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Optimal Valorization Selection in the Design of a Sustainable Fruit and Vegetable Waste Network

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Abstract:
As the food supply chain (FSC) is facing new challenges such as climate change, fair trade, food waste and food security, it is becoming a necessity to consider ways to produce, process, distribute and consume food more sustainably without compromising the underlying costs. Food industry stakeholders should consider developing models, standards, and incorporate technologies that address the development of Sustainable FSC Management (SFSCM). As such, the management of fruit and vegetable waste (FVW) has great potential output due to the high-water density and low protein content.In this research, we present and discuss different sustainable management alternatives of the FVW and investigate the valorizationof FVW to estimate sustainable benefits such as energy utilization and GHG emission reduction. Further, the sustainable benefits of FVW recovery are quantified based upon geographic distance and valorization characteristics.

Keywords: Sustainability, Food Supply Chain, Fruit and VegetableWaste, Carbon Emissions, Network Design.

I. INTRODUCTION

The trending concept: Sustainable Food Supply Chain Management (SFSCM) has been developed as a consequence of recent changes in the Food Supply Chain (FSC) management goals such as improving design networks, cold chain management, and reverse logistics efficiency. As a result, new key performance indicators are developed to capture the integrated triple bottom line of sustainability in which profit, people, and planet are working as drivers of the supply chain decision-making process (Soysal, Bloemhof-Ruwaard et al. 2012).The sustainability of the food supply chain is facing so many challenges. First, food insecurity presents in different parts of the world. In India for example, about 24% of families have days with no food at all. At the same time, it is estimated that one-third of global food production is wasted per year. food production processes consume more than 10% of the total US energy budget, about 80% of freshwater in the US, and about 50% of U.S lands. However, more than 50% of all produced food is wasted before or after reaching consumers. This is estimated to cause a loss of more than $165 billion, 25% of freshwater, and huge yearly losses of energy, lands, and other resources (Govindan, Jafarian et al. 2014). As new challenges have emerged such as climate change, fair trade, food waste and food security, all different actors in the food industry should consider ways to produce, process, distribute and consume food more sustainably without compromising costs. Food industry stakeholders should develop decision-making models and set up standards and technologies that address the development of the SFSCM(Li, Wang et al. 2014).

The food waste can be categorized based on edibility condition into food surplus or food waste. Each one of these categories can be further be classified as packaged or non-packaged. Such food loss could be avoidable or non-avoidable, (see figure 1). Further, Shukla and Jharkharia (2012) differentiate between two types of agricultural produce. The first type is animals and their products such as milk and eggs, and the second type is long shelf life produce such as grains and spices. Third is fresh produce including flowers, fruits, and vegetables. Fourth, processed produce that can be made from any type of agricultural produce such as meals and sauces, (see figure 2)(Shukla and Jharkharia 2013).This research will be focusing on exploring the recovery processes of fruit and vegetable waste (FVW). This type of waste can be defined as the edible or inedible parts of fruits and vegetables that are discarded during collection, handling, transportation, and processing(Chang, Tsai et al. 2006).

By examining the existing body of literature in the area of FVW management and recovery from a sustainability perspective, we notice that studies are insufficient and limited in terms of the lack of novel framework, objective quantitative methodologies, data-based results, or addressing the selection of various FVW recovery options. Also, the suggested FVW reduction policies in literature are limited to the household level, while the sustainability measures are not considered in the set of objectives (Fehr, Calçado et al. 2002). Similarly, other studies analyzed energy recovery such as biochar production from FVW through the pyrolysis process. However, such studies are based on subjective methodologies and consider limited types of FVW (Harsono, Grundman et al. 2013). Other attempts to develop optimization models for food systems are based on the analysis of sustainability in plant factories such as the Taiwanese vegetable market. Such analysis does not reflect the complexities of the closed-loop food supply chains and ignores essential sustainability measures such as the GHG emissions and energy use (Hu, Chen et al. 2014). On the other hand, the cost-benefit analysis is widely applied in the FVW energy recovery. In one study, the fruit juice waste recovery by anaerobic co-digestion is found to be better than the two-separate digestion. However, such an economic-driven analysis does not cover the balance between the environmental, social, and economic dimensions of sustainability. Also, this analysis usually focuses on one or two FVW recovery options and does not consider the comparison and optimal selection of multiple recovery alternatives (Hosseini Koupaie, Barrantes Leiva et al. 2014). Further, FVW energy recovery by briquetting has been investigated in different studies. However, the treatment of FVW is studied in isolation of reverse logistics and network design which include minimizing transportation costs and optimizing the treatment sites' location (Srivastava, Narnaware et al. 2014).

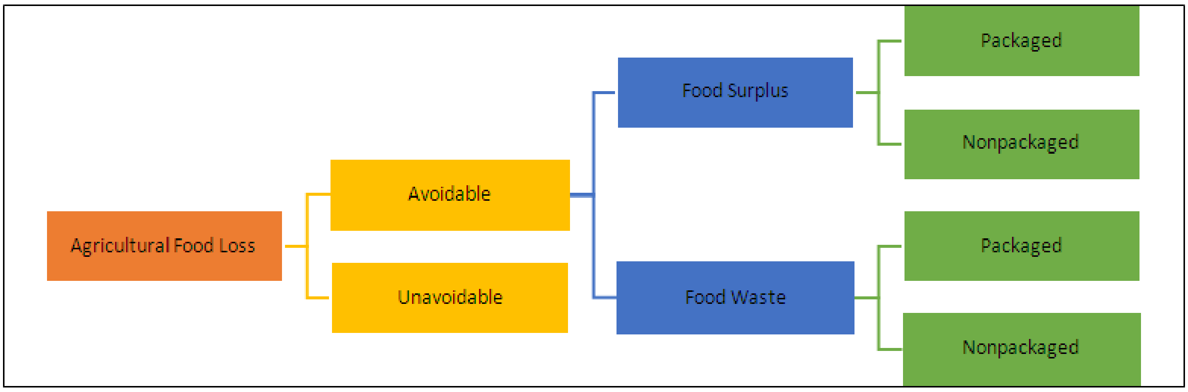

Figure 1. Food Waste Categories Based on Edibility Condition

Therefore, our aim in this study is to fill the gaps in the existing literature by proposing a thorough framework and a mathematical methodology based on realistic data that provide a generalized model and contribute tothe development of sustainableFVWmanagementthroughout all the stages of the food supply chain. As a result, we will study the sustainability in the closed-loop food supply chain in terms of FVW management that reduce its economic, social, and environmental impact (Pochampally, Nukala et al. 2008). The system boundaries include FVW resulted from farming, processing, packaging, warehousing, and distribution along with different treatment processes to mitigate the FVW impact on sustainability. The model framework includes both local operational decisions and global strategic decisions.

1. The first local decision is selecting the best FVW valorization options based on economic, environmental, and social conditions including energy use and carbon emissions.
2. The global scaled decision includes network design and FVW distribution to and from valorization sites in a sustainable design context.

To this purpose, the framework addresses reducing FVW impact on sustainability by incorporating theFVW network model that optimizes economic, social, and environmental tradeoffs.

II. LITERATURE REVIEW

The studies on the sustainability metrics within the context of the FVW reverse logistics have been growing recently as a result of increasing governmental regulations, environmental concerns, economic advantages, and customer awareness. Fehr et al. (2002) studied food waste disposal procedures at different stages of the Brazilian fruit and vegetable supply chain to improve landfill diversion rates and propose a formal reduction policy to municipal administrations. Results showed that a potential of 100% diversion for biodegradables by implementing the suggested policy at the household level (Fehr, Calçado et al. 2002). Coley et al. (2009) provided a critical comparison on the concept of food miles between a large-scale vegetable box distribution system and a local supply system where customer travels to a local farm shop. The study found that the large-scale system is better in terms of reducing carbon emissions only if a customer in the local system traveled more than 6.7 km to purchase vegetables (Coley, Howard et al. 2009).Harsono et al. (2013) presented theanalysis of biochar production from palm oil empty fruit bunches (EFB) by considering the energy balance, GHG emissions, and the economic efficiency of the slow pyrolysis process. The output shows that the net energy yield of such a process is positive and resulted in net gas emissions of 0.046 kg CO_2 eq per kg. Overall, the study showed that biochar production from EFB is profitable assuming biochar can be sold for at least $533 per ton (Harsono, Grundman et al. 2013).Hu et al. (2014) developed a Nash-Cournot model to simulate competition of a sustainable plant factory supply chain in nine Taiwanese vegetable markets. The study derived KKT optimality conditions and solved the resulted linear complementarity problem by GAMS and PATH. The results showed that the profits of the factory increase as transportation costs decrease(Hu, Chen et al. 2014). Koupaie et al. (2014) conducted an experimental and cost-benefit analysis of fruit-juice industrial waste recovery by anaerobic co-digestion. The results showed that the total capital and processing costs can be significantly decreased using co-digestion compared to two separate digestion processes(Hosseini Koupaie, Barrantes Leiva et al. 2014). Srivastava et al. (2014) investigated the energy recovery of vegetable market waste (VMW) through briquetting systems. The study showed that the calorific value of VMW ranges between 10.26 and 13.70 MJ kg^{-1} of dry matter with processing cost between $24.68 and $28.90 per ton which is comparable to the cost of a similar quantity of wood(Srivastava, Narnaware et al. 2014). Bortolini et al. (2016) developed a perishable produce distribution planner to balance operating costs, carbon footprint, and delivery time objectives. The paper applied the proposed tool to a case study of fresh fruit distribution from Italian producers to European retailers. Compared to the single-objectives model, the distribution planner resulted in 9.6% CO2 emission reduction and no food waste due to shorter delivery times, while operating cost increased by 2.7% (Bortolini, Faccio et al. 2016). Banasik et al. (2017)developed a multi-objective optimization model concerning the economic and environmental goals of organic matter alternative recycling technologies for closing the loop in the mushroom supply chain. The study found that by implementing the recycling technologies, the total profit of the mushroom chain could increase by 11%, while the environmental indicator could improve by 28%(Banasik, Kanellopoulos et al. 2017). In particular, previous studies have addressed selecting the optimal FVW management options in terms of global warming potential and energy use. A case study of the FVW management scenarios in Sweden performed a life cycle analysis for four FVW management options (incineration, anaerobic digestion, conversion, and donation), using different food waste streams from supermarkets. In the context of the food waste hierarchy, the study results showed that the re-use options better reduced the carbon emissions and energy use compared to the energy recovery options. This is because the re-used FVW substitute producing raw food that consumes higher resources compared with fossil fuel production(Eriksson and Spångberg 2017). Tasca et al. (2017) conducted a LCA comparison study for different alternatives of vegetable supply chains in north Italy in terms of the potential environmental impact. Results revealed that organic farming has reduced environmental impact in a range of 13% to 55% but increased acidification by 16% and human toxicity by 127%. Further, the direct distribution of the raw organic product at the local level has the most impact reduction(Tasca, Nessi et al. 2017). Mattsson et al. (2018) conducted a cost-benefit analysis on the fresh fruit and vegetable (FFV) waste management in Sweden retail sector. The considered benefits include the reduction of waste mass and climate impact of the FFV waste. The results identified hotspot categories of FFV that contribute the most to the food system in terms of the wasted mass, cost, and climate impact. The study concluded that investing in FFV waste management is economically viable given the reduction of wasted mass and gains in climate impact (Mattsson, Williams et al. 2018).

By analyzing the research area of the FVW recovery modeling in the sustainability context, we observe the need to extend the conventional frameworks encompassing the design of the sustainable FVW management network. The identified gaps in the existing research studies extend to the lack of addressing important parameters that estimate the sustainability of FVW management. Such parameters include different costs and economic measures, and social measures including the public health impact and food security (Bortolini, Faccio et al. 2016). Second, the case studies found in the encountered research is specific to certain FVW categories such as citrus or mushroom and are not valid in case of the general sustainable food waste management. In such cases, the considered wasted material is only limited to the organic growing medium which is a very small portion of the wasted food amount (Banasik, Kanellopoulos et al. 2017). Also, the life cycle analysis is widely followed in the FVW management literature to compare between different recycling options. However, such a methodology cannot capture the necessity to optimize the FVW system. Further, the consideration of the various food waste valorization technologies and recovery options is not fully addressed (Eriksson and Spångberg 2017). Besides, analytical approaches are widely adopted by the studies in this area. However, these approaches do not consider the balance between the conflicting objectives of sustainability, to the contrary of the quantitative modeling approaches (Mattsson, Williams et al. 2018).

Therefore, we create a closed-loop framework for a sustainable FVW recovery modeling that investigates the optimal set-up of the economic, environmental, social, and energy efficiency parameters. We adopt a mathematical modeling methodology to assess different FVWrecovery alternatives based on the proposed sustainability criteria. The developed model is implemented in the case study of the Massachusetts FVW management system and results are validated by realistic data.

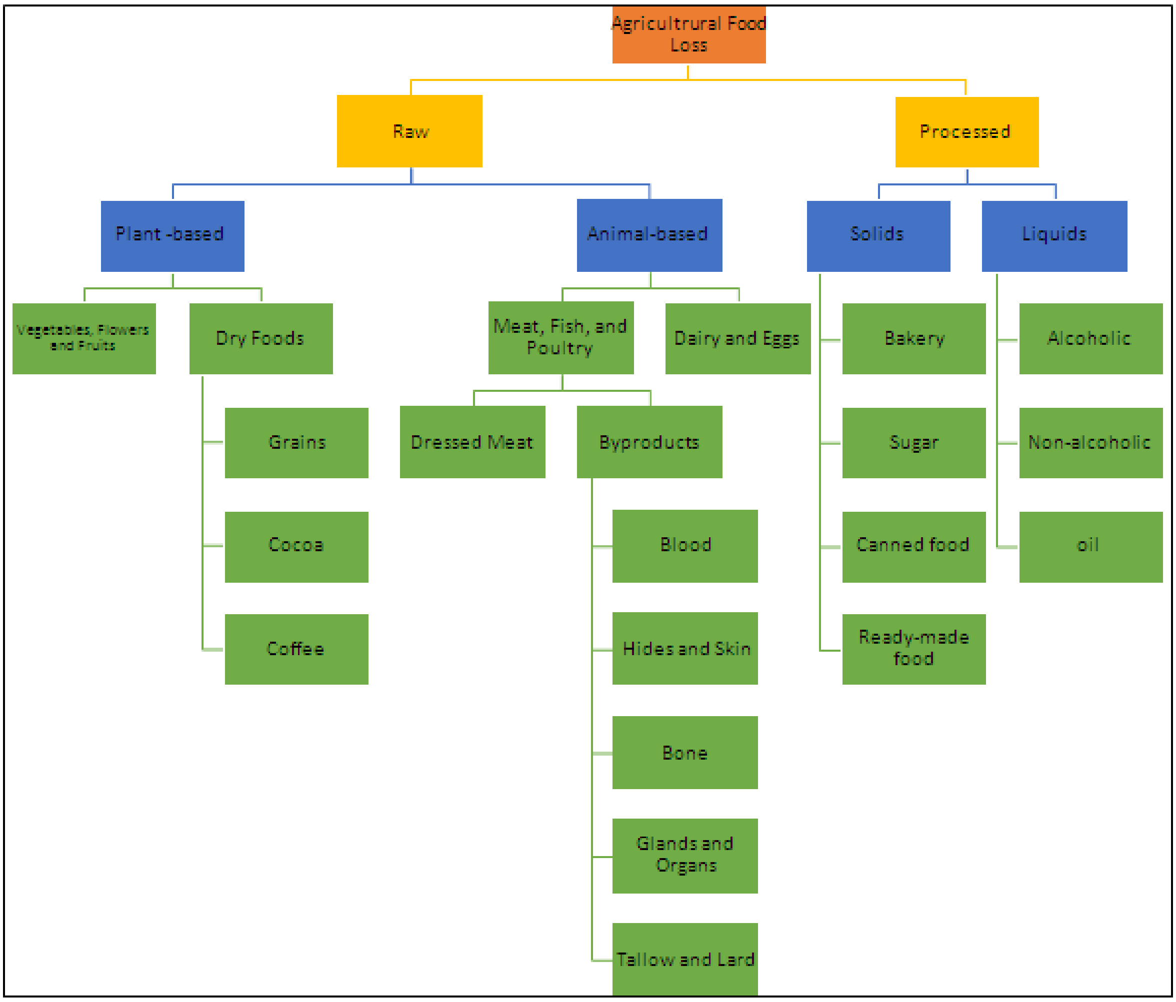

Figure 2. Food Waste Categories Based on Material Type

III. RESEARCH METHODOLOGY

Addressing the FVW reduction issue in the context of sustainable food systems requires a multidisciplinary approach to identify the intersection between valorization techniques, reverse supply chains, ecological, and social issues (Alqahtani, Kongar et al. 2019). Implementing the proposed approach of the FVW network framework can be achieved through the following steps:

1. Defining the sustainable system boundaries
2. Performing FVW assessment
3. Analyzing FVW sustainable valorization benefits
4. Solving the FVW network model

1. The Sustainable system boundaries

The first step in developing the FVW reduction framework is to identify the characteristics of the wasted fruit and vegetables accurately. Determining the best valorization option of FVW depends on the condition of the food in terms of type and quality, quantity, packaging characteristics, the source at which the waste occurred, energy and water use, and GHG emissions. These characteristics can be used to identify the system boundaries of FVW reduction. There are several different types of FVW including avoidable, non-avoidable, raw, and processed. Accordingly, each type of FVW has certain shelf life properties and temperature control requirements. The quantity of FVW can be expressed in kg per capita per year or kcal per capita per day. The FVW may occur at any stage of the food supply chain from farm to fork. The distances between these sources and between the proposed valorization center locations are required to study the process of FVW reduction with tradeoffs between economic, environmental, and social costs (Gungor and Gupta 1999).

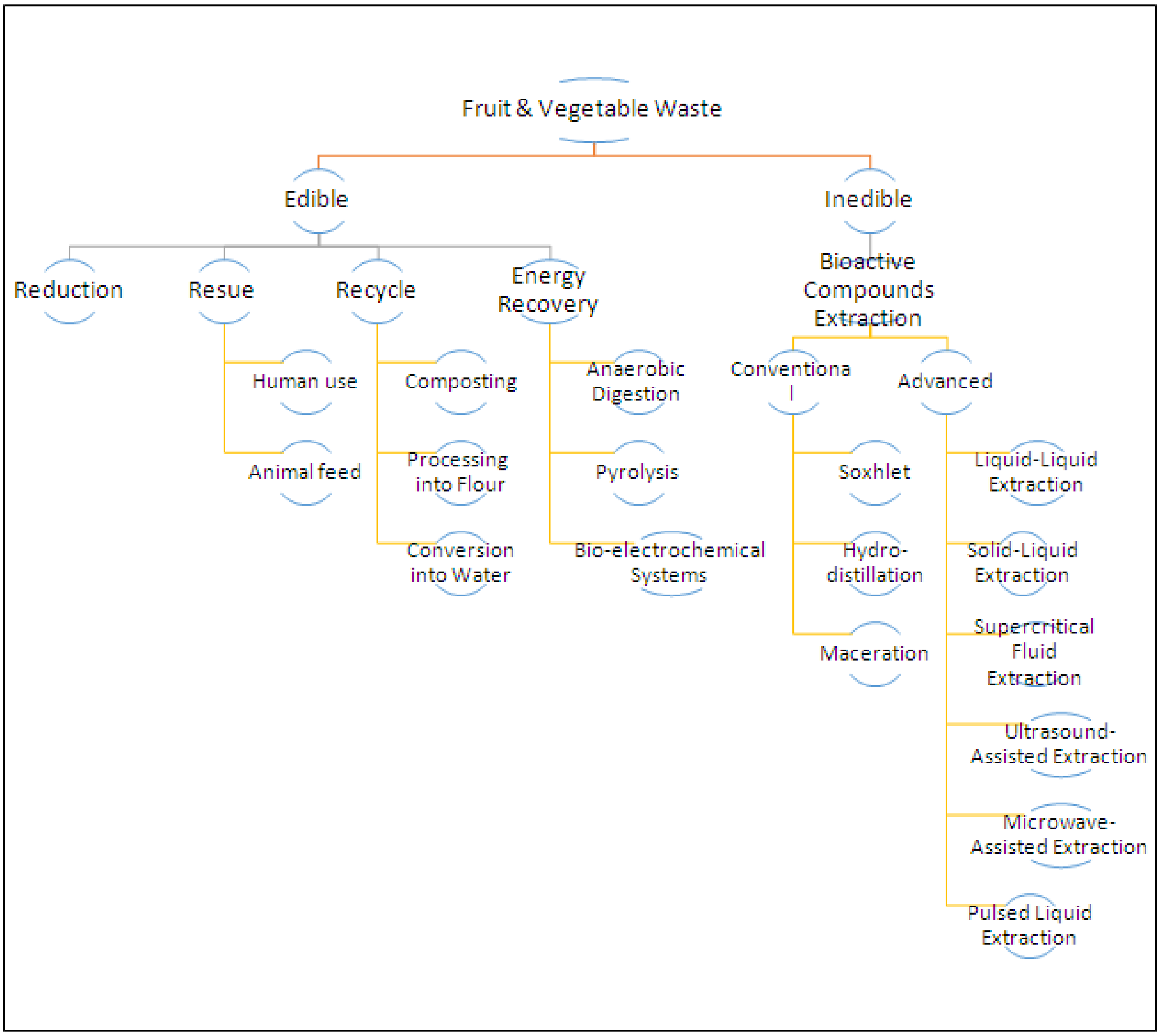

Figure 3. The FVW valorization alternatives

Moreover, reverse logistics parameters include locations of both suppliers and consumers, capacities, and transportation costs, and environmental properties such as energy use and GHG emissions (Gupta 2016). The FVW reduction framework utilizes food waste and the parameters of reverse logistics as inputs for the FVW network model.

Furthermore, the food waste hierarchy framework can be utilized to evaluate the sustainability impact of different FVW treatment options. Papargyropoulou et al. (2014) proposed a framework to identify food waste treatment options and priorities these options according to sustainability criteria by applying the waste hierarchy approach (Papargyropoulou, Lozano et al. 2014). The framework showed that the prevention of food waste is the most appealing sustainable option, then the human use option, then recycling food waste into animal feed or by composting processes, followed by energy recovery (Papargyropoulou, Lozano et al. 2014). The least favorable option according to this framework is the disposal of food waste into landfills due to the negative economic and environmental impact of this process.

2. *Food waste valorization assessment*

In this step, the FVW valorization alternatives are evaluated from a sustainability point of view. These alternatives include Human use by donations or selling at the secondary market, recycling by preparing for animal feed or composting, and resource recovery by technologies such as anaerobic digestion. Each of these alternatives has a different impact on sustainability and a specific alternative or a combination of two or more could lead to the highest level of sustainable food waste reduction. Including the reverse logistics modeling will ensure optimal utilization of the wasted food by minimizing the traveled distance. Organic material recycling can be defined as the recovery of waste materials after a major modification of their characteristics(Plazzotta, Manzocco et al. 2017). As such, the recycling of FVW has great potential output due to the high water and low protein content. Recycling strategies are divided into the whole FVW mass recycling that includes composting, conversion into water, and processing into flour. The second recycling strategy is compound extraction. Next, we present and conduct a comparative analysis of different sustainable alternatives of FVW management. The reduction, reuse, recycling of the edible FVW, and the bioactive compounds extractions of the inedible FVW will be within the scope of this research, (see figure 3).

The Sustainable Reduction of Edible FVW

The reduction of FVW is the most favorable option for managing the issue of FVW and its consequences on sustainability based on the waste management hierarchy. As FVW is occurring among all stages of the food supply chain, the reduction strategies should be addressed in each of these stages. Although natural events that could lead to harvest loss makes the production practices to produce higher than sales forecasts, other reduction practices can be easily applied. One mainstream of FVW is the small-sized, misshaped, or substandard fruit and vegetables that do not fit the quality standards of retailers and consumers. Reduction strategies to reduce such waste is proposed and employed by downgrading for by-product production (e.g. juices, vinegar), or selling these products at reduced prices(Plazzotta, Manzocco et al. 2017).

The Sustainable Reuse of Edible FVW

Humanitarian Relief

Food surplus is avoidable food waste that is edible and can be used for human consumption under normal circumstances (Papargyropoulou, Lozano et al. 2014). Hunger-relief organizations collect food surplus by cooperating with nodes of the SFSC and distribute the collected food to donation centers such as food banks, food cooperatives, and community kitchens. More than 10% of U.S. households who are affected by food insecurity receive nutritional assistance from federal programs such as Supplemental Nutrition Assistance Program (SNAP) and/or from charitable organizations such as food pantries. To encounter household and community food insecurity, the utilization of food surplus appeared to be an efficient practice to improve food access to the vulnerable. Moreover, the UK government suggested that food surplus redistribution is a potential strategy in the context of sustainable food systems for reducing food waste and generating social, environmental, and economic benefits for the food industry (Midgley 2014).

Animal Feed

One processing technology of interest is to convert food waste into animal feed. The 2017 analysis of organics diversion alternatives report states that organic input to this process is exposed to initial inspection to remove large contaminants, then ground, run through additional contaminants removal, followed by dehydration or milling for mixing with other nutrients.

The Sustainable Recycling of Edible FVW

Aerobic Composting

FVW often contains high concentrations of easily degradable organic substances such as sugars, starches, lipids, and proteins, thus it is suitable to be disposed of by composting (Chen and Hsu 2015). The inputs of the composting process include water, organic matter, and air while the outputs are carbon dioxide and compost that is used as organic fertilizer and soil enhancer. Although composting is not a new waste disposal method, the characteristics of food waste such as moisture content, nutrient content, and particle size still bring a unique challenge to the researchers, since the basic knowledge of FVW composting is inadequate for supporting successful processes with high efficiency. Other important factors that influence the quality of the compost include temperature, aeration rate, and pH levels(Kocher 2018).

Processing into Flour

FVW can be dried and processed into flour which has multiple usages. This type of FVW flour is characterized by the fibrous structure and the high contact surface which makes it a great material for pollutants absorption in the case of dyes and heavy metals existing in water and ground. These high absorption properties aremainly attributed to the physical entrapment into the porous structure of FVW and to the interaction with cellulose, hemicellulose, and lignin. Further, The FVW is used in the formulation of functional compounds such as polyphenols and fiber. The raw material to produce such flour has low cost and no residual waste needs to be disposed of as a result of this process. Despite these advantages, the FVW drying process that is a necessary step to make the flour has a very high cost due to the high-water content(Plazzotta, Manzocco et al. 2017).

Conversion into Water

Pure water can be obtained from FVW by applying the hyper-acceleration of aerobic decomposition. This technique utilizes the activity of naturally occurring microorganisms. When the environmental conditions are tightly controlled, this process is characterized by enhanced degradation capabilities. Companies, supermarkets, and restaurants have already applied patented systems to convert FVW into water(Plazzotta, Manzocco et al. 2017).

The Sustainable Energy Recovery of Edible FVW

Anaerobic Digestion

Anaerobic digestion for biogas production (methane-rich gas) is a well-established technology perfectly suited for food waste management. This technology can be applied to almost all types of biodegradable substrates as source-separated organic fraction of municipal solid waste, agricultural or industrial food waste, and food manufacturing residues(Pochampally, Nukala et al. 2008). The inputs to this process constitute food waste or any organic matter, energy, and water. The outputs include biogas that could be utilized for digester energy use, effluent, and digestate (Kocher 2018).

Pyrolysis

Pyrolysis is a process that converts organic material into bio-oil, biochar, and other volatile matter by thermochemical decomposition. The process is applied by moving the biomass at a controlled rate through a horizontal tubular kiln at a temperature of around 400 ^{0} C. Applications of this technique include power generation, fuel production, soil amendment, and carbon mitigation strategies(Harsono, Grundman et al. 2013).

Bio-electrochemical Systems

This alternative FVW energy recovery method has been recently studied for the sake of increasing by-product profitability. To this end, biologically catalyzed electrochemical systems in which microbial fuel cells are applied to convert the chemical energy of the FVW into electrical energy through redox reactions. It is noted that this technology works best with carbohydrate-rich wastes(Plazzotta, Manzocco et al. 2017).

The Sustainable Functional Compounds Extraction of Inedible FVW

Various high value-added ingredients and functional compounds can be extracted from FVW. Such compounds include bioactive extracts such as flavonoids from onions and antioxidants from fresh-cut fruits. Other compounds are essential oils and pharmaceutical oilfrom melon and other fruits. Fiber extracts include reinforced biopolymers from banana, bioplastics from pineapple, cellulose nanofibers from carrot, and dietary fiber from apple, cherry, carrot, and other FVW. Moreover, natural dyes are extracted from raspberries and onions. Also, structuring agents with unique viscosity properties are extracted from apples and carrots.

Conventional extraction methods

The conventional methods have been developed and utilized for bioactive compounds from FVW a long time ago. The scientific basis of these techniquesis to employ the solvent power under specific heat parameters. The main classical extraction methods are Soxhlet extraction, hydro-distillation, and maceration.

Soxhlet extraction

This method is extracted after the German scientist von Soxhler and considered a popular technique for lipid extraction before being widely used to extract other bioactive compounds. The first step of the extraction process is to keep a small sample of the FVW in a thimble that is kept in the distillation flask containing a selected solvent. Then, a siphon triggers the solution to transfer from the thimble to the flask when an overflow level is reached. Next, the extract remains in the distillation flask while the solvent returns to solid plant material. These steps are repeated until the extraction is completed(Sagar, Pareek et al. 2018).

Hydro-distillation

Hydro-distillation is a conventional technique for extracting several natural compounds such as oils from FVW. The process starts with packing the FVW into a still compartment before water is added and boiled that work as a removal agent of bioactive compounds. Then, the water and oil mixture is condensed before moving to a separator. Other types of the hydro-distillation are water and steam distillation, and direct steam distillation. This technique involves three major photochemical processes which are hydro-diffusion, hydrolysis, and decomposition. However, the drawback of this process is that it is slow and not suited for large-scale industries(Sagar, Pareek et al. 2018).

Maceration

This low-cost classical technique has been used originally for home tonics before becoming popular for bioactive compounds and essential oil extraction from FVW. The processes involved in this method start with grinding the FVW samples followed by mixing in a solvent called menstruum and pouring the mixture in a closed vessel. Then, pressure is applied to discard the liquids and separate them from the solid residue. Finally, the collected liquids are filtered to remove impurities. During these processes, shaking is used to increase diffusion and maximize the extraction yield(Sagar, Pareek et al. 2018).

Novel extraction Technologies

Novel sustainable extraction technologies have been recently developed that guarantee high yield and reduced amount of organic solvents. Examples of these technologies include Ultrasounds extraction, supercritical carbon dioxide, microwaves, and pulse electricfields. However, these novel technologies require high initial investments and produce high amounts of residual waste which make its industrial application is limited(Plazzotta, Manzocco et al. 2017).

Liquid-Liquid extraction

This technique is based on the separation of the solutes from the solid matrix using liquid solvents at high pressure and temperatures that are characterized by excellent physicochemical properties such as viscosity, density, diffusivity, and dielectric constant. The liquid-liquid extraction method has been successfully employed to extract several functional compounds from FVW(Soquetta, Terra et al. 2018).

Solid-Liquid extraction

In this technique, the mass transfer operation is employed bypassing the solid matrix through a solvent such as water, methanol, acetone, and methanol. Several bioactive compounds can be extracted from FVW by this method such as sucrose, proteins, oils, phytochemicals, and polyphenols. Factors impacting the yield of this process include particle size, temperature, time, liquid-solid ratio, flow-rate, diffusion coefficients, concentration gradients, and boundary layer (Sagar, Pareek et al. 2018).

Supercritical Fluids Extraction

Supercritical fluid extraction (SFE) is a fast, efficient, and clean novel technique for the extraction of multiple functional compounds from FVW. The extraction process consists of two main stages. First, the soluble compounds are extracted from the solid substratum by the supercritical fluids (SCF) solvent that can extract valuable biomolecules and remove pollutants and toxins. Second, these compounds are then separated from the SCF after the expansion by reducing the pressure and increasing the temperature rapidly. The SFE is characterized by the flexibility to manipulate the operational conditions of time, pressure, and temperature to maximize the global yield which is defined as the maximum amount of compounds that can be extracted from specific FVW under given operational conditions. Determining the optimal operational conditions is substantial information to estimate the cost of manufacturing (COM). As carbon dioxide is considered safe, non-toxic, and generally less costly, it is the most used solvent in the SFE. Other solvents such as propane, ethane, butane, and high-pressure water (HPW) are less frequently used. Other important factors for efficient extraction process include the degree of solubility of the FVW in the SCF, the interactions of the solute-solid matrix, the localization in the matrix, and the porosity of the FVW. Examples of bioactive compounds that have been successfully extracted using SFE include essential oils, phenolic compounds, carotenoids, and tocopherols(Pereira and Meireles 2010).

Ultrasound-assisted extraction

The cavitationphenomenonproduced by ultrasound-assisted extraction (UAE) has a mass transfer effect on plant cell walls that leads to the release of natural compounds. UAE is a versatile, flexible, and easy to use method that requires low initial investment compared with other extraction techniques. The process of extraction using this technique involvestwo phases. First, the diffusion phase through the cell wall and then the rinsing phase where the cell content is rinsed after breaking the walls. The process can be applied directly or indirectly. The direct application provides 100 times higher intensity while water is used to transfer waves in the indirect application. Various biomaterials have been extracted using the UAE such as essential oils, proteins, dyes, and polysaccharides. The temperature, pressure, frequency, and sonication time are all factors that impact the yield of the UAE method(Soquetta, Terra et al. 2018).

Microwave-assisted extraction

The use of microwaves which are a non-contact heat source in the microwave-assisted extraction technique (MAE) provides more effective heating and transfer of energy to extract several compounds such as antioxidants, flavorings, and essential oils. The MAE is a flourishing, safe, and allows access to high temperatures that enable reduced reaction time and increased total yield with or without the use of any solvents(Soquetta, Terra et al. 2018).

Pulsed electric fieldassisted extraction

The pulsed electric field (PEF) technique usestheelectric potential that passes through the cell membrane of the FVW to extract valuable functional compounds. PEF is considered a sustainable and green extraction technique due to its capacity to disrupt solid material cells, the use of alternative solvents such as water, reduced energy consumption, and high-quality final product. Furthermore, this method has been shown to increase the extraction yield, and allow using the treated matrix for several extraction cycles. Factors impacting the extraction process include temperature, intensity field, FVW properties, pulse number, and input energy(Soquetta, Terra et al. 2018).

3. Analyzing food waste sustainable valorization benefits

Input data of different system factors are collected and analyzed to quantify the benefit of valorizing the FVW by a specific potential technique. A sustainable benefit model can be utilized to determine the FVW reduction potentials using input data within the system boundaries. Such models use FVW characteristic data to estimate sustainable benefits such as energy reduction and GHG emission reduction. Additionally, the sustainable benefits of reverse logistics of FVW are quantified based upon geographic distance, valorization characteristics, and technologies for collection, storage, and distribution. By identifying inputs, outputs, and externalities associated with the sustainable FVW reduction system, the following sets and parameters for the food waste network problem are generated as shown in Table 1.

Table 1. Sets and parameters for the FVW network problem

Sets	
g	1,…, G Fruit and Vegetable Waste (FVW) generators
r	$1, \dots, R$ FVW recovery sites
$\mathrm{v} \in \mathcal{V}$	(Humanitarian Relief (HR), Secondary Market (SM), Animal Feed (AF), Composting (CO), By-Product Production (BP), Processing into Flour (PF), Conversion into Water (CW), Anaerobic Digestion (AD), Bio-electrochemical Systems (BS), Pyrolysis and Gasification (PG), Soxhlet Extraction (SE), Hydro-distillation (HD), Maceration (MAC), Liquid-Liquid Extraction (LLE), Solid-Liquid Extraction (SLE), Supercritical Fluids Extraction (SFE), Ultrasound-Assisted Extraction (UAE), Microwave-Assisted Extraction (MAE), Pulsed Electric Field Extraction (PEF), Landfill (LA))
Parameters	
d_{gr}	distance between FVW generator g and recovery site r(mile)
tc_{grv}	transportation cost between generator g and valorization option v at recovery site $r(\$/ton - mile)$
CO_{2rv}	carbon emissions/absorption resulting from establishing valorization option v in the recovery site r(ton CO_2eq/ton)
pCO_{2v}	carbon emission resulting from processing FVW by option v(ton CO_2eq/ton)
tCO_{2grv}	carbon emissions resulting from transport between generator g and option v in site r(ton CO_2eq/ton – mile)
w_{rv}	energy required to establish option v in site r $(kwh\ /ton)$
pw_v	energy required to process FVW with option v $(kwh\ /\ ton)$
tw_{grv}	energy required for transport between generator g and option v(kwh /ton – mile)
db_r	development budget allocated for site r(\$)
fc_v	fixed cost to establish option v$(\$/ton)$
pc_{rv}	processing cost of FVW by option v in site $r(\$/ton)$
cap_{rv}	capacity of processing facility v in site r (ton)
cp_{gv}	capacity of generator g (ton)allocated to option v
cp_g	total capacity of generator g (ton)
ew_v	power generation resulted from FVW treatment by option v(kwh /ton)
e_v	conversion factor for carbon emission associated with power generation $(tonCO_2eq/kwh)$
m_v	conversion factor for carbon emission associated with FVW treatment $(tonCO_2\ eq/ton)$
fd_v	sustainability threshold for recovered FVW by option v(ton)
max_{LA}	maximum disposal limit of FVW(ton)

4. The Fruit and Vegetable Waste network model

We formulate the FVW network framework as a strategic linear programming (LP) model that aims to minimize total FVW management costs while satisfying emissions and energy use constraints. The formulation is based on the following assumptions:

1. One year of FVW treatment with long-term use of treatment options. This is because establishing treatment facilities requires substantial time and resources, which makes short-term switching infeasible.
2. The FVW is assumed to be separated at the source and ready to be collected by the hauler.

3. The landfill does not involve gas recovery units
4. Assume expansion of existing FVW recycling facilities
5. Assume the life cycle of the treatment facility is 20 years

Given the sets and parameters in Table 1, the FVW network model is formulated as follows.

Decision Variables

Table 2. The model decision variables

x_{rv}	$\begin{cases} 1, & ifvalorizationoptionvistobeopenedinsiter \\ 0, & otherwise \end{cases}$
y_{grv}	FVW flow between generator g and recovery site r allocated to valorization option v (ton)

Table 2 shows the decision variables of the FVW network model.

Objective function

$$\min \sum_{r=1}^{R}\sum_{v\in\mathcal{V}} fc_v x_{rv} cap_{rv} + \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}} d_{gr}\, tc_{grv} y_{grv} + \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}} pc_{rv} y_{grv} \qquad (1)$$

The objective function (1) minimizes the fixed, transportation, and processing cost of the FVW treatment. The fixed cost represents establishing treatment facilities. The transportation cost is related to transporting FVW by truck from generators to treatment facilities. The processing cost is associated with all activities of FVW treatment by the designated facilities.

Demand fulfillment constraint

$$\sum_{g=1}^{G}\sum_{r=1}^{R} y_{grv} \geq fd_v \qquad \forall v \in \mathcal{V} \qquad (2)$$

$$\sum_{r=1}^{R} y_{grv} \leq max_{LA} \qquad \forall g: 1, \dots, G, v: \text{LA} \qquad (3)$$

The set of constraints (2) guarantee that the demand of each FVW recovery product is met. Constraint (3) limits the FVW disposal amount to a maximum value set by regulators.

Capacity constraints

$$\sum_{g=1}^{G} y_{grv} \leq x_{rv} cap_{rv} \qquad \forall r: 1, \dots, R,\ v \in \mathcal{V} \qquad (4)$$

$$\sum_{r=1}^{R} y_{grv} \leq cp_{gv} \qquad \forall g: 1, \dots, G, v \in \mathcal{V} \qquad (5)$$

Constraints (4) and (5) limit the flow of FVW from generators to treatment sites per the processing capacity of treatment facilities and generators capacities allocated to each treatment facility, respectively.

Flow balance constrains

$$\sum_{r=1}^{R}\sum_{v\in V} y_{grv} = cp_g \qquad \forall g: 1, \dots, G \qquad (6)$$

$$\sum_{r=1}^{R}\sum_{v\in V} x_{rv}\, cap_{rv} \geq \sum_{g=1}^{G} cp_g \qquad (7)$$

Constraint (6) force the amount of FVW flow within the system to be equal to the total capacity for each generator. Constraint (7) ensures the capacity of all FVW treatment facilities is at least as much as the total capacity of all generators.

Development budget constraint

$$\sum_{v\in V} fc_v x_{rv} cap_{rv} \leq db_r \qquad \forall r: 1, \dots, R \qquad (8)$$

Constraint (8) limits the fixed cost to establish treatment sites per the available budget for each site.

Emissions control constraint

$$\sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v=LA} m_{v} y_{grv} + \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}} pCO_{2v} y_{grv} + \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}} d_{gr}\, tCO_{2grv}\, y_{grv} + \sum_{r=1}^{R}\sum_{v\in\mathcal{V}} CO_{2rv}\, x_{rv}\, cap_{rv} \le \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}-\{\text{LA}\}} m_v y_{grv} + \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\{\text{AD,TR,IN,PG,HC}\}} e_v ew_v y_{grv} \tag{9}$$

Constraint (9) controls the net emissions resulting from the FVW treatment system. It ensures that emissions associated with establishing treatment facilities plus emissions from landfilling, processing, and transportation of FVW must either be offset by diverting FVW from landfilling or FVW used for energy recovery.

Energy control constraint

$$\sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}} pw_v y_{grv} + \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\mathcal{V}} d_{gr}\, tw_{grv}\, y_{grv} + \sum_{r=1}^{R}\sum_{v\in\mathcal{V}} w_{rv}\, x_{rv}\, cap_{rv} \le \sum_{g=1}^{G}\sum_{r=1}^{R}\sum_{v\in\{\text{AD,TR,IN,PG,HC}\}} ew_v y_{grv} \tag{10}$$

Like constraint (9), Constraint (10) ensures that the energy supply to the FVW treatment system is provided by the energy recovered from the FVW treatment activities.

$$x_{rv} \in \{0,1\}, \qquad y_{grv} \ge 0 \qquad \forall r: 1,\dots,R, v\in\mathcal{V}, g: 1,\dots,G \tag{11}$$

Finally, constraint (11) enforces binary values and non-negativity for the decision variables.

IV. DESIGNING THE FOOD WASTE NETWORK IN MASSACHUSETTS

We test the efficiency of the proposed framework by designing a sustainable FVW treatment network for the state of Massachusetts. The total amount of FVW in Massachusetts is estimated to be over four hundred tons generated from the commercial sector that include food producers, retailers, restaurants, hospitals, and other institutions. Although the wasted food has the potential to be diverted for human use, recycling, energy recovery, and other FVW recycling technologies, most of the waste is disposed of in landfills. This practice is impacting the environment negatively by increasing GHG emissions from landfills (Ilgin and Gupta 2010). As a result, the Massachusetts department of environmental protection (MassDEP) initiated a commercial food material disposal ban. The ban that took effect in 2014, limits the amount of commercial organic waste by businesses and institutions to a maximum of one ton per week. This regulation is considered as one of the agency's initiatives to achieve a 35% food waste diversion from disposal by 2020 as reported in the Waste360 research in 2014. We will focus on six processing options of food waste treatment based on the implementation feasibility of these options in the state of Massachusetts.

5. Data collection and analysis

Table 3 shows the average capacity for all FVW generators in Massachusetts to divert their food waste using six currently available processes. These processes are Humanitarianrelief, anaerobic digestion, pyrolysis, MAE, UAE, and conversion into water or wet-systems. To comply with the ban, the capacity of disposal is limited to 240,000 tons of FVW.

Table 3. The capacity of FVW generators in Massachusetts

The total capacity of FVW for all generators $cp_g\ (ton)$	Capacity for FVW to be diverted by process $vcp_{gv}\,(ton)$						
	HR	AD	Pyrolysis	MAE	UAE	Wet-system	LA
400,000	280,000	360,000	360,000	320,000	320,000	320,000	400,000

We have collected emission, energy, and demand parameters data for each of the seven potential processes that could be selected for FVW treatment. Transportation cost for humanitarian relief is higher than other treatment processes as FVW need more temperature control equipment to be transported safely (Kocher 2018). Carbon emissions cost is based on estimated emissions resulted from processing FVW by a particular process divided by the emissions social cost which is estimated to be 38$ per $tonCO_2eq$as calculated in theIndustrial Economics report in 2017. We calculated the transportation emission and energy based on using truck mode (Weber and Matthews 2008). Fixed costs include site preparation to expand processing activities and equipment purchases as shown in the 2017 analysis of organics diversion alternatives report. Processing cost includes operational costs, maintenance, and labor cost to process FVW per ton. The energy required to process a ton of FVW by the MAE is the highest compared to other processing options, followed by the UAE. On the other hand, processing food waste for human use consumes the lowest energy rates(Eriksson and Spångberg 2017). We deployed a conversion factor to calculate emissions resulted from FVW disposal in the Landfill. The data analysis is summarized as shown in Table 4. MassDEP has selected four sites for potential expansion to meet the expected increase in food waste diversion. We have derived the coordination of the average location of all generators in Massachusetts according to the 2017 analysis of organics diversion alternatives report. Accordingly, the distance from this central location to each potential processing site is calculated as shown in Table 5. Moreover, we derived the estimated budget allocated for each processing site from MassDEP relevant reports.

Table 4. Data analysis summary for the FVW network problem

Option ν	Off-site treatment options						On-site
	HR	AD	Pyrolysis	MAE	UAE	LA	Wet-system
tc_{grv}	0.915	0.5	0.5	0.5	0.5	0.5	0
CO_{2rv}	0.06	0.189	0.189	0.189	0.189	0.84	0.06
pCO_{2v}	0.01	0.159	0.046	95	15.6	5.6	0.01
tCO_{2grv}	0.03	0.01	0.01	0.01	0.01	0.0003	0
w_{rv}	123	330	330	330	330	180	123
pw_v	3.33	472.78	750	120000	41111.11	60	7.7
tw_{grv}	83.33	27.78	36.11	28	28	1.22	0
fc_v	75	90	90	90	90	50	22
pc_{rv}	16	33	33	33	33	3	70.3
ew_v	1938.89	605.56	3186.11	-	-	-	-
e_v	0.00034	0.00034	0.00034	-	-	-	-
m_v	1.02	1.02	1.02	1.02	1.02	1.02	1.02
$fd_v \times 1000$	150	100	100	50	50	-	50

Table 5. Distance from generators to potential processing sites

Site r	Distance to generators d_{gr} (mile)	Development Budget db_r $(million\ \$)$
1	104.50	10.58
2	70.62	25.51
3	30.53	616.52
4	40.70	44.79

6. *Results and discussion*

By implemented the collected data of different parameters, we run the FVW network model in LINGO and obtain an optimal solution in less than 0.1 s on a computer configured with Intel Core 3.3 GHz processor and 8 GB of RAM. To compare the results, we make three different scenarios of the model. First, we make no restrictions either on the net emissions of GHG or on the net power consumption of the system. This is achieved by relaxing constraints 9 and 10, which will show the purely economic perspective of the optimization model. Second, we employ constraint 9 that requires offset of the resulted emissions by a sustainable treatment of the FVW. Lastly, the third scenario is to make the food system self-sufficient in terms of energy in addition to mitigating the resulted emissions. This is achieved by enforcing both constraints 9 and 10. The results are summarized in Table 6 along with different KPIs to measure the sustainability impact of each scenario. The main KPIs include the cost of FVW treatment, net mitigated emissions, net energy use per ton of valorized FVW, and the food waste hierarchy impact. Figure 4 shows the results of the FVW network represented in the spider chart.

Table 6. Results and sustainability KPIs of the FW network model

	Scenario 1	Scenario 2	Scenario 3
Total Cost	$ 45,111,500.00	$ 52,683,720.00	$ 52,740,000.00
Food Treatment cost per ton	$ 112.78	$ 131.71	$ 131.85
Fixed Cost	$ 22,445,000.00	$ 24,445,000.00	$ 32,510,000.00
Fixed Cost Per ton	$ 56.11	$ 61.11	$ 81.28
Transportation Cost	$ 6,578,500.00	$ 10,302,350.15	$ 8,806,000.00

Transportation Cost per ton	$ 16.45	$ 25.76	$ 22.02
Processing Cost	$ 16,088,000.00	$ 17,936,366.48	$ 11,424,000.00
Processing Cost per ton	$ 40.22	$ 44.84	$ 28.56
Food Treatment Carbon Impact	10755327.93	0.00	0.00
Food Treatment Carbon Impact per ton	26.89	0.00	0.00
Food Energy Use impact	5012663664	768165291	-488546385.50
Food Energy Use impact per ton	12531.66	1920.41	-1221.37
Food waste hierarchy impact	22.50%	33.12%	74.00%

In the case of scenario one, the treatment cost is low, but energy consumption and emissions are relatively high. The total cost per ton reads $112.78 but emitting 26.89 $tonCO_2\ eq/ton$ and consuming energy equivalent to 12531.66 $kwh\ /ton$. On the other hand, the treatment cost has increased to $131.71 in scenario 2 as a result of diverting more food waste from landfill disposal. However, this scenario achieved zero net emissions and the recovery of energy that reduce energy consumption by %85. Moreover, with just a 0.11% increase in the treatment cost compared to scenario 2, scenario 3 has achieved zero net emissions besides the recovered energy surplus that is equivalent to $171 per ton. Furthermore, this scenario has treated more FVW by higher priority options from a sustainability perspective. As a result, the score for food waste hierarchy achieved its highest at 74% compared to the other two scenarios. Therefore, comparing all scenarios shows that planning and designing the FVW network model is vital to reach the balance between different parameters of the system and to better use of resources. These derived results are based on the data entered for the FVW characteristics and other parameters. In case of any changes to these data, the results will change accordingly. For example, if the FVW is not edible and contains a large amount of contaminates, then energy recovery treatment options are more appropriate than human use. In this case, achieving zero net emissions and zero net energy use would be more easily and less costly.

Our study demonstrates a new approach to the sustainable modeling of the FVW recovery network. We built a quantitative evaluation of sustainable FVW treatment concerning economic, environmental, and social implications. The economic performance shows that shifting the FVW into the higher levels of the food waste hierarchy will result in moderate processing costs. Other studies in the literature compare between the FVW treatment options by considering the saved resources when the FVW replaces the production from raw material (Eriksson and Spångberg 2017). In contrast, we assume that besides the substitution benefits of resource production, the FVW are valuable resources that contribute to sustainable development in the context of the FVW network and our results validate such assumption. Similar case studies in literature only considered the FVW to be recovered within the internal food supply chain which results in balancing profitability to the environmental performance of the recycling technologies. However, we extend this approach by considering the opportunity of FVW treatment in external supply chains which results in additional costs. Given this assumption, our model shows superior results by achieving energy surplus that could be sold in external markets and 100% improvement in terms of environmental performance which is measured by the net carbon emissions.

The FVW network model is a valuable tool that policymakers, generators, and processors can use to determine the best sustainable FVW management. The model incorporates data about FVW to address the tradeoffs between the cost of treatment, environmental impact, resource utilization, and social impact derived from the food hierarchy framework. Moreover, the model largely depends on the advancement of FVW separation and treatment techniques. As these techniques improve, the treatment of FVW will be more efficient which will result in increased energy recovery, reduced emissions, and minimized treatment costs. The model metrics and KPIs enables decision-makers to manage the FVW treatment from a holistic sustainable perspective. First, the treatment cost KPI enables investors to make a cost-benefit analysis and determine the economic viability of different treatment options. Second, the treatment emissions impact is crucial to comply with environmental policies relevant to climate change mitigation. Third, the energy use impact enables all stakeholders to cut back on fossil fuel dependency that has fluctuated prices and severe environmental impact. Last, the food hierarchy impact adds more value to the society by allowing more food to be distributed to the most vulnerable sectors and amplify the public good consequently. Thus, by combining all these indicators in the FVW network model, policymakers can achieve the best sustainable strategies for FVW management.

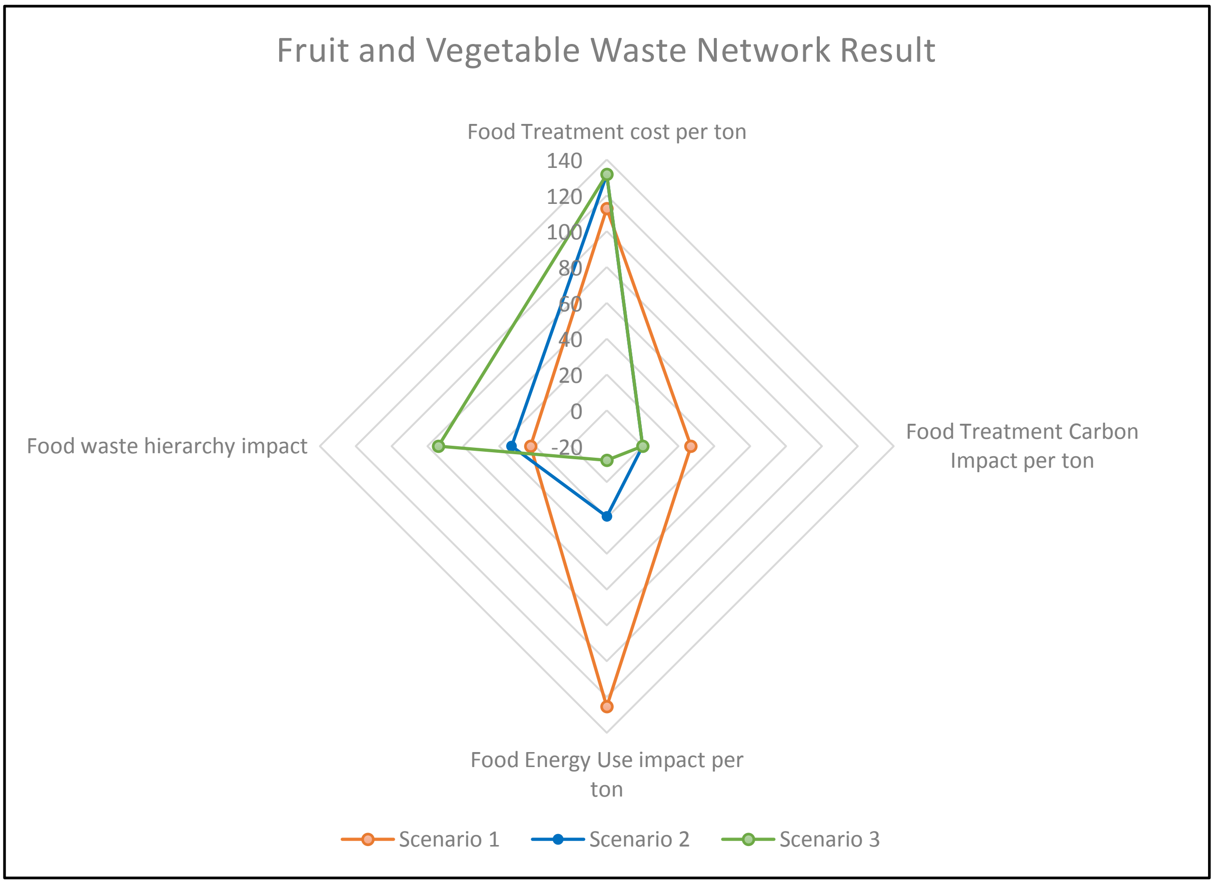

Figure 4. Spider chart of the FVW network results

V. CONCLUSION AND FUTURE RESEARCH INTHE FVW MANAGEMENT

So far, considering sustainability in the FVW managementresearch is insufficient. Developing sustainable models for FVW management are needed to improve the applicability of employing recovery technologies in a large-scale industry while achieving economic viability(Ilgin and Gupta 2010). This paper proposed a novel mathematical FVW network design underpinned by a multi-dimensional approach that balances economic, environmental, social, and resource utilization goals. The study transformed the analytical framework of the food waste recovery hierarchy into a practical decision-making policy in the context of sustainable FVW networks. Further, the adopted research methodology incorporated uncovered aspects in the current literature in terms of considering FVW treatment both in the internal food supply chain and to external systems, simultaneously. We adopted a linear programming model formulation that minimizes total treatment cost given constraints imposed by different stakeholders of the sustainable FVW recovery system. Moreover, we derived a set of metrics that enables policymakers to move towards more sustainable FVW management. The model is validated by designing the FVW network of the state of Massachusetts, USA. The results showed the potential of achieving higher sustainability performance of the FVW recovery process under budget constraints. Food producers, distributors, and consumers may utilize this model to tackle logistical issues of FVW management with a more efficient and sustainable structure.

Developing reduction strategies for all food supply chain stages will ensure the most efficient sustainable recovery of FVW. Utilizing high standard agriculture technologies can improve the quality of harvesting. Moreover, incorporating new green transportation concepts that utilize the Internet of Thing (IoT) for food quality and traceabilitywill enable efficient distribution of the highly degradable organic materials. Another area of research is to address initiatives that consider the recovery of substandard fruit and vegetable wastes.Also, one research direction could be to extend the KPIs to include more environmental measures such as air pollution impact or social measures such as public health and employment rate impact that can be analyzed by the multi-criteria decision-making techniques. Furthermore, increasing consumer awareness on the FVW impact on sustainability and ways of managing such waste on the household level is necessary as a huge amount of FVW occurs in the consumption stage. On the other hand, there is a great potential for functional compounds extraction from inedible FVW. However, developing models to optimally selecting the most suitable extraction technology is needed as this area is still not fully discovered. Moreover, the area of FVW prevention could also be investigated in the context of the food distribution efficiency given food system resilient conditions. Finally, this study shows that there is a need to design FVW management models that address complex issues in the development of sustainable food systems.

VI. REFERENCES

[1] Alqahtani, A. Y., E. Kongar, K. K. Pochampally , S. M. Gupta (2019) Responsible Manufacturing: Issues Pertaining to Sustainability, CRC Press.

[2] Banasik, A., A. Kanellopoulos, G. D. H. Claassen, J. M. Bloemhof-Ruwaard , J. G. A. J. van Der Vorst (2017) Closing loops in agricultural supply chains using multi-objective optimization: A case study of an industrial mushroom supply chain. Int J Prod Econ 183(PB): 409-420. https://doi.org/10.1016/j.ijpe.2016.08.012

[3] Bortolini, M., M. Faccio, E. Ferrari, M. Gamberi , F. Pilati (2016) Fresh food sustainable distribution: cost, delivery time and carbon footprint three-objective optimization. J Food Eng 174: 56-67. https://doi.org/10.1016/j.jfoodeng.2015.11.014

[4] Chang, J. I., J. Tsai , K. Wu (2006) Composting of vegetable waste. Waste Manag Res 24(4): 354-362. https://doi.org/10.1177/0734242X06065727

[5] Chen, W.-T. , C.-I. Hsu (2015) Greenhouse gas emission estimation for temperature-controlled food distribution systems. J Clean Prod 104: 139-147. https://doi.org/10.1016/j.jclepro.2015.05.038

[6] Coley, D., M. Howard , M. Winter (2009) Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. Food policy 34(2): 150-155. https://doi.org/10.1016/j.foodpol.2008.11.001

[7] Eriksson, M. , J. Spångberg (2017) Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. Waste Manag 60: 786-799. https://doi.org/10.1016/j.wasman.2017.01.008

[8] Fehr, M., M. D. R. Calçado , D. C. Romão (2002) The basis of a policy for minimizing and recycling food waste. Environ Sci Policy 5(3): 247-253. http://dx.doi.org/10.1016/S1462-9011(02)00036-9

[9] Govindan, K., A. Jafarian, R. Khodaverdi , K. Devika (2014) Two-echelon multiple-vehicle location–routing problem with time windows for optimization of sustainable supply chain network of perishable food. Int J Prod Econ 152: 9-28. https://doi.org/10.1016/j.ijpe.2013.12.028

[10] Gungor, A. , S. M. Gupta (1999) Issues in environmentally conscious manufacturing and product recovery: a survey. Comput Ind Eng 36(4): 811-853. https://doi.org/10.1016/S0360-8352(99)00167-9

[11] Gupta, S. M. (2013) Reverse supply chains: issues and analysis, CRC Press.

[12] Harsono, S. S., P. Grundman, L. H. Lau, A. Hansen, M. A. M. Salleh, A. Meyer-Aurich, A. Idris , T. I. M. Ghazi (2013) Energy balances, greenhouse gas emissions and economics of biochar production from palm oil empty fruit bunches. Resour Conserv Recycl 77: 108-115. https://doi.org/10.1016/j.resconrec.2013.04.005

[13] Hosseini Koupaie, E., M. Barrantes Leiva, C. Eskicioglu , C. Dutil (2014) Mesophilic batch anaerobic co-digestion of fruit-juice industrial waste and municipal waste sludge: Process and cost-benefit analysis. Bioresour Technol 152: 66-73. https://doi.org/10.1016/j.biortech.2013.10.072

[14] Hu, M.-C., Y.-H. Chen , L.-C. Huang (2014) A sustainable vegetable supply chain using plant factories in Taiwanese markets: A Nash–Cournot model. Int J Prod Econ 152: 49-56. https://doi.org/10.1016/j.ijpe.2014.01.026

[15] Ilgin, M. A. , S. M. Gupta (2010) Environmentally conscious manufacturing and product recovery (ECMPRO): A review of the state of the art. J Environ Manag 91(3): 563-591. https://doi.org/10.1016/j.jenvman.2009.09.037

[16] Kocher, N. (2018) Cost Benefit Analysis of Food Waste Processing in Massachusetts. Master Thesis, Harvard University.

[17] Li, D., X. Wang, H. K. Chan , R. Manzini (2014) Sustainable food supply chain management. Int J Prod Econ 152: 1-8. https://doi.org/10.1016/j.ijpe.2014.04.003

[18] Mattsson, L., H. Williams , J. Berghel (2018) Waste of fresh fruit and vegetables at retailers in Sweden – Measuring and calculation of mass, economic cost and climate impact. Resour Conserv Recycl 130: 118-126. https://doi.org/10.1016/j.resconrec.2017.10.037

[19] Midgley, J. L. (2014) The logics of surplus food redistribution. J Environ Plan Manag 57(12): 1872-1892. https://doi.org/10.1080/09640568.2013.848192

[20] Papargyropoulou, E., R. Lozano, J. K. Steinberger, N. Wright , Z. b. Ujang (2014) The food waste hierarchy as a framework for the management of food surplus and food waste. J Clean Prod 76: 106-115. http://dx.doi.org/10.1016/j.jclepro.2014.04.020

[21] Pereira, C. G. , M. A. A. Meireles (2010) Supercritical Fluid Extraction of Bioactive Compounds: Fundamentals, Applications and Economic Perspectives. Food Bioprocess Technol 3(3): 340-372. https://doi.org/10.1007/s11947-009-0263-2

[22] Plazzotta, S., L. Manzocco , M. C. Nicoli (2017) Fruit and vegetable waste management and the challenge of fresh-cut salad. Trends in Food Science and Technology 63: 51-59. https://doi.org/10.1016/j.tifs.2017.02.013

[23] Pochampally, K. K., S. Nukala , S. M. Gupta (2008) Strategic planning models for reverse and closed-loop supply chains, CrC Press.

[24] Sagar, N. A., S. Pareek, S. Sharma, E. M. Yahia , M. G. Lobo (2018) Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. Compr Rev Food Sci Food Saf 17(3): 512-531. https://doi.org/10.1111/1541-4337.12330

[25] Shukla, M. , S. Jharkharia (2013) Agri-fresh produce supply chain management: a state-of-the-art literature review. Int J Oper Prod Manag 33(2): 114-158. https://doi.org/10.1108/01443571311295608

[26] Soquetta, M. B., L. d. M. Terra , C. P. Bastos (2018) Green technologies for the extraction of bioactive compounds in fruits and vegetables. CyTA - J Food 16(1): 400-412. https://doi.org/10.1080/19476337.2017.1411978

[27] Soysal, M., J. M. Bloemhof-Ruwaard, M. P. Meuwissen , J. G. van der Vorst (2012) A review on quantitative models for sustainable food logistics management. Int J Food Syst Dyn 3(2): 136-155. https://doi.org/10.18461/ijfsd.v3i2.324

[28] Srivastava, N. S. L., S. L. Narnaware, J. P. Makwana, S. N. Singh , S. Vahora (2014) Investigating the energy use of vegetable market waste by briquetting. Renew Energy 68: 270-275. https://doi.org/10.1016/j.renene.2014.01.047

[29] Tasca, A. L., S. Nessi , L. Rigamonti (2017) Environmental sustainability of agri-food supply chains: An LCA comparison between two alternative forms of production and distribution of endive in northern Italy. J Clean Prod 140: 725-741. https://doi.org/10.1016/j.jclepro.2016.06.170

[30] Weber, C. L. , H. S. Matthews (2008) Food-miles and the relative climate impacts of food choices in the United States. Environ Sci Technol https://doi.org/10.1021/es702969f

Adel W. Fadhel, et. al. “Optimal Valorization Selection in the Design of a Sustainable Fruit and Vegetable Waste Network.” *IOSR Journal of Engineering (IOSRJEN)*, 11(07), 2021, pp. 39-54.