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A Comparative Life Cycle Assessment of Nutritionally Equivalent Meals with and without Pork

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A Comparative Life Cycle Assessment of Nutritionally Equivalent Meals with and without Pork

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Abstract

The following report details a life cycle assessment of several dietary and meal scenarios with and without pork. The goal of the LCA was to identify the impacts of greenhouse gas emissions, water use, and land use of pork containing and porkless diets and meal plans in a field-to-fork analysis. The dietary and meal plan scenarios are iso-caloric meaning they contain the same number of calories. The first set of diets is based on a USDA consumption pattern, 2000 kcal per day. This diet was used to create three other dietary scenarios with and without pork. The USDA recommended food pattern and the USDA Lacto-Ovo Vegetarian pattern based on a 2000 kcal diet were also analyzed. The second set of diets uses the USDA Loss Adjusted Food Availability Database (LAFA), and four dietary scenarios were created with and without pork. Four diets and three meal plans were made from the National Health and Nutrition Database Survey [42](NHANES) data, but from these only two meal plans were used. Input output and process modeling were used in SimaPro for the different life cycle stages of the diets and meals. It was found that the four major food groups that contribute to greenhouse gas emissions are beef, poultry, vegetables, and fish/seafood. There were no significant differences in greenhouse gas emissions of pork containing and porkless diets. For land use impacts, it was found that the foods that had the highest impacts are poultry, beef, and grains. Porkless meals show an overall increase in land use by approximately 6-8%. Results for water impacts were found to be similar to those of land use impacts. The highest contributors are grains, poultry, and beef. However, irrigation for crop growth requires the most water. Meals without pork show a reduction of water use by approximately 3-4%. The information presents possibilities to improve greenhouse gas emissions, land impact, and water impact for the pork industry. This information could provide the pork industry with a beneficial marketing opportunity.

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List of Acronyms

ASHRAE: American Society of Heating, Refrigerating and Air-conditioning Engineers
BEA: Bureau of Economic Analysis
BTS: Bureau of Transportation Statistics CEDA: Comprehensive Environmental Data Archive
CNPP: Center for Nutrition Policy and Promotion
CO_2: Carbon Dioxide
EIO-LCA: Economic Input-Output Life Cycle Assessment
ERS: Economic Research Service
FP: Food Pattern
FPED: Food Pattern Equivalents Database
GHG: Greenhouse Gas
GWP: Global Warming Potential
LAFA: Loss-Adjusted Food Availability
LCA: Life Cycle Assessment
LCI: Life Cycle Inventory
LCIA: Life Cycle Impact Assessment
MT: Million Tons
NADA: National Automobile Dealers Association
NAICS: North American Industry Classification System
RITA: Research and Innovative Technology Administration
USDA: United States Department of Agriculture
USDOC: United States Department of Commerce
USEPA: United States Environmental Protection Agency
NHANES: National Health and Nutrition Database Survey
DALYs: Disability Adjusted Life Years

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Introduction and Background

As people and companies become more aware of environmental and health problems due to food production, distribution, and consumption, many studies have focused on nutritionally sound solutions to solve these problems. This study aims to complete a field-to-fork life cycle assessment of land, carbon, and water footprints of diets with pork versus nutritionally equivalent diets without pork as well as assess health impacts.

Life cycle assessments have been used to analyze the entire life cycle of specific foods from production to consumption to access their overall environmental impact. There is increasing interest in using life cycle assessment methods for analyzing environmental impacts as well as determining environmental impacts in connection with food consumption[1]. Yet, many of these life cycle assessments fail to address the nutritional aspects of the food[2]. Life cycle assessment studies tend to focus on one environmental impact from food, for example carbon emissions, instead of multiple impacts such as water use, land use, and greenhouse gas emissions. The USDA Dietary Guidelines concentrate on nutritional meal plans to ensure health; however, they do not take environmental impacts of the food life cycle into account[2]. Heller et al. studied a shift from the average American diet to USDA recommended dietary guidelines[3]. The study used a meta-analysis of life cycle assessment data to construct values for individual food greenhouse gas emissions[3]. The results from this study conclude that by shifting from an average American diet to the recommended USDA dietary guidelines, there will be a very small increase in greenhouse gas emissions[3].

Many organizations have addressed the need for a comparison between meat containing meals versus meatless meals. Switching from meat containing meals to meatless meals does not necessarily mean the environmental impact will be less[4]. In several studies including[4] Tom et al.

(2015), it was reported that shifting from more sustainable meat products, such as pork and chicken, to a diet with high amounts of fruits, vegetables, and seafood, the environmental impact is greater. This is because fruits, vegetables, and seafood use significant resources and have higher emissions per calorie intake[4].

On the contrary, some studies have surmised that meat containing meals are much more environmentally detrimental. Dettling et al. studied whether switching to a plant based diet from diets containing meat will decrease environmental impacts[5]. The meat and meatless meals that were studied were based on equal weights; however, nutritional content was not taken into account. Subcategories for environmental impacts in this study included carbon footprint, water use, resource consumption, and ecosystem quality[5]. The study reported that by shifting from a meat containing meal to a meatless meal the environmental impact will decrease by approximately 40%[5]. Many environmental factors were incorporated in this report contributing to its credibility. However, the study did not take nutritional equivalency into account for meat containing meals versus meatless meals. If this had been included, the results from this study would be much more applicable in creating dietary guidelines that are nutritional and environmentally sensible; however, it was not in the goal or scope of the study to incorporate that data.

My study will present further data on environmental and health impacts related to several meals and diets. This study will specifically focus on sample meals and diets containing pork versus sample meals and diets without pork. I will include life cycle assessments of carbon, water, and land footprints to further contribute to a detailed analysis of environmental impacts. Each meal studied will be iso-caloric which will create valid comparisons between the diets. The results from this study could provide the pork industry with an opportunity to find ways to reduce their greenhouse gas emissions, land use, and water use. It is important for consumers and food industries to know which foods are creating the most environmental impacts in order to make conscious environmental friendly decisions. The results from this study can also educate consumers that sustainable diets are more complex than what is commonly believed.

Our analysis uses SimaPro to perform life cycle assessments throughout the supply chain of several diets and meals. This model calculates carbon, water, and land footprints giving total environmental impacts for meals with pork versus iso-caloric meals without pork. The data used in this study will be primarily from USDA food patterns 2010, the Loss Adjusted Food Availability database, and National Health and Nutrition Examination Survey (NHANES) as well as existing scientific literature and academic reports[42]. Life cycle inventories (LCI), databases compiled from the previously mentioned sources, are used to compute possible environmental impacts of the diets and meal plans.

2. Literature Review

The main focus of this project is to analyze several different daily meal plan scenarios and their respective environmental and health impacts. Tom et al. looked at several categories of environmental impacts for three different dietary scenarios based on current consumption and USDA recommended plans[4]. The environmental impacts focused on are water footprint, greenhouse gas emissions, and energy consumption. The methodology used in this study consists of calories consumed per person as well as the three environmental categories (water footprint, greenhouse gas emissions, and energy consumption). The results of this study show that by decreasing the caloric intake of the current food consumption the impacts of all three environmental categories will decrease. However, by following the USDA recommended guidelines the impact for three environmental categories will increase. The reason for this is that the USDA's dietary suggestions involve increased consumption of fruits, vegetables, dairy products, and fish/seafood. Production of all these food items consume high resources and produce considerably high emissions[4]. Following the recommended USDA dietary guidelines while reducing caloric intake will also increase the environmental categories. This study suggests that shifting diets away from meat will not necessarily decrease the environmental impact.

Hallstrom et al. provide an evaluation of the scientific basis of dietary scenario analysis of several research papers that have focused on this topic[6]. It also identifies potential environmental effects of these dietary changes, important methodological aspects, and gaps in knowledge. First, it is suggested that functional units representing nutritional content instead of just weight provides a more fair comparison between the food groups[7]. The most common method for this approach is to use dietary plans that are iso-caloric this way the diets will all have the same energy content for comparison. Many studies provide additional specifications to ensure the dietary meal plans are in accordance with recommended health and nutritional guidelines such as USDA food patterns[6]. Dietary meal plans based on reported consumption data, such as NHANES or the Loss Adjusted Food Availability database, are considered by some to be more accurate, realistic representation of food intake[6]. However, it is also noted that people tend to change their food consumption when it is being reported, or they will falsely report data[8]. Most of the articles reviewed in Hallstrom et al. are based on a specific population, for example Americans, and average per capita consumption data. In some articles, dietary scenarios are all based on reported consumption data[6].

Some studies focus on overall environmental and health impacts from a specific food group. Ernstoff et al. create a system to compare the environmental impacts and health effects of dairy consumption[2]. It uses global burden of disease information and Disability Adjusted Life Years (DALYs) to differentiate and quantify health and environmental impacts. DALY is a way of measuring burden of disease through number of years lost because of ill-health[9]. This article also performs a study on dairy to establish a way to study population health responses to dietary change. This article concludes that the entire diet and food life cycle should be taken into account when evaluating the sustainability of recommended nutritionally balanced diets. The study provides a basic analysis for health effects in a life cycle assessment framework. It offers a basis for evaluating environmental and nutritional impacts to human health and stresses the importance of understanding both of these aspects as they may contradict each other. Aston et al. focus only on red and processed meat. This study concludes that by reducing intake of red and processed meat there will be both health and environmental benefits. However, this study does not substitute other food groups for meat consumption to determine substitution effects on environmental and health impacts.

The results presented in my study will provide a vegetarian scenario as well as nutritionally equivalent sample meals and dietary scenarios featuring different levels of pork and red meat consumption. The study will include greenhouse gas emissions, land use, water use, and human health effects.

Although it is ideal to include a field to fork life cycle assessment, many activities are often excluded because they have a negligible effect on the overall environmental impact. Many studies include activities only up to the farm gate because agricultural production generally has the largest environmental impact[10]. However, post-farm activities are also important. For foods that have small greenhouse gas emissions during production, ignoring activities after farm gate may have a significant effect[6]. Research articles most commonly include the retail stage inside the system boundaries; however, the following articles[11][12][13] only account for greenhouse gas emissions from the agricultural phase to the farm gate.

Some articles are limited in their coverage of food groups as well as the number of assessed environmental impacts. Saxe et al. analyze the environmental impacts of 31 food categories only farm to retail[14]. Three different diets were analyzed, the average Danish diet, the recommended Danish diet, and the New Nordic Diet. The research concluded that by reducing alcohol drinks, hot drinks, and sweets by 50% would reduce greenhouse gas emissions by the same amount as reducing red meat intake by 30% [14].

Accounting for food loss should be within the system boundary. Adjusted food loss is usually found from the difference of per capita supply data and consumption data as reported by Berners-Lee et al.; and Hoolohan et al.[15]. In the article, Venkat et al., avoidable waste was calculated through the life cycles of each food commodity and greenhouse gas emissions were assessed for each stage including production and processing, packaging, distribution and retail, and disposal[16]. It was found that beef is the largest contributor to greenhouse gas emissions of the 16 food groups tested (134 food commodities total). It was also reported in this study that production, by the farm gate, and processing emissions were the highest of all the food stages. Heller et al. explored greenhouse gas emissions caused by food production losses during the retail and consumer phases using a life-cycle analysis[17]. It specifically looked at the edible amount of food wasted at the consumer and retail level. This study also analyzes the greenhouse gas emissions of a shift from an average American diet to food patterns described in the USDA dietary guidelines. The research was conducted using Loss-Adjusted Food Availability Data Series and the 2010 USDA Dietary Guidelines for Americans. This study reported that by shifting from the average American diet to the USDA recommended diet greenhouse gas emissions will increase.

The potential to reduce greenhouse gases seems to predominantly be affected by the type of meat and animal products consumed in diets [6]. The amount of red meat and ruminant meat in recommended diets is a major factor in accessing overall greenhouse gas emissions. Replacing ruminant meat in all diets with poultry and pork can decrease greenhouse gas emissions by up to 35% [6]. Dettling et al. uses a life cycle assessment to determine the environmental impacts of several individual meals[5]. The study argues that raising animals as food for humans has a greater environmental impact than meatless meals, however, nutrient content and equivalency was not accounted in this study.

The potential for reduction of land use seems to also rely mostly on decreasing consumption of ruminant animals[6]. A study by Audsley et al. shows that by substituting 75% of ruminant meat consumed with poultry and pork, the land use demand can be reduced by 40%[6,18]. It has been calculated that global average per capita demand for land in 2030 and 2050 will be 5000 m^2, and by altering normal consumption to a diet with a reduced intake of ruminant and red meat, global average per capita land demand in 2030 and 2050 will be 2200-3500 m^2 [19,20,21]. Stehfest et al. studied the possible changes that can be made to stabilize global warming from dietary modifications[20]. By 2050, greenhouse gas emissions need to be lowered by 40-80% according to the IPCC to avoid a substantial increase in global temperatures [20]. In the other dietary alternatives featuring a global transition of consuming less meat or completely meatless protein diets, a significant reduction in land use is expected. Approximately 2700 Mha of pasture land and 100 Mha of cropland could be used for reforestation and natural habitation. Greenhouse gas emissions would also decrease dramatically. A low meat diet would decrease greenhouse gas emissions by 50% in 2050[20]. This article concludes that by mitigating diets, changes in the energy system, and reforestation etc. there will be a significant reduction in greenhouse gas emissions; however, this study does not take nutritional equivalency into account.

Richer or more affluent areas in the world also greatly affect environmental impacts [6]. These affluent diets, if altered, could possibly reduce 50% of land demand and greenhouse gas emissions [6]. The environmental impact is additionally affected by air transported vegetables and fruit and cheese[22][23].

Weber et al. compared a life cycle analysis of greenhouse gas emissions of food commodities to the distance the products travel to be distributed (food-miles) [23]. This study reports a complete life cycle assessment of greenhouse gas emissions resulting from food products in the production, transportation and distribution phases. This analysis includes upstream impacts (input and output life cycle assessments) as well as examines all food and nonalcoholic beverages. The study found that if the average American household bought locally grown food they would decrease greenhouse gas emission max 4-5%[23]. According to the study, if a consumer altered less than a day of red meat or dairy to other protein containing foods or a vegetable diet, they would have the same environmental impact as if they bought their food locally[23].

In future research studies, it is suggested that more sustainability factors need to be assessed such as loss of biodiversity, acidification etc. [6]. These factors can sometimes be correlated with greenhouse gas emission and land demand for agriculture[24][25][13].

As reported by Audsley et al. and several other studies, by replacing ruminant and red meat with chicken and pork environmental impacts will greatly decrease[18]. Therefore, it is worth researching the specific health and environmental effects of these food products in pushing this dietary transition into recommended nutritional guidelines. As suggested by Ernstoff et al., it is important to consider both nutritional and environmental impacts as each of these factors together are incredibly significant in the preservation of human kind and the world alike[2]. Nutritional equivalency is also an important factor in determining realistic and healthy dietary scenarios. By performing life cycle assessments on iso-caloric diets, the results will show realistic alternatives to environmentally taxing diets.

3. Goal of the Study

Comparing the environmental and health impacts associated with food production and consumption is becoming increasingly common, as individual foods provide a variety of nutrients in various concentrations. Pluimers et al. report that life cycle assessments are a widely adopted method for determining environmental impacts and analyzing them in relation to food consumption[1]. LCA is a tool to account for complete interactions and combined effects in an agricultural production supply chain. LCAs provide quantitative, confirmable, and manageable models to evaluate production processes, analyze options for innovation, and improve understanding of the complexity in systems. LCA's have been used as a tool to identify "hot spots" in the production chain that may introduce opportunities for lowering environmental impacts while enabling a fair comparison of other nutritionally equivalent goods.

The goal of this project is to conduct a LCA that will compare the environmental and health impacts associated with the production and consumption of a diet and meal samples that include pork versus iso-caloric diets and meal samples without pork. My portion of this project is focused on environmental impacts. This LCA will be based on scientifically sound models and peer reviewed data. The primary objective of this study is to perform a life cycle assessment of greenhouse gas emissions, land use, and water use from production to consumption of iso-caloric pork containing meals and porkless meals in a field-to-fork analysis.

This study focuses on the overall environmental and health impacts of several pork containing and porkless diets and meals through the production, distribution, and consumption of the product. The results will offer the audience an opportunity to decrease their environmental impact while increasing efficiency and maintaining a healthy diet.

There were several diets chosen for comparison. Six diets are based on a 2000 kcal per day consumption. The first diet is the "Usual U.S. Intake: Adults" consumption pattern as reported in the USDA dietary Guidelines 2010, Table 5-1 Eating Pattern Comparison[26]. This diet is adjusted in three ways to create three other dietary scenarios. The USDA Lacto-Ovo Vegetarian Adaptation of the USDA Food Patterns and the USDA Food Pattern based on a 2000 calorie diet from 2010 is also analyzed[27]. Four diets were constructed from the Loss Adjusted Food Availability Database for the most recent year available, 2015[28]. The first diet is based on current food consumption while the other three diets are adjusted from this diet to create iso-caloric alternative diets. The fourth LAFA diet takes all calories consumed from meats and distributes them equally to all other food groups. There are four diets constructed from NHANES (2011-2012)[42]. This data was previously compiled in the Dettling et al. report[5]. The first NHANES diet is the average food consumption[42]. There are three alternative diets that were created by adjusting this diet. All adjusted diets are iso-caloric which signifies they contain the same amount of calories. None of the NHANES diets were used in the analysis, however. Several sample meal plans were also created using information from this same report. Three meal plans were constructed using the average consumption as reported by Dettling et al. for meat containing meals, and the fourth meal plan is meatless[5]. Only two meals out of the four created were analyzed in this study. The pork containing meal for breakfast, lunch, and dinner was compared to the porkless meal. The porkless meal substituted pork calories to poultry and beef only.

4. Scope of the Study

The scope of this project includes the production, distribution, and consumption of the food products in a field-to-fork life cycle analysis of greenhouse gas emissions, water use, and land use. The two main components analyzed in this study are dietary scenarios and meal plans. The goal of this study is to compare health and environmental impacts of diets and meal plans with varying amounts of pork based on current food consumption and recommended food consumption. Pork allocations are made based on the ratio of ingestion to all food groups or just “poultry” and “beef” groups. Vegetarian or meatless diets and meal plans are also compared with the meat containing diets and meal plans.

5. Functional Unit

Life cycle assessments require clearly defined and measurable functional units. Functional units are necessary when analyzing single or multiple component systems. The functional unit is used as a source in identifying various elements in the systems being studied. It can be related to the inputs and outputs of a system and is a measure of the function of the system. In this study the functional unit for the life cycle assessment is calories. The sample meal plans and diets used in this study are iso-caloric.

6. System Boundaries and Cut-Off Criteria

System boundaries are activities that are incorporated in a research project. This study was a field to fork analysis of diets and meals with and without pork. The LCA started with the production of raw materials and ended with the consumption of the food at the consumer’s home. In other words, all of the activities and processes required to get these foods on a plate are taken into consideration. This includes the growth, harvesting, processing, distribution, and storing of the food products. The environmental impacts associated with the production of raw materials to the preparation and consumption of the food are reported and analyzed.

7. Representation of Meals Life Cycle

All dietary scenarios and meal plans were analyzed for their environmental impacts from "field to fork". **Figure 1** depicts the lifecycle stages of food products.

Figure 1. Lifecycle food product stages

Existing lifecycle inventory data has been constructed for the raw food product stage (field or farm) for the food groups analyzed in this study. The raw food product stage consists of assessments of the greenhouse gas emissions, land use, and water use during the time the plant or animal product is grown in a field or raised on a farm. Therefore, this takes into consideration the amount of land needed to produce the food products or house the animals, and the amount of water and electricity consumed in this process. Data for this stage and the other life cycle stages of food production are based on the number of calories consumed for each food product.

The processing life cycle food stage consists of preparation and production of the food products. The environmental impacts in this stage come from energy use i.e. machinery, refrigeration etc., water use, and land use that the facility operates on. Packaging and transportation environmental impacts for meal and diet plans will not be calculated on an individual food basis but will be assumed based on the overall amount of food. Impacts associated with packaging of food products comes from energy use, land, and water use that would be needed to acquire and make packaging materials. The transportation and retail stage includes air, land, and/or water travel to get the food products to their retail destinations and from retail to consumer homes. Once the products are in their proper retail locations, they need to be maintained through energy and possibly water use. As soon as the food products are obtained by the consumer, they will again have to be preserved and cooked through energy and water usage.

The life cycle of a food supply chain is shown in **Figure 2** below. The approximate percent of food loss is shown during each stage. The food loss contributes to the environmental effects in each life cycle stage on a mass basis.

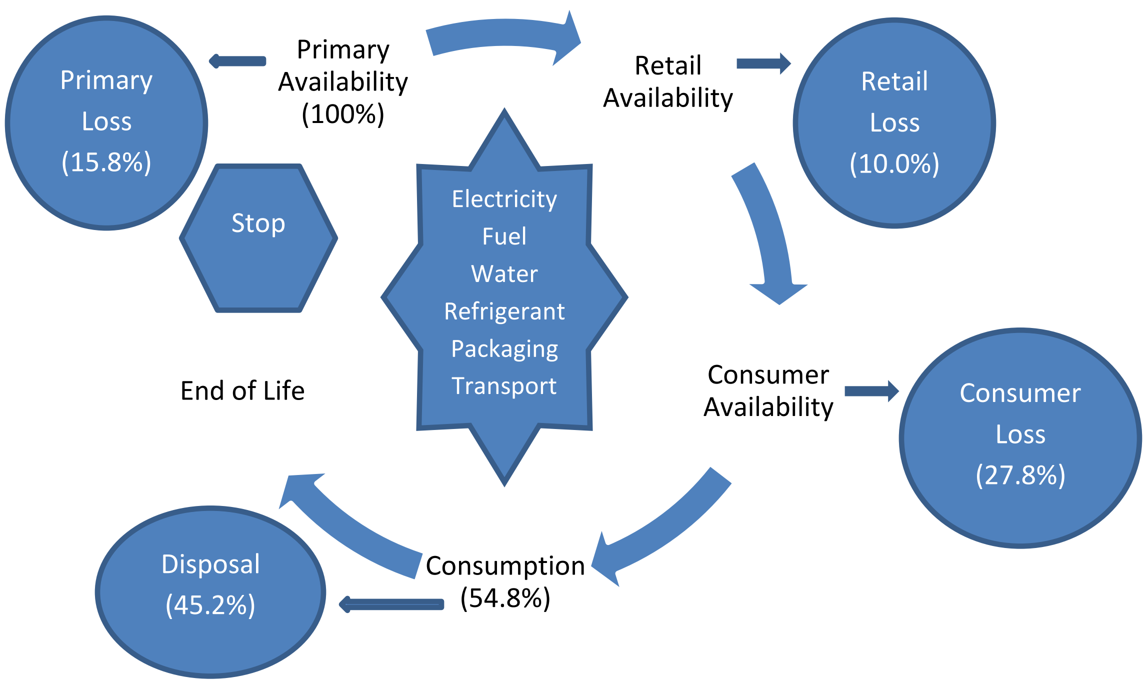

Figure 2. Schematic flow of food supply chain driven from USDA LAFA database.

Dettling et al. scaled meatless meals, breakfast, lunch, and dinner to have the same weights as the meat containing meals, breakfast, lunch, and dinner[5]. However, for the purposes of this study scaled data for "meatless meals" was not used. This is because caloric intake would drastically increase compared to "meat containing meals" if weight-scaled values were used. The most accurate depiction of meatless or vegetarian meal scenarios is obtained through data reported directly to NHANES.

8. Description of the Systems Studied

Diet and meal compositions were primarily derived from USDA Dietary Guidelines and Food Patterns, LAFA database, and NHANES data. There were total of eleven dietary scenarios created and six sample meal plans. The dietary scenarios include two framework diets: USDA Dietary Guidelines/Food Patterns and LAFA database. Two other dietary scenarios were adapted from USDA recommended food patterns with and without meat (USDA, 2011). Several meal plans were constructed in a similar way, but only two were analyzed. The following sections include the detailed descriptions and sources of the dietary and meal plan scenarios.

The first dietary scenarios are based on a 2,000 kcal/day baseline diet adopted from the "Usual U.S. Intake: Adults" consumption pattern as reported in the USDA Dietary Guidelines 2010, Table 5-1 Eating Pattern Comparison [26]. This diet was adjusted in three ways to create three alternative iso-caloric dietary scenarios: removing pork from the baseline diet and distributing the equal number of removed pork calories to the remaining food groups, doubling daily consumption of pork to the diet by subtracting equal number of added calories from the remaining food groups, and doubling daily consumption of pork to the diet by subtracting equal number of added calories from beef and poultry only. Two other iso-caloric (2,000 kcal) dietary scenarios are USDA Food Patterns and USDA recommended vegetarian diet [27]. The second dietary scenarios were constructed using the LAFA database for the most recent year available, 2015. The first diet is based on current food consumption patterns, approximately 2,550 kcal, while the other three diets were adjusted from this diet to create three calorically equivalent alternative diets using the same caloric substitution approach as the first dietary scenarios. LAFA-based vegetarian diet was also constructed using the same food ingredients as USDA recommended vegetarian diet (no fish/seafood and no meat), but the consumption of each food group was adjusted to have the same total number of calories as the baseline diet of 2,550 kcal by distributing must-add calories to each food group based on the consumption ratio.

In addition, there are six meal plan scenarios constructed from NHANES data (2011-2012). This data was previously compiled in Dettling et al. report. The first NHANES meals are the average food consumption as reported for pork-containing breakfast, lunch and dinner. There are three alternative meals that were made from these meals. Only two meal plans are analyzed in this study. The meal plan of pork containing meals is compared to the meal plan of porkless meals. The porkless meals were constructed by removing pork from the meals by substituting equal number of removed calories with beef and poultry only. All meals were iso-caloric.

8.1. Dietary and Meal Food Groups

Foods and food groups have been chosen in reference to USDA food patterns and the LAFA database. Further distribution of food groups has been made based on the primary goal of this report which is to access environmental and health impacts of diets and meals with varying amounts of pork consumed. The main food groups are bolded in **Table 1** and their subcategories are underneath them. The “protein foods” category was disaggregated into eggs, fish/seafood, nuts/seed/soy, poultry, beans/peas (legumes), and red meat group. It was necessary to separate the “red meat” category represented in USDA food patterns. This category was separated into “beef”, “pork”, and “other meats”. The “Other meats” group represents lamb, veal, and game meat.

Table 1. List of dietary food groups from USDA LAFA database

Food groups
Fruits and Juices
• Whole fruit
• Fruit juice
Vegetables
• Dark green vegetables
• Starchy vegetables
• Red and orange vegetables
Grains
• Whole grains
• Refined grains
Dairy Products
• Fluid milk
• Dry milk
• Ice cream
• Yogurt
• Cheese
• Soymilk
Protein Foods
• Eggs
• Fish/seafood
• Nuts, seeds, soy products
• Poultry
• Beef
• Pork
• Other meats
• Legumes (beans and peas)
Oils
Solid Fats
Added Sugars

9. Methodology of Dietary Scenarios

The dietary scenarios are split into two sections. The first section is based on a 2000 calorie diet and includes the USDA Food Pattern 2010, the USDA Lacto-Ovo Vegetarian Adaptation of the USDA Food Patterns 2010, and the "Usual U.S. Intake: Adults" consumption pattern from the USDA dietary Guidelines 2010, Table 5-1 Eating Pattern Comparison. Three iso-caloric dietary scenarios are created from “Usual U.S. Intake: Adults”.

The second section of dietary scenarios is based on the LAFA Database. This database has information on consumption of food adjusted for loss. There are several years presented in the database. For the purposes of this study, the most recent year available, 2015, was used. Values for consumption of each food group per day were used to create the first framework dietary scenario. The data was converted from grams to calories based on the conversion ratios provided by the LAFA database. From this diet, three alternative, iso-caloric diets were constructed.

9.1. USDA Dietary Scenarios

The “Usual U.S. Intake: Adults” consumption pattern was used to create three alternative, iso-caloric dietary scenarios. The first alternative dietary scenario takes the pork calories consumed calculated from the “Usual U.S. Intake: Adults” consumption pattern and distributes them to all food groups based on the ratio that these food groups are consumed. This leaves zero calories of pork consumed with additional calories for all other food groups. The second alternative dietary scenario doubles the amount of pork calories consumed from the “Usual U.S. Intake: Adults” while decreasing this added amount of pork calories from all other food groups based on the ratio of their consumption. The third alternative dietary scenario is similar to the second as it doubles the amount of pork calories, but it only decreases this amount of calories from the poultry and beef food groups based on their ratio of consumption. All three of these alternative dietary scenarios have the same amount of calories consumed as the original “Usual U.S. Intake: Adults” consumption pattern which is based on a 2000 calorie diet. These four diets were then compared to the USDA Food Pattern 2010 and the USDA Lacto-Ovo Vegetarian Adaptation of the USDA Food Pattern 2010 both based on a 2000 calories. The “Usual U.S. Intake: Adults” consumption pattern, USDA Food Pattern, and USDA Lacto-Ovo Vegetarian Food Pattern were all reported in grams by the USDA. Gram to calorie conversions were calculated based on the conversion ratios provided by Appendix E-3.1: Adequacy of USDA Food Patterns[41].

Below in **Table 2** is the "Usual U.S. Intake of Adults" consumption pattern with each corresponding food group. This consumption pattern was used to create three other dietary scenarios based on the daily number of pork calories ingested.

Table 2. "Usual U.S. Intake of Adults" in grams and calories.

Food Groups	Grams	Kcal
Fruits and Juices total	171	101
Whole Fruit	99.3	58.6
Fruit Juice	71.9	42.4
Vegetables: total	174	131
Dark Green Vegetables	11.6	4.28
Starchy Vegetables	57.9	92.1
Red and Orange Vegetables	46.4	12.3
Other Vegetables	57.9	22.2
Grains: total	181	523
Whole Grains	17.0	53.4
Refined Grains	164	470
Dairy Products	207	122
Milk	107	62.6
Dry Milk	0.621	0.365
Ice cream	5.38	3.16
Yogurt	3.74	2.20
Cheese	88.3	51.9
Soymilk	2.28	1.34
Protein Foods	149	298
Eggs	11.3	31.2
Fish/seafood	14.2	21.0
Nuts, Seeds, and Soy Products	14.2	34.0
Poultry	34.0	60.0
Beef	47.2	90.0
Pork	22.1	34.5
Other Meats	1.56	2.68
Legumes (beans and peas)	4.43	24.2
Oils	18.0	155
Solid Fats	43.0	348
Added Sugars	79.0	301

The USDA recommended food pattern and the USDA Lacto-Ovo Vegetarian Food Pattern were compared to this scenario and the other three derived from it. The calorie conversions for

USDA recommended food pattern and the USDA Lacto-Ovo Vegetarian Food Pattern were also taken from Appendix E-3.1: Adequacy of USDA Food Patterns[41].

9.2. LAFA Dietary Scenarios

Three alternative diets were constructed from the LAFA database. The methodology of these alternative diets is the same as was used in the three alternative diets based on "Usual U.S. Intake: Adults" consumption pattern. The first alternative diet takes the pork calories consumed as reported by the LAFA database and distributes them to all the other food groups based on their ratio of consumption. The second alternative diet doubles the amount of pork consumed as reported by the LAFA Database and subtracts the exact amount that was added from all other food groups based on their ratio of consumption. The third alternative diet doubles the amount of pork consumed exactly as the second alternative diet did, and subtracts the increased amount of calories from only poultry and beef based on their ratio of consumption. All three of these alternative diets are iso-caloric with the original current consumption diet as reported by the LAFA database.

Average American food consumption as presented by LAFA for each food groups is shown below in **Table 3** grams and calories. This food consumption pattern was used to create three other dietary scenarios based on average daily pork calories consumed.

Table 3. Average American food consumption in grams and calories from LAFA database.

Food Group	Grams	Kcal
Fruits and Juices total	149	81.5
Whole Fruit	80.6	50.2
Fruit Juice	68.4	31.3
Vegetables: total	192	147
Dark Green Vegetables	23.7	8.02
Starchy Vegetables	70.5	110
Red and Orange Vegetables	59.4	14.1
Other Vegetables	38.9	14.9
Grains: total	152	553
Whole Grains	14.2	56.7
Refined Grains	138	496
Dairy Products	204	240
Milk	138	70.6
Dry Milk	2.86	10.7
Ice Cream	16.8	32.7
Yogurt	16.9	18.6
Cheese	29.8	108
Soymilk	0	0
Protein Foods	193	506
Eggs	25.2	69.4
Fish/seafood	10.8	12.1
Nuts, Seeds, and Soy Products	0.981	4.68
Poultry	69.2	188
Beef	49.4	143
Pork	36.6	86.6
Other Meats	0.753	1.96
Legumes (beans and peas)	7.400	9.90
Oils	20.8	184
Solid Fats	49.8	418
Added Sugars	96.1	366

10. NHANES Meals with and without Pork

The NHANES section sourced data directly from Dettling et al. Dettling et al. presents a table of meat containing and meatless meals for breakfast, lunch, and dinner. The table lists specific foods that are consumed during these meal times. The information from this report was taken from National Health and Nutrition Examination Survey (NHANES) 2011-2012 and adjusted. NHANES is a program meant to assess the health and nutrition of children and adults in America through physical examinations and interviews [42]. NHANES conducts surveys that ask the participants what they eat throughout the day for each eating occasion, breakfast, lunch, dinner, and snacks. Since this data is self-reported, it may be altered to include more or less food than was actually consumed. In NHANES 2011-2012, approximately 5,000 adult male and females completed the survey describing in detail the foods consumed during a 24 hour period for breakfast, lunch, dinner, and snacks[42]. For the purposes of this study, snacks were not taken into account for dietary or meal plan scenarios. The data sourced from NHANES is not indicative of specific individuals but of a sample of the American population[42].

The third dietary scenario section takes the specific foods as listed in Table 6 from Dettling et al. and distributes them to the food subgroups used in the previous dietary scenario sections[5]. Dettling et al. calculated consumed meals as reported by NHANES and meal adjusted for waste. This study is focused on the actual amount of food that is consumed daily and during meals. Some specific foods from Dettling et al. are mixtures[5]. The consumption of these mixtures was distributed to all food groups they encompassed based on an equal ratio depending on the weight of the food. The distribution between different food groups such as meat, vegetables, and grains was based on equal allocation as was done in Dettling et al[5]. The specific foods that were used for the distribution are listed below.

- Meat, not specific as to type
- Organ, sausages, lunchmeats, spreads
- Meat, poultry, fish, with nonmeat items

- Vegetables with meat, poultry, fish
- Frozen, shelf stable plate with meat

For the total amount of “Meat, not specific as to type” eaten, breakfast, lunch, and dinner added together for the dietary scenarios, weight ingested was distributed among beef, poultry, pork, fish, and other meat subgroups based on the percent consumption of each of these subgroups. The total amount consumed (breakfast, lunch, and dinner added together) of “Organ, sausages, lunchmeats, spreads” was distributed to beef, pork, poultry, fish, and other meat by percent consumption calculations. For “Meat, poultry, fish, with nonmeat items” there was a calculated 50% consumption of meats and a 50% consumption of vegetables. The 50% meat consumption was distributed to beef, pork, poultry, fish, and other meat from percent consumption values of 50% of the total “Meat, poultry, fish, with nonmeat items” consumed. The other 50% was distributed to the vegetables food group. The food group “Vegetables with meat, poultry, and fish” was distributed to the same groups as “Meat, poultry, fish, with nonmeat items”. The allocation of meats and vegetables is also 50% each with further distributions based on the percent consumption of the food subcategories. The final mixture category from Dettling et al, “Frozen, shelf stable plate with meat”, was distributed among meats, vegetables, and grains evenly, on a 1/3 ratio. From there the amount is further allocated to the meat, vegetable, and grain subgroups based on the percent consumption of each subgroup.

Once all specific foods from Dettling et al were allocated to their corresponding subgroups and gram values were determined for the third dietary scenario section, calorie conversions were calculated from LAFA as was used previously in the second dietary scenario section. These calorie conversions were used as they are representative of many different kinds of foods consumed for each subcategory which displays an accurate value for calorie conversion and consumption.

Data for the third section of dietary scenarios comes from Dettling et al[5]. Dettling et al. used meals in the study, so for this dietary scenario meals were combined[5]. Dettling et al. directly obtained data from NHANES (2011-2012). Data for the framework dietary scenario was acquired from “meat containing meals”, and data from NHANES as provided by Dettling et al. The foods listed in Table 6 from Dettling et al. are specific and therefore had to be distributed to the food groups used in this study[5]. The consumption data was presented in grams and converted into calories based on the conversion ratios found in the LAFA database. The dietary scenario framework previously described was used to create three alternative dietary scenarios. The first scenario takes the amount of pork calories consumed as reported by Dettling et al. and distributes them to all other food groups based on their ratio of consumption[5]. The second alternative diet doubles the amount of pork calories consumed and subtracts this increased amount from all other food groups based on their ratio of consumption. The third alternative dietary scenario doubles the amount of pork calories and subtracts this increased amount by only poultry and beef based on their ratio of consumption.

The specific food distribution into food groups for these three dietary scenario sections are in **Figure 3**. Main food groups are bolded, and subcategories are below their corresponding main food groups. Specific foods are listed in a blue font color underneath their matched subcategories. The specific foods listed as “mixtures” are referring to the specific food mixtures from Dettling et al. The allocation of these mixtures is described in detail under “Dietary Scenario Systems-Third Dietary Section”. In the “Grains” food group, the amount of each specific food consumed for each meal was added together and then allocated to whole and refined grains based on the percent consumption of whole and refined grains from the LAFA database. The meals were added together to create a diet. A diet is defined as a whole day of food consumption. Distributing foods for meal times is not necessary for diets.

- **Fruits and Juices total**
- **Whole Fruit**
- dried fruits
- other fruits
- **Fruit Juice**
- citrus fruits; juices
- fruit juices and nectars excl. citrus
- **Vegetables: total**
- **Dark Green Vegetables**
- dark green vegetables
- **Starchy Vegetables**
- white potato, starch vegetables
- **Red and Orange Vegetables**
- deep yellow vegetables
- tomato and tomato mixtures
- **Other Vegetables**
- other vegetables
- Mixtures
- mixtures mostly vegetables without meat
- **Grains: total**
- yeast breads, rolls
- quick breads
- cakes, cookies, pies, pastries
- crackers and salty snacks from grain
- pancakes, waffles, French toast, other
- pasta, cooked cereals, rice

- cereals not cooked or not specified
- grains mixtures, frozen plate meals, soup
- meat substitutes mainly cereal protein
- Mixtures
- **Whole Grains**
- **Refined Grains**
- **Dairy Products**
- **Fruits and Juices Total**
- **Milk**
- milk and milk drinks
- cream and cream substitutes
- **Dry Milk**
- **Ice Cream**
- milk desserts, sauces and gravy
- **Yogurt**
- **Cheese**
- Cheeses
- **Soymilk**
- **Protein Foods**
- **Eggs**
- Eggs
- egg mixtures
- egg substitutes
- **Fish/seafood**
- fish and shellfish
- Mixtures

- **Nuts, Seeds, and Soy Products**
- nuts and nut butters
- seed and seed mixtures
- **Poultry**
- Poultry
- Mixtures
- **Beef**
- Beef
- Mixtures
- **Pork**
- Pork
- Mixtures
- **Other Meats**
- lamb, veal, game, other carcass meat
- Mixtures
- **Legumes (beans and peas)**
- Legumes
- **Oils**
- Oils
- salad dressings
- **Fruit and Juices Total**
- **Solid Fats**
- Fats
- **Added Sugars**
- sugars and sweets

Figure 3. Specific food distribution into food groups

Once the specific foods were distributed to their corresponding groups, the consumption in grams was recorded for each category and subcategory and calorie conversions were also made. **Table 4** depicts NHANES data after specific foods were distributed to this study's categories in grams and calories.

Table 4. NHANES data for meat containing meals after specific foods were distributed in grams and calories

Food Group	Grams	Kcal
Fruits and Juices	116	59.0
Whole Fruit	36.9	23.0
Fruit Juice	78.7	36.0
Vegetables	322	203
Dark Green Vegetables	17.2	5.82
Starchy Vegetables	73.6	114
Red and Orange Vegetables	39.9	9.48
Other Vegetables	191	73.2
Grains	294	1,136
Whole Grains	29.2	116
Refined Grains	265	956
Dairy Products	93.9	113
Milk	67.6	34.6
Dry Milk	0	0
Ice Cream	9.96	19.4
Yogurt	0	0
Cheese	16.3	58.8
Soymilk	0	0
Protein Foods	359	934
Eggs	48.7	134
Fish/seafood	49.6	55.5
Nuts, Seeds, and Soy Products	2.09	9.97
Poultry	108	293
Beef	96.5	279
Pork	51.1	121
Other Meats	3.47	9.05
Legumes	25.1	33.6
Oils	10.5	92.9
Solid Fats	3.61	30.3
Added Sugars	14.6	55.5
Total	1,238	2,560

10.1. Meals Containing Pork

Three sample meal plan scenarios (breakfast, lunch, and dinner) were constructed using the original NHANES meal data, the "meals containing meat"[5]. The following table presents the aggregated NHANES meal data into each food group for breakfast, lunch, and dinner. It shows a tendency that American consume the most of fruits/juices, vegetables, grains, milk/dairy, and eggs during breakfast. The amount of pork consumption increases from breakfast through dinner, but the increment is small. Vegetables are consumed more, but grain consumption is responsible for the highest caloric intakes. This is because grains are more nutrient (energy)-dense food than vegetables as a group.

Table 5. NHANES meals in grams and kcal after segregation

Food Group	Breakfast		Lunch		Dinner	
	Grams	Kcal	Grams	Kcal	grams	kcal
Fruits/Juices	57.1	30.1	29.2	15.4	29.3	15.4
Vegetables	45.6	28.5	120	75.0	156	97.5
Grains	92.1	337	102	375	117	429
Milk/Dairy	50.2	54.2	10.7	11.6	33.0	35.7
Eggs	43.6	62.8	2.48	3.57	2.62	3.77
Fish/Seafood	7.88	9.38	15.8	18.8	25.9	30.8
Nuts/Seeds/Soy	0.37	2.27	0.99	6.07	0.73	4.47
Poultry	17.6	40.3	43.2	98.8	46.9	107
Beef	19.2	58.2	35.1	106	42.3	128
Pork	15.4	41.8	17.0	46.4	18.7	50.9
Other meats	0.60	1.58	0.97	2.53	1.89	4.94
Legumes	4.29	5.83	8.49	11.5	12.3	16.8
Oils	1.10	9.71	4.61	40.7	4.82	42.5
Solid Fats	1.73	14.5	0.60	5.04	1.28	10.8
Sweeteners	8.94	34.1	2.45	9.33	3.19	12.2

10.2. Porkless Meals

Porkless meals were constructed by using the meal data containing meat. I removed pork from each meal and distributed equal number of removed pork calories (breakfast = 41.8 kcal, lunch = 46.4 kcal and dinner = 50.9 kcal) to beef and poultry only based on initial consumption ratio (beef : poultry = 55 : 45) for breakfast, lunch and dinner. The caloric contents of meals containing pork and porkless meals are the same. **Table 6** presents aggregated food group of porkless meal scenarios for breakfast, lunch and dinner.

Table 6. Porkless meal in grams and kcal

Food Group	Breakfast		Lunch		Dinner	
	Grams	Kcal	Grams	Kcal	grams	kcal
Fruits/Juices	57.1	30.1	29.2	15.4	29.3	15.4
Vegetables	45.6	28.5	120	75.0	156	97.5
Grains	92.1	337	102	375	117	429
Milk/Dairy	50.2	54.2	10.7	11.6	33.0	35.7
Eggs	43.6	62.8	2.48	3.57	2.62	3.77
Fish/Seafood	7.88	9.38	15.8	18.8	25.9	30.8
Nuts/Seeds/Soy	0.37	2.27	0.99	6.07	0.73	4.47
Poultry	25.8	59.1	52.2	120	56.8	130
Beef	26.8	81.2	43.5	132	51.5	156
Pork	0.00	0.00	0.00	0.00	0.00	0.00
Other meats	0.60	1.58	0.97	2.53	1.89	4.94
Legumes	4.29	5.83	8.49	11.5	12.3	16.8
Oils	1.10	9.71	4.61	40.7	4.82	42.5
Solid Fats	1.73	14.5	0.60	5.04	1.28	10.8
Sweeteners	8.94	34.1	2.45	9.33	3.19	12.2

11. LCA Methodology

Two types of methodology were used in the LCA model. The first type is called an input output model (IO), and the second type is the process model. In the input output model each food group is modeled based on economic input output data. The IO-based model uses energy and materials data that is taken from economic data. I was not responsible for creating the IO model; however, the results are important for this project, so I included them below. The process-based modeling follows standard recommendations from the Society of Environmental Toxicology and Chemistry. Inputs and outputs are based on data from the agriculture stages of a product to its end of life, and the entire process is modeled. All the raw materials are accounted for as well as the byproducts that are created in the life cycle process[44].

11.1. IO-Based Model Methodology

The purchaser price for each food group is in Table 7. This is an important component to the IO model.

Table 7. Average producer's price per kg of each food group.

Food Group	Expenditure per household [1]	Producer price in dollars per kg	Consumer price in dollars per kg	CEDA price conversion factor
Grains	$ 471	$ 2.04	$ 2.04	1
Beef	$ 429	$ 5.54	$ 6.32	0.876392
Pork	$ 289	$ 4.76	$ 5.43	0.876392
Other Meat	$ 217	$ 10.4	$ 11.9	0.876392
Poultry	$ 301	$ 3.44	$ 3.67	0.937044
Eggs	$ 110	$ 2.66	$ 2.88	0.923671
Fats and Oils	$ 194	$ 1.50	$ 1.62	0.925119
Vegetables	$ 659	$ 1.81	$ 2.08	0.870729
Fruits and Juices	$ 686	$ 2.42	$ 2.78	0.870729
Dairy	$ 722	$ 2.17	$ 2.38	0.910615
Seafood	$ 220	$ 8.66	$ 11.6	0.744562
Nuts, seeds, and soy	$ 39.0	$ 2.90	$ 3.14	0.924242
Legumes	$ 19.7	$ 2.21	$ 2.52	0.877288
Sweeteners	$ 271	$ 1.36	$ 1.59	0.855876

11.2. Process Based Model Methodology

For a thorough approach and understanding of environmental impacts for specific food items as presented in Dettling et al. and NHANES, a process based model is analyzed as well as an IO model. The process model allocates the specific foods to the broader food groups used in the IO model. The following table shows each food product and how it was represented with life cycle inventory data.

Food groups with the classification of mixture are evenly distributed to all categories they represent.

Table 8. Unit process chosen for each food item.

Category from NHANES	Broader Food Groups
Dairy Products	
Milk and milk drinks	Milk
Cream and cream substitutes	Milk
Milk, desserts, sauces, gravies	Ice Cream
Cheeses	Cheese
Protein Foods	
Meat, NS as to type	Beef, pork, poultry, fish, and other meats
Lamb, veal, game, other carcass meat1	Other meat
Organ, sausages, lunchmeats, spreads	Beef, pork, poultry, fish, and other meats
Beef	Beef
Pork	Pork
Poultry	Poultry
Fish and shellfish	Fish/seafood
Meat, poultry, fish with nonmeat items	Meat and vegetable mixture (50/50)
Vegetables with meat, poultry, fish	Meat and vegetable mixture (50/50)
Frozen, shelf-stable plate meals with meat	Meat, vegetable, and grain mixture (1/3)
Eggs	Eggs
Egg mixtures	Eggs
Egg substitutes	Eggs
Legumes	Legumes
Nuts, nut butters, and nut mixtures	Nuts, seeds and soy
Seeds and seed mixtures	Nuts, seeds and soy
Vegetables	
White potatoes, Puerto Rican starch vegetables	Starchy vegetables
Dark-green vegetables	Dark-green vegetables
Deep-yellow vegetables	Red and orange vegetables
Tomatoes and tomato mixtures	Red and orange vegetables
Other Vegetables	Other Vegetables
Mixtures mostly vegetables without meat	Other Vegetables
Grain Products	
Yeast breads, rolls	Grain*
Crackers and salty snacks from grain	Grain
Pasta, cooked cereals, rice	Grain
Cereals, not cooked or NS as to cooked	Grain
Grain mixtures, frozen plate meals, soup	Grain
Quick breads	Grain
Cakes, cookies, pies, pastries	Grain
Pancakes, waffles, French toast, other	Grain
Meat substitutes, mainly cereal protein	Grain
Fruits	
Citrus fruits, juices	Fruit juice
Dried fruits	Whole fruit
Other fruits	Whole fruit
Fruit juices and nectars excl. citrus	Fruit juice
Fats, Oils, Sugars, and Sweets	
Fats	Solid fats
Oils	Oils
Salad dressings	Oils
Sugars and sweets	Added Sugars

*****Grains were distributed to whole and refined grain groups based on the ratio of consumption for these grains according to LAFA[28].

12. Assumptions

LAFA, USDA, and NHANES data have been the main sources of data used for this study. They are the most accurate and best references for this research of daily diets and meal consumption. The purpose of this study is to evaluate several meat and meatless dietary scenarios and meal plans based on current consumption and 2000 calories with variations of pork consumed. The evaluation determined the severity of environmental impacts, greenhouse gas emissions, land use, and water use, as well as health effects of the different dietary and meal plan scenarios. LAFA, USDA, and NHANES data are the best sources for this data collection and research. Unfortunately, these sources are still conducive to error; therefore the following assumptions have been made.

1. The data is correct and representative (for current consumption) of the average amount of daily consumption in LAFA and Dettling et al., or accurately portrays consumption based on a 2000 calorie diet[5].
2. The NHANES surveys contains accurate representations of what is currently consumed on a daily basis in the whole American population.
3. It is assumed that the daily consumption information is completely and correctly applicable to the population of which the results would pertain to.
4. It is understood that the non-included beverages in Dettling et al. for meat containing and meatless meals are equal in amount consumed[5].
5. Calorie conversions taken from USDA and LAFA sources are encompassing and accurate of the food groups they constitute.
6. Location that the food is consumed (home, restaurant etc.) does not affect the values of consumption reported.

7. The food groups chosen for dietary and meal plan scenarios are encompassing of the total types of food consumed daily by the average American, and the food groups allocated for the specific foods of the process based simulation are accurately represented.
8. The data from USDA, LAFA, and Dettling et al. sources are correctly used and distributed in the life cycle assessment inventory database created for this research[5].

13. LCA Stages

The following sections describe the food life cycle stages that were analyzed in this assessment. The stages include food manufacturing, packaging, transport, retail, consumption, and end of life.

13.1. Agriculture

The agriculture stage of an LCA consists of environmental impacts associated with harvesting a crop, or raising an animal including food, water, and land required. This stage also accounts for any electricity used in the process of maintaining the crop of livestock.

13.2. Food Manufacturing

Food manufacturing plants process raw agricultural yields for final products for consumption by applying energy, water, machinery, labor, etc. There are about 30,000 food processing plants in U.S. according to the comprehensive data available in the Census Bureau[43]. Since the circumstances of food manufacturing and processing are very broad, USDA ERS estimates of food manufacturing value of shipments in 2011 were adopted.

13.3. Packaging

Approximately one third of the “waste stream” in the United States is from product packaging[30]. Currently, the U.S. population is over 325 million and increasing[29]. The total meals consumed per day is approximately 975 million (375 million*3 meals a day per person). Total municipal solid waste generation in 2014 was approximately 258 million tons[30]. This is the generated amount of waste before “combustion with energy recovery, recycling, and composting[30]. It was reported in 2005 that about 31% of the total MSW is packaging waste[31]. Food packaging waste accounts for two thirds of all packaging waste in the United States[5]. This ratio was used in calculating estimated food packaging assuming that it is accurate. The proportion of food packaging waste thrown away compared to other packaging materials is concluded to be the same.

Food packaging waste can be calculated based on the percent of each type of packaging wasted. Each type of packaging used can be found from “marketing shares of packaging material”[32] (Food Packaging Materials). **Figure 4** shows the amount of different kinds of food packaging material and their percent use in the market. Rigid plastic makes up the majority of food packaging materials used at 27% (**Figure 4**).

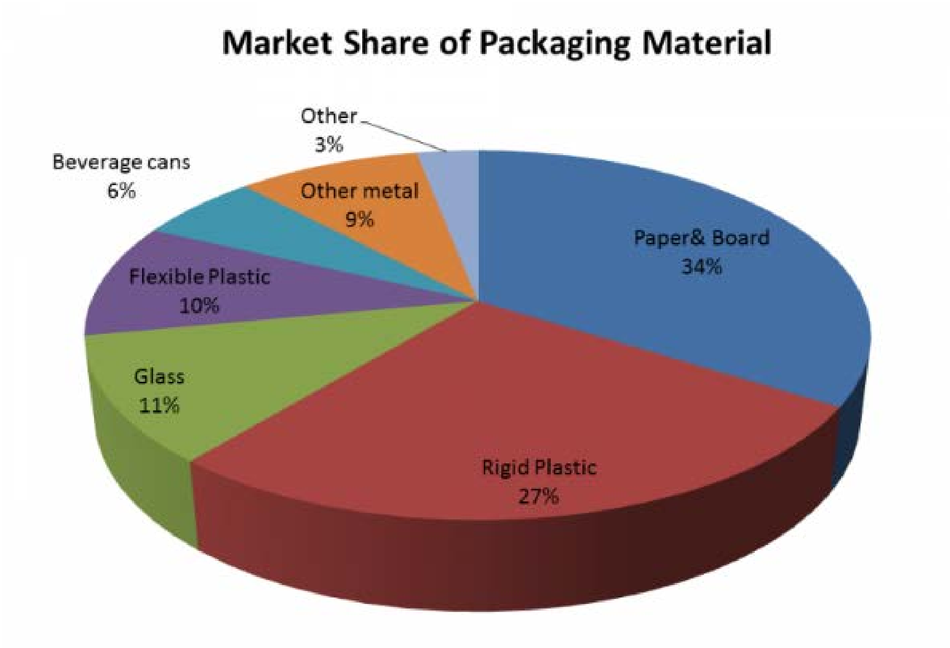

Figure 4. "Market Share of Packaging Material"[32] (Food Packaging Materials).

Packaging for each food item can therefore be determined by multiplying the total municipal solid waste by the percent of this waste that is from packaging waste. That value can then be multiplied by the ratio of packaging waste that is from food packaging which is approximately $5676*10^4$ tons of food packaging waste per year.

This value is then divided to find the amount of food packaging waste per person per meal and per kilogram. Each food group is allocated packaging values for each packaging material based on the "Market Share of Packaging Material" (**Figure 4**) ratios.

The total amount of food consumed in the "Usual U.S. Intake: Adults" dietary scenario based on a 2000 calorie diet is approximately 1022 grams[26]. The amount of food consumed in the current consumption diet according to the LAFA database is approximately 1064 grams[28]. The NHANES daily diet and meals from Dettling et al. report an amount of food consumed per person daily to be around 1255 grams[5]. The average of grams consumed daily for these sources is about 1113.67 grams, and the average amount of food consumed per meal per person is 371.22.

The amount of food packaging wasted per person in the U.S is (($5676*10^4$ tons)/ (365 days) = 155506.85 tons/day; (155506.85 tons/day)/ (325 million people)*(907185 grams/ton)/ (3 meals/day) = 144.69 grams of food packaging/person/meal.

Therefore, for every one gram of food consumed, 0.39 grams of food packaging material is wasted ((371.22 grams of food consumed)/ (144.69 grams of food packaging wasted) = (1 gram of food consumed/ X grams food packaging wasted). Likewise, for every one gram of food packaging material wasted, 2.57 grams of food is consumed ((371.22 grams of food consumed)/ (144.69 grams of food packaging wasted) = (X grams of food consumed/ 1 gram food packaging wasted)). Food packaging used daily can be allocated to each food group based on the amount of consumption with the ratio food packaging wasted to one gram of food consumed. The packaging materials used for each food group is calculated with the proportions provided by **Figure 4**. **Table 9** shows each food group with its corresponding amount of food packaging waste per kg and the assumed type of food packaging.

Table 9. Food Packaging Waste and Type of Food Packaging

Food Groups	Type of Food Packaging
Fruits and Juices	
Whole Fruit	Polymeric films, metal cans[34]
Fruit Juice	Cardboard carton, PET[33]
Vegetables	
Dark Green Vegetables	Flexible packaging, polymeric films, metal cans[34]
Starchy Vegetables	Flexible packaging, polymeric films, metal cans[34]
Red and Orange Vegetables	Flexible packaging, polymeric films, metal cans[34]
Other Vegetables	Flexible packaging, polymeric films, metal cans[34]
Grains	
Whole Grains	Kraft paper bags with LDPE liner, OTR packages, PVC, LDPE, PET, OPP[34]
Refined Grains	Kraft paper bags with LDPE liner, OTR packages, PVC, LDPE, PET, OPP[34]
Dairy Products	
Milk	Paperboard cartons, glass, plastic containers (HDPE, PET, LDPE)[34]
Dry Milk	Metal cans, aluminum foil plastic laminates, fiber cans[34]
Ice cream	Glass, plastic (PS, HIPS, PP)[34]
Yogurt	Glass, plastic (PS, HIPS, PP)[34]
Cheese	Plastic (PET, LDPE, OPET, OPA)[34]
Soymilk	Paperboard cartons, glass, plastic containers (HDPE, PET, LDPE)[35]
Protein Foods	
Eggs	Paperboard cartons, molded wood pulp, filler tray[36]
Fish/seafood	Poly bags, laminated films, vacuum bags, thermoforming film, metal cans[37]
Nuts, Seeds, and Soy Products	
Poultry	Thermoplastic, non-barrier shrink bags, and foam[37]
Beef	Thermoplastic and foam[37]
Pork	Thermoplastic and foam[37]
Other Meats	Thermoplastic and foam[37]
Legumes (beans and peas)	Flexible packaging, polymeric films, metal cans[37]
Oils	X
Solid Fats	X
Added Sugars	X

Marsh et al. provide important information on food packaging materials and uses[38]. The amount of packaging material discarded and recovered from recycling and composting is shown in **Table 10** below.

Table 10. Amount of food packaging recycled/recovered and the percent recovery

Materials	Weight (kg) recovered per kg of waste generated	Percent of recovery to generation
Paper and paperboards (34.1%)	0.59	58.8
Metals (7.6%)	0.51	51.3
Plastics (11.8%)	0.09	9.4
Glass (5.2%)	0.25	25.3
Wood packaging (5.7%)	NA	NA
Other miscellaneous (1.9%)	NA	NA
Total packaging	0.4	39.9

13.4. Transport

It has been reported that food transportation represents approximately 11% of life cycle greenhouse gas emissions[23]. The average American meal has ingredients from five different countries not including the U.S.[39]. In 1997, it was estimated that the total freight of food products from production to retail is about 12,000 t-km per U.S. household per year[23]. There were roughly 125.82 million households in the U.S. in the year 2016[40]. The average total supply chain of food requires 6760 km of travel[23]. Dettling et al. state that the normal meal in the U.S. is about $7.19[5].

This dollar amount equals approximately .014 MJ of energy used from the retail and transportation stages, not including customers driving to pick up food[5].

13.5. Retail

Daesoo et al. did the calculations for this section, but it is an important part of the LCA, so I included it here[43]. Retail is a highly concentrated industry, which has substantial input flows. Retail stores consume great amounts of energy and resources that contribute to environmental impacts. The largest impact streams are electricity for store operations (overhead) and refrigeration system, loss of refrigerants due to leakage, natural gas consumption, and water usage[39][40]. Data on the sales volume and information of space occupancy were analyzed to determine burdens assigned for each food group. Each refrigerated food group was distributed a share of refrigerated space and a share of total grocery space to account for the refrigeration and overhead burdens. Each non-refrigerated food group was allocated a share of total grocery space to account for the overhead burdens which includes air-conditioning.

13.6. Consumption and End-of-Life

Daesoo et al. did this portion of the project; however, it is an important part of the LCA, so I have included it here[43]. The resources used at the consumer phase: transportation for shopping trips, home refrigeration, food preparation appliances, dishwashing, and waste treatment were analyzed. The electricity usage burden was allocated to each food group based on consumer food expenditure data. The **Table 11** represents allocation for food groups at the retail and consumer phase.

Table 7. Food group allocation from retail and consumer phase

Food Group	Supermarket cooling plus refrigeration	Supermarket overhead or Passenger car	Home refrigerator [a]	Food preparation or Dish washer [a]
Vegetables	10.2%	5.30%	14.0%	11.6%
Fruit and Juices	10.8%	5.63%	14.8%	12.3%
Milk and Dairy	13.0%	6.76%	17.8%	14.8%
Grains	2.31%	4.12%	-	9.02%
Red meat	16.0%	8.30%	21.9%	18.2%
Poultry	4.81%	2.50%	6.60%	5.48%
Eggs	1.49%	0.78%	2.05%	1.70%
Fish and Seafood	4.07%	2.12%	5.58%	4.64%
Beans and Peas	0.11%	0.19%	-	0.42%
Nuts and Seeds	0.21%	0.38%	-	0.84%
Fats and Oils	2.10%	1.69%	2.22%	3.69%
Sweeteners	1.24%	2.22%	-	4.86%
Total	66.4%	40.0%	85.0%	87.6%

14. Results and Discussion

Greenhouse gas emissions for the USDA six dietary patterns associated with process mechanisms were analyzed. All of the patterns studied were all iso-caloric based on 2000 kcal. The process and IO analysis showed similar trends in impacts. It was found that the current food consumption patterns emit approximately 7.95 kg CO_2-eq/person/day of greenhouse gasses from the process modeling analysis. The main contributors to these emissions are dairy products and red meat. The USDA recommended consumption pattern (2000 kcal) using the process-based analysis has the highest amount of greenhouse gas emission at 9.8 kg CO_2-eq/person/day. The main emissions for this dietary pattern is red meat, dairy, fruit, and juices. Retail and consumption stages also significantly contributed to greater emissions.

The current consumption pattern dietary scenario 2, CCP_2000_S2, doubles the daily amount of pork consumed while subtracting that amount of calories equally from the remaining food groups. This diet increases the greenhouse gas emissions. The current consumption pattern dietary scenario 3, CCP_2000_S3, doubles the amount of daily pork calorie intake while subtracting this value only from beef and poultry. This scenario has the second smallest amount of greenhouse gas emissions at 7.8 kg CO2-eq/person/day from the IO based analysis. This value is lower than the current food consumption patterns on a 2000 kcal per day diet. This indicates that by doubling the calories of pork consumed per day while decreasing this value from beef and poultry could leads to reduction of greenhouse gas emissions. The lowest greenhouse gas emissions per day are seen in the USDA Lacto-Ovo Vegetarian Food Pattern, RCP_2000_Veg, using the process based analysis at 6.9 kg CO2-eq/person/day. **Figure 5** compares the greenhouse gas emissions of process based and IO based dietary scenarios from the USDA dietary guidelines and food patterns[43]. I did not do any IO based calculations; however, I do find the inclusion of them in this report to be important. A pairwise statistical analysis was used to compare diets with a 99.9% confidence interval[45]. It can be concluded that because there were 1000 simulations, there are significant differences between the diets. The statistical analysis is in the Appendix. The different letters above each diet in the following graph represents the statistical variation between the diets.

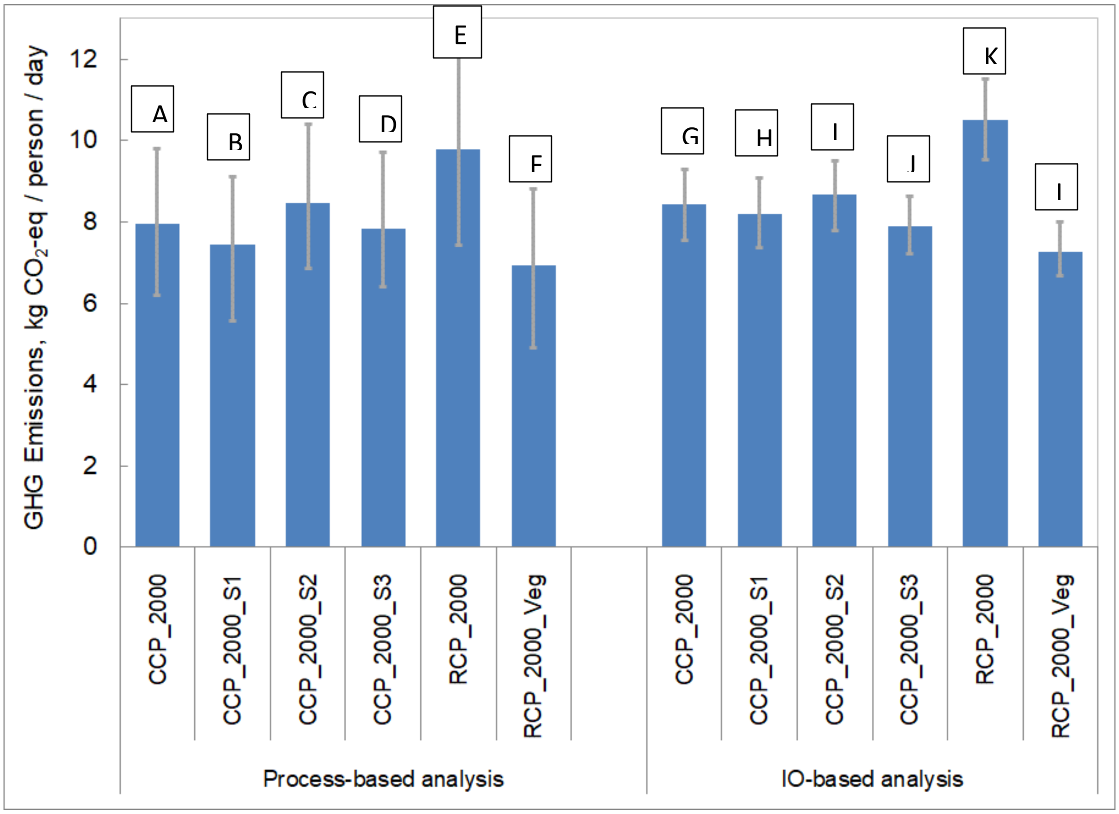

Figure 5. Greenhouse gas emissions of process based and IO based dietary scenarios[43]

Figure 6 compares greenhouse gas emissions among meal scenarios with and without pork for breakfast, lunch, and dinner. The porkless meal was created by distributing the amount of pork calories consumed during breakfast, lunch, and dinner to poultry and beef only. The other meal plans I created were not compared. The four major food groups that cause the greatest amount of greenhouse gas emissions are beef, poultry, vegetables, and fish/seafood. There are no significant differences between pork containing versus porkless meals and greenhouse gas emissions. There is a table in the Appendix of all values for each food group and meal.

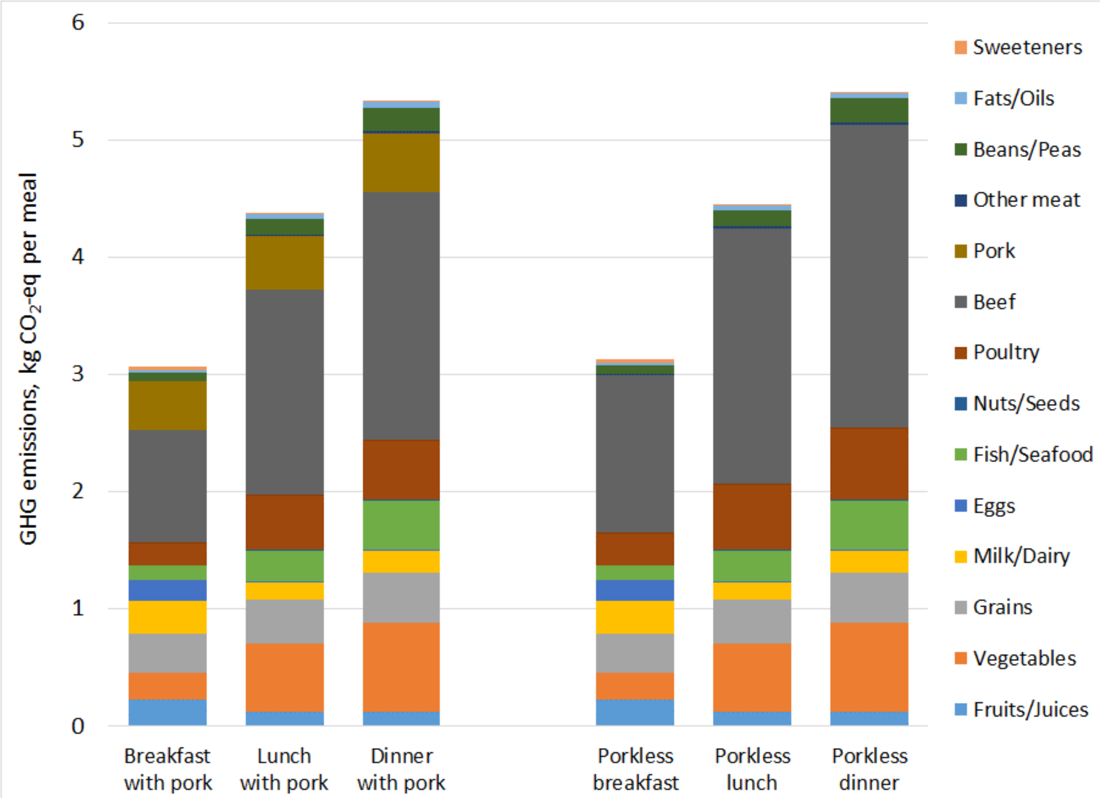

Figure 6. Greenhouse gas emissions for meal scenarios[43]

<u>Figure 7</u> compares the LAFA diet scenarios using a process-based and IO-based analysis. LAFA_Current represents current U.S. consumption, approximately 2,550 kcal per day. LAFA_S1 is the diet that has no pork consumption with the calories distributed evenly to all other food groups. LAFA_S2 is the diet that doubled the amount of pork consumed while consumption in all other food groups were decreased evenly. LAFA_S3 is the diet that doubled the amount of pork consumed and decreased the calories from only beef and poultry. LAFA_Veg is the meatless LAFA diet. All meat calories were distributed evenly to all other food groups. Greenhouse gas emissions were approximately equal across all dietary scenarios except LAFA_Veg which was the lowest diet. A pairwise statistical analysis was used to compare diets with a 99.9% confidence interval[45]. It can be concluded that because there were 1000 simulations, there are significant differences between the diets. The statistical analysis is in the Appendix. The different letters above each diet in the following graph represents the statistical variation between the diets.

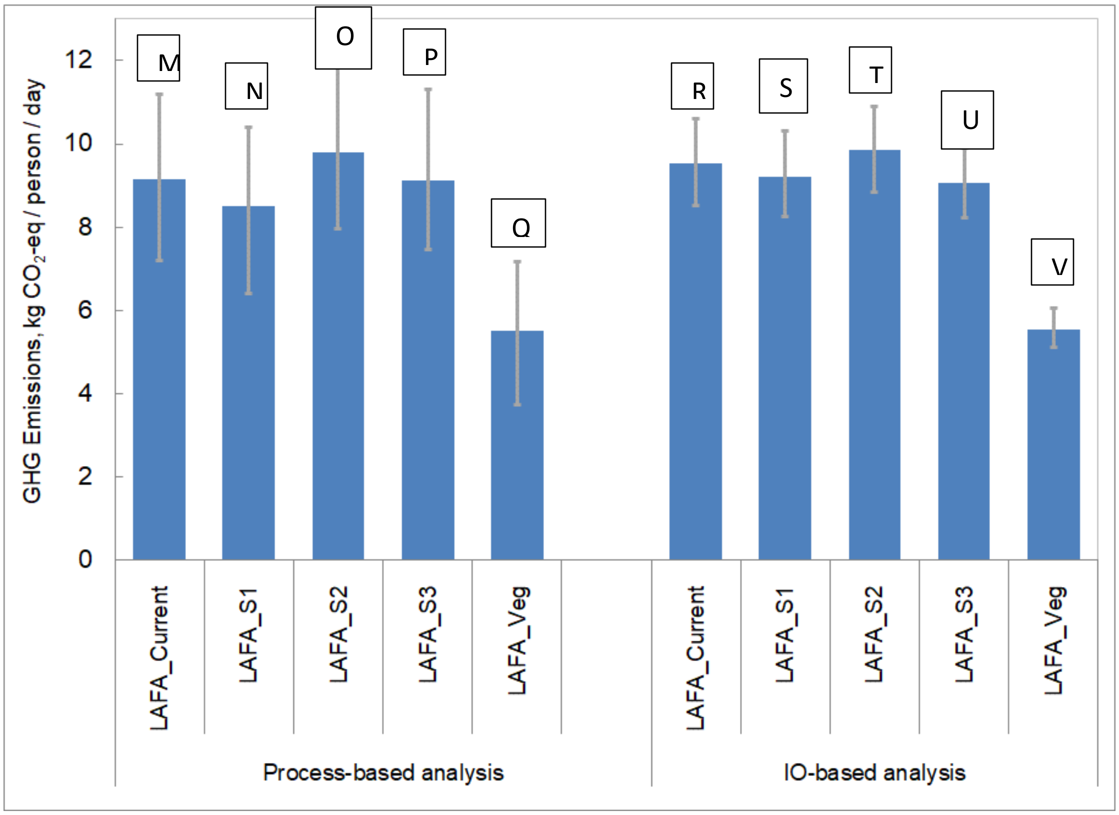

Figure 7 Greenhouse gas emission comparison for LAFA diets[43]

In **Figure 8** impact of land use is compared for the pork containing and porkless meal scenarios. This graph only compares meal consumption with pork to porkless meals that are substituted entirely with beef and poultry. Not all of the meals that I created from NHANES data were analyzed. The food groups that contribute the most to land use in porkless meals are poultry, beef, and grains. A porkless meal results in an overall increase in land use impacts by 6-8%. There is a table in the Appendix of all values for each food group and meal.

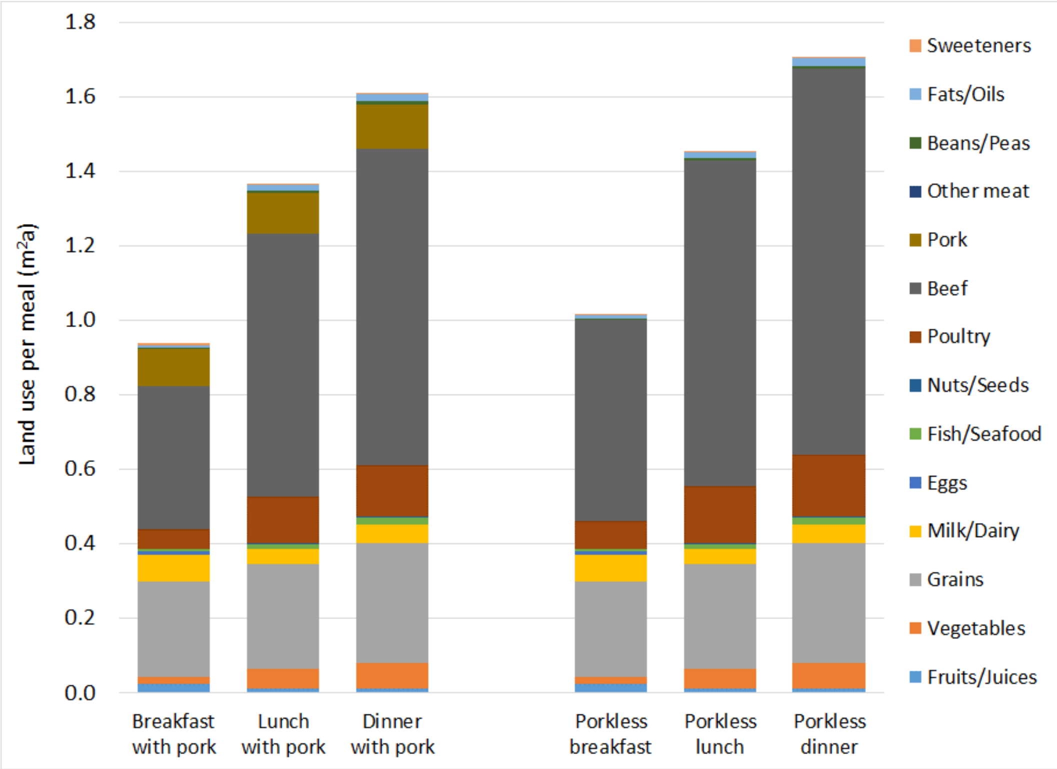

Figure 8. Land use of pork versus porkless meals[43]

The **Figure 9** compares water use impacts of the pork containing and porkless meal scenarios. This graph only compares meal consumption with pork to porkless meals that are substituted entirely with beef and poultry. The other meal scenarios I created were not analyzed. In porkless meals, grains, poultry, and beef have the highest water impact. Irrigation to grow crops requires the most water. Porkless meals for breakfast, lunch, and dinner show a reduction in water use by 3-4%. There is a table in the Appendix of all values for each food group and meal.

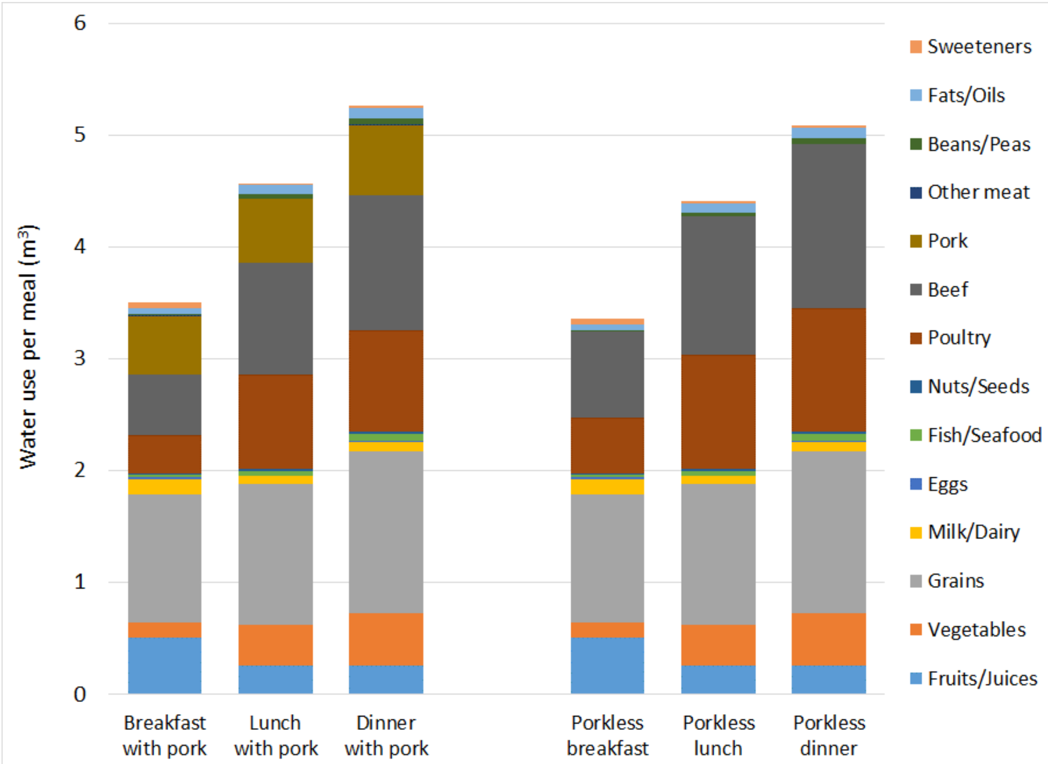

Figure 9. Water use of pork versus porkless meals[43]

Greenhouse gas emissions, water use, and land use are important environmental impacts to consider in food consumption. These environmental impacts are critical for educating the public about how choosing a sustainable diet is not as easy as many may think. The results are also helpful for the pork industry for identifying hot spots in their food supply chain which could allow for the increase in pork production while decreasing negative environmental impacts and environmental burdens. Greenhouse gas emission data is generally the most significant of the other environmental impacts. However, in this study it was found that the emissions for a porkless diet and pork diet are approximately the same. The results show that the largest greenhouse gas contributors are beef, poultry, vegetables, and fish/seafood. This result is consistent with results from previous studies. Even though one diet is not less environmentally impactful than the other it would be beneficial for the pork industry reduce its greenhouse gas emissions where possible in order to decrease environmental burden. This could also provide the pork industry an advantageous marketing opportunity. For land use, it was found that porkless meals use more land mainly because of beef, poultry, and grains. This is good marketing material for the pork industry. The water consumption comparison between the different diets showed that porkless meals use less water overall. This information allows an opportunity for the pork industry to find ways to reduce water in the production of pork.

15. Conclusion

The statistical pairwise analysis used for the USDA and LAFA diets concluded that there are significant variations between the different diets in the process and IO based analyses[45]. This can be seen in the Appendix. Not all pairs of diets were analyzed because it can be concluded that the large number of runs may be the reason for the calculations showing significant variation. To have a complete statistical analysis comparing the differences between diets would require additional evaluation of statistical methods.

Calculating environmental impacts of different food groups is important for consumers as well as food industries. The consumer can use this information as educational in understanding that choosing sustainable diets is complex, and the pork industry can use these results in identifying hotspots in the production of pork. Although pork and porkless diets produce approximately the same amount of greenhouse gas emissions, there is still opportunity to decrease this value in the pork industry. By decreasing greenhouse gas emissions, the pork industry could potentially increase production and decrease cost and environmental burden. Porkless meals have a higher land impact than meals that contain pork. This is good marketing information for the pork industry, and other food industries can look at ways to potentially decrease their land usage. Pork containing meals use more water than porkless meals. It would be beneficial for the pork industry to identify the hot spots in pork production where water usage can be decreased. This will lessen the environmental impact as well as save money. The conclusion that can be made for health impacts, which is a part of the study I did not work on, is that red meat and processed meat are much less healthy than other food groups. This result is supported by previous studies as well.

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Appendices

Food Group Calculations

Fruit and Juices

For the main food group of “Fruits and Juices”, data from “Total fruit-fresh and processed” is used for daily per capita gram and calorie consumption. The two subcategories of “Fruits and Juices” are “whole fruit” and “fruit juice”. Data for “whole fruit” is calculated from consumed fruit from the ratio of what is considered whole fruit under specific subcategories in LAFA from the “Fruit” spreadsheet. This ratio is based on the amount of total fruit consumed in grams from the “Total fruit-fresh and processed” spreadsheet. The value of fruit consumed in grams per day is found under the column “per capita availability adjusted for loss-G/day” for the year 2014. “Fruit juice” data is calculated from the ratio of consumed fruit juice as depicted in the “Fruit” section of the LAFA data. Gram to calorie conversions were calculated from the LAFA database as well for the second dietary scenarios. For the subgroup “whole fruits”, gram to calorie conversions came from the “Total fresh fruit” category in the “Fruits” LAFA database. For “fruit juice” gram to calorie conversions came from the “Total fruit Juice” category in the “Fruits” LAFA database.

Vegetables

Data for daily per capita consumption of the main food group “Vegetables” is taken from the “Total vegetables-fresh and processed” category from the LAFA database. There are four subgroups under this main food group which include dark green vegetables, starchy vegetables, red and orange vegetables, and other vegetables. To calculate the daily per capita consumption for each subcategory, the consumption under “per capita availability adjusted for loss-G/day” from “Total vegetables-fresh and processed” (LAFA) is used to create the ratio of each specific subcategory consumed. Gram to calorie conversions for each sub category were sourced from Appendix E-3.1: Adequacy of USDA Food Patterns[41]. This appendix presents calories per cup for all the “Vegetable” subgroups. This source was used instead of the LAFA database for two reasons. The first reason is because many specific vegetables listed in the “Vegetables” LAFA database do not fit under the vegetable subgroup categories. It would be inaccurate to separate and average the calories per gram of each specific vegetable in the LAFA database and distribute them to the “Vegetable” subgroups for this study. Second, the calories listed for each vegetable subgroup in Appendix E-3.1[41], or “essential calories”, are consistent with the actual caloric content for these subgroups. This is because there are not many variations between vegetable calorie conversions.

Grain

Per capita per day consumption for the main food group “Grain” is taken from the LAFA grain spreadsheet. The daily consumption in grams is sourced specifically from the “Total grains” category. The two subgroups for this category are whole grains, and refined grains. The gram per day consumption of the “whole grains” subcategory is calculated by dividing the consumption of whole grains with the total amount in grams of grain consumption daily. The “refined grains” subcategory was computed in the same way by dividing the consumption of “refined grains” by the total gram/day per capita consumption of grains as depicted by the “Total grains” LAFA data. Calorie conversions for whole grains was sourced from averaging the calories/day from the following categories of the “Grains” section from the LAFA database: “whole grains”, “wheat flour”, “rye flour”, “oat products”, and “barley products”. Calorie per day conversions for the “refined grain” category was sourced from averaging calories/day of the following groups under “Grains” in the LAFA database: “corn products”, “corn flour and meal”, “corn hominy and grits”, “corn starch”, and “rice”. The LAFA calorie conversions is the most accurate source when converting from grams to calories for the grains food group.

Dairy Products

The “Dairy products” category uses “Total dairy products” from the LAFA database. The daily consumption per capita of “Total dairy products” is distributed to the dairy product subcategories based on the ratio under the different subgroups of dairy in the dairy database. Calorie conversions were found for each subgroup on the LAFA dairy database.

Protein Foods

The “Protein foods” category is mainly taken from the LAFA spreadsheet titled “Meat, poultry, fish, eggs, and nuts”. All subcategories for the protein foods are accounted for in this spreadsheet except for legumes. Information for legumes was sourced from the “vegetable” LAFA spreadsheet. Exact values for the amount of consumption per capita per day for each subcategory are available on the LAFA database. Gram to calorie conversions were sourced from the specific subgroups in the LAFA database.

Environmental Impacts of Meals Tables

Greenhouse Gas Emissions for Pork Containing and Pork Free Meals

GHGEs	kg CO_2 eq						
	Breakfast with pork	Lunch with pork	Dinner with pork			Pork-free breakfast	Pork-free lunch
Fruits/Juices	0.23	0.12	0.12		0.23	0.12	
Vegetables	0.22	0.59	0.76		0.22	0.59	
Grains	0.33	0.37	0.43		0.33	0.37	
Milk/Dairy	0.29	0.15	0.19		0.29	0.15	
Eggs	0.17	0.01	0.01		0.17	0.01	
Fish/Seafood	0.13	0.26	0.42		0.13	0.26	
Nuts/Seeds	0.00	0.01	0.01		0.00	0.01	
Poultry	0.19	0.47	0.51		0.28	0.57	
Beef	0.96	1.75	2.11		1.34	2.18	
Pork	0.41	0.45	0.50		0.00	0.00	
Other meat	0.01	0.01	0.02		0.01	0.01	
Beans/Peas	0.07	0.14	0.20		0.07	0.14	
Fats/Oils	0.02	0.04	0.05		0.02	0.04	
Sweeteners	0.04	0.01	0.01		0.04	0.01	
Total	3.07	4.38	5.34		3.13	4.45	

Land Use for Pork Containing and Pork Free Meals

Land Use	m2a						
	Breakfast with pork	Lunch with pork	Dinner with pork			Pork-free breakfast	Pork-free lunch
Fruits/Juices	0.02	0.01	0.01		0.02	0.01	0.01
Vegetables	0.02	0.05	0.07		0.02	0.05	0.07
Grains	0.25	0.28	0.32		0.25	0.28	0.32
Milk/Dairy	0.07	0.04	0.05		0.07	0.04	0.05
Eggs	0.01	0.00	0.00		0.01	0.00	0.00
Fish/Seafood	0.01	0.01	0.02		0.01	0.01	0.02
Nuts/Seeds	0.00	0.00	0.00		0.00	0.00	0.00
Poultry	0.05	0.13	0.14		0.08	0.15	0.17
Beef	0.39	0.70	0.85		0.54	0.87	1.04
Pork	0.10	0.11	0.12				
Other meat	0.00	0.00	0.00		0.00	0.00	0.00
Beans/Peas	0.00	0.00	0.01		0.00	0.00	0.01
Fats/Oils	0.01	0.02	0.02		0.01	0.02	0.02
Sweeteners	0.00	0.00	0.00		0.00	0.00	0.00
Total	0.94	1.36	1.61		1.02	1.45	1.70

Water Use for Pork Containing and Pork Free Meals

Water use	m3						
	Breakfast with pork	Lunch with pork	Dinner with pork			Pork-free breakfast	Pork-free lunch
Fruits/Juices	0.51	0.26	0.26		0.51	0.26	0.26
Vegetables	0.13	0.35	0.46		0.13	0.35	0.46
Grains	1.14	1.27	1.45		1.14	1.27	1.45
Milk/Dairy	0.13	0.07	0.09		0.13	0.07	0.09
Eggs	0.03	0.00	0.00		0.03	0.00	0.00
Fish/Seafood	0.02	0.04	0.07		0.02	0.04	0.07
Nuts/Seeds	0.01	0.02	0.02		0.01	0.02	0.02
Poultry	0.34	0.84	0.91		0.50	1.01	1.10
Beef	0.55	1.00	1.20		0.76	1.24	1.47
Pork	0.52	0.58	0.63				
Other meat	0.00	0.00	0.01		0.00	0.00	0.01
Beans/Peas	0.02	0.03	0.05		0.02	0.03	0.05
Fats/Oils	0.04	0.08	0.10		0.04	0.08	0.10
Sweeteners	0.06	0.02	0.02		0.06	0.02	0.02
Total	3.50	4.57	5.26		3.36	4.41	5.09

Statistical Analysis

Pairwise Analysis of Some USDA Diets Process and IO

p-value	3.300302		
Diet	**Mean**	**Standard Deviation**	**T-Value**
CCP_2000	7.95	0.89	
CCP_2000_S1	7.45	0.91	
			12.42
CCP_2000	7.95	0.89	
CCP_2000_S2	8.45	0.89	
			-12.56
CCP_2000	7.95	0.89	
RCP_2000	9.8	1.17	
			-39.8
CCP_2000	7.95	0.89	
IO CCP_2000	8.43	0.44	
			-15.29
CCP_2000	7.95	0.89	
IO CCP_2000_S1	8.19	0.44	
			-7.64
CCP_2000	7.95	0.89	
IO CCP_2000_S2	8.66	0.44	
			-22.61
CCP_2000	7.95	0.89	
IO RCP_2000	10.5	0.45	
			-80.86

Pairwise Analysis of Some LAFA Diets Process and IO

p-value	3.300302		
Diet	**Mean**	**Standard Deviation**	**T-Value**
LAFA_Current	9.15	1	
LAFA_S1	8.5	1.01	
			14.46
LAFA_Current	9.15	1	
LAFA_S2	9.8	1	
			-14.53
LAFA_Current	9.15	1	
LAFA_Veg	5.49	0.88	
			86.89
LAFA_Current	9.15	1	
IO LAFA_Current	9.54	0.52	
			-10.94