organic Waste:**

$$OWr = OWF * (FEr + OVr) \tag{7}$$

$$OWV = OWr - OWPr \tag{8}$$

$$OWPr = RANDOM\ UNIFORM(OWr, Max\ OWV) \tag{9}$$

4. **Alternate Solution Cost:**

$$ASCr = (OWPr * ASR) + BFR \tag{10}$$

$$ASC = ASCr \tag{11}$$

5. **Landfill & Incineration:**

$$LIr = (1 - FS) * SGr \tag{12}$$

$$LIV = LIr - LIPr \tag{13}$$

$$LIPr = RANDOM\ UNIFORM(LIr, Max\ L\&I\ Volume) \tag{14}$$

6. **Landfill & Incineration Cost:**

$$LICr = LIPr * \ LIR \tag{15}$$

$$LIC = LICr \tag{16}$$

7. **CO_2 Eq Emissions:**

$$Er = (LIPr * ELI) + (OWPr * EO) \tag{17}$$

$$E = Er - TXr \tag{18}$$

$$** \, TXr = Er * 0.40 \tag{19}$$

8. **Emissions Cost:**

$$TXCr = TXr * ETXr \tag{20}$$

$$E = TXCr \tag{21}$$

With these relationships, we could model the system accurately and explore the relationships between the variables. In some cases, like the taxable emissions tax rate, we decided to explore a range of theoretical values since this is not defined for the sponsoring company. Given that we are primarily focusing on the Zurich unit in Switzerland, and there is no emissions tax defined for these types of companies yet, we decided to take a theoretical range based on the taxes imposed on industry in Switzerland. This effort will give us theoretical insights into the potential future cost of emissions once a broader range of companies is taxed on their environmental impact. The results related to the emissions, costs, and other relationships defined above will be further explored in the results section of this report. In the following subsection, we will go over how we leveraged the results from the analysis in the Zurich unit to cover a broader unit scope through machine learning algorithms.

3.6 Solutions Table & Process Map Development

Having completed the System Dynamics simulation model and the machine learning clustering exercise, the team decided to provide the sponsoring company with an actional toolkit as a blueprint for strategy development. We developed a food waste solution table and decision flow map that operations managers can utilize when designing their waste management strategies based on their unit characteristics. The food waste solution table follows a two-way internal versus external disposal dimension. We include their reference and description for each solution, their financial impact (i.e., CAPEX, OPEX), and their environmental impact (i.e., CO_2 Eq emissions). Additionally, we included a breakdown of the technology maturity and constraints to further inform the users about potential limitations. In terms of the decision flow map, this incorporates the key features of the solution table in a decision tree format with additional considerations such as the waste configurations (i.e., edible versus inedible food) and the potential for food bank donations. All this is to provide a practical aspect to our research that will allow the sponsoring company to build a framework around improved waste management practices. This report's results and discussion sections will further explore how we leverage these items to provide insights and recommendations.

4 Results & Analysis

This section will focus on the results we obtained during the development and analysis of the methodology for this capstone project. It begins with an initial exploratory study, identifying waste generation streams and drivers in the current operations. Next, the simulation results of the System Dynamics model are presented and explored. Finally, the matrix for food waste management solutions containing financial and environmental parameters will be discussed. Different solutions were run through the validated System Dynamics model to generate scenario testing results. All of these seek to understand the effectiveness, cost, and environmental impact of the current waste management practices versus the solutions we propose.

4.1 Initial Analysis

During the exploratory phase of this capstone project, the team wanted to understand the waste generation, locations, stages, and common indicators from the interviews and surveys conducted that could further confirm the sources and causes of waste. The team explored the ERP Waste Data reports across eight different units, namely, London Heathrow North, Bogota, Dublin, Hong Kong, Incheon, London Gatwick, Lima, and Sydney which responded to the project data request and operate with the same ERP system and hence provide the same report format. These reports provided us with the reason codes for waste generation and the department where each unit generated the waste. However, these reports were not standardized across units, so the team had to standardize the reason codes and departments for further analysis. The team came up with the following set of standard reason codes and departments based on the management interviews conducted during our site visits and the unit process maps provided by the corporate headquarters office.

Table 4

Standardized Reason Codes

Standard Reason Codes
Expired Stock
Damaged Goods
Overproduction
Under/Over Cooked
Menu Change
Quality
Cancellation
Other
Overordering
Raw Material Yield
Equipment Failure
Packing Issue
Shortage

Table 5

Standardized Departments

Standard Departments
Storage
Hot Kitchen
Make & Pack
Transport
Cold Kitchen
Baking & Pastry
Other
Central Recipe Assembly
Equipment

Once this standardization was completed, the team isolated all the top reason codes and departments that contribute to most of the waste generated by each unit. The results are graphically represented in Figure 8 and Figure 9 below.

Figure 8

Top Standardized Waste Departments

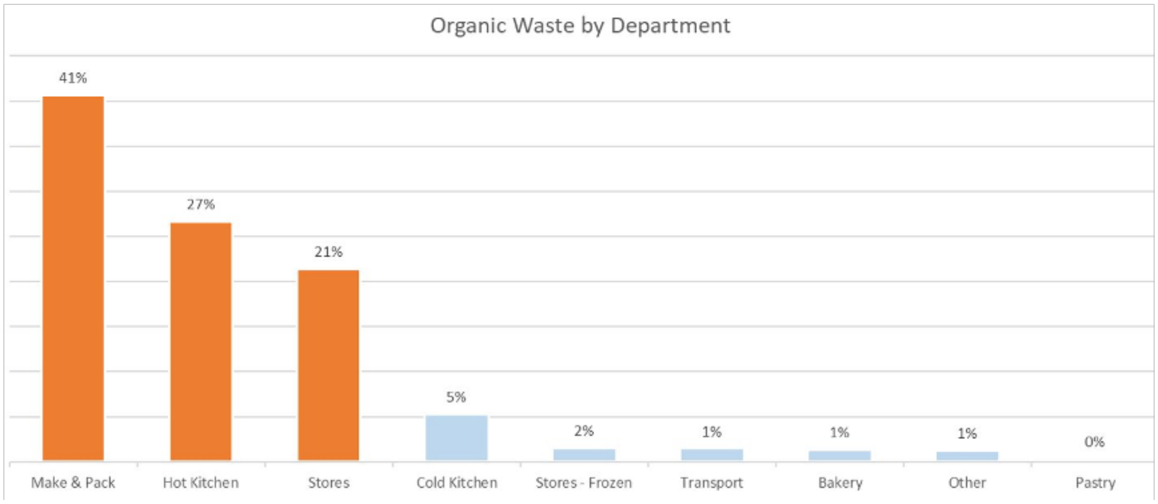
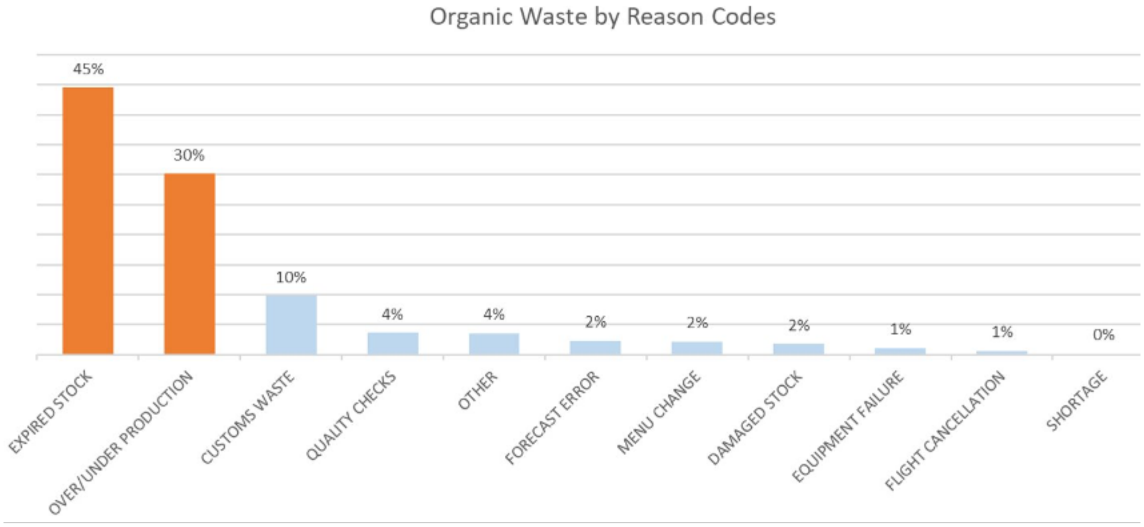


Figure 9

Top Standardized Reason Codes for Waste Generation



From the graphs above, it is clear the areas that contribute to the majority of waste are the Make & Pack area, the Hot Kitchen area, and the Stores or Storage areas. Additionally, the primary reasons for waste generation can be reduced to two, Expired Stock and Overproduction. This analysis allowed the team to understand the primary waste generation streams and departments that were critical to developing the Causal Loop Diagrams, the Stock and Flow diagrams, and the simulation models.

Finally, to validate the findings described above, the team decided to perform a word analysis on the survey responses from eleven different units around the world. Since the survey was structured to allow the site operations managers to enter free text, the team wanted to understand what words appeared the most frequently. It could potentially be an indication of where and how waste is generated. The team leveraged Python language to code the breakdown and performed a simple count of the words that appeared the most on the survey free responses. The results of that analysis are shown below in Figure 10.

Figure 10

Word Count Frequency

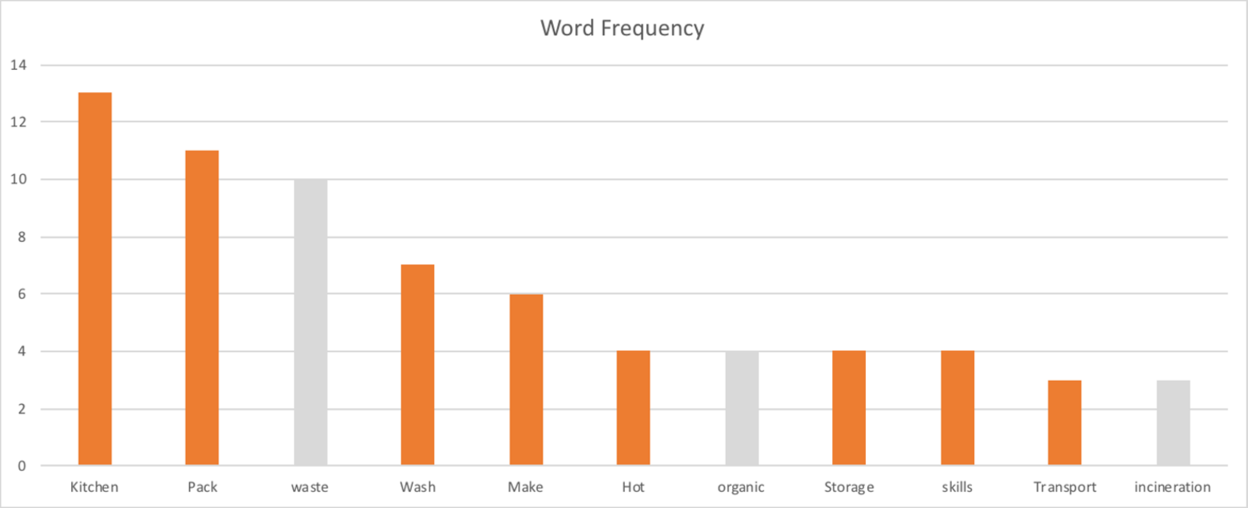


Figure 10 shows that the most common words in the free-text responses from the catering unit operations managers coincide with the reason codes and the departments displayed in Figures 8 and 9. This further validated our approach and results and served as the basis for creating the system dynamics diagrams and simulation models.

4.2 Unsupervised Machine Learning Results

Once we had explored the data in its entirety, we decided to analyze the relationship between the different features in the data. As described in section 3.4, we ran unsupervised machine learning techniques across the 72 units in scope to uncover how we should potentially group these units in new informative ways. The three-step process involved selecting the features of interest, running principal component analysis to reduce the dimensionality of the dataset, and finally clustering the units using K-means clustering.

The features we selected for the analysis were the following:

- Number of Full-Time Employees
- Maximum Meal Production Capacity per day
- Total Number of Customers

The team decided on these features since they were complete data sets from the sponsoring company's data sources. They were the ones with the least ambiguity. They represent the operational capabilities of each unit regardless of their location. With these features, we then ran principal component analysis (PCA) to reduce the dimensionality of the data and capture the most considerable amount of the variability in the data. The first principal component (PC1) captured 75.07% of the variability and the second one (PC2) 20.78%. Since these two captured over 95% of the variability, we decided to leverage them for the analysis. Figure 11 below shows these results graphically.

Once we had reduced the dimensionality of the data, we ran K-means clustering using the two principal components as our clustering space to see how the algorithm would group the 72 units in scope based on the features. Based on the initial plotting of datapoints, we observe three main groups of units where units are close to each other (k=3). To capture the characteristics of some datapoints that are further away from the group centroids without losing the generosity, we experimented with five clustering (k=5) and find that a good representation. Figure 12 shows the results of the k=5 analysis.

The scatterplot above shows a clear distinction between the cluster regions, which indicates that the clustering exercise was effective. Additionally, we computed descriptive statistics for all the clusters to investigate and validate the results.

Figure 11

Principal Component Analysis

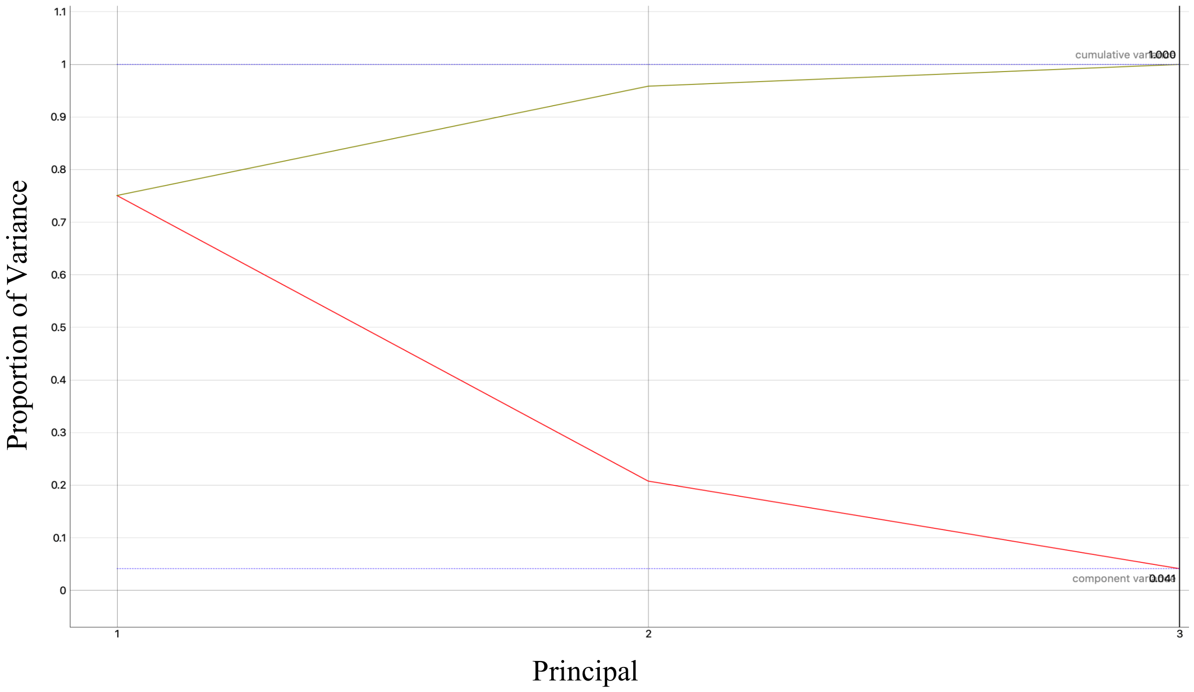
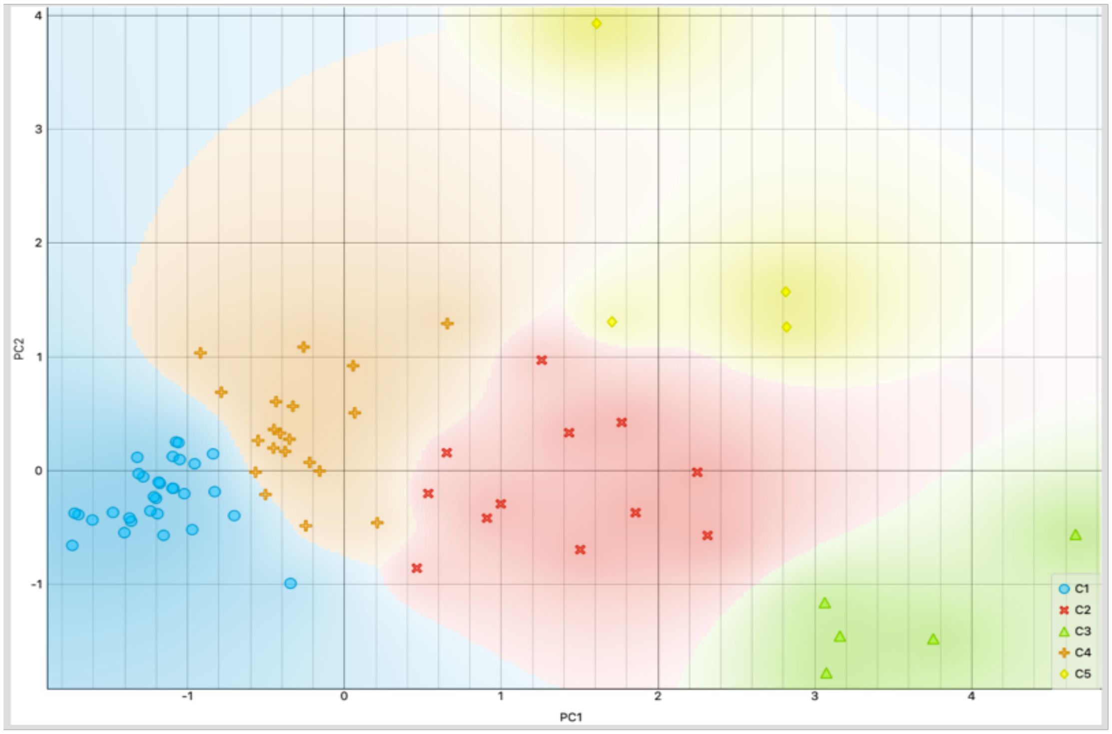


Figure 12

K-means clustering with k=5



We found that the clustering exercise was able to identify small hot kitchens, medium-sized hot kitchens, large hot kitchens, and large kitchen hubs with minimal errors. These different kitchen types are already internally defined and described in Figure 3 and Table 2. The results from that analysis are shown in Table 6 below. These results will be later utilized to compare the units within and across clusters regarding their waste management practices and the potential success of the alternate solutions we have explored. According to Table 6, we observed that cluster C1 contains the biggest number of catering units whereas clusters C3 and C5 represent the least number of units given the business nature with the majority of units in small to medium size whereas large size kitchens are limited.

4.3 Simulation Model Validation

Once we had understood the top sources of waste, the main reasons for waste generation, and the relationships between the catering units in terms of their production capacity and number of customers, we run our simulation model. This exercise captured the intricacies of the catering unit operations and allowed us to explore potential alternative waste management solutions to those applied today. Here again, we leveraged the data from the catering unit in Zurich since it had the most detailed and structured waste data.

The model validation was performed in three steps. First, we validated the relationships among the variables.Second, we selected the level of accuracy we wanted to achieve, and finally, we compared the results and interpreted our findings. To validate the relationships between the variables, we explored two different distributions, the random uniform distribution, and the random triangular distribution. We selected these probability distribution functions because they require minimal amounts of data and will allow us to model the inherent volatility of the airline catering industry. The random uniform distribution (m,x,s) requires two inputs from minimum (m) and maximum (x) values of the input data while the random triangular distribution (m,x,S,P,T,s) requires minimum (m), maximum (x), start value (2019 January Zurich data), peak value (same as x) and stop value (2019 December Zurich data). Weperformed several simulation runs to compare the outputs against the 2019 actuals provided by the sponsoring company to select the most appropriate distribution or a mix of distributions for the model. We decided to compare the results across two different parameters: first, the company's total yearly landfill and incineration cost, and second, the waste generation rate per month for landfill and incineration waste, recyclable waste, and organic waste. The results are shown in tables 7 and 8.

Table 6

Descriptive Statistics of K-means clustering exercise

Descriptive Statistics C1	KPI 01-Number of Employees (FTE's)	KPI 12-Meal Production Capacity per day Max	KPI 20-Number of Customers (Total)	S Kitchens
Mean	68	5184	6	
Median	50	4500	7	
Std Deviation	59	3610	2	
Min	10	200	1	
Max	318	15000	10	
Range	308	14800	9	
Count of Units	31			

Descriptive Statistics C2	KPI 01-Number of Employees (FTE's)	KPI 12-Meal Production Capacity per day Max	KPI 20-Number of Customers (Total)	L Kitchens
Mean	553	24470	17	
Median	566	22469	17	
Std Deviation	156	5334	4	
Min	340	20000	8	
Max	892	35000	24	
Range	552	15000	16	
Count of Units	12			

Descriptive Statistics C3	KPI 01-Number of Employees (FTE's)	KPI 12-Meal Production Capacity per day Max	KPI 20-Number of Customers (Total)	XL Kitchens
Mean	1033	50400	17	
Median	950	45000	16	
Std Deviation	196	11074	5	
Min	850	40000	12	
Max	1350	70000	27	
Range	500	30000	15	
Count of Units	5			

Descriptive Statistics C4	KPI 01-Number of Employees (FTE's)	KPI 12-Meal Production Capacity per day Max	KPI 20-Number of Customers (Total)	M Kitchens
Mean	165	10118	14	
Median	172	9500	13	
Std Deviation	74	4898	4	
Min	11	600	8	
Max	300	20000	24	
Range	289	19400	16	
Count of Units	20			

Descriptive Statistics C5	KPI 01-Number of Employees (FTE's)	KPI 12-Meal Production Capacity per day Max	KPI 20-Number of Customers (Total)	L Kitchens
Mean	548	20250	35	
Median	600	22500	33	
Std Deviation	201	8955	7	
Min	240	6000	28	
Max	750	30000	46	
Range	510	24000	18	
Count of Units	4			

Table 7

Landfill and Incineration Yearly Cost Comparison

Model Distributions	Landfill & Incineration Cost Absolute Percent Error
Mixed_Model_Triangular+Uniform_Optimal	8.88%
Mixed_Model_Triangular+Uniform	17.15%
Triangular_Model_MIX	5.06%
Triangular_Model_END	8.05%
Triangular_Model_START	8.76%
Uniform_Model_MIX	21.05%
Uniform_Model_MAX	21.05%
Uniform_Model_MIN	1.47%
Constant_Model	6.47%

Table 8

Waste Generation Rates Comparison

	Waste Generation Rates Optimal Model
Rates	**RMSE**
Landfill & Incineration Waste Generation Rate	46.21
Recycling Waste Generation Rate	52.38
Organic Waste Generation Rate	4.26

To maintain the confidentiality of the sponsoring company, we only display the absolute percent error and the root mean squared error (RMSE) from the different simulation runs we performed. We created nine different model runs using both distributions independently and together to compare the results. Each simulation run was named after the parameters leveraged. For example, the "Uniform_Model_MIN" run used only the random uniform distribution throughout the model and used a dynamic parameter as the minimum value for the model input. In the case of the organic waste processing rate (OWPr), we are using the organic waste rate (OWr) as the minimum parameter, forcing the model to process at a minimum the same amount of organic waste that was produced, as seen in equation (7) and (9).

As we continued exploring the model, it became evident that there were two competing parameters we needed to optimize. One was the accuracy at which we wanted to model the landfill and incineration cost for the company. Another was the accumulation of waste at each of the different waste stocks (i.e., Recyclable Waste Volume, Organic Waste Volume, etc.) in the system. As we learned from the interviews and our site visits, the catering units do not accumulate or hold waste in their facilities for more than one or two days. This fact conflicted with our model as we were showing an accumulation of waste over different periods. For that reason, we had to find the correct model parameters and distributions that would minimize the amount of waste left in the system and capture the cost impact accurately.

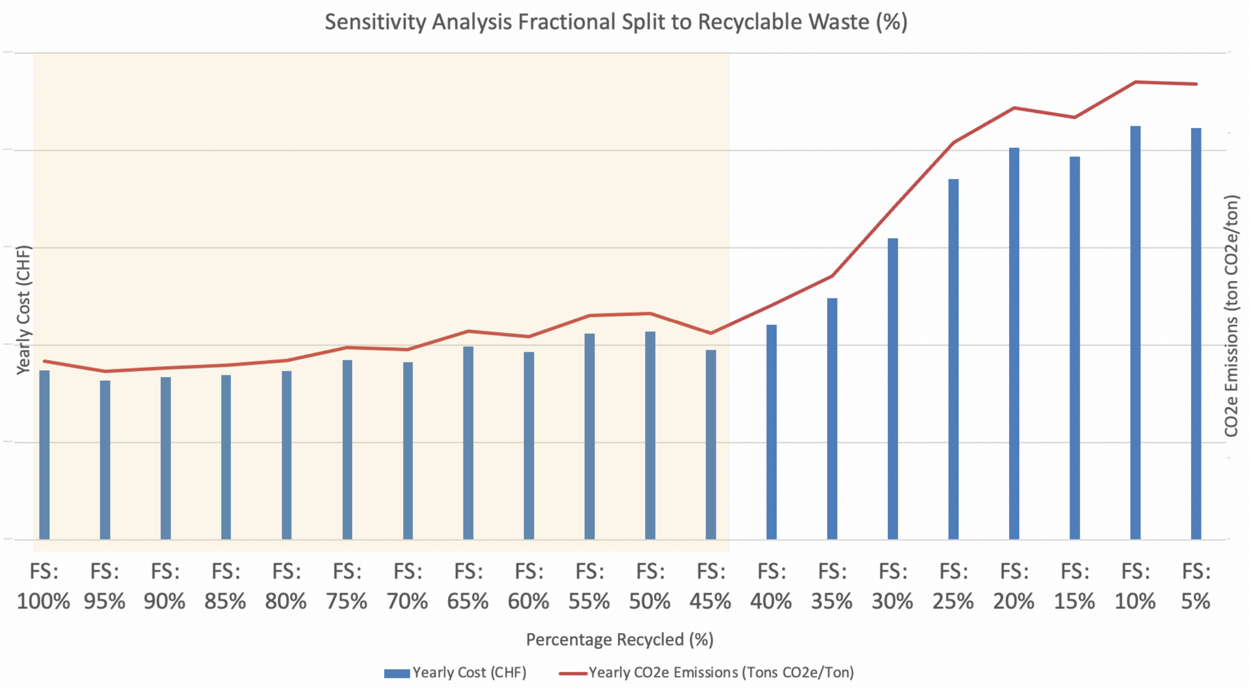
We decided to leverage a mixed model that leverages both the random triangular and random uniform distributions. This mixed model minimizes the waste left in the system while achieving 91.12% accuracy in modeling the company's actual landfill and incineration cost. Even though this model does not provide the highest accuracy in cost, nor the lowest root mean squared error for the different waste generation rates, it is the one that allows us to model the system the closest to reality. We will discuss various ways the model can be improved in the future in this report's discussion and limitations section.

4.4 Sensitivity Analysis

We decided to perform a sensitivity analysis to understand the effects of small changes in one of the variables would have on the overall results. We changed the "Fractional Split to Recyclable Waste" to accomplish this. We evaluated its influence on the overall results in terms of environmental impact and cost for the sponsoring company. The fractional split for the Zurich unit in 2019 was 36%, meaning that 36% of all waste was segregated as recyclable waste, and the rest was going to landfills or incineration. We tested all options, from not recycling any waste (i.e., 0%) to recycling 100% of the waste generated by the catering unit, to be able to map out the true impact of this variable in the system. The results are shown in Figure 13.

Figure 13

Effect of Fractional Split on Recyclable Waste on Cost and Environmental Impact



The blue bars show the cost for the company, and the red line represents the environmental impact in tons of CO_2 equivalent per ton of waste. The axis for the cost impact has been removed to mask important information for the sponsoring company. Figure 13 shows that the more the company can segregate waste and avoid sending it to landfills or incineration, the less expensive and the less damaging it is for the environment. There are very sizeable gains in cost impact and environmental impact when the segregation rate moves from 5% to 45%. However, as we keep increasing the segregation rate, the benefits become less evident, and the curve almost plateaus. Intriguingly, there is also a slight increase in cost from 45% to 55% of total waste being recycled. The latter suggests that for units like Zurich, the optimal fractional split between what is sent to landfills and incineration and what gets recycled is around 45% of the total waste produced.

This exercise allowed us to understand better the system's sensitivity to different variable parameters and the most effective waste recycling rate to minimize both cost and environmental impact.

4.5 Solutions Table and Process Flow Chart

Now that the simulation of the SD model is validated with actual 2019 Zurich waste data, we better understand the underlying mechanisms and variables that control the behavior of the local waste system. We developed a solutions table to explore waste management and provide a holistic and practical review for the sponsoring company (see Appendix B). Operations managers can use it for the evaluation of various waste management solutions in terms of financial and environmental impact (e.g., OpEx, CAPEX, CO2 Eq Emission) and maturity and potential implementation constraints. Vertically, the solution matrix evaluates the solutions from internal versus external implementation, edibility, and nutritional dimensions. Horizontally, solutions are assessed through quantifiable metrics such as financial and environmental measurements, maturity of the technology in terms of their availability and advancement, and potential constraints for airline catering businesses. Additionally, the team developed a food waste solution process flow map (see Appendix C) that visualizes the decision-making process step by step in line with the solutions table. This aims to provide catering unit managers with a simple framework that can be leveraged to improve their waste management practices.

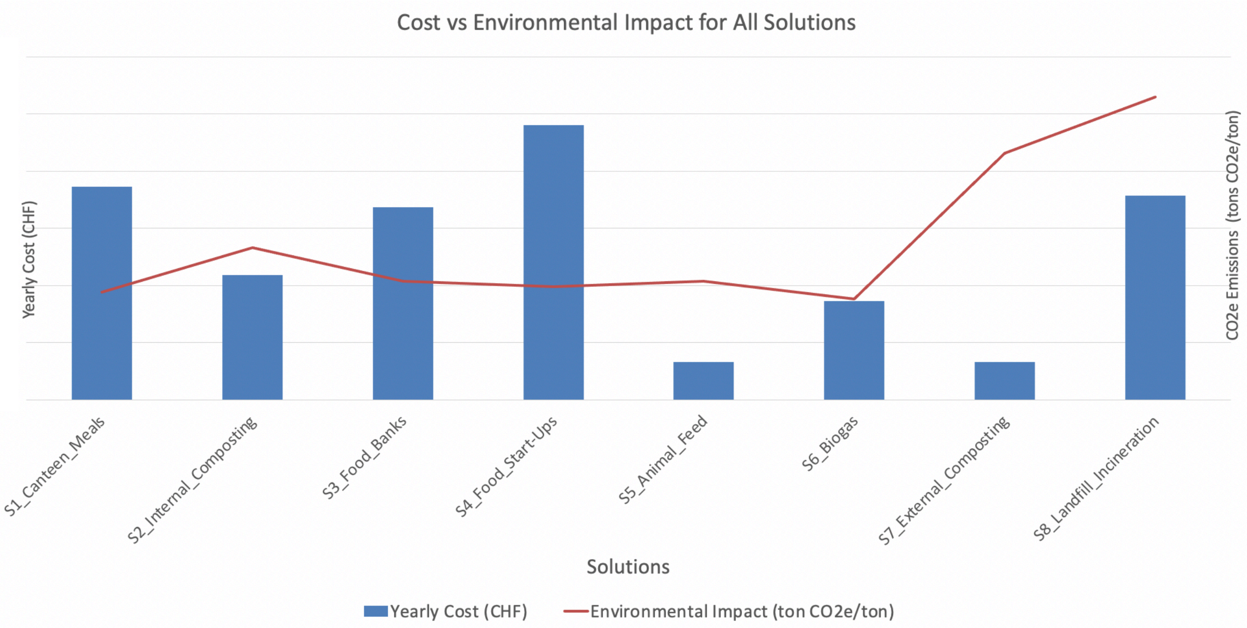
The solutions table feeds the system dynamics model with realistic figures from various solutions for scenario testing. It shows different CO_2 Eq Emission (tons CO_2e/ton) and solution costs that contribute to the model's applicability and provides the sponsoring company options to choose from based on the kitchen's financial and operational conditions.

4.6 Scenario Testing Results

The team was keen to test and evaluate cost and environmental impact for multiple solutions under several scenarios. To capture the effect quantitatively, the team introduced the operating cost, capital expenditure cost, and CO_2 equivalent emissions for all the solutions into the system dynamics model. To effectively compare the results, the team used the current baseline operations for Zurich, where they leveraged on a partnership with a biogas facility to process their organic waste. The solutions from each of the simulations are shown in the figure below.

Figure 14

Cost and Environmental Impact for all Alternate Waste Management Solutions



Blue bars in Figure 14 represent the cost for each solution, and the red line is their environmental impact. The figure shows that while landfill and incineration might seem cost-effective, they are not the lowest cost solution. It is definitely the most detrimental to the environment. Likewise, even though biogas is the most environmentally friendly solution, it is not the most cost-effective alternative. These tradeoffs are not surprising as sustainable practices often meet at the intersection of cost and environmental impact. This framework and analysis will aid the sponsoring company in making more informed decisions when evaluating organic waste solutions.

5 Discussion and Implications

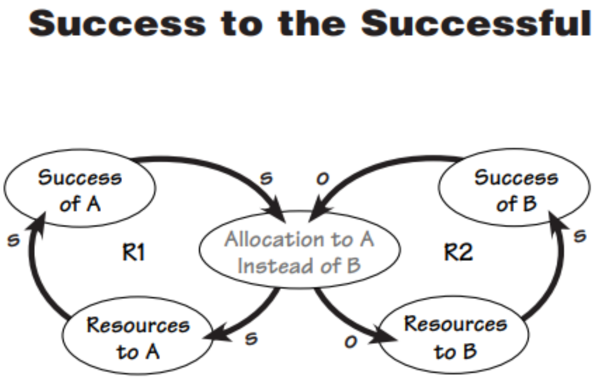
Having exploring one of the main units in Zurich, Switzerland, the team was able to understand the underlying waste production reasons, departments, and behaviors through simulation model and scenario testing with varying parameters , the team compared different results and was able to map out the potential solutions that would minimize both cost and environmental impact. In this section of the report, the team will critically evaluate the results and highlight the recommendations and limitations for the sponsoring company to deploy a global organic waste management strategy effectively.

5.1 Success to the Successful

As we worked to understand the overall system and the dynamic relationships between key variables and drivers, it became clear that the catering unit operations around recyclable and organic waste management represented one of the eight different systems archetypes that are widely studied in system dynamics. From the Causal Loop Diagram in Figure 5, the system follows the archetype "Success to the Successful." in Figure 15. This archetype represents two competing ideas or alternatives that are initially assumed equally capable of succeeding and assigns a higher likelihood of succeeding to the one that receives more resources. The initial success of the chosen idea reinforces the resource commitment to developing it further and thus discourages the alternative (Kim, 2016).

Figure 15

Success to the Successful Systems Archetype



Note. Based on Kim (2016)

We can see this competing behavior happen across the catering unit landscape. They are presented with different options of either prioritizing recycling practices or leveraging the convenience of landfills and incineration. For countries with higher regulatory pressures, such as those in the European Union, we see there is a prioritization of more sustainable practices and a heavy allocation of resources to segregate recyclable and organic waste as much as possible. However, in countries like the United States, the convenience of landfill and incineration solutions is far more attractive and thus prioritized. A primary recommendation from this capstone project is to minimize this type of prioritization environment and approach waste solutions as an integral and strategic effort where both convenience and environmental impact are part of the same strategy and are not seen as competing goals. Managing waste should be an all-encompassing approach and one that should be defined by the overall corporate strategic objectives of the company. The solutions outlined in this report should be used under those goals and supported by the company's leadership.

5.2 Optimal Waste Split

As we continued exploring our results, it was essential to understand the system's sensitivity and uncover the key variables that would significantly influence the overall cost and environmental impact. Our model was influenced by two distinct variables that drive the system. These variables are the Meal Production and the Fractional Split to Recyclable Waste. The Meal Production variable was intended to capture the demand shifts and uncertainty inherent in the airline industry. To achieve this, we leveraged pink noise, which is a way to introduce simple random series with autocorrelation as the core disruptor of the system (Fiddaman 2010). Even though this introduced variability in the system, it also prevented us from introducing different seasonal trends we were able to observe from the data. The latter limited the results to the bounds of the data without considering seasonality. For future studies, the team recommends exploring introducing seasonality along with pink noise into the system. This variable is critical in the entire process and is a determining factor in the model results.

The other variable that heavily influences the system's sensitivity is the Fractional Split to Recyclable Waste. This variable captures how much of the total waste volume generated by the system gets segregated as recyclable waste for proper disposal. Inherently, there is some amount of waste that cannot be recycled. Still, through our modeling, we were able to find the optimal percentage of total waste that should be recycled based on the Zurich catering unit data. The team explored everything from not recycling any waste to recycling 100% of the waste produced to understand the system's behavior.

Interestingly, around 45% (see Figure 13) of the total waste was the optimal split found by the team when it comes to dividing recyclable waste from landfill waste. This reduced the landfill and incineration cost, the organic waste cost, and the environmental impact of the catering unit. Similar results have been observed in other industries that leverage catering services. For example, in a study conducted at the University of Baja California, it was found that out of every ton of waste, around 65% has the potential to be recycled (Armijo de Vega et al. 2008). Unsurprisingly, our results represent a lower percentage since our model also considers the financial burden that this would have on the sponsoring company. The team thus recommends the sponsoring company works toward segregating recyclable waste as close to 45% of total waste in the unit as an optimal strategy. Finally, as a global strategy, the team proposes a similar data collection exercise be followed in the rest of the units worldwide to understand the optimal segregation rate that would minimize both cost and CO_2 emissions.

5.3 Solutions for a Global Strategy

After understanding the sensitivity of the model and the critical relationships among the variables, the team aimed to explore different waste solutions that could be effective for the sponsoring company to consider as they design a global waste management strategy. We explored eight different solutions, which encompassed both internal and external approaches. As shown in Figure 14 of this report, the solutions vary significantly in environmental impact and cost. While more straightforward solutions like external composting or landfill and incineration seemed like the most convenient and practical approaches, these proved to be more expensive and more detrimental to the environment than other more complex solutions in the medium and long term.

As expected, the biogas solution yielded the best results for environmental impact. However, it was surprising to discover that it also proved to be one of the most cost-effective. The catering unit in Zurich has been able to work out a deal to pay a flat rate for the pick-up of organic waste from their facilities which minimizes the cost impact and reduces environmental emissions significantly. However, biogas solutions are still not widely available across the globe and can prove unrealistic for less developed countries than Switzerland. For this reason, the team suggests considering alternate solutions that exist at the intersection of cost, environmental impact, and availability for crafting a global waste management strategy. In broad terms, the sponsoring company could leverage internal composting as their primary global strategy and look to partner with companies in the space to minimize both cost and environmental impact. Internal composting proved to be a good alternative with minimal investment and significantly reduced emissions compared to landfill and incineration.

To provide the sponsoring company with the tools to craft a global strategy we also explored different geographies and unit characteristics. By leveraging a k-means clustering algorithm we were able to identify five distinct clusters that allow us to evaluate the feasibility of our alternative solutions across multiple catering units. Even though the results in this report are not generalizable for all units across the globe, based on our clustering they should prove effective for five different units with similar characteristics to the one used for this analysis. The units in the cluster are the following: Zurich, Madrid, Los Angeles, San Francisco, and Toronto. As the sponsoring company works towards securing waste data for multiple units around the globe, the same approach can be taken and the overall results expanded to cover the full unit scope with minimal effort. Going forward the sponsoring company should focus its efforts in securing reliable data and leveraging the k-means clustering breakdown to approximate the solutions impact based on the unit characteristics.

5.4 Limitations

While this study has generated valuable insights for the sponsoring company to act on kitchen food waste management, there is still an opportunity for improvement from three perspectives. First, the current system dynamics model is confined to actual data from only one kitchen with structured and complete food waste figures across various categories in terms of volume and cost. Given this constraint, the solution for this kitchen may not be replicable for other kitchens of very different characteristics. Second, in the lack of actual figures, the team refers to literature for cost and environmental impact as approximations for the alternate solutions. While this is not an uncommon practice in the field, this may not fully reflect the actual implementation cost or pollution. Third, the current System Dynamics simulation uses the standard add-in function to generate randomness that may not fully mimic reality.

Data Availability and Configuration

Through initial internal investigations, the team learned that most catering kitchens within the sponsoring company currently do not segregate kitchen food waste from in-flight waste. As a result, it is tough for the team to analyze waste streams individually and their contribution to the overall cost and environmental impact. On top of that, catering kitchens that keep track of waste do not necessarily share the same reporting structure and scope. This becomes challenging when comparing units as the comparisons are not one-to-one. Even though the team was able to standardize the reporting structure, the accuracy of the overall report could be increased if the corporate office pushed these efforts. In addition, the outbreak of the 2020 pandemic struck the aviation industry hard and deteriorated everyday operations and data collection. This, in turn, limited the available data for analysis and forced the team to rely on data from 2019 operations. For future analysis and simulation using the system dynamics model, it would be best to have updated data from the last year or the current year to provide more accurate insights.

Cost and CO_2 Emissions Approximations

When developing the different simulation scenarios for each proposed solution, the team had to rely on internal interviews, survey results, and literature reviews to come up with the cost and CO_2 equivalent emissions. Without actual implementation data, the team had to rely on market benchmarks and academic literature to estimate alternate waste solution costs as our best-educated guess. For instance, when it comes to assessing the operational cost of food donation, we use the industry standard from the *Food for Feed project* commissioned by the EU as a benchmarking value. Their project objective is similar to ours in terms of food waste management specialized for animal feed (insert reference here). Similarly, when it comes to external solutions like 3rd party composting, the team utilized approximations of the transportation cost and CO_2 emissions based on research in the transportation industry (insert reference here). While these approximations are adequate for our research purposes, we recommend critically evaluating the different waste solutions based on the catering unit's geographical, economic, and political conditions before fully implementing them as a waste management strategy. In the future, if more data around cost and environmental impact can be recorded across the catering unit landscape, this could drastically improve the selection process for a new waste management solution strategy in the different regions.

Seasonality of System Dynamics simulation

Finally, to the best of our knowledge, our study is the first attempt at modeling the dynamic behavior of food waste management in the HoReCa (Hotel, Restaurant, and Catering) industry. Through the random pink noise function, we were able to generate a simple random series with an autocorrelation that adds more realism to the simulation. However, given the current Vensim functionality, there is room for future research to include seasonality in the modeling to reflect the volatility of meal demand and waste throughput. In the future, more accurate results can be realized if there is proper data collection on the seasonality of the meal demand and if this is introduced effectively into the simulation model.

6 Conclusion

Food waste is costing the airline catering industry money, consuming valuable natural resources that bring the food from farm to fork, polluting the environment with greenhouse gases, and threatening the aviation sector's sustainability reputation. To address that, the team partnered with the sponsoring company, a global leader in the airline catering industry, serving more than 700 million passengers annually pre-covid from over 200 operating units in over 60 countries/territories across all continents, to carry out first-of-its-kind industry research. This study aims to accomplish three goals. First, we want to understand where and how waste is currently being generated at the sponsoring company's catering kitchens. Second, we modeled the dynamic relationships of variables within these waste streams to break down the system and optimize our approach to reduce waste cost and environmental impact. Finally, we explored different waste solutions that would help the company understand the potential alternatives for processing organic waste. These efforts align with the sponsoring company's objective of evaluating other frameworks that can be applied as a global strategy for organic waste processing.

Our exploration of organic waste streams within the catering kitchen's layout concluded that three main areas significantly contribute to waste generation. The make-and-pack, hot kitchen, and storage areas are the main culprits in organic waste production. They are the first to be evaluated when thinking about waste prevention and processing strategies. Additionally, within these areas, there are clear trends as to why waste is being generated in the first place, which indicates that overproduction and expired stock contributes to over 75% of all organic waste generated by these catering kitchens. These insights serve as good indicators of where the sponsoring company should focus their efforts upstream in their processes.

As we continued to explore the dynamic relationships between the variables, it was evident that our model of the system would have some limitations. The lack of data, the environmental impact approximations, and the lack of seasonality in the demand signals limited the team's approach. Nevertheless, we captured the underlying relationships between the variables and modeled the system with a 91.12% level of accuracy. By exploring the right variable relationships and the simulation of different waste processing distributions, the team formulated a model that accurately captured the total cost of processing waste and minimized the accumulation of waste in the system. The model is not only representative of reality but a good blueprint for testing different waste solutions and scaling our research to a broader scope of catering units.

Finally, through our research, we explored different waste strategies and compared them in terms of cost and environmental impact. Interestingly, our study discovered that more complex and environmentally friendly solutions such as biogas are not as cost-intensive. They have a considerable potential to reduce overall emissions. However, these are not widely available across the globe, and their application as a global strategy might be infeasible. Fortunately, through the eight different solutions explored, we were able to find multiple that balance both cost and environmental impact. The solution that proved to be at the intersection between cost, convenience, and environmental impact is the internal composting solution. Even though it is not the most cost-effective or environmentally friendly, internal composting is the best way to approach a more circular supply chain solution. It provides the company with complete control over its organic waste processing, and it mitigates the impact on the environment without being too cost-intensive. This is a fully developed solution around the globe and one that would be easily implemented as a global organic waste management strategy.

Human society is at stake with more frequent disruptive natural disasters than ever and a drastic spike in world hunger (UN report, 2021). As a result, organic waste and organic waste processing strategies have never been a more relevant topic. Yet, governments, companies, and even individuals find it very complex to quantify their organic waste volumes and impact on the environment. Similarly, minimal academic attention has been raised to investigate this topic within the aviation industry thus far compared to the aviation market size. Through this research, we have provided the sponsoring company with a framework and model to evaluate the waste management efficiency of their catering kitchens and test potential alternate solutions that can be beneficial financially and environmentally. Academically, to our best knowledge, this research is the first study that applies both quantitative and qualitative methods in evaluating the financial & environmental impact of food waste in the airline catering kitchens. This research should not only helps the sponsoring company improve its business performance and environmental footprint but also serves as an opening window and landmark for the industry (e.g., airlines and airline catering companies), regulators, and academia in bringing food waste management to the plan for action and collaborating in a joint commitment with more concrete plans to contribute for a more sustainable world.

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Appendix A - Summary of food waste management studies in the airline catering industry

Year	Source	Geographical scope of analysis	Type of food waste	Focus of Analysis	Limitations	Our Research's Contribution
2014	Ross	New Zealand	Airline catering kitchen food waste	• Airline catering kitchen food waste drivers • Kitchen food waste prevention & reduction solutions	• Kitchen food waste weight & financial quantification • Static and linear relationship of elements in airline catering kitchen system	• Kitchen food waste reuse and recycle solutions • Food waste weight & financial quantification • System dynamics framework to map out the non-linear relationship of elements in airline catering kitchen system
2016	Gerber	Switzerland	Airline catering kitchen food waste and non-food waste	• Airline catering kitchen food waste drivers • Kitchen food waste prevention & reduction solutions	• Kitchen food waste weight & financial quantification • Waste data from one kitchen only •	• Kitchen food waste reuse and recycle solutions • Kitchen food waste weight & financial quantification • Kitchen clustering of seventy-two kitchens
2018	Royer	Switzerland	Airline catering kitchen food waste	• Airline catering kitchen food waste drivers	• Kitchen food waste weight & financial quantification • Static and linear relationship of elements in airline catering kitchen system • Waste data from one kitchen only	• Food waste weight & financial quantification • System dynamics framework to map out the non-linear relationship of elements in airline catering kitchen system • Kitchen clustering of seventy-two kitchens
2018	Sambo	South Africa	Airline catering post-flight food waste	• Restrictive factors of reusing post-flight food waste • Post-flight food waste weight quantification and categorization	• Kitchen food waste financial quantification • Waste data from one kitchen only	• Kitchen food waste financial quantification • Kitchen clustering of seventy-two kitchens
2018	Megodawickrama	Sri Lanka	Airline catering kitchen food waste	• The relationship between meal demand forecasting accuracy and kitchen food waste • Food waste weight quantification	• Kitchen food waste financial quantification • Simple linear regression • Waste data from one kitchen only	• Kitchen food waste financial quantification • Unsupervised machine learning • Kitchen clustering of seventy-two kitchens
2019	Thamagasorn and Pharino	Thailand	Airline catering Halal kitchen food waste	• Airline catering Halal kitchen food waste drivers, weight & financial quantification and categorization	• Waste data from one Halal kitchen only	• Airline catering general kitchens, food waste drivers • Kitchen clustering of seventy-two kitchens

Appendix B - Food Waste Management Solutions for Airline Catering Kitchens

Int/Ext	Solution Name	Description	Reference	OPEX	CAPEX	CO2 Eq Emission (tons CO2e/ton)	Maturity (0-5)	Constraints
Internal	Canteen meals	Resell complete edible meals as canteen meals to employees	Internal interview	0	0	0	5	• Demand for canteen meals may be smaller than the supply of edible wasted meals • German labor union requires weekly canteen menu changes which may not match the edible wasted meals characteristics for mainly frozen meals are wasted
Internal	Internal composting	Process of composting organic waste within sponsoring company's facilities. Dry and wet composting are well studied and widely available solutions that help minimize GHG release and impact. Composting types: open pile, windrow, static pile, in-vessel, and vermicomposting are all widely available solutions in the composting space.	Komilis & Ham, 2005; Zaman, 2013	**Assuming open pile: 0.00 CHF Virtually no operational cost to maintain open pile composting.	10,000 CHF per unit *Based on available industrial models (FoodCycler)	0.370-0.750 tons CO2e/ton	5	• Space for composting within company's facility • Composting machine investment - processing rate up to 500lb of food waste per day
External	Foodbank donation	Donate complete edible meals to a non-profit organization that collects and distributes food to hunger-relief charities.	Castrica, M., Tedesco, D. E., Panseri, S., Ferrazzi, G., Ventura, V., Frisio, D. G., & Balzaretti, C. M., 2018; European Commission, 2021	33754.70062	0	0.058 ton CO2e/ton	3	• Sophisticated requirement on donated food (volume, meal-type, delivery time unmatched) • Risk of GG playing the logistics & warehouse partner • Risk of food contamination liability by GG Better fit for non-temperature-sensitive packaged food such as snacks

Appendix B - Food Waste Management Solutions for Airline Catering Kitchens

Int/Ext	Solution Name	Description	Reference	OPEX	CAPEX	CO2 Eq Emission (tons CO2e/ton)	Maturity (0-5)	Constraints
External	Food apps startups	Donate complete edible meals through a platform that connects individuals in need of food with donors.	Castrica, M., Tedesco, D. E., Panseri, S., Ferrazzi, G., Ventura, V., Frisio, D. G., & Balzaretti, C. M., 2018; European Commission, 2021	33754.70062	0	0.058 ton CO2e/ton	3	• Sophisticated requirement on donated food (volume, meal type, delivery time unmatched) • Risk of GG playing the logistics & warehouse partner • Risk of food contamination liability by GG Better fit for non-temperature-sensitive packaged food such as snacks
External	Animal feed	Send food waste as feed for farmed animals, aquarium fish and pets	Castrica, M., Tedesco, D. E., Panseri, S., Ferrazzi, G., Ventura, V., Frisio, D. G., & Balzaretti, C. M., 2018; European Commission, 2021	318.3788598	0	0.058 ton CO2e/ton	3	Food wastes have to be cooked to sterilized to prevent disease-transfer
External	Biogas	Process of extracting methane gas from organic waste through anaerobic digestion. Methane is then used as fuel in gas turbines to generate electricity. Dry and wet anaerobic digestors can and are already being used in this process.	Weiland, 2009	25,000-30,000 CHF per year based on company data (Zurich) from 2019.	No capital expenditure - 3rd party solution	(0.036-0.010) tons CO2e/ton	3	• Highly developed in European countries • Not widely available around the globe • Rates for operation may differ by country/region

Appendix B - Food Waste Management Solutions for Airline Catering Kitchens

Int/Ext	Solution Name	Description	Reference	OPEX	CAPEX	CO2 Eq Emission (tons CO2e/ton)	Maturity (0-5)	Constraints
External	External composting	Process of composting organic waste leveraging 3rd party partners. All composting types are considered similar to Internal Composting. Composing type dependent on 3rd party partners, not controlled by sponsoring company.	Komilis & Ham 2005; Zaman 2013	**Pending market research	No capital expenditure - 3rd party solution	0.370-0.750 tons CO2e/ton	5	Varying levels of CO2e emissions, highly dependent on practices
External	Landfill & incineration	Landfill refers to the process of dumping waste into landfills with no treatment. Incineration refers to the process of burning waste in order to kill all potential pathogens found in it. Incineration helps prevent the spread of these malignant pathogens and is the preferred method for cabin waste in the airline catering industry.	Park & Shin, 2001	50,000-75,000 CHF per year Based on company data (Zurich) from 2019.	No capital expenditure - 3rd party solution. *Rare cases where incineration is an internal process in certain units.	0.400-1.70 tons CO2e/ton	5	Creates air pollution and requires strong environmental controls

Appendix C - Food Waste Solution Process Map