Calculating the University of Hawaii at Manoa Environmental Footprint from Food Procurement at Sodexo Cafeterias; Nitrogen, Carbon and Water Withdrawal

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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Abstract

Tracking an organization or campus's environmental footprint can shed light on those activities and operations that contribute the most emissions to or withdrawals from the environment. This work investigates the environmental footprint, specifically nitrogen and carbon emissions, as well as water withdrawals, that result from the University of Hawaii at Manoa's (UHM) Sodexo cafeterias. An additional objective of this work was to create the foundational methods and procedures for measuring and estimating the emissions from *all* campus food procurement. To execute this objective, the system boundaries were defined, and a central database was designed into which mass amounts resulting from all food procurement is be aggregated and converted to their respective carbon and nitrogen emissions as well as water withdrawal. To communicate those food categories that contribute the most to the aggregate footprint, food inventories were broken down into their top three ingredients which were then placed into common food categories. Conversion factors were then applied to convert mass (kg) quantities in each food category to mass (kg) contributions to each environmental footprint (N emission, C emission, H_2O withdrawals). Results revealed that beef had the largest contributions to the environmental footprints while pork and cheese followed closely behind, indicating that animal products are likely the largest contributors to UHM's environmental footprint.

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Introduction 1.0

1.1 Footprinting; Explanation and Relevance

Environmental footprints are a method to account and track the quantities of select emissions into or withdrawals from the environment that an entity, such as the University of Hawai'i at Manoa, produces as a result of various activities or operations (Čuček et al., 2015). Environmental footprints can be further grouped into a family of pressure indicators applied to a compartment of the environment. Tracking an organization's environmental footprint is an important first step towards analyzing an entity's impact upon the environment. More, environmental footprints quantified over their full life cycle can shed detail on which activities and operations contribute the most emissions or withdrawals to the environment. This work describes a procedure to evaluate three key environmental footprints of the University of Hawai'i at Manoa campus: carbon and nitrogen emissions, and water withdrawals. The activities and operations audited for each environmental footprint followed the guidelines and recommendations of the Greenhouse Gas Protocol (Russel & Sotos, 2010). The Greenhouse Gas Protocol has set global standards, guidance, tools, and training that allows organizations to create environmental footprints from activities organized under three scopes and that cover a full life cycle chain.

1.2 Carbon, Nitrogen and Water Withdrawal Procurement Footprints

Although the estimation of each environmental footprint assessed emissions from each activity identified under the three scopes of the GHG protocol over a one-year basis, the underlying calculations used to estimate each footprint varied. Nitrogen emissions from food procurement (i.e., which is really a proxy for production), for example, were calculated by taking the produced nitrogen from food production, transportation, and the nitrogen contained within the food and multiplying these factors by the amounts of food procured on the UHM campus (Leach et al, 2016). These results were then aggregated and presented as total nitrogen production. Carbon emissions, by contrast, were estimated by accounting for the emissions associated with the production and transportation of food but also excluded emissions beyond the consumer level (Heller & Keoleian, 2014). Specifically, the specific carbon emissions (kg) from food production and transportation were multiplied by the weight (kg) of food procured on campus to produce a total carbon emission aggregate in kilograms. For the water footprint, water withdrawals were estimated by multiplying food categories by factors that converted those amounts to quantities of water withdrawals.

1.3 University of Hawaii at Manoa Environmental Footprint Project Group

The UHM Environmental Footprint project group was created in 2020 in collaboration with the Office of Sustainability with the primary goal of quantifying and providing a comprehensive family of environmental footprints that accurately estimate the aggregate emissions of CO_2 and N, as well as withdrawals of H_2O as a function of defined activities and operations performed on the University of Hawaiʻi at Manoa campus. Secondary goals include mapping estimated footprints to defined activities, operations, functions and/or demographics as a means to identify "hotspots" where emissions are highest. This collective sum of data will provide contextual support for administrative policy actions designed to reduce the University's environmental footprint and to reach its environmental goals, such as Net Zero by 2035 (HB 1509, 2015).

1.4 Scopes; Activity and Operation Breakdown

The activities and operations adopted for assessment follow the Greenhouse Gas Protocol guidelines (Russel & Sotos, 2010). These guidelines organize activities to be tracked under three scopes that attempt to organize and group emission sources as a function of the type of operation(s). The scopes are further organized on the basis of whether the emission source is direct or indirect. This is shown in Figure 1 below.

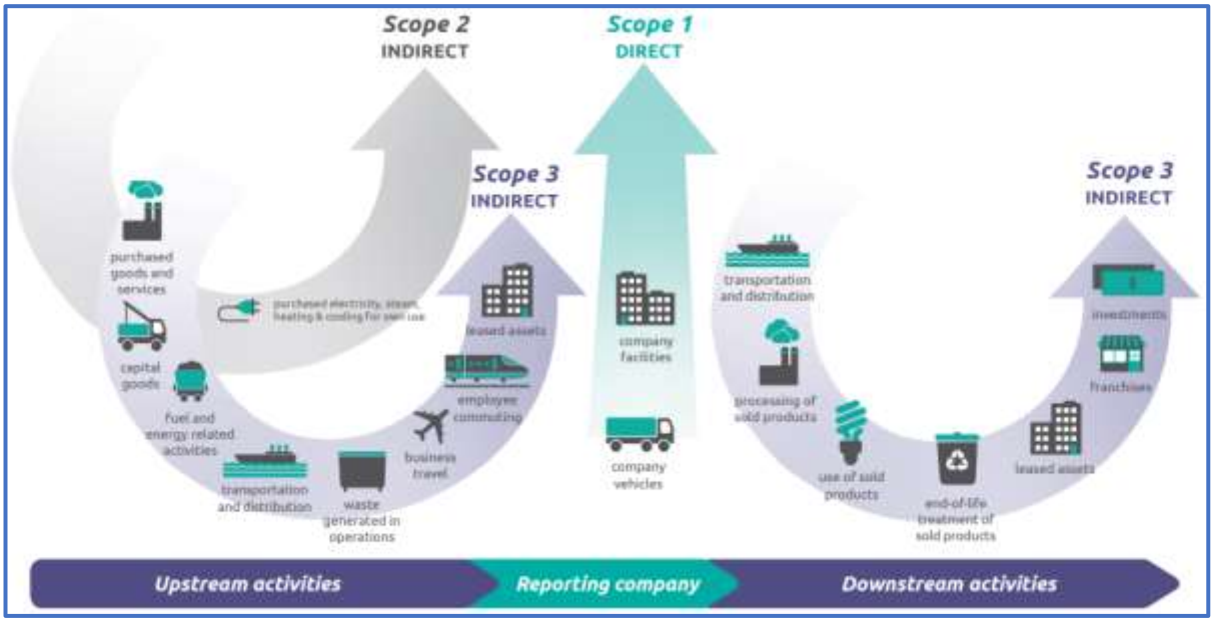

Figure 1: Overview of Greenhouse gas scopes as a function of indirect or direct activities

Scope 1 defines emissions that are direct and from sources that are owned or controlled by the enterprise. Scope 2 comprises indirect emissions that result from the generation of purchased electricity. Scope 3 comprises indirect emissions that result from the activities or operations that are not owned or controlled by the organization or entity. Scope 1 and 2 ensure that two or more entities do not account for the same emissions, which would result in double counting. Although the Greenhouse Protocol guidelines recommend that organizations or entities report on scope 1 and 2 at a minimum and have the option to report on scope 3 (Russel & Sotos, 2010), we have optioned to include activities under scope 3. The scopes and associated activities considered are presented in Table 1 below. In total there are 24 different associated activities designated under the three scopes. The UHM Environmental Footprint Working Group aims to ultimately assess emissions from each activity defined under all three scopes and to calculate the aggregate environmental footprints. To that end, this work specifically focuses on defining the procedures necessary to accurately estimate the emissions associated with the activity Food Procurement (Table 1, Scope 3).

Table 1: UHM Scopes.

The three scopes of the Greenhouse Gas Protocol to be used in this work to define activities from which CO_2 and N emissions, along with H_2O withdrawals are calculated.

Scope 1 (direct)	Scope 2 (purchased)	Scope 3 (indirect)
Stationary Fuels (or Cogeneration Efficiencies and Outputs), Transportation Fuels, Fertilizer, Direct Fugitive Emissions from Refrigeration, Air Conditioning, Fire Suppression, Industrial Gases	Purchased electricity	Off-Island Travel (Air Transportation to Oahu), On-island Commuting, Admin Travel, Research Travel, Athletic Travel, **Food Procurement**, Paper, Bulk Waste, Landfill Waste, H-Power waste, Organic Waste, E-waste, Chemical & Hazardous Waste, Wastewater, Green Waste Composted on Campus, Shipping and Distribution

1.5 System Boundary

The Greenhouse Gas Protocol guidelines require that the boundary conditions governing the project scopes be defined prior to their use in calculating environmental footprints. To execute this, the *operational control approach*[1] of the Greenhouse Gas Protocol was used to define the boundaries from which all emissions from activities listed in Table 1 would be estimated. Here, the term operational control refers to the authority to introduce and physically implement operating policies over operations and activities that an entity or one of its sub-organizations has

[1] Refer to Chapter 3 and 4 in **The Greenhouse Gas Protocol for the U.S. Public Sector** for more definitions and approaches (Russel & Sotos, 2010).

full control. Under this approach an organization or entity accounts for 100 percent of the GHG emissions and environmental contributors from designated operations and activities.

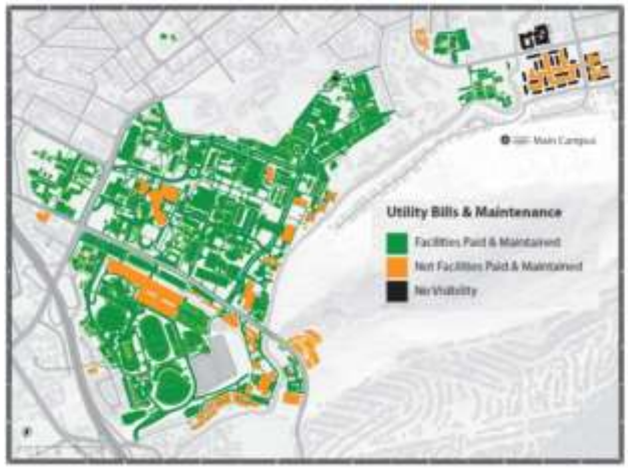

Figure 2: UHM Physical Boundary

The boundaries of the UHM Environmental Footprint Working Group encompasses activities and operations that are authorized, implemented, and controlled by the Manoa campus[2] and do not account for any operations or activities over which the University has no administrative control. These boundaries are limited by the physical boundaries of the UHM campus, highlighted in Figure 1 above.

1.6 Procurement

Food procurement can be defined as the activities or operations that are necessary to ensure the production, delivery and distribution of food to an organization such as UHM (Leach et al, 2016). Food procurement places many pressures on the environment in addition to greenhouse gas emissions (Ritchie and Roser, 2020), including disruption of the N biogeochemical cycle (i.e., nutrient pollution), the water cycle (withdrawal of ground water), and to ecosystem function (biodiversity loss and land use). As such the "food procurement footprint" of a community the size of the UHM campus is important to track and understand.

[2] Boundary inclusions and exemptions can be found in Appendix I.

1.7 University Food Providers

Under the system boundary, described in section 1.5 above, twenty-seven (27) different food providers were identified under the operation Food Procurement on the UHM campus. These food providers are housed in various buildings and food trucks around campus. It is important to note that each of the food providers have their own hierarchy of command (Table 2). For example, 11 of the food providers operate under Sodexo (L. Ideta, personal communication, November 17, 2020). Thus, when seeking required inventory data to calculate the footprints the operational entity should be contacted. The highlighted portions of Table 2 represent the food providers that are included in this work.

Table 2: Food Providers and Control.			
Management Control	**Operational Entity**	**Location**	**Site Description**
Student Affairs	**Sodexo**	**Hale Aloha Towers**	**Hale Aloha Café**
Student Affairs	Sodexo	Hale Noelani	The Market
Student Affairs	**Sodexo**	**Gateway House**	**Gateway Café**
Student Affairs	**Sodexo**	**Campus Center**	**Campus Center Food Court**
Student Affairs	Sodexo	Campus Center	Starbucks
Campus Center	Subway	Campus Center	
Student Affairs	Sodexo	Campus Center	The Market at Campus Center
Student Affairs	Sodexo	Campus Center	Jamba Juice
Student Affairs	Sodexo	Campus Center	Pizza Hut Express
Student Affairs	Sodexo	Campus Center	Stir Fresh
Student Affairs	Sodexo	Campus Center	Simply To Go
Student Affairs	Sodexo	Hemenway Hall	Ba-Le
Auxiliary Services	Island Pita	TBA	
Auxiliary Services	The Bean Counter	Shidler College of Business	1st floor
Auxiliary Services	L&L Hawaiian Barbecue	Athletics Complex	2nd floor
Auxiliary Services	L&L Hawaiian Barbecue	Paradise Palms	
Auxiliary Services	Panda Express	Paradise Palms	
Auxiliary Services	Dunkin' Donuts	Paradise Palms	
Auxiliary Services	Holoholo Grill	Paradise Palms	
Auxiliary Services	Lasoon	Paradise Palms	
Auxiliary Services	Le Crepe Cafe	Paradise Palms	
Auxiliary Services	Sistah Truck	Rotating locations	Food Truck
Auxiliary Services	Da Spot	Krauss Circle	Food Truck
Auxiliary Services	Govindas	Sustainability Courtyard	Food Truck
Auxiliary Services	Hot Tacos	Rotating locations	Food Truck
Auxiliary Services	Kamitoku Ramen	POST	Food Truck
Auxiliary Services	Ono Seafood	Krauss Hall	Food Truck

This information can also be found on the *Food Procurement Operational Control* spreadsheet page of the *Food Procurement Sodexo Data Spreadsheet* (See section 2.1). *The Food Procurement Operational Control* spreadsheet is a database which lists all the food providers on UHM's campus within the systems boundaries as defined in sections 1.5 above. The primary goal for this data sheet is to identify the university's sources and streams of food that will be used in the future to calculate the aggregate emissions that define the environmental footprints of the total campus food procurement for UHM. However, this work will specifically focus on the 3 campus cafeterias and the related environmental footprints.

Methods 2.0

2.1 Food Procurement Sodexo Data Spreadsheet

Data collections and calculations for this project were completed in Excel to ensure that the data was organized thoroughly and was easily accessible. Specifically, the file *Food Procurement Sodexo Data Spreadsheet* was created. This spreadsheet file is made up of 5 subpages titled: *Index, Food Procurement (FP) Operational Control, Emission Footprint Calculations, Sodexo Inventory Data, and Footnotes*. The subpage, *Index*, was used as an organizational page that informs the user of the last revision, instructions of use and table of contents. The *Food Procurement Operational Control* subpage listed all the food providers on campus and the corresponding hierarchy of operational control (Table 2). The *Emissions Footprint Calculations* organized all the values and data necessary to calculate the environmental footprints. The *Sodexo Inventory Data* organized all the listed inventory food items that were collected from Sodexo (see section 2.2). The inventory data was used to estimate the procurement of food at UHM. Lastly, the *Footnotes* tab compiled all related notes, citations, and assumptions for the food procurement footprint calculations, variables and, recipes used.

2.2 Sodexo Inventory Data

Inventory data was collected from a Sodexo cafeteria over a 5-week period in 2020[3], scaled from 5 weeks to one year and then multiplied by 3 to mimic the additional 3 Sodexo cafeterias on campus. The inventory data collected from Sodexo consisted of a broad array of food items and the assumption was made that everything purchased was consumed. Examples of food items listed in the inventory include muffins, cheddar cheese, artichokes, coke zero and ketchup. The inventory data was listed in terms of weight (pounds) or volume (US gallons), depending upon

[3] Collected by Cherryle Heu and provided by the Office of Sustainability.

whether the listed food item was a liquid or a solid. Once collected, this data was listed on a spreadsheet called *Sodexo Inventory Data*. An example of what the *Sodexo Inventory Data* spreadsheet looked like can be found in Table 3 below.

Table 3: Sodexo Inventory Data Sample.

Food Item	Value	Unit
1% chocolate milk	918	US gallon
1000 island dressing	36	US gallon
2% milk	1183.5	Us gallon
apple cider vinegar	180	US gallon
apple juice	234.14	US gallon
apricot halves	95.98	US gallon
apricot in juice	36.91	US gallon
balsamic vinegar	75.3	US gallon
muffin whole grain	81	lbs
bread ciabatta sliced bread	225	lbs
bread rustic panini	162	lbs
barley	2250	lbs
bulgur wheat	5400	lbs
all spice	18	lbs
american cheese	4320	lbs
angel hair pasta	360	lbs
apple	1368	lbs
applesauce	2457	lbs
artichoke	693	lbs

2.3 Categorizing Food Items

To estimate the emissions and water withdrawal from all food items inventoried, all food items (e.g., those listed in Table 3) were broken down into common food categories such as grains, beef, vegetables, and oils[4] described elsewhere by (Leach et al, 2016). These food categories organize inventory data from food procurement into groups that support efficient environmental

[4] For reference guide see appendix ii

footprint calculations. For example, cereals were broken down into their mass contribution to grains, sugar, oil etc. While some foods only contributed to one or two categories, many food items contributed to multiple categories. The utilized food categories are identified in Table 4 below.

Table 4: Food Categories.

Grains	Coffee & Tea	Nuts	Fruits	Dairy	Pork
Potatoes	Spices	Oils	Vegetables	Cheese	Poultry
Liquids	Beans	Sugars	Eggs	Beef	Fish

2.4 Conversion of Food Items to Food Categories

The breakdown of inventory food items into food categories (Table 4) was executed through simple recipe formulas created for this project. Specifically, the relative percentage of the three most used ingredients of each food item was calculated. This was accomplished by searching for commonly used recipes online and identifying the three most used ingredients, converting them to the same units (cups, grams etc.), and then taking each ingredient amount (in converted units) and then dividing it by the combined amount of the three ingredients. These steps can be found in Equation 1 below.

$$RF(\%) = \frac{x\ (units)}{F\ (units)} \times 100 + \frac{y\ (units)}{F\ (units)} \times 100 + \frac{z\ (units)}{F\ (units)} \times 100 \qquad (1)$$

Where RF is the recipe formula, F is the food item from the inventory list, x is ingredient 1, y is ingredient 2 and z is ingredient 3 (with ingredients 1, 2, and 3 being the relatively highest). Once the recipe formula (made up of the ingredients percentages of representation) was calculated, RF was then multiplied by the weight or volume[5] (wp or wg) of the food item, seen in Equations 2 and 3, to populate the food categories (FC) within the *Sodexo Inventory Data* spreadsheet.

$$FCp\ (lbs) = \ RF \times wp\ (lbs) \tag{2}$$

$$FCg\ (gal) = RF \times wg\ (gal) \tag{3}$$

Where FCp is the food category's weight in pounds, FCg is the food category weight in US gallons, wp is weight in pounds, wg is weight/volume in US gallons and RF is the recipe formula.

Example: Calculating the recipe formulas and food category weight of a Plain Bagel

Using Equation 1 and a common recipe (Humes) a recipe formula (RF) for a plain bagel was created. The first step was to identify the ingredients used to make a plain bagel. The ingredients were as follows: 1 tablespoon instant yeast, 4 cups of bread flour, 3 tablespoons of granulated sugar, 1 teaspoon of salt and 2 tablespoons of vegetable oil. Analysis of this recipe showed that the three most common ingredients were bread flour (x), granulated sugar (y), and vegetable oil (z)[6]. These ingredients fit into the previously defined food categories[7] and were referred to as; flour (x), sugar (y), and oil (z). Normalizing the ingredients (now referred to by their food category) to the same units (e.g., tablespoons) resulted in 64 tablespoons of x, 3 tablespoons of y and 2 tablespoons of z, for a total of 69 tablespoons of plain bagel (F). Converting the food categories into percentages yields:

$\frac{64}{69}$ or ~93% for x, $\frac{3}{69}$ or 4% for y, and $\frac{2}{69}$ or 3% for z.

Approximately 93% grains, 3% oils, and 4% sugar, creating a recipe formula that can now be used to

[5] Inventory data was labeled by weight (kg) or volume (US gallons), depending on whether it was a liquid or a solid.
[6] Although bagels do have other ingredients that are not used in the recipe formula above, those ingredients are not accounted for as their amounts were considered negligible.
[7] See Table 4

calculate the footprints of a plain bagel.

Using Equation 3, the food categories (FCp) [8] by weight were determined. The procured weight of plain bagels for one year was 162 pounds. Therefore, the weight for grains was determined by multiplying the RF by the wp.

$$93\%\ grains\ (x) \times 162\ (lbs) = 152.28\ (lbs)$$

The same was then done for the other two food categories to calculate the final FC weight. This resulted in a final FC weight of 152.28 lbs for grains, 3.24 lbs for oils, and 6.48 lbs for sugar.

2.5 Total Food Category Weight

Once the inventoried food items were processed, their recipe formulas (RF) created, and the corresponding food categories (FCp and FCg) populated, the total weights and volumes of each of the 18 food categories were aggregated. Summing all the FCp values together and all of the FCg values together for each category yields the total food category weight (TFCp) and volume (TFCg) per category. The math required can be found in Equations 4 and 5.

$$TFCp = \sum FCp\ \ (lbs/FC) \tag{4}$$

$$TFCg = \sum FCg\ (US\ gal/FC) \tag{5}$$

After the total weight in pounds of food categories (FCp) and the total volume in US gallons of food categories (FCg) were calculated, both values for each food category were converted into kilograms. This resulted in two separate values in kilograms for each food category. These were added together to create a total weight (w) in kilograms for each food category.

[8] In this example we chose wp and FCp rather than wg and FCg because the Plain Bagels inventory was given by weight in pounds rather than volume (US gallons).

2.6 Emission Factor

After calculating the total weight (w) in kilograms for each category, the data was placed into the "Food Weight (kg)" column in the *Emission Factor Worksheet.* The *Emission Factor Worksheet* is a working spreadsheet/data base where all the necessary data, weights and factors to solve for UHMs food procurement environmental footprints are stored[9]. The use for each column is elaborated throughout the section 2.0 Methods and the *Emission Factor Worksheet* is presented below in Figure 3.

[9] To align the methods and results, the same data sources are used for both the carbon and nitrogen footprint whenever possible.

Food Categories	Food Weight (kg)	N Content (kg)	N footprint factor (kg)	Conventional Virtual N Factor	Supply (kgN)	Food Waste (%)	Food waste (kg N)	C Footprint Factor (kg)	# of Trips	N Transport EF (kg N/mi)	Truck Capacity (kg)	Transport distance (mi)	Transport equation	Waste Water (kg/N)	Water Factors (m^3/ton)	Water Factors (m^3/kg)	Total N footprint (kg)	Total C footprint (kg)	Water Withdrawal (m^3)
Grains	54304	0.0148	0.9	749	805	0.3	602532	0.9	2.4	0.00201	22700	1350	6.5	3191993904	1644	1.812	603287	46701	98409
Potatos	24939	0.0036	1.4	125	90	0.4	11234	0.2	1.1	0.00201	22700	1500	3.3	60121822	387	0.427	11363	5237	10639
Liquids	48944	0.0014	3.4	240	70	0.4	16889	1.0	2.2	0.00201	22700	800	3.5	90644764	2290	2.524	17132	50412	123548
Coffee & Tea	7166	0.0164	3.4	400	118	0.4	46963	0.4	0.3	0.00201	22700	800	0.5	250598105	13880	15.300	47363	2580	109645
Spices	7858	0.0088	2.8	194	69	0.4	13434	0.7	0.3	0.00201	22700	800	0.6	72107864	7000	7.716	13628	5737	60636
Beans	9349	0.0144	0.4	55	135	0.6	7452	0.8	0.4	0.00201	22700	1500	1.2	39726151	4055	4.470	7508	7292	41787
Nuts	2761	0.0297	0.4	34	82	0.1	2755	1.2	0.1	0.00201	22700	1500	0.4	14754351	9063	9.990	2789	3230	27584
Oils	8930	0.0006	0.4	2	5	0.1	11	1.6	0.4	0.00201	22700	800	0.6	75090	2364	2.606	14	14556	23271
Sugars	15259	0.0005	3.4	27	8	0.4	208	0.9	0.7	0.00201	22700	800	1.1	1244215	197	0.217	235	14190	3313
Fruits	17342	0.0008	3.4	46	14	0.4	629	0.4	0.8	0.00201	22700	1500	2.3	3582353	962	1.060	677	6243	18390
Vegetables	30965	0.0028	2.8	246	88	0.4	21606	0.7	1.4	0.00201	22700	1500	4.1	115638419	322	0.355	21856	22605	10991
Eggs	7108	0.0185	3.3	435	132	0.2	57362	3.5	0.3	0.00201	22700	250	0.2	305805168	3265	3.599	57797	25161	25581
Dairy	32954	0.0063	3.1	646	209	0.2	134767	1.3	1.5	0.00201	22700	250	0.7	716478998	3287	3.623	135415	44158	119383
Cheese	13860	0.0301	3.1	1293	417	0.2	539404	9.8	0.6	0.00201	22700	250	0.3	2860832181	5060	5.578	540697	135552	77308
Beef	10706	0.0292	11.3	3527	312	0.2	1101015	26.5	0.5	0.00201	22700	950	0.9	5844141050	15415	16.992	1104543	283175	181919
Pork	15227	0.0283	4.7	2022	430	0.2	869827	6.9	0.7	0.00201	22700	950	1.3	4612961626	5988	6.601	871850	104613	100511
Poultry	12330	0.0278	4.2	1441	343	0.2	494110	5.1	0.5	0.00201	22700	950	1.0	2621966915	4325	4.767	495552	62267	58784
Fish	13144	0.0287	2.5	943	377	0.4	356040	3.8	0.6	0.00201	22700	950	1.1	1888805509	3110	3.428	356984	50343	45061
																TOTAL:	4288689	884053	1136761

Figure 3: Emission Factor Worksheet

2.7 Nitrogen Footprint Calculation

The nitrogen footprint represents the total elemental nitrogen[10] released to the environment due to food procurement by the UHM Sodexo cafeterias. The total nitrogen footprint is comprised of 18 individual nitrogen footprints from each of the 18 food categories. The total nitrogen footprint can be calculated by summing all of the individual nitrogen footprints, as seen in Equation 6 below.

$$TNF\ (kg\ N/yr) = \sum_{i=1}^{N=18} NF_i \qquad (6)$$

Where TNF is the total aggregate nitrogen footprint and NF is the elemental nitrogen footprint for each of the 18 food categories (Table 4). The nitrogen footprint (NF) for each food category was calculated using three important components: (i) the Conventional Virtual Nitrogen Factor (VF)[11] in kilograms of N, (ii) Transport (T) in kilograms of N, and (iii) Food Waste (FW) in kilograms of N. This is shown in Equation 7 below.

$$NF\ (kg\ N) = VF\ (kg\ N) + T\ (kg\ N) + FW\ (kg\ N) \qquad (7)$$

Where VF, the conventional virtual nitrogen factor (kg N), is the amount of reactive nitrogen that is released to the environment during the food production process (Leach et al, 2012). The conventional virtual nitrogen factor is comprised of 3 components: (i) the Weight of food in kilograms (w), (ii) the Nitrogen Content[12] (NC) in percent and (iii) the Nitrogen Footprint Factor[13] in kilograms (NFF). The equation to solve for VF can be seen below in Equation 8.

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[10] The calculations break down nitrogen into elemental nitrogen regardless of form.
[11] Values can be found in appendix IV.
[12] Values for NC can be found in appendix IV.
[13] NCC values can be found in appendix IV.

$$VF\ (kg\ N) = w\ (kg) \times NC\ \times NFF\left(\frac{kg\ N}{kg\ food}\right) \tag{8}$$

Where the food Weight (w) is the weight of each of the 18 food categories in kilograms[14]. The Nitrogen Content (NC) is taken as the average amount of nitrogen contained in any given food item in a specific food category[15]. The Nitrogen Footprint Factor (NFF) is the amount of nitrogen released during the food production process (Leach et al, 2012).

Next is the calculation of the Transport (T) nitrogen which represents the estimated amount (kg) of nitrogen produced from transporting food items to the university. Transport (T) nitrogen was calculated by multiplying Number of Trips (B), by the Transport Distance in miles (D) and by the Transport Nitrogen Emission Factor (TEF).

$$T(kg\ N) = B\ \times D(mi) \times TEF\ (\frac{kg\ N}{mi}) \tag{9}$$

The Number of Trips[16] (B) represents the predicted number of trips needed to deliver foods based on food categories to a given campus. The transport Distance (D) (Hendrickson, 1996)[17] is the average mileage driven by a shipping truck to deliver foods from specific food categories across the country. The Transport Nitrogen Emission Factor (TEF) represents the average nitrogen emissions produced from a diesel truck per unit distance travelled and is the same value regardless of the food category. The Number of Trips (B) used in Equation 9 above was solved by

[14] Weight (w) for each food category was found using equations 2-5.
[15] NC values can be found in appendix VI.
[16] B values for each food category can be found in appendix IV.
[17] Values can be found in appendix IV.

dividing the total food Weight (w) by the Shipping Truck Capacity[18] (TC) (USDOT, 2000), demonstrated in Equation 10 below.

$$B = \frac{w}{TC} \ \left(\frac{kg}{kg}\right) \tag{10}$$

The last component required to calculate the Nitrogen Footprint (NF) in Equation 7 is Food Waste (FW). FW is the average nitrogen contained within the foods in each food category during the final two steps in food production, distribution and consumption (Leach et al., 2012). The steps to solve for FW is shown in Equation 11 below.

$$FW\ (kg\ N) = S\ (kg\ N) \times P(\%) \tag{11}$$

Where S is the Supply (calculated in Equation 12 below) and P is the Food Waste Percentage Factors which represent the average nitrogen contained by food categories by percent, during production, consumption, and waste. The Food Waste Percentage Factors can be found in appendix VIII. The value of supply (S) used in equation 11, can be calculated using Equation 12 below and represents the average amount (kg) of nitrogen contained within foods in each food category.

$$S\ (kg\ N) = w\ (kg) \times\ NC\ (N) \tag{12}$$

Where w is the weight of the food in the food categories (kg) and NC is the nitrogen content[19], which was used and explained in Equation 8.

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[18] Average capacity of a shipping truck is approximately 22,700 kilograms.
[19] The Nitrogen Content values can be found in appendix IV

2.8 Carbon Footprint Calculation

The carbon footprint represents the total greenhouse gas/carbon emissions to the environment due to food procurement. The carbon footprints for each food category (CF) were calculated by taking the Carbon Footprint Factors (CFF) (Heller & Keoleian, 2014)[20] and multiplying them by the weight (w) of the food categories (kg) as shown in Equation 13.

$$CF\ (kg\ C) = w\ (kg) \times (CFF)\ (kg) \qquad (13)$$

Where CF[21] is the Carbon Footprint per food category, w is the weight of each food category and CFF is the Carbon Footprint Factors[22]. The CFF represents the emissions associated with food production and transportation that are lost at the retail and consumer level (Heller & Keoleian, 2014)[23]. The Total Carbon Footprint (TCF) is calculated by summing all the Carbon Footprints (CF) for each food category together. This can be seen in Equation 14 below.

$$TCF = \sum_{i=1}^{N=18} CF_i \text{ (kg C)} \qquad (14)$$

Where CF_i is the 18 different carbon footprints for each category and TCF is the total carbon footprint.

2.9 Water Withdrawal Footprint Calculation

The Water Withdrawal Footprint (WWF) represents the total water withdrawn and pressure placed on the environment due to food procurement. The equations to solve for the WWF utilized

[20] Also referred to as the greenhouse gas emission factor in relevant literature, values can be found in appendix V.
[21] Values for CF can be found in Table 5.
[22] Values for CFF are listed in appendix V
[23] Note that these values differ depending on the food category.

the Water Footprint Factors[24] (WFF) for each of the 18 food categories (Table 4) and the corresponding Weight (w) of food for each category. This can be seen in equation 15 below.

$$WWF\ (m^3) = w\ (kg) \times WFF\ \ (\frac{m^3}{kg}) \tag{15}$$

Where WWF[25] represents the Water Withdrawal Footprint per food category, w represents the Weight of the food in kilograms and WFF represents the Water Footprint Factor. The values for the Water Footprint Factor (WFF) were taken from published literature (Mekonnen & Hoekstra, 2010 & 2011 and Yuan et al., 2017), and include the estimated global average of water required to raise, grow, and process varieties of foods across the world. The utilized WFF for each food category can be found in Appendix VI.

After each WWF was calculated for all 18 food categories, the Total Water Withdrawal Footprint (TWF) was calculated by summing all the individual WWFs together. This can be seen in equation 16 below.

$$TWF = \sum_{i=1}^{N=18} WWF_i \ \ (kg) \tag{16}$$

Where WWF_i is the 18 different water withdrawal footprints for each category and TWF is the total water withdrawal footprint.

[24] Values for WFF can be found in appendix VI
[25] The values for WF can be found in Table 5

3.0 Results

Contributions of each food category[26] to the environmental footprints (carbon and nitrogen emissions, and water withdrawals), along with their aggregate totals are presented in Table 5 and Figures 4 through 7 below. The results show that the total nitrogen footprint was about 4 million kg of nitrogen per year, with beef comprising the majority, and oils[27] contributing the least. The total carbon footprint was about 880,000 kg of carbon released to the environment per year. Beef was the largest contributor to the carbon footprint while coffee & tea was the contributed the least. The total water withdrawal due to UHMs cafeteria food procurement was approximately 1,000,000 cubic meters of water per year. Beef was also the largest contributor to the water withdrawal footprint, while sugar was the smallest contributor.

[26] Food categories are outlined in Table 4
[27] Oils is listed under the category of "other" in the nitrogen footprint graph, along with the other lowest contribution of environmental nitrogen.

Table 5: Environmental Footprint.

Food Categories	Food Weight (kg)	Total Nitrogen (kg)	Total Carbon (kg)	Total Water Withdrawal (m^3)
Grains	54,303	603,286	46,701	98,409
Potatoes	24,938	11,363	5,237	10,639
Liquids	48,943	1,7131	50,412	123,548
Coffee & Tea	7,166	47,363	2,579	109,645
Spices	7,858	13,628	5,736	60,636
Beans	9,348	7,508	7,291	41,787
Nuts	2,761	2,788	3,230	27,584
Oils	8,930	14	14,556	23,271
Sugars	15,258	235	14,190	3,313
Fruits	17,342	677	6,243	18,390
Vegetables	30,965	21,855	22,604	10,991
Eggs	7,107	57,797	25,161	25,581
Dairy	32,953	135,414	44,158	119,383
Cheese	13,860	540,697	135,552	77,308
Beef	10,706	1,104,542	283,175	181,919
Pork	15,227	871,849	104,612	100,511
Poultry	12,330	495,551	62,267	58,784
Fish	13,144	356,984	50,342	40,879
	Total	**4,288,689**	**884,053**	**1,132,578**

Note: The total weight of each food category is given in column 2, the estimated nitrogen, carbon and water footprints for each food category are given in columns 3-5. Total sums of each footprint are at the bottom of columns 3-5.

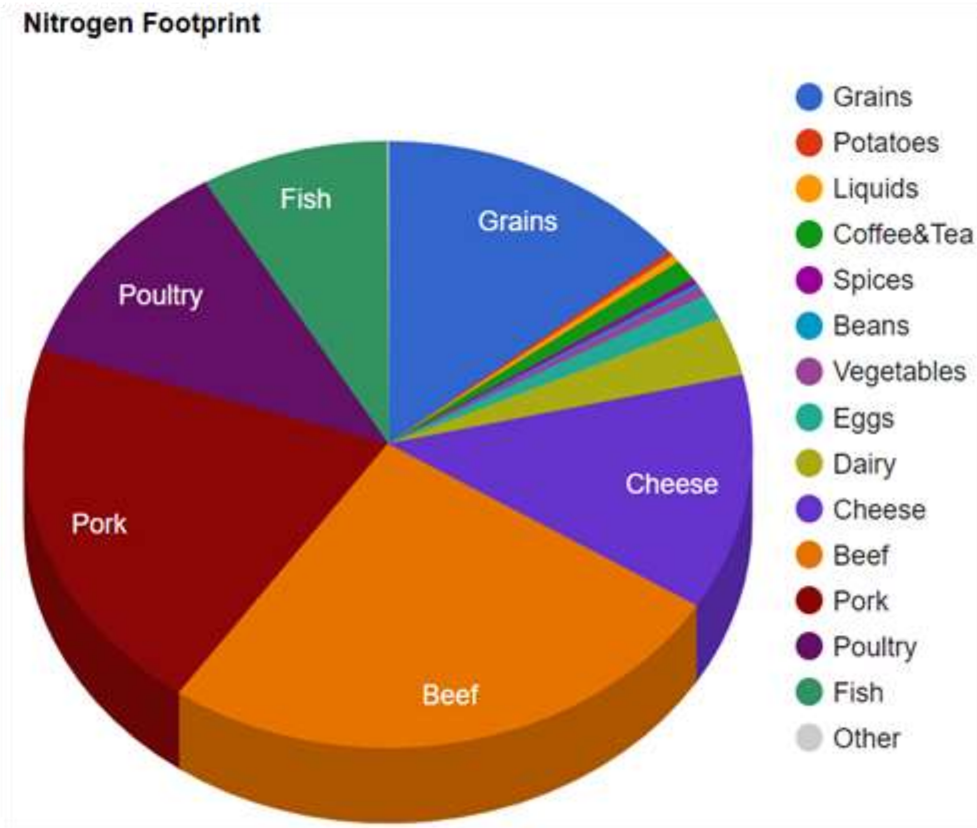

Figure 4: Nitrogen Footprint

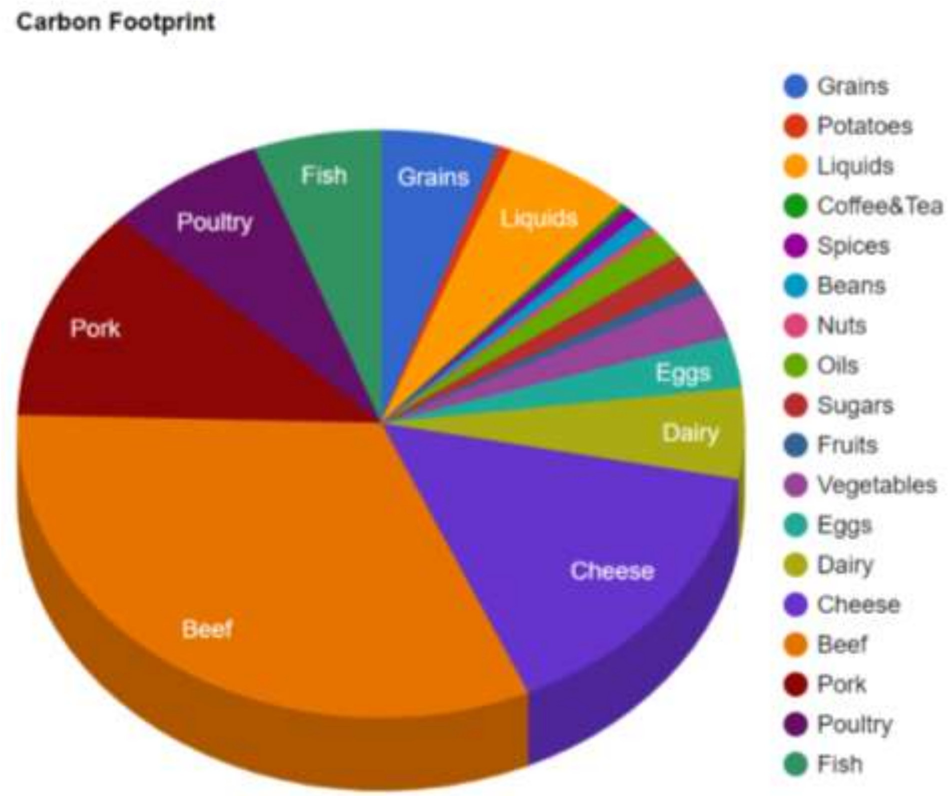

Figure 5: Carbon Footprint

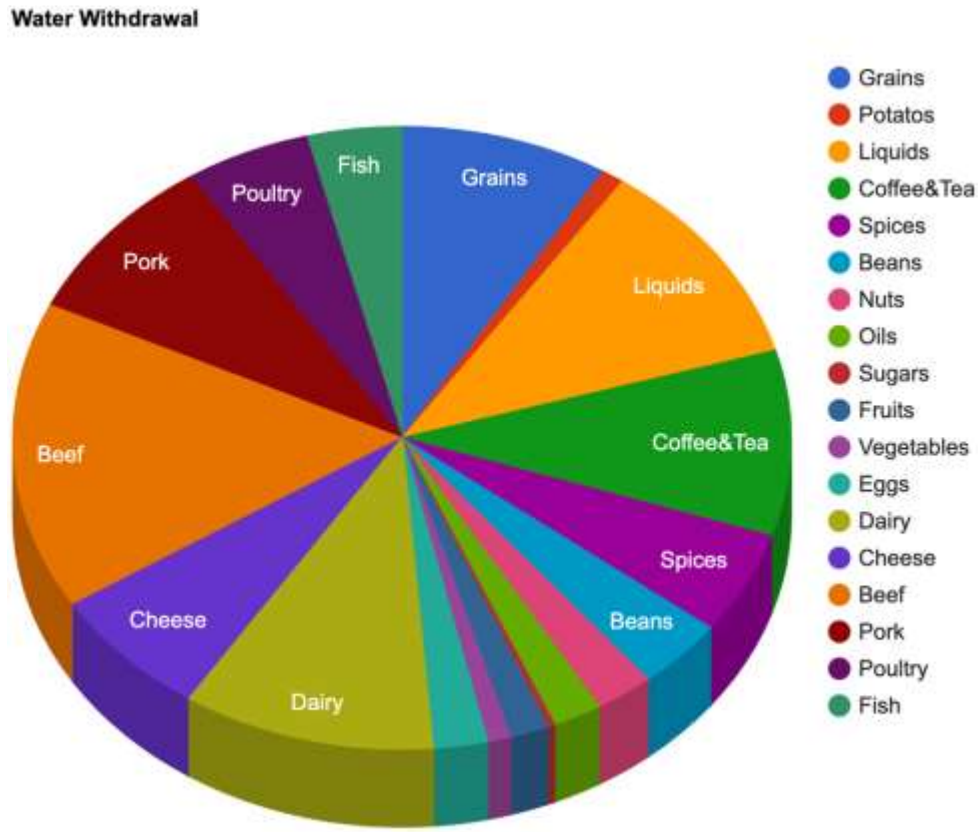

Figure 6: Water Withdrawal Footprint

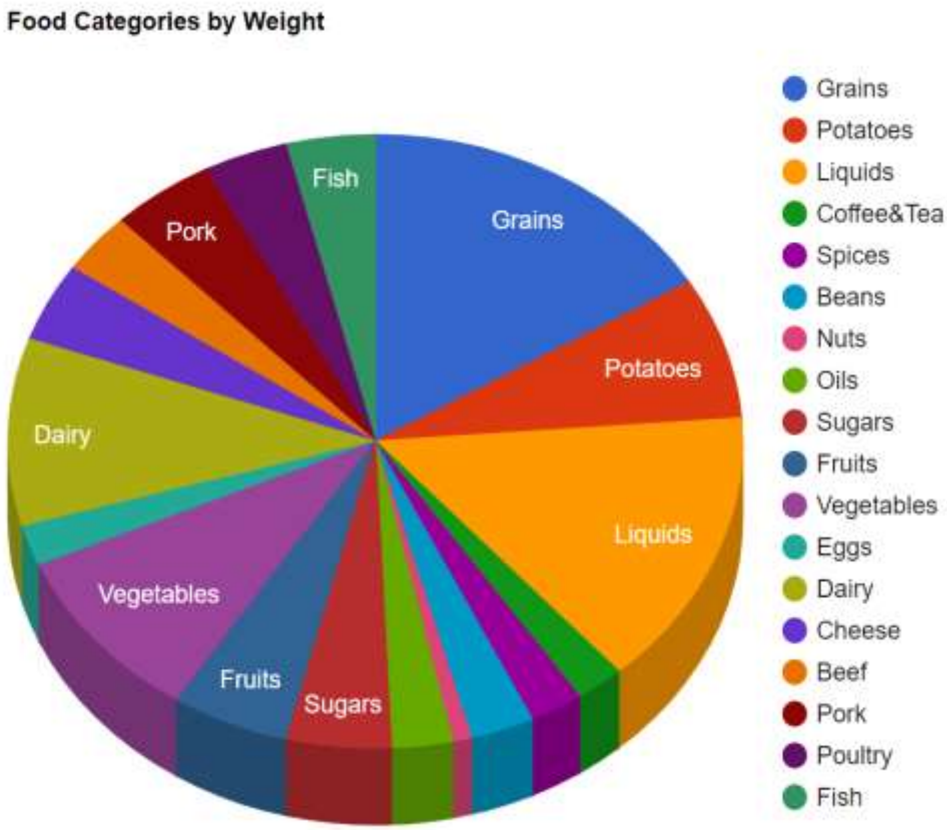

Figure 7: Food Categories by Weight

4.0 Discussion

The results suggest that the environmental footprints from food procurement are complex and a function of numerous inputs. That being said, there are a few food categories that most notably contribute to UHM's environmental footprints. In particular, beef, pork and cheese were responsible for over half of all nitrogen and carbon emissions and about 32% of the water withdrawals.

4.1 Nitrogen Footprint

The results for the nitrogen footprint show that UHMs beef consumption was the highest contributor of environmental nitrogen at over 1,000,000 kg (1100 US tons) of nitrogen per year. The second largest nitrogen contributor was pork at 870,000 kg (960 US tons) of nitrogen per year. Beef procurement was responsible for almost 200,000 kg more of environmental nitrogen per year than pork procurement, making it a sensible target for reduction efforts. The third largest contributor towards UHMs nitrogen footprint was grains. Campus grain procurement produced 600,000 kg of nitrogen to the environment each year, equivalent to approximately 660 US tons of nitrogen per year. Combined, these three food categories account for 60% of the total aggregate nitrogen footprint.

4.2 Carbon Footprint

Similar to the nitrogen footprint, beef was the highest contributor of carbon emissions per year for food procurement on the UHM campus. Beef contributed about 280,000 kg (312 US tons) of carbon per year. The next largest contributor was cheese. Procurement of cheese produced approximately 140,000 kg of carbon per year, which is half the emissions of beef. Pork was the 3rd largest contributor with a procurement of 100,000 kg of carbon per year. These three food categories combined, account for approximately 59% of the total food procurement carbon footprint.

4.3 Water Footprint

Beef was the largest contributor for the water withdrawal footprint. One year's consumption of beef caused 180,000 cubic meters of water withdrawal, equivalent to the water contained in 72 Olympic-sized swimming pools. The water withdrawn due to consumption of beef was about 1.5 times the amount of water withdrawn due to liquids, which was the second largest contributor to UHMs water withdrawal footprint. Consumption of liquids required 120,000 cubic meters of water. The next food category was dairy which caused about 100,000 cubic meters of water withdrawal, approximately 1.8 times less than that of beef. The water withdrawal of beef, liquids, and dairy made up 32% of the total food procurement water withdrawal footprint.

4.4 Summary

Overall beef was shown to have the largest environmental contribution to nitrogen and carbon emissions, and water withdrawals. Beef had the largest contribution for all the measured footprints by a large margin. With respect to nitrogen, beef's contribution was 1.2 times larger than the next closest category, and for the carbon and water withdrawal footprints, beef was often over 1.5 times larger than the next ingredient. The second largest contributor overall was pork. Overall pork ranked second, ranking second for nitrogen, third for carbon, and fifth for water withdrawal. The third food category that contributed the most to UHMs environmental food procurement footprint was cheese. Cheese was found to be the fourth largest contributor for nitrogen, second-largest contributor for carbon, and seventh for water withdrawal.

Although all the different food categories individually contributed to UHMs food procurement footprints, these rankings have similarities; for example, the three largest contributors to UHMs environmental footprints are all defined as animal products[28] and are under scrutiny by some communities due to environmental and ethical concerns caused by their method of production (Cornish et al., 2016 & De Vries et al., 2010). Of items that were not animal products, grains contributed the most to UHMs environmental footprint, followed closely by liquids. However, the large contribution by grains and liquids was just as likely due to their large procurements, see Figure 7. Approximately 54,000 kg of grains and 49,000 kg of liquids were procured for UHMs cafeterias each year compared to only 10,000 kg of beef procured in the same locations yearly, see Table 5. Implying that although much more grains and liquids were procured for UHM than beef, the environmental contributions of grains and liquids were much less than beef.

4.5 Improvement

While this thesis is a thorough analysis of the largest contributors of the food procurement environmental footprints of UHM, it contains room for improvement. One area noted for improvement is the type of data sources. There are a wide variety of data sources utilized for this thesis, some of which are out of date, from international sources, and/or are generalized or estimated coefficients[29]. These inconsistencies in the data sources are limitations of analysis. Future improvement of these data sources could include utilizing data sources and coefficients that are created specifically for UHM and the state of Hawai'i. For example, the mileage data for each food category is generalized for universities across the country. However, these universities likely don't reside outside of the continental US as Hawai'i does. Improvement to the mileage data could then include accurate mileage for each food category as well as the type of transportation (truck, boat and/or plane) that is utilized. Other noted room for improvement is the

[28] Products derived from animals rather than plants.
[29] Many of the limitations of analysis were done to ensure consistency of methods and results.

food vendors considered on the UHM campus. While this thesis is designed to account for the food procurement environmental footprint of the entire UHM campus, the food vendor data is limited to the three cafeterias on campus. Future improvement could include all of the accounted food vendors (Table 2) on campus, including cafeterias, food trucks and campus restaurants. Lastly, the specific food data collected from the cafeterias was in the form of weekly inventory records. This creates the assumption that all food listed is completely consumed each week. To ensure more accurate results and to avoid double counting, purchase receipts could be utilized instead.

5.0 Conclusion

This study created a comprehensive data methodology to identify the largest contributors of food procurement to the aggregate environmental footprint of UHM. Although there are many food categories contributing to UHM's environmental footprint, beef, pork, and cheese were the largest contributors. These results may give guidance for policy decisions by Administration to create efforts to reduce the environmental footprint UHM's campus. By eliminating beef, for example, the university could potentially reduce its food procurement nitrogen footprint by 26%, carbon footprint by 32%, and the water withdrawal footprint by 16%. As such, a reduction in the procurement of beef would be a logical target to reduce the universities environmental impact. More, reducing any of the largest contributors and replacing them with less harmful options would positively effect UHM's footprint outcomes and push the university further towards its environmental goals. For example, one such solution could be reducing the number of days a week where beef or pork is served, like "Meatless Mondays." Overall, encouraging a dietary shift away from beef and other animal products will be necessary for future important changes regarding UHM's environmental footprint and environmental goals.

Appendix

Appendix I: Physical activities and operations by UHM on off-campus facilities exclusions and exceptions

- Lyon Arboretum EXCLUDED
- Cancer Research Center EXCLUDED
- JABSOM EXCLUDED
- Waikiki Aquarium EXCLUDED
- University of Hawai'i Community Design Center, Charlot Residence INCLUDED
- CTHAR Facilities EXCLUDE OFF CAMPUS FACILITIES
    - Big Island - Lalamilo
    - Big Island - Kona Extension
    - Big Island - Ag Experimental
    - Big Island - Volcano
    - Big Island - Komohana Agricultural Complex
    - Big Island - Mealani Res Sta
    - Big Island - Hamakua sta ag farm
    - Maui - Kula Maui Branch Station
    - Oahu - Waialee Livestock Research (North Shore)
    - Oahu - Pearl City Urban Garden
    - Oahu - Waimanalo Research Station
    - Oahu - Poamoho Research Station - Waialua
- Marine Center Pier 35 EXCLUDED
- Coconut Island - HIMB EXCLUDED
- Institute for Astronomy Facilities EXCLUDED
    - Big Island - Mauna Kea Summit
    - Big Island - Mauna Kea Support
    - Big Island - Hilo
    - Maui - Waikaloa
    - Maui- Ohia
- Research Corporation of the University of Hawai'i EXCLUDED
    - UHM Joint Astronomy Center - UKIR

- UHM Marine Science Department MIXED
- Makai Pier - Office VC research
- Pacific Cooperative Studies
- Maui - Haleakala Cottage
- UH CCRT
- Big Island - Crt Conservation R&T

Appendix II: Food Categorization Guidelines

Food categories with examples of common foods in that Category
Some foods will fit into more than one category, which is why it's important to find the top 3 ingredients in a food item/dish.

Food categories	**Foods in this category**
Beef	Beef, steak, ground beef, hamburger, meatball, beef lasagna*, goat meat, sheep, and other ruminants
Pork	Sausage, bologna, bacon, pepperoni
Poultry	Chicken, turkey, and other poultry
Cheese	Cheddar, parmesan, cream cheese, feta, gouda, alfredo sauce, cheese pizza*, and other cheeses
Eggs	Eggs, liquid eggs, egg whites
Dairy	Milk, yogurt, ice cream, cream, butter, condensed milk, pudding, and other dairy products (other than cheese)
Fish	Fish, lobsters, shrimp, cod, anchovy, salmon, tuna, fried seafood, clams and other seafood
Beverages/Liquids	Fruit juice, soda, broth, beverage powders, sports drinks, vinegars, cooking wine, and other beverages. Exclude milk (report as milk) and coffee and tea (report as coffee and tea).
Grains	noodles, pasta, pizza*, tortilla chips, barley, rye, oats, millet, sorghum, and other grains
Fruits	Apples, oranges, lemons, grapefruit, citrus, bananas, blueberries, strawberries, plantains, apples, pineapples, dates, grapes, avocadoes, melons, fruit/granola mix*, fruit cocktail, fruit preserves, and other fruits
Nuts	Cashews, almonds, walnuts, pistachios, peanuts, peanut butter, tahini paste, and other nuts
Oils	Vegetable oil, canola oil, olive oil, soybean-based oil, salad dressings, non-dairy creamer, mayonnaise, margarine, and other oils
Beans	Soybeans, tofu, black beans, kidney beans, cannellini beans, pinto beans, chickpeas, lentils, refried beans, hummus, and other beans and pulses
Spices	Pepper, pimento, cloves, mustard, other spices and seasoning
Potatoes	Potatoes, sweet potatoes, potato chips, fries, hash browns, yams, cassava, yams, and other roots
Coffee and tea	Coffee, tea, chocolate bars*
Sugars	Sugar, sweeteners, honey, candy, glaze, sprinkles, marshmallow, syrups
Vegetables	Tomatoes, onions, lettuce, greens, green beans, peas, string beans, carrots, squash, vegetable soup*, and other vegetables
*Multiple Ingredients	Foods that fit into multiple categories must be broken down into their top 3 ingredients by percentage and then placed into their food categories Ex: Veggie Pizza – grains, cheese, vegetables; Mustard- spices, oil

Appendix III: Acronym Table	
UHM	University of Hawaii at Manoa
WWF	Water Withdrawal Footprint for each food category
TWF	Total Water Footprint
W	Total Weight for each food category (kg)
RF	Recipe Formula
F	Food Item
wp	Weight in pounds
wg	Volume in US gallons
FCp	Food category by weight in pounds
FCg	Food category by volume in US gallons
TFCp	Total weight in pounds of food category
TFCg	Total volume in US gallons of food category
VF	Conventional Virtual Nitrogen Factor
T	Transport
FW	Food Waste
P	Food Waste Percentage Factor
X, Y, Z	Ingredients 1, 2, 3
NC	Nitrogen Content
NFF	Nitrogen Footprint Factor
B	Number of trips
D	Average Transport Distance
TEF	Transport Nitrogen Emissions Factor
TC	Shipping truck capacity
CF	Carbon Footprint
TCF	Total Carbon Footprint
CFF	Carbon Footprint Factor

Appendix IV: Nitrogen Equation Values			
Food Categories	Nitrogen Footprint Factors (NFF) (kg)	Nitrogen Content (NC) (kg)	Conventional Virtual N Factor (VF)
Grains	0.9	0.0148	750
Potatoes	1.4	0.0036	125
Liquids	3.4	0.0014	240
Coffee & Tea	3.4	0.0164	400
Spices	2.8	0.0088	194
Beans	0.4	0.0144	55
Nuts	0.4	0.0297	34
Oils	0.4	0.0006	2
Sugars	3.4	0.0005	27
Fruits	3.4	0.0008	46
Vegetables	2.8	0.0028	246
Eggs	3.3	0.0185	435
Dairy	3.1	0.0063	646
Cheese	3.1	0.0301	1290
Beef	11.3	0.0292	3530
Pork	4.7	0.0283	2020
Poultry	4.2	0.0278	1440
Fish	2.5	0.0287	943
NC was found by using the average protein contents for the most common foods purchased[30] by campus across the country and multiplying it by 16% because protein[31] is on average 16% nitrogen (Leach et al. 2019).			

[30] The most common food purchases were identified by reviewing the top 10 purchases by food category at college campuses across the country.
[31] Protein contents were identified using the USDA Food Composition Database (aka FoodData Central), a data system that shows nutrient profile data for foods.

Appendix V: Carbon Footprint	
Food Category	Carbon Footprint Factors (CFF) (kg)
Grains	0.86
Potatoes	0.21
Liquids	1.03
Coffee & Tea	0.36
Spices	0.73
Beans	0.78
Nuts	1.17
Oils	1.63
Sugars	0.93
Fruits	0.36
Vegetables	0.73
Eggs	3.54
Dairy	1.34
Cheese	9.78
Beef	26.45
Pork	6.87
Poultry	5.05
Fish	3.83

Appendix VI: Water Withdrawal Footprint Factor	
Food Categories	Water Footprint Factor (WFF) (m^3/kg)
Grains	1.810
Potatoes	0.430
Liquids	2.520
Coffee & Tea	15.300
Spices	7.720
Beans	4.470
Nuts	9.990
Oils	2.600
Sugars	0.217
Fruits	1.060
Vegetables	0.355
Eggs	3.600
Dairy	3.620
Cheese	5.580
Beef	16.990
Pork	6.600
Poultry	4.767
Fish	3.110

	Appendix VII: List of Equations
1	$RF(\%) = \frac{x\ (units)}{F\ (units)} \times 100 + \frac{y\ (units)}{F\ (units)} \times 100 + \frac{z\ (units)}{F\ (units)} \times 100$
2	$FCp\ (lbs) = RF \times wp\ (lbs)$
3	$FCg\ (gal) = RF \times wg\ (gal)$
4	$TFCp = \sum FCp\ \ (lbs/FC)$
5	$TFCg = \sum FCg\ (US\ gal/FC)$
6	$TNF\ (\frac{kgN}{yr}) = \sum_{i=1}^{N=18} NF_i\ (kg\ N)$
7	$NF\ (kg\ N) = VF\ (kg\ N) + T\ (kg\ N) + FW\ (kg\ N)$
8	$VF\ (kg\ N) = w\ (kg) \times NC\ \times NFF \left(\frac{kg\ N}{kg\ food}\right)$
9	$T(kg\ N) = B\ \times D(mi) \times TEF\ (\frac{kg\ N}{mi})$
10	$B = \frac{w}{TC}\ \ \left(\frac{kg}{kg}\right)$
11	$FW\ (kg\ N) = S\ (kg\ N) \times P(\%)$
12	$S\ (kg\ N) = w\ (kg) \times\ NC\ (N)$
13	$CF\ (kg\ C) = w\ (kg) \times (CFF)\ (kg\ N)$
14	$TCF\ (\frac{kgN}{yr}) = \sum_{i=1}^{N=18} CF_i$
15	$WWF\ (m^3) = w\ (kg) \times WFF\ \ (\frac{m^3}{kg})$
16	$TWF\ (m^3/yr) = \sum_{i=1}^{N=18} WWF_i$

Appendix VIII: Food Waste % Factors per Food Category	
Food Categories	Food Waste Percentage Factors (%)
Grains	0.28
Potatoes	0.35
Liquids	0.37
Coffee & Tea	0.37
Spices	0.37
Beans	0.56
Nuts	0.05
Oils	0.05
Sugars	0.37
Fruits	0.37
Vegetables	0.37
Eggs	0.15
Dairy	0.15
Cheese	0.15
Beef	0.15
Pork	0.15
Poultry	0.15
Fish	0.39
Food Waste Percentage Factors were calculated[32] using the FAO Report for North America; Annex 4 (Gustavsson, 2011)	

[32] (Leach et al., 2019)

Appendix IV: Transport Equation Values			
Food Categories	Average Transport Distance (D) (mi)	Transport N Emission Factor (TEF) (kg N/mile)	Number of Trips (B)
Grains	1350	0.00201	2.4
Potatoes	1500	0.00201	1.1
Liquids	800	0.00201	2.2
Coffee & Tea	800	0.00201	0.3
Spices	800	0.00201	0.3
Beans	1500	0.00201	0.4
Nuts	1500	0.00201	0.1
Oils	800	0.00201	0.4
Sugars	800	0.00201	0.7
Fruits	1500	0.00201	0.8
Vegetables	1500	0.00201	1.4
Eggs	250	0.00201	0.3
Dairy	250	0.00201	1.5
Cheese	250	0.00201	0.6
Beef	950	0.00201	0.5
Pork	950	0.00201	0.7
Poultry	950	0.00201	0.5
Fish	950	0.00201	0.6
The Transport Nitrogen Emission Factor was calculated by the EPA by taking the NOx and N2O emission factors for a diesel truck and combining them into a single emission factor, and then converting it into units of nitrogen by using the nitrogen content of NOx (0.3043) and N2O (0.6364) (Leach et al., 2019).			

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