Comparison of Life Cycle Assessments of Grass Fed Beef, In Vitro Beef, and Plant Based Substitute Beef

By:

Ashley DeLay

An Undergraduate Thesis
Submitted in Partial Fulfillment for the Requirements of
Bachelor Arts
in

Environmental Science

Carthage College

Kenosha, WI

May 2020

Abstract

Our individual environmental impact is composed of a variety of aspects within our lifestyles. Where we source our food from is a major component in our overall environmental impact. Industrial agriculture is a main source of food for many, however the resources we obtain from it vary in environmental impact. As more individuals become aware of this, many resort to altering their diets in partial effort to reduce their ecological footprints. The purpose of this study was to analyze three sources of beef like protein to determine the most environmentally sustainable option a consumer could choose. Additionally, economic feasibility and nutritional value of each protein source was addressed in this study as this information plays a vital role in one's dietary choices. Life cycle analyses were conducted in order to assess the environmental impact of traditionally harvested beef, a plant based substitute, and a new technology, In-vitro beef. The total amount of carbon emissions, water consumption, and energy consumption of a quarter pound serving of each protein source were also compared.

Introduction

Industrial agriculture is a growing industry with unsustainable practices. While it does efficiently feed large quantities of people, it negatively impacts air quality, water quality, public health, and climate change which in turn impacts the listed factors creating a feedback loop. A major product of the agricultural industry that significantly contributes to environmental damage is beef. The purpose of this report is to analyze data in order to determine if consuming an alternative protein source to traditionally harvested beef will lower a person's ecological footprint and to determine if these alternative sources are nutritionally and economically sustainable. This report will explore three different methods to provide beef like protein: traditionally harvested beef, in-vitro beef, and a plant-based substitute. In addition, the economic feasibility and nutritional value of each protein source will be investigated as these components play a role in human diet.

A major source of air pollution comes from the agricultural industry, with livestock production contributing to about 9% of carbon dioxide (when including land use) from human related activities and about 65% of human related nitrous oxides (Matthews, 2006). Global warming potential (GWP) can be defined as the measure of how much heat a unit of greenhouse gas traps in relative to a unit of carbon dioxide gas. Nitrous oxides have about 296 times the GWP of carbon dioxide, a majority originating from manure (Matthews, 2006). Most air pollution from agriculture comes in the form of ammonia gas which is produced from heavily fertilized land and livestock waste. After entering the atmosphere, ammonia gas combines with combustion gasses like nitrous oxides and sulfates from automotives to form aerosols which diminishes air quality and pose a major threat to human health. Another major pollutant resulting from agriculture is methane gas which is produced by cows. During their digestion process, cows release methane gas through belching and flatulence. While other animals do produce methane, cows account for 75% of methane released by animals overall (Matthews, 2006). Cows produce a greater amount of methane due to the immense amount of bacteria found in their multiple stomachs that help them to better process their food.

Most of the freshwater used by humans is used for industrial agriculture. U.S. agriculture accounts for about 87% of freshwater usage annually (Khokhar, 2017). While livestock only uses about 1.3% of this, when water needed for grain production used in order to sustain livestock is taken into account, this percentage drastically increases (Khokhar, 2017). Roughly 40% of the world's grain is fed to livestock rather than being consumed by humans and for every kilogram of beef produced, about 100,000 liters is used (Khokhar, 2017). Aside from usage of freshwater, agriculture also damages water quality. Fertilizers used contain nitrogen which enter waterways through runoff. When nitrogen enters a body water it enables eutrophication which in turn lowers the oxygen levels in water affecting the growth of fish. With the industry being as prominent as is, it contributes substantially to global climate change.

Despite it being an efficient means of supplying food, agricultural methods are not sustainable enough to feed our growing world population without causing significant damage to the environment. An ecological footprint can be defined as the impact an individual makes on the environment, generally expressed in the amount of land required to sustain human activities. An example of said human activities would be food consumption. In response to the ongoing issue, many individuals today are altering their diets in part to lower their ecological footprints. For many, a major change in diet is lowering or diminishing their intake of traditionally harvested beef. The purpose of this report is to compare different aspects of protein sources to determine if consuming an alternative protein source to traditionally harvested beef will lower a carbon footprint.

Literature Review

Harvested Livestock (Traditional Beef)

Grass fed beef can be defined as beef that is taken from a once living cow raised in an industrial agriculture setting and is the most popular option of the three with only 5% of adult Americans considering themselves to be vegetarian according to a Gallup poll taken in 2018 (Hrynowski, 2019). There are various types of beef available to consumers whose packaging includes terminology like grain fed, grass fed, grain finished, grass finished, organic, etc. Calves generally are born on the pasture where they spend their lives either grazing (and fed hay in the winter) on a large pasture or being raised on grain feed depending on the desired result of the beef product. The desired result could be grain fed, grass fed, grain finished, grass finished, organic, etc. At about 16 months of age the cows are harvested with an average weight of 581 kg. Raising livestock became a practice after humankind transitioned from a hunter and gatherer culture to settled farming.

In-Vitro Beef

A new alternative to traditionally harvested beef would be in vitro beef, which can be defined as lab grown beef. In-vitro meat is developed from an isolated sample of an adult stem cell or embryonic cell from an animal, in this case a cow (Bartholet, 2011). These stem cells, also known as myosatellite cells, are then grown in bioreactors using cultures derived from plants. In the bioreactors the cells multiply undergoing a process called proliferation. This is essentially the sample “growing.” Once there are enough proliferated cells and the “growth” is complete, they will be induced to differentiate. This essentially means that the cells become specialized to perform a certain function, for example a liver cell. To produce in-vitro beef, the cells will need to become muscle cells as these constitute the majority of meat we as humans typically consume. There are challenges with this process as it is still in its early stages of development. In 2013, a Dutch scientist named Mark Post produced the world’s first lab-grown burger. It consisted of about 20,000 fibres of beef, cost about $325,000 to make, and took 3 months to grow (Lee, 2017). While the appearance and texture appeared similar to that of agriculture derived beef, the taste was not comparable. This is attributed to the cellular makeup of lab grown beef being different from that of a cow's since Post's lab grown burger was made solely of muscle tissue whereas traditional beef would consist of fat cells as well. It is possible to grow fat tissue in a lab, however, it is not currently possible to perfectly mimic the taste of beef derived from livestock. The discussion of implementing in-vitro meats into our diets is growing. A fictitious restaurant named "Bistro In-vitro" developed an imaginary menu consisting of in-vitro meat products to promote the discussion of having these products as a source of meat in the future.

Plant-Based Beef Substitute

Another option is a completely meat free and plant based imitation of traditional beef. As of 2020, there are a multitude of companies that sell plant based burgers and other meat substitutes including Impossible Burger, Gardien, MorningStar, Boca, and more. One could also find recipes online to make their own plant based patties right from home. While there are multiple companies that produce similar products this study will be researching the company Beyond Meat and its plant based beef alternative the *Beyond Burger* in order to maintain consistency. Beyond Meat was first established in 2009 in Los Angeles, California and their products became available across the United States by 2012. This protein source is derived completely from plant based sources. This company was chosen over others as it is one of the most popular plant based substitutes for beef and their product mimics the texture, taste, and appearance of traditional beef quite closely. Today, many burger restaurants offer a plant based option as more and more people are choosing to lower or completely eradicate meat from their diets.

Water Quality

One of the consequences of unsustainable practices in the agricultural industry is the pollution of water quality. One example of this is eutrophication which is the ecological process in which algal blooms form from land runoff. The land runoff consists of nutrients that are applied to cropland and can make their way into waterways often by rainfall. These algal blooms can be visibly seen as they turn bodies of water green.

Runoff generated from the fertilizers used on agricultural land which generally contain nitrogen as described by the U.S. National Oceanic and Atmospheric Administration. The excess levels of nitrogen enable the overgrowth of algae which in turn prevents sunlight from reaching aquatic plants therefore causing a decline in their populations. The absence of aquatic plants increases carbon dioxide levels in aquatic ecosystems thus slowing the growth of fish and deteriorating the shells of shellfish. As a result, the catch of commercial fisheries is reduced causing seafood prices to rise and lowering harvest levels (National Oceanic and Atmospheric Administration). This in turn negatively affects the accessibility of certain foods to consumers. To produce a quarter pound of grass fed beef, 3.8 m^2 of land is required for processing from cradle to grave whereas less than 8% of land is required for cradle to grave processing for the Beyond Burger Patty at 0.3m^2 (Heller & Keoleian, 2018 p. 27). In vitro beef is still in its early stages of developments but it is expected to require smaller amounts of inputs like land for production. The greater the land area required is, the more fertilizers used to produce product output. Since 1960, the amount of fertilizer used per acre of agricultural cropland has increased from 46.2 nutrient pounds per acre to 142 nutrient pounds per acre as of 2014, an increase of over 200% (EPA's Report on the Environment, 2019). This leads to significantly greater levels of nitrogen being added in earth's water sources making it crucial that both producers and consumers be conscientious of their land use.

Air Quality

Within the agricultural industry there is a variety of livestock but this report will focus specifically on cows which are used to produce beef. Cows produce methane gas, which is listed as a GHG. It is reported that cattle can produce around 250 to 500 L of methane gas per day making it estimated that cows will contribute to slightly less than 2% to global climate change within the next 50 to 100 years (Johnson, Johnson, 1995). With traditionally harvested beef deriving their product directly from cattle, these statistics convey an environmental downside to their consumption. However it should be noted that these estimates were made over two decades ago in 1995 and accessibility to data has changed since this time.

The Earth's air, wind and land all make up what is known as the Earth's atmosphere. Gasses are exchanged within the atmosphere and these exchange processes are what determine the Earth's climate (ABD and WGA, 2013. p.1). The planet has warmed and cooled throughout its existence gradually. However in recent years it has been heating at rapid rates. The IPCC has determined that it is 'extremely likely' that mankind is the reason for the Earth's climate rapidly warming (ABD and WGA, 2013. p.1). Agriculture has contributed to this by producing a substantial amount of greenhouse gases (GHGs.) GHGs include carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and hydrofluorocarbons. GHGs trap heat in the Earth's atmosphere by absorbing radiation and trapping heat close to the planet's surface thus causing the phenomenon known as climate change. Mankind began to produce higher amounts of GHGs at the start of the industrial revolution in 1760 when large factories were being built and the human population was rapidly increasing. Commercial agriculture was used as a response to feed a continuously growing population. Both commercial agriculture and large factories were practicing unsustainable methods that society was made better aware of during the environmental movement in the 1970s. However, by this time the Earth's atmosphere had already suffered irreversible damage and we can now only make efforts to reduce what further impact we may have.

Climate Change

The fluctuations in the Earth's climate have a direct effect on various ecosystems. These effects can harm flora and fauna by disrupting food webs, range shifts (as temperatures increase many plants and animals are moving further North and to higher elevations), and increasing the risk of extinction ("Climate Change Impacts on Ecosystems," 2016). Climate change can also pose threats to human beings. According to the U.S. Global Change Research Program, an increase in GHGs in the atmosphere can cause extreme hot and cold temperatures leading to temperature related illnesses and deaths such as heat stroke and hypothermia. This source also lists other risks to human health that will increase from GHGs in our atmosphere including respiratory issues from compromised air quality, contaminated water supply leading to the spread of disease and pathogens, vector borne (spread by mosquitoes, ticks, or fleas) diseases, mental health and wellbeing due to stress induced by environmental changes, and extreme events such as heat waves or flash floods ("The Impacts of Climate Change on Human Health In The

United States: A Scientific Assessment," 2016). Climate change additionally will impact one of our major resources for food, the agricultural industry.

An increase in GHGs in the atmosphere is predicted to further impact U.S. climate change by reducing crop yields and therefore taking a toll on the agricultural industry and thus the economy according to the Environmental Protection Agency (EPA.) The EPA has discovered some experiments that suggest that an increase in carbon dioxide (a GHG) can lead to increased plant growth but other factors such as changes in temperature, water deficiencies, and ozone depletion outweigh any potential benefits climate change may have on crops. The EPA also suggests that the extreme events that may occur as a result of climate change like droughts, flash floods, and tornadoes can severely damage crops thus lowering yields ("Climate Impacts on Agriculture and Food Supply," 2016).

The world's population as of 2019 is reported to be roughly 7.7 billion with the U.S. population being reported to be about 326.8 million as of 2018 according to research published by Max Roser, Hannah Ritchie and Esteban Ortiz-Ospina on the web page Our World in Data. According to this research, the world population is no longer growing exponentially as population growth rate has begun to steadily decline as is the US population (Roser, Ritchie, Ortiz-Ospinoza, 2013). While growth is declining both the world and US populations are still continuing to grow. Those who follow the standard American diet (SAD) need to use roughly two football fields worth of land to sustain their diets (Food and Agricultural Organization of the United Nations). This means that if all of earth's occupants were to follow the standard American diet (SAD) then we would need at least two earths to sustain us all.

Economic Accessibility

Economic accessibility is a major factory in the diets that a person will not only choose but be able to access. Government subsidies can affect the prices consumers pay for different food items. A government subsidy can be defined as a benefit that is given to an individual, business, or institution usually by the government. It is generally given in the form of a cash payment or tax reduction. The reason government subsidies are distributed is for economic or social benefit, so in the best interest of the public. The meat and dairy industry as well as the fruit and vegetable industry both receive some form of government subsidies. According to PETA, the U.S. government spends about $38 billion each year to subsidize the meat and dairy industry whereas only 0.04% of that ($17 million) is spent on subsidizing fruits and vegetables (PETA, 2019). This in turn impacts the prices that consumers pay for these food products.

Nutrition

All nutrients have what is referred to as bioavailability. Bioavailability can be defined as the proportion of a nutrient that is absorbed and utilized by the body. According to a micronutrient lecture by Dr. Suzanne Cole at the University of Michigan, bioavailability is determined by multiple factors including diet, nutrient concentration, nutritional status, health, and the processing or treatment of a particular food (Ostrenga, 2013). Since traditionally harvested, in-vitro, and plant based beef are all processed differently and derived from different sources differently their nutrient absorptions will vary. As a result, a basic nutrient comparison may not accurately describe the nutritional value of each protein source.

Social Outlook

Diet continues to be a prevalent topic in the media leaving many consumers questioning if they are truly doing best by their health. However recently, there have been an influx of food related documentaries revolving around plant based diets and veganism. A plant based diet can be defined as one that consists mostly or entirely of foods derived from plants whereas veganism (the term originally coined in 1944) is a lifestyle that excludes all animal derived products. These documentaries have shed light onto plant-based diets and raising the awareness of unethical tactics used when deriving animal byproducts as well as environmental damage. In addition to activism, these documentaries promote plant based diets with claims of the diet drastically improving the health of those who abide by it. Many make counter arguments to these claims by stating that one cannot sustain a healthy lifestyle without animal derived ingredients. With such heavy bias coming from all directions, many consumers find themselves questioning these dietary claims and are unsure of what diet they should follow to benefit their health, the environment, and financial wellbeing. This essay aims to objectively analyze meat and non-meat derived burgers for their environmental impacts, health benefits, and financial impacts.

Methods

The three beef products to be analyzed were identified. The food products were traditionally harvested beef, in vitro beef, and the plant based substitute, Beyond Meat's *Beyond Burger*. A life cycle analysis chart was created for each of the subjects of analysis. Four charts for each of the protein sources were made. These charts described the resources input and resulting outputs throughout each product's life cycle. The four charts were as follows; Raw Material Acquisition, Harvesting/Manufacturing Acquisition, Use/Reuse/Maintenance Acquisition, and Recycle/Waste Management Acquisition. Raw Material Acquisition describes the basic resources that make up the components of the product itself and their impact on the environment. Harvesting/Manufacturing describes resources that assist in manufacturing the product and their impacts on the environment. Use/Reuse/Maintenance Acquisition describes the materials needed for the maintenance of the product/production process. Recycle/Waste Management Acquisition describes the waste produced or materials recycled.

Said charts containing five columns labeled as follows; Input/Source, Constituent, Description, Quantity, and Output. "Input" can be described as the raw material or source of the resources used to produce the desired product. It can also be described as defined as the broad terms for resources that are spent on producing each food item. For instance, this category contained raw materials, manufacturing, transportation/distribution, use by consumers, and waste. "Constituent" can be described as what product is derived from the "Input/Source." The category "description" sufficed as a definition or elaboration of the input and product created. This category usually contains details that help readers better understand the sources included and are relevant to the output of the life cycle analysis. "Quantity" can be described as how much of something is produced that will impact the "Output" category. The "quantity" category labeled a measurable amount to base environmental impact analysis. "Output" served to label and measure the environmental impact of a product and show readers how a single source impacts the environment. Conclusions were drawn from these tables which provided a brief assessment of actions that could be taken in order to reduce the environmental impact of each of the broad categories listed in the first column labeled "Inputs/Sources." For example, consumers could be incentivized to choose more sustainable protein sources in order to reduce the environmental impacts from the consumer usage process.

Three values were then obtained from the databases utilized to create the life cycle analyses. These values were total carbon emissions (kg eq.), total water usage (Liters), and total energy consumption (MJ) of a quarter pound size serving for each of the three studied protein sources. The word “total” describes the quantity of these resources emitted/consumed from cradle to grave for the quarter pound serving of these protein sources. Quarter pound serving sizes were selected as this is the standard serving size for a beef patty. These values were selected as they provide insight to how the life cycle assessments of each of the three protein sources compare to one another.

Data for these life cycle analysis was collected from Carnegie Mellon University’s Economic Input Output Life-Cycle Assessment database, the University of Michigan's Center for Sustainable Systems research, an article from the *Environmental Sciences and Technology*, and an article from the *International Journal of Life Cycle Assessment.* In order to analyze and compare the nutritional value of the three studies protein sources, nutrition labels were obtained. The nutrition label for traditionally harvested beef that was obtained described the nutrition facts for *Verde 100% Grass Fed Meat* that is 80% fat and 20% lean, which is the average ratio for ground beef, which is shown in *Figure 4*. This brand was chosen as it is a popular choice for 100% grass fed meat consumption. The nutrition label obtained for plant based beef alternatives described the nutrition facts of the company “Beyond Meat’s” product “The Beyond Burger,” which is shown in *Figure 5*. They were compared by isolating major nutrients and multiplying them accordingly so that equal serving sizes were being compared to maintain consistency. The serving sizes compared were quarter pound servings as this is the standard serving size for a beef patty.

An economic comparison was done by comparing the average prices for a pound of each of the protein sources in the United States. A pound was selected as the retail pricing as beef is typically sold in grocery stores by the pound. To maintain consistency the average cost of these products in Chicago, IL was utilized for the comparison.

Results

The following life cycle assessment describes the resources input and the consequential outputs of producing beef in a traditional agricultural setting in the United States. Its production is described in four categories; raw materials, harvesting/manufacturing, use/reuse/maintenance, and recycle/waste management. This life cycle assessment follows the production process from cradle to grave of a traditionally harvested burger.

Raw Material Acquisition Traditionally Harvested Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Land	Grazing land	Land for cattle to graze/ grow food for cattle	3.8 m^2 per ¼ lb patty	Land usage, soil nutrient depletion, deforestation
Cattle	Ground Beef	Raised and bred on farm	¼ lb ground beef 29% of live weight consumed as edible beef	6.61 lb of CO_2e
Water	Hydrates cattle and crops	Used for drinking, irrigation of grains/grasses, and processing	218.4 liters per ¼ lb patty (Cradle to distribution)	Wastewater runoff pollutes nearby bodies of water, water usage

Harvesting/Manufacturing Acquisition Traditionally Harvested Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Nitrogen, phosphorus, and potassium compounds	Fertilizers	Applied on fields to maintain grass fed to cattle	17.8 t CO2e	Runoff causes eutrophication in nearby bodies of water
Energy	Electricity and power	Total energy needed to power machinery to produce ¼ lb beef	11.4 MJ	Air and water pollution
Lumber	Cardboard Sleeve	Packaging material	27.4g per tray	Deforestation
Soybean oil	Printing Ink	Packaging has	0.33g per tray	Land use for

		information/graphics printed on it		agriculture
Crude Oil	Thermoformed Tray	Tray holding patties	23.5g per tray	Waste, Oil well (destruction of land)
Crude Oil	PE Lid Film	Seals product	1.68g per tray	Waste, Oil well (destruction of land)
Lumber	Patty Paper (Tissue Paper 90%)	Used to separate patties in packaging	1.17g per tray	Deforestation Waste
Crude Oil, Lumber	Patty Paper (Paraffin Wax 10%)	Applied to tissue paper used to separate patties	0.13g per tray	Waste, Oil well (destruction of land), Deforestation
Lumber	Corrugated Carton	Cardboard boxes for transport	239g per 8 trays	Deforestation

Use/Reuse/Maintenance Acquisition Traditionally Harvested Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Lumber	Wood pallet	EUR-flat pallet, reused to transport product	1 used per 156 cartons	Deforestation

Recycle/Waste Management Traditionally Harvested Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Cattle	Fat, bone shrink	Loss in packing process	24.8 g	Waste
Cattle	Fat, bone, shrink	Loss in consumer phase	13.9 g	Waste
Cattle	Fat, bone, shrink	Loss in retail phase	16.7 g	Waste

The following life cycle assessment describes the resources input and the consequential outputs of producing In-vitro beef in a laboratory setting in the United States. Its production is described in four categories; raw materials, harvesting/manufacturing, use/reuse/maintenance, and recycle/waste management. This life cycle assessment follows the production process from cradle to grave of In-Vitro beef.

Raw Material Acquisition In-Vitro Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Land	Facility space	Space for livestock being used for sampling	717 m^2 per batch	Deforestation, soil nutrient depletion
Biomass	Cell samples	For both proliferation and differentiation	220.5 kg per batch	GHG production from animal use, waste
Corn	Starch microcarrier beads	Provide structural support during proliferation for developing tissue	75 kg per batch for proliferation	Land use
Water	Deionized water	For proliferation and differentiation	29,600 L per batch	Water use
Carbohydrate rich foods	Glucose	For proliferation and differentiation	206 kg per batch	Land use, water use
Protein Rich foods	Glutamine	For proliferation and differentiation	17.3 kg per batch	Land use
Oxygen	Stimulant	For proliferation and differentiation	67.6 kg per batch	Waste (when producing oxygen in a lab)
Soy	Soy hydrolysate	For proliferation, source of protein	0.8 kg per batch	Land use
Basal medium	Cell culture	For proliferation	29,600 L per batch	Waste (when

		and differentiation		producing oxygen in a lab)

Harvesting/Manufacturing Acquisition In-Vitro Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Energy	Electricity/power	Operate facility	368033 MJ per year per facility	Air pollution, fossil fuel usage
Energy	Sterile Filtration	For proliferation and differentiation	16 MJ	Air pollution, fossil fuel usage
Energy	Heating water	For proliferation and differentiation	1733 MJ	Air pollution, fossil fuel usage
Energy	Agitation	For proliferation and differentiation	307 MJ	Air pollution, fossil fuel usage
Energy	Aeration	For proliferation and differentiation	121.8 MJ	Air pollution, fossil fuel usage
Energy	Heat exchanger	For proliferation and differentiation	1.1 MJ	Air pollution, fossil fuel usage
Energy	Transportation	For proliferation and differentiation	372 t km	Air pollution, fossil fuel usage
Lumber	Cardboard Sleeve	Packaging material	27.4g per tray	Deforestation
Soybean oil	Printing Ink	Packaging has information/graphics printed on it	0.33g per tray	Land use for agriculture
Crude Oil	Thermoformed Tray	Tray holding patties	23.5g per tray	Waste, Oil well (destruction of land)
Crude Oil	PE Lid Film	Seals product	1.68g per tray	Waste, Oil well

				(destruction of land)
Lumber	Patty Paper (Tissue Paper 90%)	Used to separate patties in packaging	1.17g per tray	Deforestation Waste
Crude Oil, Lumber	Patty Paper (Paraffin Wax 10%)	Applied to tissue paper used to separate patties	0.13g per tray	Waste, Oil well (destruction of land), Deforestation
Lumber	Corrugated Carton	Cardboard boxes for transport	239g per 8 trays	Deforestation

Use/Reuse/Maintenance Acquisition In-Vitro Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Water	Deionized water	Cleaning	45,000 L per batch	Water use
Energy	Heating water	Cleaning	3417 MJ	Air pollution, fossil fuel usage
Lumber	Wood pallet	EUR-flat pallet, reused to transport product	1 used per 156 cartons	Deforestation

Recycle/Waste Management Acquisition In-Vitro Beef

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Biomass	Production waste	If culture does not contain enough muscle tissue then it is considered inedible and discarded; from proliferation and differentiation	555 kg	Waste

The following life cycle assessment describes the resources input and the consequential outputs of producing plant based beef in a factory setting in the United States. Its production is described in four categories; raw materials, harvesting/manufacturing, use/reuse/maintenance, and recycle/waste management. This life cycle assessment follows the production process from cradle to grave of a plant based burger.

Raw Material Acquisition Plant Based Protein Substitute

Inputs/Source	Constituent	Description	Quantity	Output
Peas	Pea Protein Isolate	Source of protein	20 grams (about 18% of total)	5% of waste (left in machine after processing);
Refined Rapeseed Oil	Expeller Pressed Canola	For cooking, 70% sourced from Canada, 30% sourced from U.S.	<18% of total	Water usage, land usage
Refined Coconut Oil	High smoke point oil	For cooking, sourced from Indonesia/Malaysia (ocean freight trip approx. 22224 km) (Port of entry Boston or New York, truck trip 4835 km)	<18% of total	Water usage, land usage
Water	Adds moisture	Washing product/retaining moisture	1.1 liters (cradle to distribution)	Water usage, water pollution
Yeast	Yeast Extract	Used to mimic savory flavor (yeast with absence of cell wall)	<18% of total	Water usage, land usage
Corn	Maltodextrin	Food additive derived from plant based sources. Cooked then enzymes added to further breakdown.	<18% of total	Water usage, land usage
Natural Flavors	Flavoring to mimic freshness	Derived from spices, herbs, or roots	<2% of total	Water usage, land usage

Acacia	Gum Arabic	Thickening agent	<2% of total	Water usage, land usage
Sunflowers	Sunflower Oil	Oil used for cooking, low in saturated fat	<2% of total	Water usage, land usage
Salt	Flavor	Added as flavoring agent, balances hydration of food	<2% of toal	Land damage from hydraulic mining
Sugar	Succinic Acid	Fermented to become an acidity regulator, flavoring agent	<2% of total	Water usage, land usage
Acetobacter and Clostridium acetobutylicum (Bacteria)	Acetic Acid	Flavoring purposes	<2% of total	Water usage, land usage
Corn	Non GMO Modified Food Starch	Texturing and thickening agent	<2% of total	Land/water usage
Bamboo	Cellulose	Adds fiber content	<2% of total	Land/water usage
Vegetable Cellulose	Methylcellulose	Food thickener/emulsifier	<2% of total	Water usage, land usage
Potato	Potato Starch	Food thickener	<2% of total	Land/water usage
Beets	Juice Extract	Used for color	<2% of total	Land/water usage
GMO Corn	Ascorbic Acid	To maintain color	<2% of total	Water usage, land usage
Achiote Trees	Annatto Extract	Used for color	<2% of total	Water usage, land usage
Citrus Fruits	Citrus Fruit Extract	Maintain quality	<2% of total	Land/water usage
Plant Oils	Vegetable Glycerin	Helps oil and water based ingredients mix	<2% of total	Water usage, land usage

Harvesting/Manufacturing Acquisition Plant Based Protein Substitute

Inputs/Source	Constituent	Description	Quantity	Output
Lumber	Cardboard Sleeve	Packaging material	27.4g per tray	Deforestation
Soybean oil	Printing Ink	Packaging has information/graphics printed on it	0.33g per tray	Land use for agriculture
Crude Oil	Thermoformed Tray	Tray holding patties	23.5g per tray	Waste, Oil well (destruction of land)
Crude Oil	PE Lid Film	Seals product	1.68g per tray	Waste, Oil well (destruction of land)
Lumber	Patty Paper (Tissue Paper 90%)	Used to separate patties in packaging	1.17g per tray	Deforestation Waste
Crude Oil, Lumber	Patty Paper (Paraffin Wax 10%)	Applied to tissue paper used to separate patties	0.13g per tray	Waste, Oil well (destruction of land), Deforestation
Lumber	Corrugated Carton	Cardboard boxes for transport	239g per 8 trays	Deforestation
Water	Manufacturing material	Processing, packaging, cold storage	2.79 liters per ¼ pound of BB	Water pollution/usage

Use/Reuse/Maintenance Acquisition Plant Based Protein Substitute

Inputs/Source	Constituent	Description	Quantity	Output
Lumber	Wood pallet	EUR-flat pallet, reused to transport product	1 used per 156 cartons	Deforestation

Recycle/Waste Management Acquisition Plant Based Protein Substitute

Inputs/Source	**Constituent**	**Description**	**Quantity**	**Output**
Lumber	Cardboard sleeve waste	Board scrap waste during manufacturing	12% of production goes to waste	Deforestation
Beyond Burger Patty Ingredients/Finished Product	Beyond Burger Patty "Meat"	Product left in machinery during processing	5% of all production goes to waste	Wasted ingredients/manufacturing efforts
Lumber	Corrugated Cardboard	Disposal pathway for general material	89.5% Recycled 8.4% Landfill 2.1% Combusted	Waste, Air pollution
Lumber	Other Paper	Disposal pathway for general material	25.6% Recycled 59.8% Landfill 14.6% Combusted	Waste, Air pollution
Lumber	Wood	Disposal pathway for general material	25.1% Recycled 60.2% Landfill 17.7% Combusted	Waste, Air pollution
LDPE (Low density polyethylene)	Plastic	Disposal pathway for general material	12.3% Recycled 70.5% Landfill 17.2% Combusted	Waste, Air pollution
PP (Polypropylene)	Thermoplastic	Disposal pathway for general material	3.5% Recycled 77.6% Landfill 17.2% Combusted	Waste, Air pollution

To visually compare the environmental impacts of the three protein sources, total CO_2 emissions, total water usage, and energy usage were gathered and then compared as seen in *Figure 1, Figure 2,* and *Figure 3.*

Table 1 depicts a total CO_2 emission, water usage, and energy usage comparison

Usage/Emissions per Serving	**Traditionally Harvested Burger**	**In-Vitro Beef**	**Plant Based Substitute**
Total CO_2 Emissions (kg eq.)	3.7	0.009	0.4
Total Water Usage (Liters)	218.4	27.07	1.1
Energy Use (MJ)	11.4	1.08	6.1

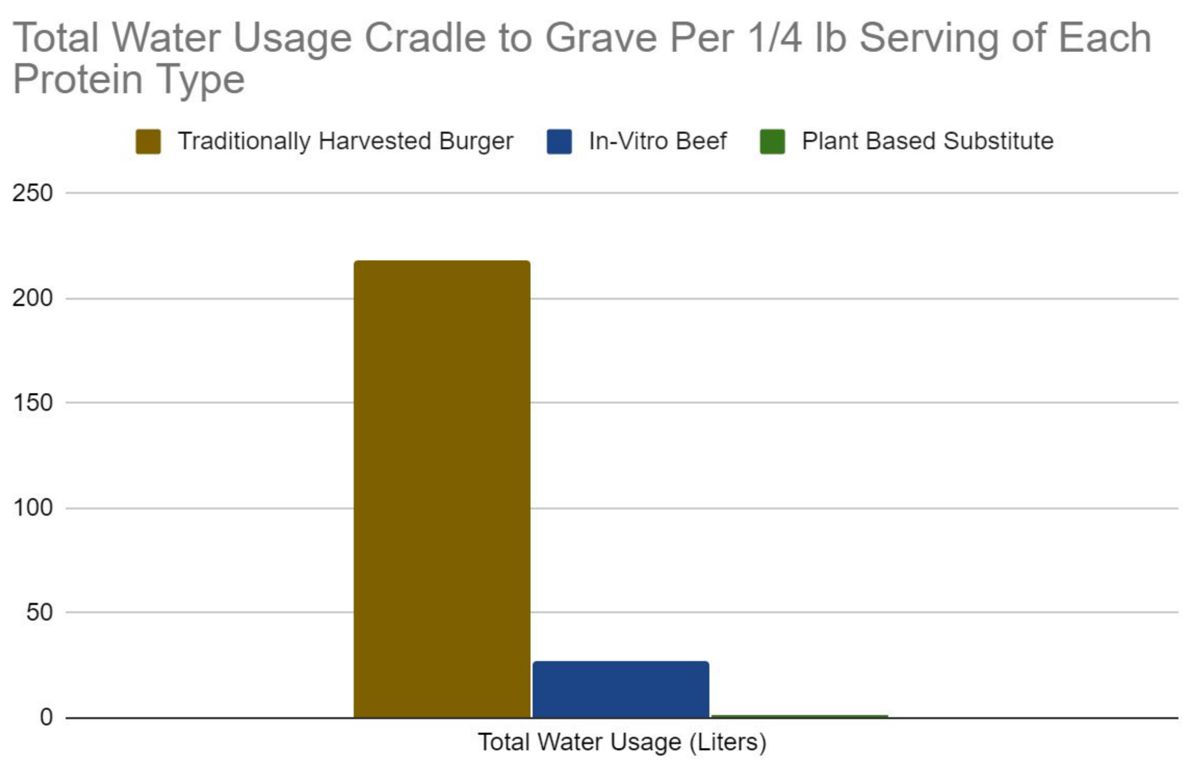

Figure 1 depicts the total water usage per quarter pound serving of each protein type

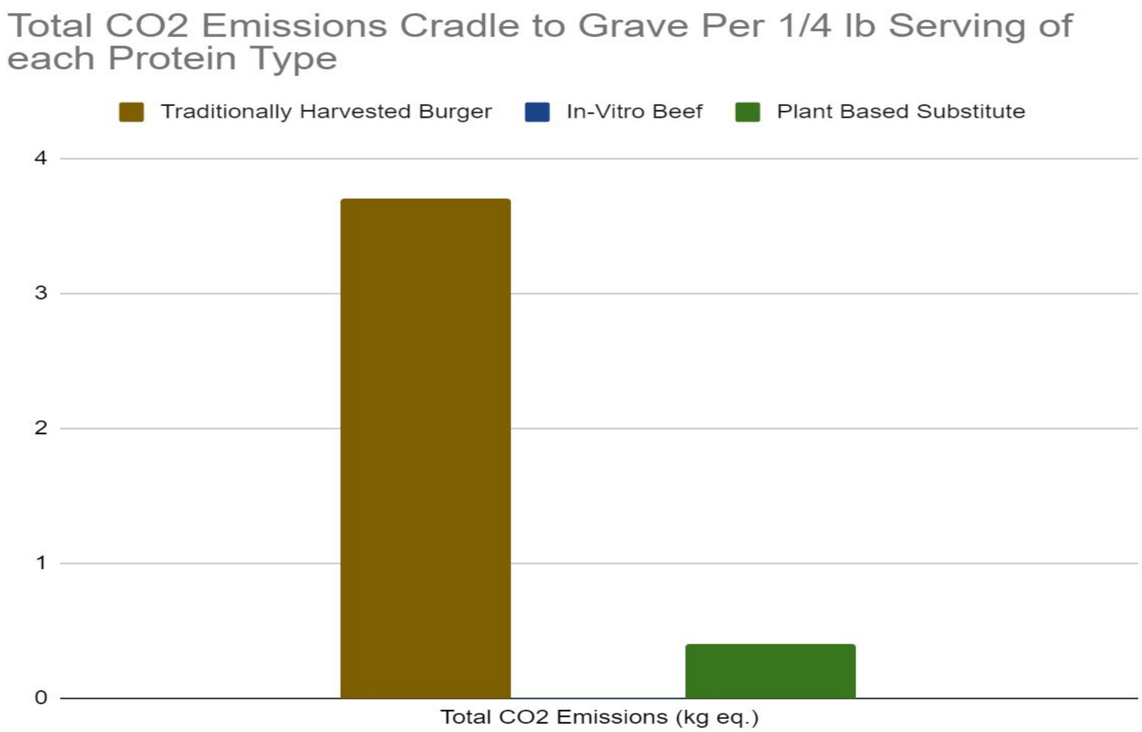

Figure 2 depicts the total CO_2 emissions per quarter pound serving of each protein type

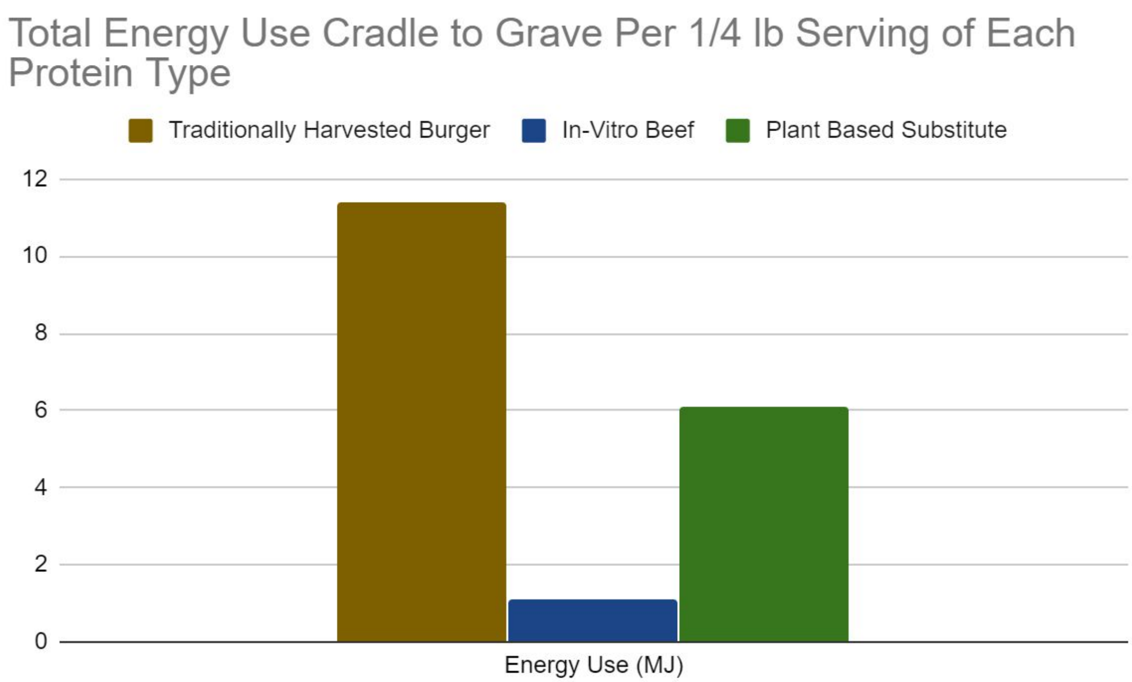

Figure 3 depicts the total energy usage per quarter pound serving of each protein type

Nutrition labels were obtained for the protein sources that had this information available (traditional beef and plant based substitute) to assess and compare their nutritional value.

Figure 4 depicts the nutrition facts for 100% grass fed ground beef that is 80% lean and 20% fat

Source:

https://docs.google.com/document/d/1wcyEHEcaYOMEbv4Qux9Dj5duAdq1RACxWXFuQa45_OI/edit

Figure 5 depicts the nutrition facts for a serving of "Beyond Beef"

Source: https://hpmi.us/2019/07/17/great-tasting-veggie-burgers-are-here-but-are-they-healthy/

Table 2 depicts Calorie values for traditionally harvested beef and plant based beef

Calories	Per 4 oz. Serving	From Fat
Beef	280	200
Plant Based	290	190

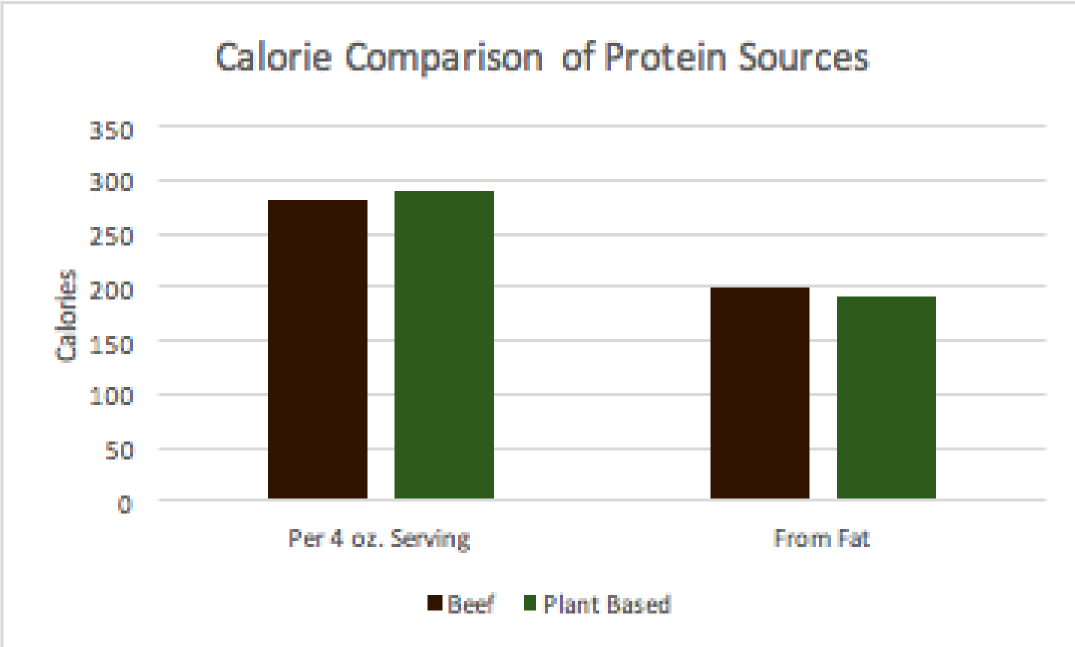

Figure 6 depicts a visual comparison of caloric values for the Beyond Burger and Verde 100% Grass Fed Beef

Table 3 depicts macronutrient values for traditionally harvested beef and plant based beef

Macronutrients	Protein	Carbohydrates	Total Fat	Saturated Fat	Trans Fat	Sodium
Beef	19	0	22	8	1.5	0.075
Plant Based	20	6	22	5	0	0.45

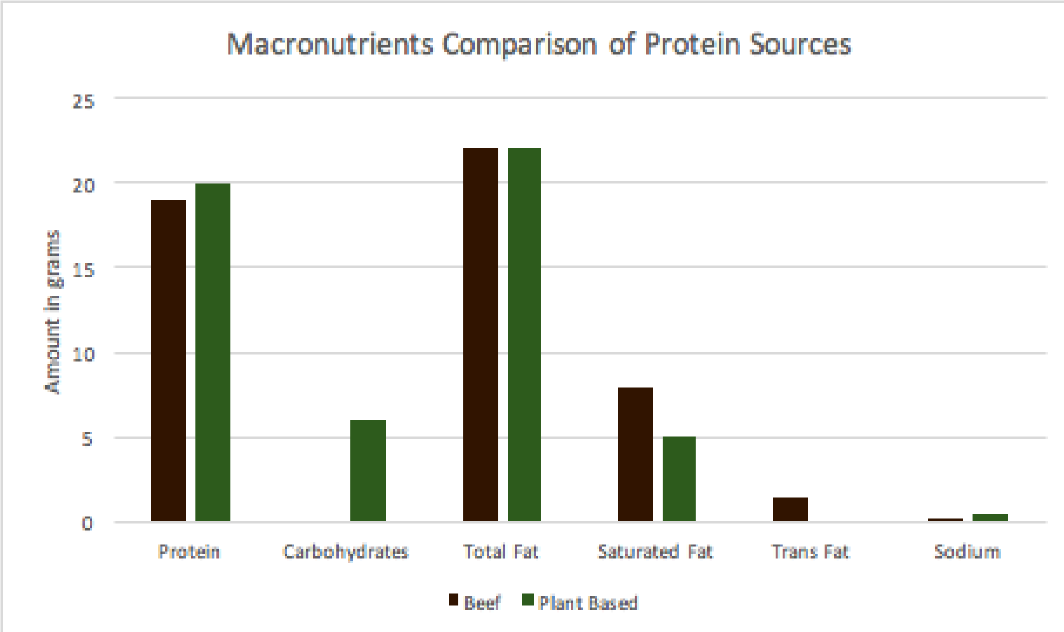

Figure 7 depicts a macronutrient a visual comparison of Beyond Burger and Verde 100% Grass Fed Beef

Table 4 depicts micronutrient values for traditionally harvested beef and plant based beef

Micronutrients (% needed based on 2,000 calories diet)	Iron	Vitamin A	Calcium	Vitamin C
Beef	10	0	2	10
Plant Based	25	0	2	90

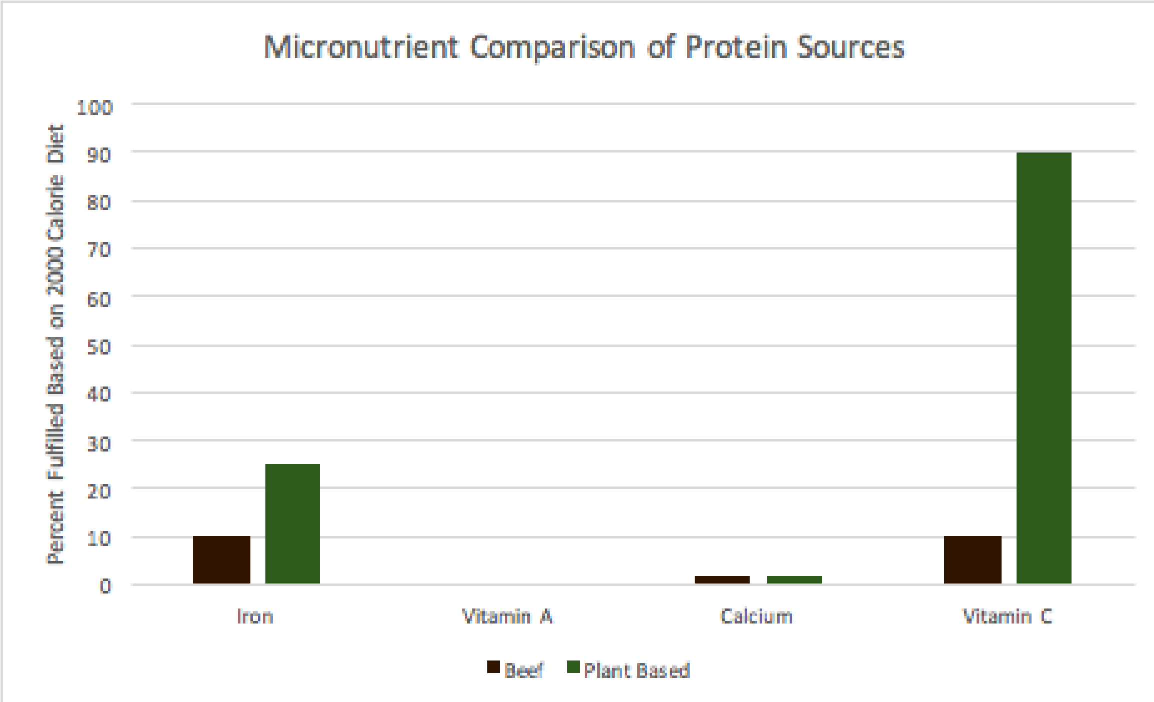

Figure 8 depicts a visual comparison of the micronutrient contents of Beyond Burger and Verde 100% grass fed beef

The retail price for a pound of each of the protein sources were compared to assess and compare the economic availability to consumers.

Table 5 depicts the consumer prices of a pound of traditionally harvested beef, Beyond Burger, and In-Vitro beef

Protein Source	**Cost (in dollars) of 1 pound**
Traditionally Harvested Burger	5.46
Beyond Burger	9.72
In-Vitro Beef	45.44

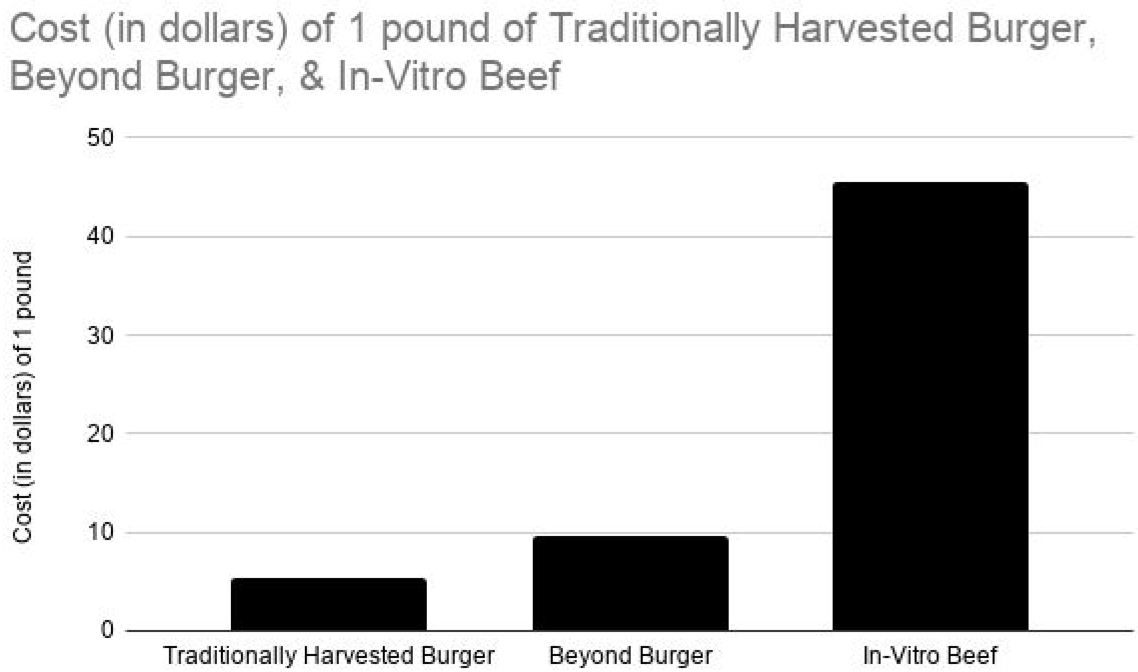

Figure 9 depicts price comparison of a pound of traditionally harvested beef, Beyond Burger, and In-Vitro beef

Discussion

Life Cycle Assessments

It should be noted that the data found in the life cycle assessments for In-vitro beef is anticipatory as the technologies for in-vitro meat production are still in relatively early stages. The facility being described can produce 192 batches or 60,000 kg of biomass per year. So, a single batch consists of 312.5 kg of biomass which is about 2755.6 quarter pound servings. Estimates were made for the packaging materials described in the *Harvesting and Manufacturing Acquisition of Traditionally Harvested Beef* and for *Harvesting and Manufacturing Acquisition of In Vitro Beef* sections of the life cycle analysis. These estimations were made utilizing the data of packaging materials for the *Beyond Burger*. This estimate was made due to traditionally harvested beef having similar packaging to the *Beyond Burger* and under the assumption that In-vitro beef would utilize similar packaging once on the market. Estimates were also made for data regarding an EUR-flat pallet, which is used for transporting large quantities of products. The estimations are found within the *Use, Reuse and Maintenance Acquisition for Traditionally Harvested Beef* and the *Use, Reuse and Maintenance Acquisition for In-Vitro Beef.* These estimates were made due to EUR-flat pallets being commonly used to transport a variety of products which led to the conclusion that companies that produce traditionally harvested beef utilize these materials and that future companies mass producing In-Vitro beef will follow this pattern. The data conveyed within the life cycle assessments describes quantities of resources that are used (or anticipated to be used) for ¼ lb size servings of each protein source. ¼ lb servings were analyzed as this is the standard size for a beef or beef-like patty.

Since the three protein sources in this study were all composed of varying ingredients and processes to come to a final product, three values were obtained from the life cycle assessments to compare the overall environmental impacts that each protein source's quarter pound serving has. These values were total water usage (Liters), total CO_2 emissions (Kg), and total energy usage (MJ) and all measured from cradle to grave whose values are depicted in *Table 1. Figure 1* depicts a visual comparison of total water usage for each serving of the studied protein sources. Traditionally harvested beef had a significantly higher water usage than both in-vitro beef and plant based substitute using 218.4 liters per quarter pound serving produced whereas In-vitro beef used 27.07 liters and the plant based substitute uses 1.1 liters. When comparing the total CO_2 emissions of the three protein sources, traditionally harvested beef produced the highest amount of carbon dioxide emissions at 3.7 kg eq. per quarter pound serving of product as seen in *Table 1.* In-vitro beef produced 0.009 kg eq. and the plant based substitute produced 0.4 kg eq. of carbon dioxide emissions. A visual comparison of these values is represented in *Figure 2* where it is evident that the traditionally harvested burger produces more CO_2 emissions than the In-vitro burger and the plant based substitute combined. This in turn means that the traditionally harvested burger has a greater environmental impact than the In-vitro burger or the plant based substitute. Total energy usage in MegaJoules (MJ) to produce a quarter pound serving of each of the protein sources is also depicted in *Table 1.* Again the traditionally harvested burger possessed the highest value at 11.4 MJ per quarter pound serving. In-vitro beef had the lowest energy usage at 1.08 MJ of energy consumed per quarter pound serving produced and the plant based substitute fell near the mid range of these two values at 6.1 MJ of energy used per quarter pound serving produced. A visual comparison of the total energy usage of the three protein sources can be seen in *Figure 3.* Here it can be seen that the traditionally harvested beef followed a similar pattern to water usage in *Figure 1* and CO_2 emissions in *Figure 2* by having the largest value of the three protein sources. However, it should be noted that the plant based substitute did not follow its previous pattern of having a value similar to that of the In-vitro burger like in *Figure 1* and *Figure 2.* In *Figure 3*, it can be seen that the energy usage plant based substitute was nearly half that of the traditionally harvested burger. This may be due to the transportation needs of the resources used to cultivate the *Beyond Burger*. Since this product is composed completely of plant based sources, ingredients may need to be transported over long distances depending on seasonal availability of resources and geographic location of the factory producing the *Beyond Burger.*

Nutritional Analysis

Since the method of producing In-vitro meat is relatively new, there is not any official data for nutrition facts available. However, it can be inferred that the nutrition facts of In-vitro beef would be similar to that of traditionally harvested beef with the major nutritional differences being seen in the amount of saturated fat and micronutrients. This is because when growing meat from a culture, it is possible to instruct the meat to grow in the desired way which typically means containing close to being 100% lean (and therefore having less fat) and to contain higher percentages of micronutrients, therefore making In-vitro beef a healthier option than traditionally harvested beef. The nutritional content for *Beyond Burger* (plant based substitute) and *Verde 100% Organic Grass Fed Beef* (traditionally harvested burger/beef). Their nutritional information was obtained using Nutrition Facts labels. The Nutrition Facts for *Verde 100% Organic Grass Fed Beef* can be seen in *Figure 4.* The Nutrition Facts for *Beyond Burger* can be seen in *Figure 5.* When comparing caloric content (and calories from fat) for the plant based substitute to traditionally harvested beef, there is not a substantial difference. A quarter pound serving of traditionally harvested beef (280 calories) contains less than 10 calories less than the plant based substitute (290 calories) as shown in *Table 2.* In terms of calories from fat, the plant based substitute (190 calories from fat) was 10 less than that of traditionally harvested beef (200 calories from fat) as shown in *Table 2.* A visual representation of this comparison can be viewed in *Figure 6* the lack of substantial variation can be seen. In *Table 3* the macronutrient content between the plant based substitute and traditionally harvested beef was shown. The most substantial difference within the macronutrient comparison was between carbohydrate content which can be visually seen in *Figure 7*. The plant based protein source contained 6 grams of carbohydrates per serving while the traditionally harvested burger contained 0 grams of carbohydrates. This may raise concern for people who are abiding by a dietary regimen that prohibits or limits their intake of carbohydrates, making the traditionally harvested burger a more ideal option between the two for these individuals. As for protein, total fat, saturated fat, trans fat, and sodium, the differentiation is as follows (in order) when comparing traditionally harvested beef to the plant based substitute; 1 gram more, no difference, 3 grams more, 1.5 grams more, 0.375 grams less. The traditionally harvested burger was greater in both saturated and trans fat content which may raise concern for individuals who are limiting their fat intake. For these individuals, the plant based substitute would be considered a more suitable option between the two. Micronutrient content was conveyed in *Table 4.* When comparing micronutrient content, the substantial differences were found when comparing iron and vitamin C content as depicted in *Figure 8.* The plant based substitute (25% of daily intake) contained 1.5 times more iron than the traditionally harvested burger (10%). A serving of the plant based substitute contained 9 times the recommended daily intake of vitamin C than the traditionally harvested burger did, which only contained 10% of the daily recommended intake. This is most likely attributed to the plant based substitute's being made completely up of plants that naturally contain vitamin C. As for vitamin A and calcium content, there is no difference between the amounts of these micronutrients' content in servings of the plant based substitute and traditionally harvested beef.

Overall, the plant based option either meets or exceeds the nutritional content of the traditionally harvested burger. The only major issue that one may encounter with the plant based option is if their diet calls for a limit on carbohydrates intake, in which the traditional burger may be a more suitable option. These results contradicted a common belief that nutritional needs cannot be derived solely from plant based sources. A study published in 2014 that analyzed the nutritional intake of people with diets varying from completely plant based to an omnivorous diet arrived at the conclusion (when using a mediterainian diet as a basis for comparison) that a solely plant based diet was the most healthy option (Clarys, Deliens, Huybrechts, Deriemaeker, Vanaelst, De Keyzer, Hebbelinck, & Mullie, 2014).

Economic Accessibility

In terms of economic accessibility, the traditionally harvested burger is the most cost efficient option for the consumer. A pound of grass fed beef costs around $5.46 per pound in the Chicagoland area whereas a pound of *Beyond Burger* costs around $9.72 to the consumer which can be seen in *Table 5*. This variation may be due to different government subsidies being offered to the meat industry than the fruit and vegetable industry. Another reason for *Beyond Burger* being more expensive than traditionally harvested beef may be transportation costs as some plant based sources may need to be imported over greater distances than meat depending on location and season. Since the technology that produces In-vitro beef is relatively new and is not yet efficient enough to mass produce, a pound of beef costs are $45.44 per pound as seen in *Table 5*. This however is much cheaper than its previous cost of producing a pound of beef to be around $1.3 million. Of the three options, In-vitro beef currently is substantially more expensive to consumers. This comparison is made visually evident in *Figure 9.* With future advances in technology for In-vitro beef, this option is anticipated to become a more financially accessible option to consumers.

Looking Forward

Choosing life cycle assessments as a mean of comparison for the three studied protein sources was beneficial as it showed every resource that was required to process these beef sources from cradle to grave. This then provides more information regarding the origins of one's food and therefore better insight of one’s environmental impact. However, there are still some complications to this approach. Not every resource was easily compared for each protein source as there were not exact numbers always available, so estimates had to be made. In addition to this, In-vitro beef is still a newer product that has not yet been mass produced for the market so the data provided was all based on anticipatory results. Because of this, when/if this data is available, traditionally harvested beef and the plant based substitute may have more efficient means of producing their product causing the comparison to be much different. For a more accurate depiction of how these protein sources' environmental impacts compare to one another, a future study should be performed once data for mass producing In-vitro beef is available. Since different sources of food vary in their bioavailability, the nutritional analysis completed may not accurately describe the nutritional benefits consumers gain from consuming the protein sources. For a future study, analyzing the bioavailability of the ingredients described in the life cycle assessments may give better insight as to which option is truly the most nutritionally viable.

Conclusion

According to the present data, the environmental impact of the plant based option *Beyond Burger* is substantially less than that of the traditionally harvested burger. Current practices in the traditional agriculture industry are not a sustainable option if we wish to reduce our environmental impacts and therefore lessen the rate at which climate change is occuring. Therefore, this would mean that the plant based option is the most environmentally sustainable option on the market as of 2020. However, In-vitro beef presents itself as a promising future option as technology advances, it may eventually become a more environmentally viable option than the *Beyond Burger*. In terms of nutritional viability (without the availability of data for In-vitro beef's Nutrition Facts), the *Beyond Burger* was a more nutritional option than *Verde*'s 100% grass fed beef, with the exception of the *Beyond Burger* containing a higher carbohydrate content which may pose as an issue for individuals whose diets limit carbohydrate intake. Since there was no available data for the In-vitro burger's nutrition as of yet, it may be possible that this could be the most nutritious option in the future with further advancement of technologies. When analyzing economic accessibility, the traditionally harvested burger is currently the cheapest option for consumers while the In-vitro burger is the most expensive but this data is subject to change as technology for the In-vitro beef advances or if allocation of government subsidies change for the meat and dairy industry.

References

Adams, R. M., Rosenweig, C., Pearl, R. M., Ritchie, J. T., McCarl, B. A., Glyer, J. D., … Allen, L. H. (1990). Global Climate Change and U.S. Agriculture, 219–224. Retrieved from https://www.researchgate.net/profile/Joe_Ritchie/publication/232779436_Global_climate_change_and_US_agriculture/links/572b514b08ae057b0a094e4f/Global-climate-change-and-US-agriculture.pdf

Asem-Hiablie, S., Battagliese, T., Stackhouse-Lawson, K. R., & Rotz, C. A. (2018). A life cycle assessment of the environmental impacts of a beef system in the USA. *The International Journal of Life Cycle Assessment*, *24*(3), 441–455. doi: 10.1007/s11367-018-1464-6

Asian Development Bank (ADB) and GMS Working Group on Agriculture (WGA). (2013, November). What is Climate Change? *Bio-Brief#2: Climate Change*, 1-2 Retrieved from http://www.keneamazon.net/Documents/Publications/Virtual-Library/Impacto/9.pdf

Bartholet, J. (2011). Inside the Meat Lab. *Scientific American*, *304*(6), 64–69. doi: 10.1038/scientificamerican0611-64

Carnegie Mellon University Green Design Institute. (2008) Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model [Internet], Available from:<http://www.eiolca.net> Accessed 15 September, 2019.

Clarys, P., Deliens, T., Huybrechts, I., Deriemaeker, P., Vanaelst, B., De Keyzer, W., . . . Mullie, P. (2014). Comparison of Nutritional Quality of the Vegan, Vegetarian, Semi-Vegetarian, Pesco-Vegetarian and Omnivorous Diet. *Nutrients*. doi:10.3390/nu6031318

Climate Impacts on Agriculture and Food Supply. (2016, October 6). Retrieved October 3, 2019, from https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html.

Climate Impacts on Ecosystems. (2016, December 22). Retrieved September 30, 2019, from https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-ecosystems_.html.

EPA's Report on the Environment (ROE). (2019, December 3). Retrieved from https://www.epa.gov/report-environment

Heller, Martin C. and Gregory A. Keoleian. (2018) "Beyond Meat's Beyond Burger Life Cycle Assessment: A detailed comparison between a plant-based and an animal-based protein source." CSS Report, University of Michigan: Ann Arbor 1-38.

Hrynowski, Z. (2019, October 11). What Percentage of Americans Are Vegetarian? Retrieved from https://news.gallup.com/poll/267074/percentage-americans-vegetarian.aspx.

ISO 14044: 2006. Environmental Management - Life Cycle Assessment – Requirements and Guidelines ISO/TS 14071: 2014. Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Kahleova, H., Levin, S., & Barnard, N. (2017). Cardio-Metabolic Benefits of Plant-Based Diets. *Nutrients*. Retrieved from https://www.mdpi.com/2072-6643/9/8/848

Khokhar, T. (2017, March 22). Chart: Globally, 70% of Freshwater is Used for Agriculture.

Retrieved November 20, 2019, from https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture

Lea, E. J., Crawford, D., & Worsley, A. (2006). Public views of the benefits and barriers to the consumption of a plant-based diet. *European Journal of Clinical Nutrition*, 828–837. Retrieved from http://resolver.ebscohost.com/openurl?sid=google&auinit=EJ&aulast=Lea&atitle=Public views of the benefits and barriers to the consumption of a plant-based diet&id=doi:10.1038/sj.ejcn.1602387&title=European Journal of Clinical Nutrition&volume=60&issue=7&date=2006&spage=828&site=ftf-live

Lee, C. (2017, July 26). What is In Vitro Meat? Retrieved from https://www.mcgill.ca/oss/article/technology-health-and-nutrition/what-vitro-meat

Matthews, C. (2006, November 29). Livestock a major threat to environment. Retrieved from http://www.fao.org/newsroom/en/news/2006/1000448/index.html

Nelson, G. C. (2009). *Climate change: impact on agriculture and costs of adaptation*. Retrieved from https://books.google.com/books?hl=en&lr=&id=1Vpe0JvYTJYC&oi=fnd&pg=PR7&dq=climate change from beef&ots=Xmt95aXuj5&sig=OahIkdCBJViCz00cc1sct2SYUqk#v=onepage&q=climate change from beef&f=false

Nutrition Facts Beyond Burger Plant Based Patties [Digital image]. (n.d.). Retrieved from https://hpmi.us/2019/07/17/great-tasting-veggie-burgers-are-here-but-are-they-healthy/

Nutrition Label Verde 100% Organic Grass Fed Beef [Digital image]. (n.d.). Retrieved from https://www.verdefarms.com/

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), 37–42. doi: 10.1038/nature01286

Roser, M., Ritchie, H., & Ortiz-Ospina, E. (2013, May 9). World Population Growth. Retrieved from https://ourworldindata.org/world-population-growth.

Stehfest, E., Bouwman, L., van Vuuren, D. P., den Elzen, M. G. J., Eickhout, B., & Kabat, P. (2009). Climate Benefits of Changing Diet. *Climate Change*, 83–84. doi: 10.1007/s10584-008-9534-6

Waite, R., Searchinger, T., & Ranganathen, J. (2019, September 13). 6 Pressing Questions About Beef and Climate Change, Answered. Retrieved from https://www.wri.org/blog/2019/04/6-pressing-questions-about-beef-and-climate-change-answered

What is a carbon footprint - definition. (n.d.). Retrieved October 10, 2019, from https://timeforchange.org/what-is-a-carbon-footprint-definition.

USGCRP, 2016: *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. http://dx.doi.org/10.7930/J0R49NQX

What is eutrophication? (2017, October 5). Retrieved October 23, 2019, from https://oceanservice.noaa.gov/facts/eutrophication.html.

Why We Build Meat Directly from Plants? (n.d.). Retrieved from https://www.beyondmeat.com/about/

10 Secrets the Meat and Dairy Industries Try to Hide. (2013, December 6). Retrieved from https://www.peta.org/living/food/10-things-wish-everyone-knew-meat-dairy-industries/