Tracing the Environmental Impact of an Energy-dense Diet from Production to Consumption

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Abstract

The U.S. population has grown from ~40 million in 1870 to over 300 million today. To meet the demands of a growing population, agriculture has seen the rise of technological advances including the tractor, hybridization, agrochemicals, and genetic engineering. Improved methods leading to excess yields from agriculture have has major environmental impacts. Agriculture produces up to 30% of greenhouse gas (GHG) emissions in developed countries (Clark and Tilman, 2017; Hallström *et al*., 2015; Klein *et al*., 2014), accounts for more than 70% of global freshwater use (Clark and Tilman, 2017; Jalava *et al*., 2014), and uses 30% of available global energy (Food and Agriculture Organization of the United Nations, 2012). Additionally, agricultural chemicals degrade up to 7 million hectares of arable land per year (Maredia and Pingali, 2001), decommission aquatic breeding grounds, and significantly reduce species biodiversity. Increasing efficiency and crop yield from agricultural technologies have created a surplus of certain commodity crops. These surplus crops are refined into cheap, energy-dense foods that provide excess calories. Excessive caloric intake is the major contributor to the more than three-fold increase in adult obesity in the U.S. since 1960. Obesity increases food energy demands by 19% (Mann, 2017) and transportation fuel consumption by nearly 2% (Tom *et al*., 2014). With nearly 40% of U.S. adults classified as obese (Hales *et al*., 2017), the environmental impacts of a population growing in both number and weight is considered in this thesis.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BMI	Body mass index
Bt	*Bacillus thuringiensis*
CO_2	Carbon dioxide
FAO	Food and Agriculture Organization
ft^3	Cubic foot
GHG	Greenhouse gas
GMO	Genetically modified organism
ha	Hectare
HFCS	High-fructose corn syrup
HT	Herbicide tolerant
J	Joule
kcal	Kilocalorie
kcal/g	Kilocalories per gram
kg	Kilogram
kg/m^2	Kilograms per square meter
kJ/g	Kilojoules per gram
kWh	Kilowatt hour
m^3	Cubic meter
MJ/kg	Megajoules per kilogram
mm	Millimeter
NASS	National Agricultural Statistics Service
N_20	Nitrous oxide
U.S.	United States
UK	United Kingdom
WHO	World Health Organization
$/MJ	Cost per megajoule

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Introduction

Recent climate concern has directed research towards understanding the environmental impact of food production and distribution. Much of that research has focused on the impacts of different dietary patterns (omnivorous, vegetarian, vegan) with far less focus on the energy-dense foods that reach broadly across all dietary patterns (Baroni *et al*., 2006; Hallström *et al*., 2015). Energy density is defined as the measure of food energy per gram of food (kJ/g) (Drewnowski and Darmon, 2005; National Center for Chronic Disease Prevention and Health Promotion, 2011; Stubbs and Whybrow, 2004). Foods containing “refined grains, added sugars, and added fats” are considered to be energy-dense foods (Drewnowski and Darmon, 2005). This paper will focus on the impacts of energy-dense foods on the environment.

All crops have environmental impacts ranging from fertilizer and pesticide use to soil and water resource degradation. However, the process of creating energy-dense foods magnifies those impacts through means of refinement. Additionally, energy-dense foods have been shown to be a major pathway to obesity encompassing a new set of environmental impacts including increased fuel for transportation, higher sustained calorie requirement, and additional environmental contamination from medications for obesity related diseases (Mann, 2017).

Consistent population growth in the U.S. has led, in large part, to the industrialization of agriculture. The twentieth century brought about numerous technological advances in agriculture. Crop yields prior to the 1930s were low, but stable (Figure 1). The introduction of mechanization by tractor along with hybridization of crops signaled the first upward inflection in crop yields (Bogue, 1983). Partnered with an unstable U.S. economy and a need for greater food production, the U.S. government began to subsidize crop production in an efficacious attempt to increase supply. The nationwide shift of focus towards mass production of crops demanded the invention and use of synthetic agrochemicals, such as fertilizers, pesticides, and herbicides (Klein *et al*., 2014; Selman and Greenhalgh, 2010). In 1970s, the invention and acceptance of genetic engineering generated even higher crop yields (Hughes, 2011). In all, over a period shy of a century, the crop yield in the U.S. increased between three and seven-fold for the top three commodity crops (i.e. crops that are commonly traded): corn, soybeans, and wheat, respectively (113th Congress, 2014; Food and Agriculture Organization of the United Nations, 2016; United States Department of Agriculture, 2018a). Population is projected to continue to increase in the U.S. by approximately 2.1 million people per year for a total of 400 million by 2060, furthering the demand for agriculture (Colby and Ortman, 2017; The World Bank, 2010)

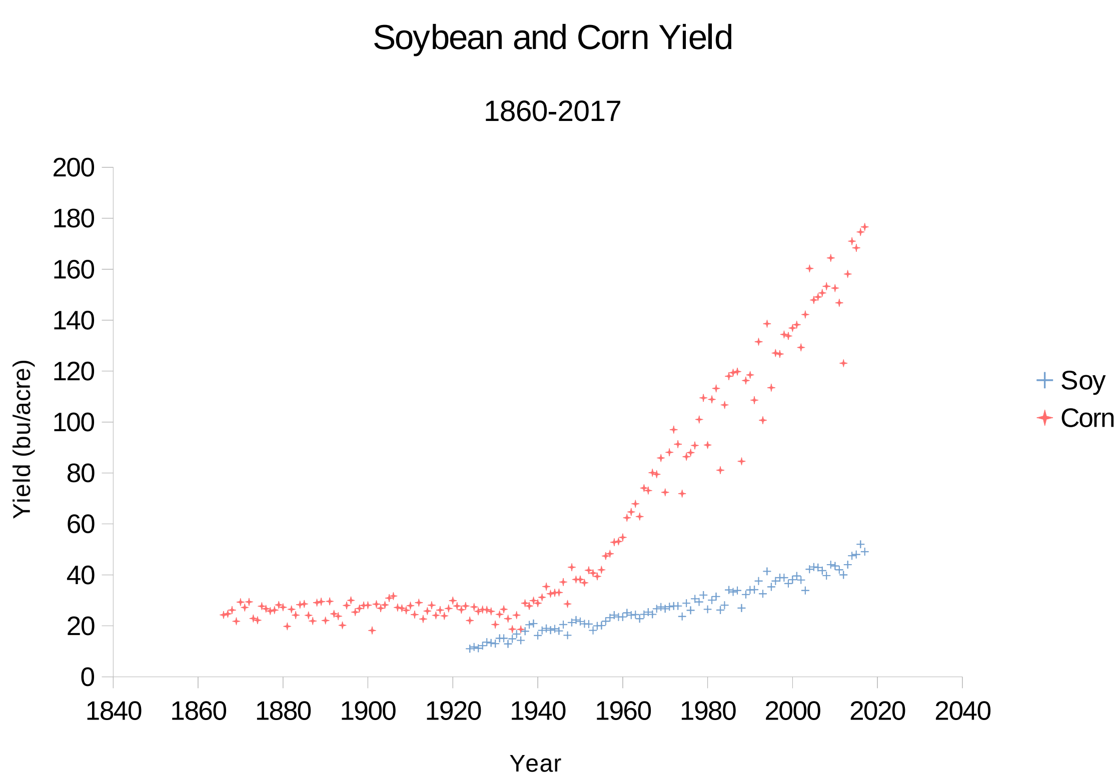

Figure 1: Corn and soy yields (bu/acre) between 1860 and 2017 generated from USDA National Agricultural Statistics Service (NASS) corn and soy yield data (United States Department of Agriculture, 2018a)

The U.S. food system is continually evolving in reaction to its interrelationships with public health, the environment, equity, and society (Neff, 2014). The contribution of an energy-dense diet on health is well documented in literature. The energy-dense dietary pattern has significant impacts on the health of the U.S. population with obesity-related health costs as high as $147 billion (Finkelstein *et al*., 2009). The U.S. has approached the obesity epidemic through education, taxation, and some policy changes, but with little effect. The contribution of an energy-dense diet on the environment, however, is not well documented in literature. In this thesis, I examine the environmental impacts of an energy-dense diet from production to consumption as a critical component in the U.S. and global food system. First, I discuss the history of agriculture in the U.S. to set the stage for examining the environmental impacts of modern agriculture. Next, in three steps, I review the links between energy-dense diets, obesity, and the increased environmental impacts caused by obesity. Finally, I discuss the interconnected components of the food system web with the hope of consideration of the importance of incorporating agricultural policy in the obesity epidemic discussion.

History of U.S. Agriculture

Agricultural Mechanization

The earliest agricultural shift in the U.S. came by means of specializations and mechanization. Farmers first increased their yield efficiency simply by growing large quantities of a single crop allowing them to invest in farm equipment particular to that crop. Farm equipment, notably the tractor, sharply reduced the number of farms and farm workers while maintaining farm outputs (Binswanger, 1986). In fact, the farming workforce in the U.S. dropped from 41% of the population in 1900 to just 2% in 2000 (Dimitri *et al*., 2005). The repetitive tasks involved in specializing in a single crop were most efficiently performed by machinery. The increase in number of farms (Table 1) between 1870 and 1910 represents a nearly three-fold population increase from ~40 million in 1870 to ~100 million in

1910 without change to farming technique (Table 1, Figure 2). Population continued to increase between 1910 and 1940 (~100 million to ~140 million), but the number of farms remained fairly constant meeting an inflection point around 1935. The number of farms began to dwindle relative to population from a peak of 6.8 million in 1935 to 2.05 million in 2017 (United States Department of Agriculture, 2018b). Fewer farms gave rise to larger farms averaging from 155 acres in 1935 to 444 acres in 2017 (United States Department of Agriculture, 2018b). This transition is marked by the introduction and rapid expansion of the tractor (Binswanger, 1986). The demand for able farm workers to fight in World War 1 further expedited the shift towards mechanization as farm owners were left shorthanded for labor (Fitzgerald, 2003).

Prior to the 1920s, small farms grew a diverse set of crops. Without the financial burden of tractor equipment investments, farmers interests were in supplying a variety of food to their families and community. The introduction of industrialization in the farming sector along with the post-war financial downturn led farmers to grow as much of a single crop most well suited to their land as was possible. The result is known as monocropping (or mono-culture). The economic hardship drove out many small farms in favor of fewer, but larger farms that could afford to practice large-scale monocropping (Fitzgerald, 2003).

Table 1: Sources of Farm Power in the United States between 1870 and 1979 showing the transition from workstock to tractors (Binswanger, 1986).

		Workstock above two years						Tractors (exclusive of steam and garden)		
Year	Number of farms	Oxen	Mules	Horses	Windmills	Steam engines	Gas engines	Number	Horse-power (millions)	Trucks
1870	2,660	1,319	1,125	7,145	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1880	4,009	994	1,813	10,357	200	24	n.a.	n.a.	n.a.	n.a.
1890	4,565	1,117	2,252	15,266	400	40	n.a.	n.a.	n.a.	n.a.
1900	5,737	960	2,753	15,506	600	70	200	n.a.	n.a.	n.a.
1910	6,406	640	3,787	17,430	900	72	600	10	0.5	0
1920	6,518	370	4,652	17,221	1,000	70	1,000	246	5	139
1930	6,546	n.a.	17,612[a]	n.a.	1,000	25	1,131	920	22	900
1940	6,350	n.a.	13,029	n.a.	n.a.	n.a.	n.a.	1,567	62[b]	1,047
1945	5,967	n.a.	11,116	n.a.	n.a.	n.a.	n.a.	2,354	88[c]	1,490
1950	5,648	n.a.	7,415	n.a.	n.a.	n.a.	n.a.	3,394	93	2,207
1955	4,654	n.a.	4,101	n.a.	n.a.	n.a.	n.a.	4,345	126	2,675
1959	4,105	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1960	3,963[d]	n.a.	2,883	n.a.	n.a.	n.a.	n.a.	4,685	153	2,826
1965	3,356	n.a.	—[e]	n.a.	n.a.	n.a.	n.a.	4,787	176	3,030
1970	2,949	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	4,619	203	2,984
1975	2,767	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	4,469	222	3,031
1979	2,672[f]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	4,350[g]	243	3,045

n.a. Not available.
a. From 1930 onward refers to total workstock on farm.
b. Average horsepower for 1930–34 multiplied by number of tractors in 1930.
c. Average horsepower for 1940–44 multiplied by number of tractors in 1940.
d. After 1960 corresponds to 1969 definition.
e. Discontinued.
f. Figure corresponds to 1978.
g. Tractors over 40 horsepower only.

Sources: Number of farms: up to 1959, U.S. Department of Agriculture, *Century of Agriculture in Charts and Tables;* 1960–79: U.S. Department of Commerce, *Statistical Abstract of the United States* (1980).

Oxen, mules, horses, windmills, gas engines, and steam engines, 1850–1930: W. M. Hurst and L. M. Church, *Power and Machinery in Agriculture* (1933), table 8, p. 12; 1930–79: U.S. Department of Commerce, *Historical Statistics of the United States: Colonial Times to 1970* (1975).

Tractors, horsepower, and trucks, 1870–30: W. M. Hurst and L. M. Church, *Power and Machinery in Agriculture* (1933), table 8, p. 12; 1940–59: U.S. Department of Agriculture, *Changes in Farm Production and Efficiency, 1964 and 1973;* 1960–79: U.S. Department of Commerce, *Statistical Abstract of the United States* (1980).

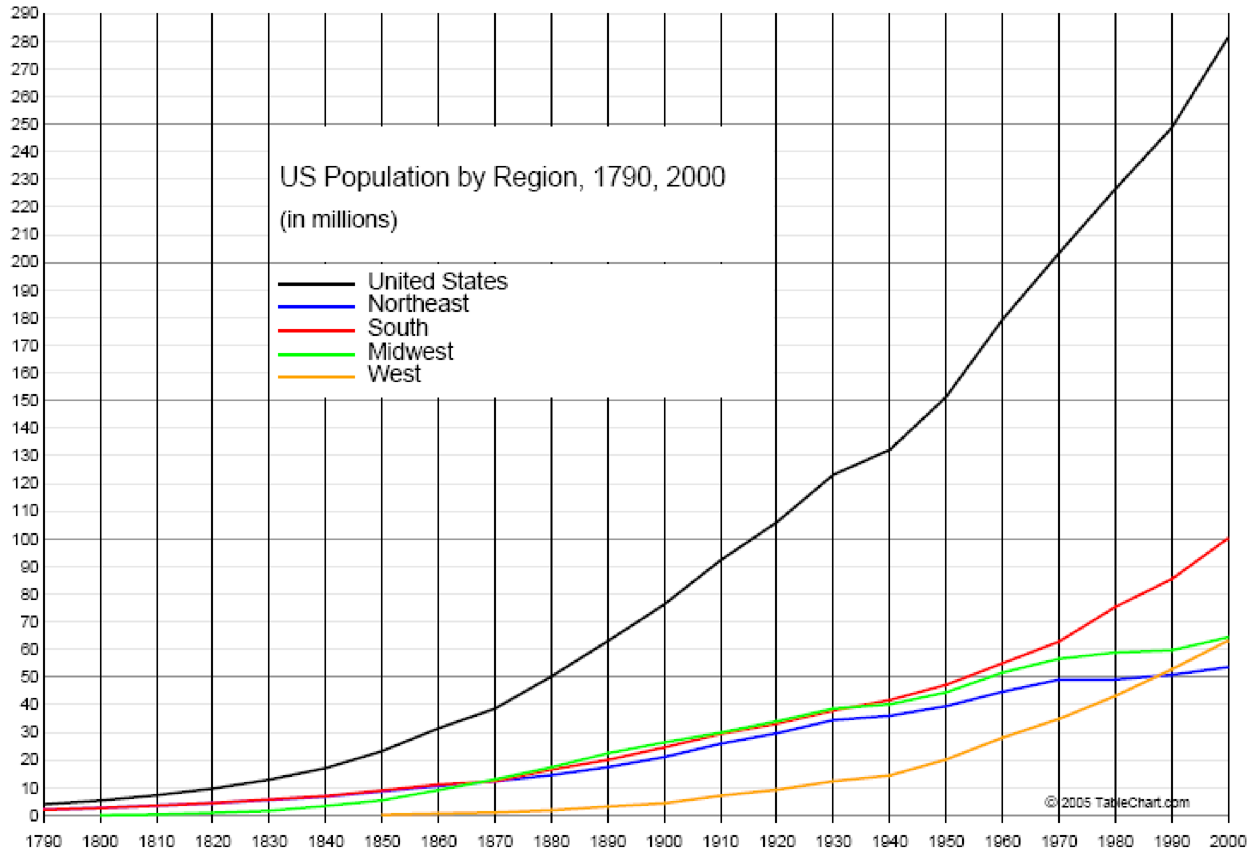

Figure 2: U.S. Population growth between 1790 and 2000 (Casey, 2006).

Crop Hybridization

Crop hybridization work began in the early 1900s pioneered by George Shull as a way to enhance the productivity of crops; in particular, corn. Prior to Shull's work, corn breeding was done by farmers through the process of open-pollination. Using this method, farmers simply selected seeds from the most desirable plants to be grown in the following growing season (Corn Breeding: Lessons From the Past, https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1075412493). However, seed selections were made for many different features rather than production alone (Corn Breeding: Lessons From the Past, https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1075412493). Corn yield from 1866 - ~1930 remained stagnant as a consequence and most often below 30 bushels per acre (Figure 1) (Hallauer, 2009; United States

Department of Agriculture, 2018a). Shull first introduced the idea of inbred-hybrid corn in 1908 as a means to boost corn plant productivity (Hallauer, 2009; Corn Breeding: Lessons From the Past, https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1075412493). However, due to the undesirable trade-off of plant strength and disease resistance for productivity, the hybrid crop was not utilized until a stable crop was bred in 1919 (Hallauer, 2009). By 1935, hybrid corn had proven advantageous to production yield and was widely used. Corn has since been further hybridized and improved to relieve other problems such as disease and insect infestation while still increasing productivity (Hallauer, 2009; Shull, 1946). Other field crops have followed a similar path to corn, including rice and wheat (Jain, 2012).

Agrochemicals

Agrochemicals including synthetic fertilizers, herbicides, and pesticides have become increasingly important to ensuring the high yields of hybrid crops. Since the beginning of the Green Revolution in the 1940s, much of the increase in crop yield has been attributed to synthetic fertilizers (Binswanger, 1986; Selman and Greenhalgh, 2010; Walpole *et al*., 2012). Though they increase production yield, hybrid crops often have genetic weaknesses that leave them susceptible to diseases and pests. (Hallauer, 2009; Maredia and Pingali, 2001). Additionally, monocropping promoted the excessive growth of weeds in crop fields by removing symbiotic crops (Hallauer, 2009; Maredia and Pingali, 2001). To combat these problems, scientists synthesized pesticides and herbicides that farmers rely upon heavily (Jain, 2012; Maredia and Pingali, 2001). The side effects of the introduction and use of agrochemicals to combat the problems and vulnerabilities of monocropping are poorly understood.

Transgenic Crops

Research into developing crops capable of mitigating disease and pest problems without the use of agrochemicals resulted in transgenic crops; that is, crops in which target genes have been replaced

(Jain, 2012). Transgenic crops were first commercialized in 1996 and have rapidly taken hold in the U.S. By 2015, over 90% of corn and soy fields were planted with transgenic crops (Figure 3) (Hallauer, 2009; ISAAA, 2016). For example, Bt-crops are those in which a gene from the soil bacterium, *Bacillus thuringiensis*, along with additional supporting genetic material is inserted into the particular crop (Kumar *et al.*, 2008). The genetically modified organism (GMO) or crop then contains the genes necessary to produce a toxic protein defending the crop against the targeted insect. In addition to herbicide and insect resistance, transgenic crops have been modified to have much higher productivity per acre relative to traditional crops (ISAAA, 2016).

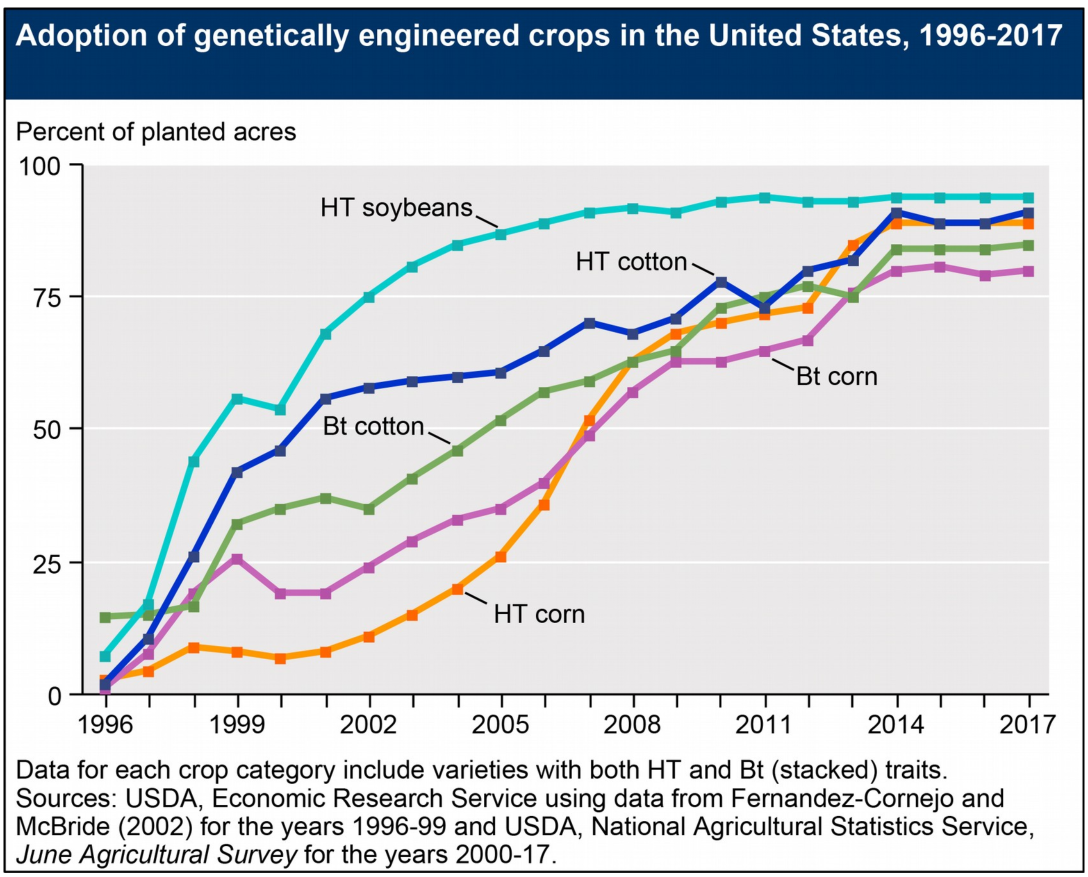

Figure 3: Adoption of genetically engineered Bt and HT crops in the United States between 1996 and 2017.

Farm Subsidies

It is often suggested that the increasing per acre yield of commodity crops can be attributed to farm subsidies (Alston *et al*., 2008; Mann, 2017; Morath, 2014). The first farm subsidy, known as the Agricultural Adjustment Act of 1933 emerged during The Great Depression, a period of both economic and environmental hardship (see corn yields at ~1933 in Figure 1) (Morath, 2014). During this period, commodity crop prices had fallen below the cost of production. The Agricultural Adjustment Act paid farmers to produce less in order to equilibrate the cost discrepancy. Since 1933, fourteen editions of the bill have been passed including the most recent Agricultural Act of 2014. Although more recent bills have expanded to benefit more stakeholders than just farmers, parallel subsidies have continued to drive commodity crop production, such as those for ethanol production, a corn-derived automotive fuel (Appel, 2016; Pimentel and Patzek, 2005). Large government subsidies have ultimately shifted agricultural markets toward the over-production of commodity crops (Elinder, 2005; Klein *et al*., 2014).

Agricultural Excess

Global food production is sufficient to alleviate all malnutrition; however, access is the limiting factor (Elinder, 2005). The U.S. is currently producing nearly 3900 calories per capita each day, nearly double the recommended daily intake (Table 2) (Franck *et al*., 2013). The continual over production of commodity crops has left food markets saturated. The excess is absorbed by processing them into alternative products (Klein *et al*., 2014). For example, corn can be processed into ethanol fuel, animal feed and sweeteners (Appel, 2016; Pimentel and Patzek, 2005). Despite these efforts to absorb the excess, these methods remain particularly inefficient uses of surplus corn. Commodity crops are commonly refined for consumption by means of dehydration, chemical alterations, extraction of oil, and protein conversion (Buck, 2001; Drewnowski and Specter, 2004; Mann, 2017; Siegel *et al*., 2016).

No matter the method, the refined product will generally have a higher energy density and lower satiety (Drewnowski and Specter, 2004).

Table 2: Estimated Calorie Needs per Day by Age, Gender, and Physical Activity Level (United States Food and Drug Administration, 2011).

Estimated amounts of calories[a] needed to maintain calorie balance for various gender and age groups at three different levels of physical activity. The estimates are rounded to the nearest 200 calories for assignment to a USDA Food Pattern. An individual's calorie needs may be higher or lower than these average estimates.

	Male			Female[c]		
Activity level[b]	**Sedentary**	**Moderately active**	**Active**	**Sedentary**	**Moderately active**	**Active**
Age (years)						
2	1,000	1,000	1,000	1,000	1,000	1,000
3	1,200	1,400	1,400	1,000	1,200	1,400
4	1,200	1,400	1,600	1,200	1,400	1,400
5	1,200	1,400	1,600	1,200	1,400	1,600
6	1,400	1,600	1,800	1,200	1,400	1,600
7	1,400	1,600	1,800	1,200	1,600	1,800
8	1,400	1,600	2,000	1,400	1,600	1,800
9	1,600	1,800	2,000	1,400	1,600	1,800
10	1,600	1,800	2,200	1,400	1,800	2,000
11	1,800	2,000	2,200	1,600	1,800	2,000
12	1,800	2,200	2,400	1,600	2,000	2,200
13	2,000	2,200	2,600	1,600	2,000	2,200
14	2,000	2,400	2,800	1,800	2,000	2,400
15	2,200	2,600	3,000	1,800	2,000	2,400
16	2,400	2,800	3,200	1,800	2,000	2,400
17	2,400	2,800	3,200	1,800	2,000	2,400
18	2,400	2,800	3,200	1,800	2,000	2,400
19–20	2,600	2,800	3,000	2,000	2,200	2,400
21–25	2,400	2,800	3,000	2,000	2,200	2,400
26–30	2,400	2,600	3,000	1,800	2,000	2,400
31–35	2,400	2,600	3,000	1,800	2,000	2,200
36–40	2,400	2,600	2,800	1,800	2,000	2,200
41–45	2,200	2,600	2,800	1,800	2,000	2,200
46–50	2,200	2,400	2,800	1,800	2,000	2,200
51–55	2,200	2,400	2,800	1,600	1,800	2,200
56–60	2,200	2,400	2,600	1,600	1,800	2,200
61–65	2,000	2,400	2,600	1,600	1,800	2,000
66–70	2,000	2,200	2,600	1,600	1,800	2,000
71–75	2,000	2,200	2,600	1,600	1,800	2,000
76+	2,000	2,200	2,400	1,600	1,800	2,000

a. Based on Estimated Energy Requirements (EER) equations, using reference heights (average) and reference weights (healthy) for each age-gender group. For children and adolescents, reference height and weight vary. For adults, the reference man is 5 feet 10 inches tall and weighs 154 pounds. The reference woman is 5 feet 4 inches tall and weighs 126 pounds. EER equations are from the Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington (DC): The National Academies Press; 2002.

b. Sedentary means a lifestyle that includes only the light physical activity associated with typical day-to-day life. Moderately active means a lifestyle that includes physical activity equivalent to walking about 1.5 to 3 miles per day at 3 to 4 miles per hour, in addition to the light physical activity associated with typical day-to-day life. Active means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3 to 4 miles per hour, in addition to the light physical activity associated with typical day-to-day life.

c. Estimates for females do not include women who are pregnant or breastfeeding.

Food Environment

Energy Density

The U.S. Food and Drug Administration mandates standardized nutrition labeling on most processed foods. This label provides an indirect measure of the energy density of a food item to the consumer where energy density is defined as the amount of energy per unit mass (MJ/kg (Drewnowski, 2004; Drewnowski and Specter, 2004), kcal/g (Drewnowski, 2004; National Center for Chronic Disease Prevention and Health Promotion, 2011; Thomson *et al*., 2017), kJ/g (Drewnowski and Darmon, 2005; Drewnowski and Rolls, 2005; Ledikwe *et al*., 2005; Thomson *et al*., 2017)). The consumer can calculate energy density by dividing kilocalories by the serving size in grams. Energy density will be used throughout this paper to establish a comparative measurement for different food items.

Historically, energy density has been used to describe the amount of energy (J) contained within a particular fuel. For a non-food example, 1 kg of uranium is more energy-dense than 1 kg of a biofuel. More recently, the term’s use has extended into nutrition and obesity research to describe the energy within a mass or volume of a particular food item. In this case, high energy density food components are sugars and fats. For simplicity, foods are categorized into four energy density groupings (Table 3). The range of energy densities falls between two extremes: water and oil, 0 to 9 kcal/g, respectively (National Center for Chronic Disease Prevention and Health Promotion, 2011).

Table 3: Energy density ratings and examples. Adapted from British Nutrition Foundation (British Nutrition Foundation, 2016).

Energy Density Rank	Energy Density Range	Examples
Very Low	>0.6 kcal/g	Vegetables, fruits
Low	0.6 – 1.5 kcal/g	Soups, stews, breakfast cereals, yogurt
Medium	1.5 – 4 kcal/g	Salmon, lower fat cheese, lean red meat
High	>4 kcal/g	Confectionery, peanuts, butter, oils

Sweeteners

In more recent years, U.S. grocery stores are stocking their shelves with energy-dense foods commonly referred to as 'junk food.' Merriam-Webster defines junk food as "food that is high in calories but low in nutritional content (Merriam-Webster, 2018)." Items such as soft drinks, french fries, and most desserts fit such classification. Interestingly, many of these foods are manufactured using refined products from commodity crops. One refined product, high-fructose corn syrup (HFCS), accounts for almost all of the added caloric sweeteners used by beverage manufactures (Duffey and Popkin, 2008). While there is no significant difference in taste to the consumer between sugar derived from sugar cane or beets and HFCS, the affordability of the latter has made it a popular choice in food manufacturing. For example, soda has always been sweetened, but traditionally table sugar (sucrose), a more expensive source of sweetener. By 1984, both Coca-Cola and Pepsi brand had replaced sugar completely by HFCS (Nabors and Gelardi, 2001). With non-diet soft drinks now accounting for 47% of added sugar in the American diet, it is an important marker for understanding the role of commodity crops play in the obesity epidemic (Malik *et al*., 2006).

Between 1997 and 2005 corn was sold at up to 30% below the cost of production (Duffey and Popkin, 2008). Ultimately, the low cost of HFCS drove food manufactures to replace traditional sweeteners with HFCS, a sweeter and less expensive alternative (Duffey and Popkin, 2008). As a result, food manufactures were able to increase product size with little increase in cost. The perceived increased value for consumers dramatically increased consumption of sodas alongside other products favoring the use of HFCS (Figure 4) (Cavadini *et al*., 2000).

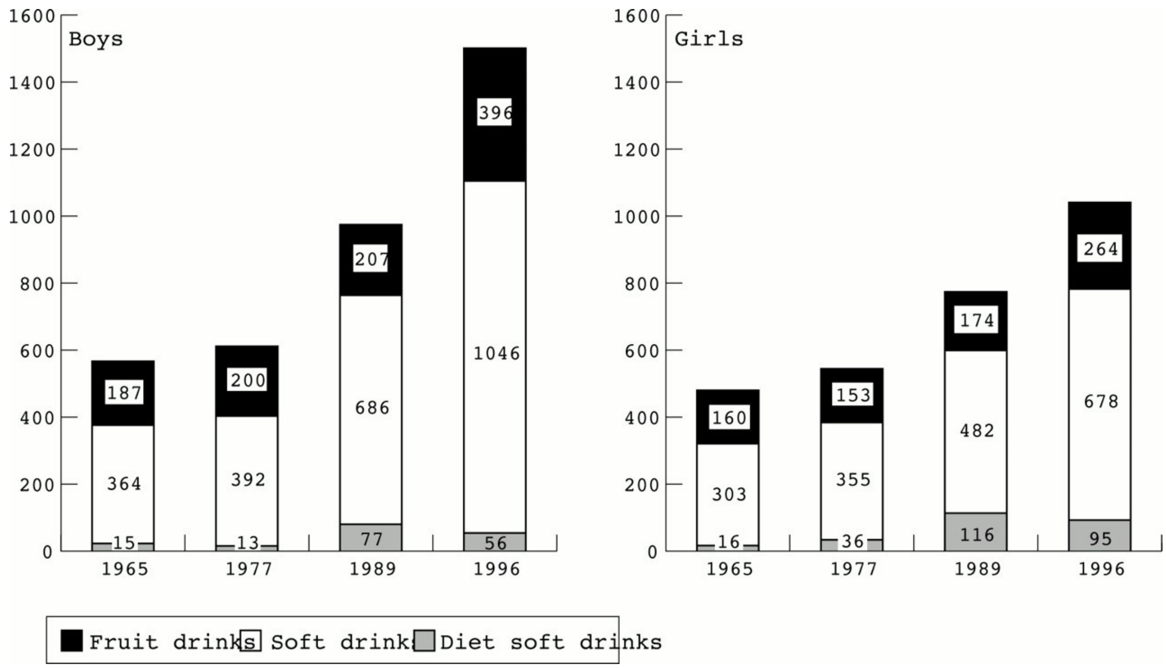

Figure 4: Trends in beverage consumption among U.S. adolescent; 1965-96 in per capita grams of beverage consumed per day (Cavadini et al., 2000).

Seed Oils

HFCS is hardly the lone product behind the increased availability of energy-dense food. Just as corn is grown in excess, so are soybeans. Half of the soybeans grown in the U.S. are used to make oils (Mann, 2017). Soybean oils are commonly partnered with HFCS in many junk food items sold to U.S. consumers. Adding soybean oils to products improves taste and increases energy density, both without impacting cost.

Livestock

The remaining half of the soybean produced in the United States go towards feeding livestock (Mann, 2017). Corn also makes up a large percentage of U.S. livestock feed (United States Department of Agriculture, 2016). Both corn and soy in whole (unrefined) form have a relatively lower energy density rating. As with any whole-grain, they are high in fiber and have higher satiety power than a processed grain. The conversion of corn, soy, and other feed grain proteins into livestock protein increases the energy density of the consumable product – meat. In the U.S., 67% of available crop calories are fed to livestock (Cassidy *et al*., 2013). The low cost of commodity crops for livestock feed ultimately reduces the cost of meat production. Lower costs, again, drive sales of energy-dense meats.

Food Psychology

Energy-dense foods often contain starch, added sugar, and fat (Drewnowski, 2004). The addition of these substances increase a food item's palatability, or its appeal to a consumer's orosensory perception (Stubbs and Whybrow, 2004). Humans, like most mammals, are neurobiologically drawn to energy-rewarding food items such as fats, carbohydrates (sugar and starch), and protein which have energy densities of 37 kJ/g, 16 kJ/g, and 17 kJ/g, respectively (Drewnowski and Specter, 2004; Stubbs and Whybrow, 2004). As such, increased availability of energy-dense foods leads to increased energy intake (Drewnowski and Specter, 2004; Stubbs and Whybrow, 2004).

Energy intake is not only controlled by the palatability of a food item, but also its ability to make the consumer feel full, or satiated. Numerous dietary studies have agreed that, on average, consumers will consume a constant weight or volume of food (Ledikwe *et al*., 2005; National Center for Chronic Disease Prevention and Health Promotion, 2011; Rolls *et al.*, 1998). However, the energy density of a set volume of food can vary widely, as can the calorie uptake rate. For example, sweetened soft-drinks are energy-dense and palatable, but do not promote sustained satiety (Malik *et al*., 2006). Because beverages are mostly water by volume and contain no dietary fiber to lengthen digestion duration, their calories are rapidly absorbed and stored. Satiety may be met briefly, but is not maintained and the consumer is unlikely to compensate at later meals for the calories consumed, resulting in excess energy intake (Malik *et al*., 2013; Thomson *et al*., 2017).

Many of the most palatable foods are also the cheapest providing the highest caloric value per dollar spent (Figure 5) (Drewnowski, 2004). As a result, many studies show a trend between low income and high consumption of energy-dense junk foods (Drewnowski, 2004; Franck *et al*., 2013; Siegel *et al*., 2016). However, the impacts of energy-dense food are not limited to an income class. Half of the calories consumed by adults between 2001 and 2006 originated from commodity crops (Siegel *et al*., 2016). The energy-dense food products that make up these calories encourage excessive energy intake.

Obesity

Since 1960, the United States has seen a rise in the percentage of adults that classify as obese. Obesity is defined in (Table 4) by the world health organization (WHO) as a body mass index (BMI) greater than 30 kg/m^2. Recent data from the 2015-2016 National Health and Nutrition Examination Survey found the adult obesity prevalence to be 39.6% (Hales *et al*., 2017). The percent of obese adults between the ages of 20 and 74 during the period between 1960 and 1962, however was only 13.4% (Ogden and Carroll, 2010). Perhaps most disturbing is the increase in obesity between the 1976-1980 survey period and the 1999-2000 survey period. The number of obese adults doubled during that 20 year period from 15% to 31% (Ogden and Carroll, 2010). Unfortunately, similar trends in obesity prevalence have been seen globally (Figure 6).

Table 4: The International Classification of adult underweight, overweight, and obesity according to BMI (World Health Organization, n.d.)

Classification	BMI(kg/m^2)	
	Principal cut-off points	Additional cut-off points
Underweight	**<18.50**	**<18.50**
Severe thinness	<16.00	<16.00
Moderate thinness	16.00 - 16.99	16.00 - 16.99
Mild thinness	17.00 - 18.49	17.00 - 18.49
Normal range	**18.50 - 24.99**	**18.50 - 22.99**
		23.00 - 24.99
Overweight	**≥25.00**	**≥25.00**
Pre-obese	25.00 - 29.99	25.00 - 27.49
		27.50 - 29.99
Obese	**≥30.00**	**≥30.00**
Obese class I	30.00 - 34.99	30.00 - 32.49
		32.50 - 34.99
Obese class II	35.00 - 39.99	35.00 - 37.49
		37.50 - 39.99
Obese class III	≥40.00	≥40.00

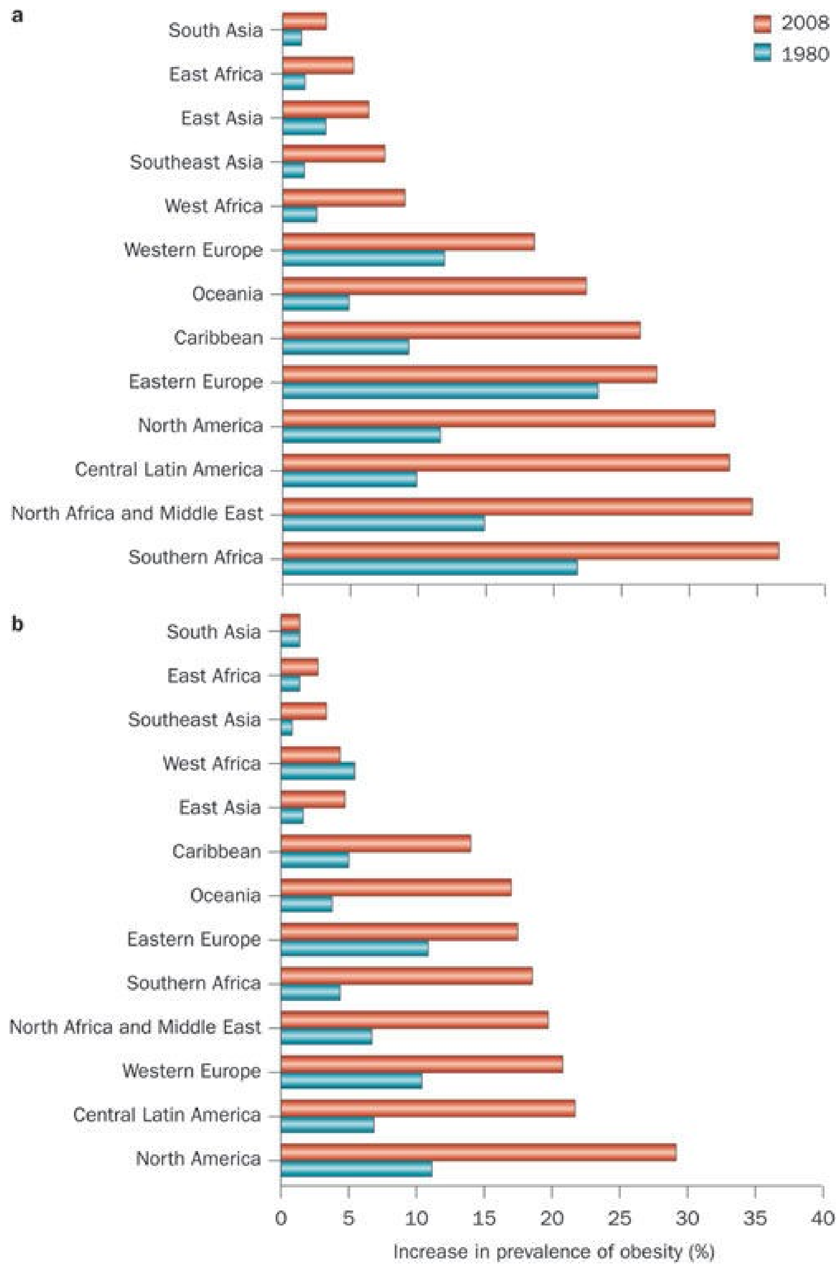

Figure 6: Global trends in the prevalence of obesity among (a) women and (b) men in 1980 and 2008 from select regions of the world

Studies disagree on the root cause for the worldwide trend in obesity (Drewnowski and Darmon, 2005). Suggestions for the increased rate of obesity include environmental factors (Mann, 2017; Pérez-Escamilla *et al*., 2012), inadequate sleep (Beccuti and Pannain, 2011; Gangwisch *et al*., 2005), economics (Drewnowski and Darmon, 2005; Mann, 2017; Popkin, 2007), activity level changes

(Pérez-Escamilla *et al*., 2012), and even temporal human habit changes such as smoking, home temperature, and medications (Keith *et al*., 2006).The most well understood cause for weight gain, however, is an imbalance between calorie input versus calorie expenditure (Hill *et al*., 2012). The consumption of energy-dense foods accelerates this imbalance, leading to weight gain. Obesity and associated weight and diet related diseases are the leading causes of death in the U.S. today (Elinder, 2005; Franck *et al*., 2013; Siegel *et al*., 2016; Thomson *et al*., 2017).

The methods of producing and manufacturing energy-dense foods from commodity crops also have profound effects on the environment. Recently, there is concern about the role of food production on climate change. Global food production accounts for around 30% of greenhouse gas (GHG) emissions (Clark and Tilman, 2017; Hallström *et al*., 2015; Klein *et al*., 2014). Conditions associated with excessive calorie intake emit additional GHG discussed in later section. Both creating energy-dense food and consuming energy-dense foods must be considered together as necessary measures to reduce the impact of climate change. The following sections trace the environmental impacts of modern agriculture and food processing from field to final.

Environmental Impacts

Greenhouse Gas

Direct greenhouse gas (GHG) emissions from agriculture account for 10% to 12% of global emissions, however when indirect emissions are included, that figure rises up to greater than 30% (Clark and Tilman, 2017; Hallström *et al*., 2015; Heller and Keoleian, 2015; Klein *et al*., 2014; Martin *et al*., 2014). Agriculture contributes to GHG emissions from start to finish. Inputs of fertilizers and agrochemicals release nitrous oxide. After harvest, the decomposition of crop roots releases additional nitrous oxide particularly in nitrogen-fixing crops such as soybeans (Figure 7) (Uchida and Akiyama, 2013). In fact, it is estimated that 19% of agricultural emissions of nitrous oxide is a product of soybean production (Mann, 2017). Further, the production of livestock, a major consumer of soybeans, is also a major source of methane emissions. Nitrous oxide and methane combined make up nearly 80% of the total agricultural emissions (Friel *et al*., 2009). Additional contributions of carbon dioxide emissions from land use changes, burning fossil fuels in tractors and transportation, and the storage and refinement of foods have increased dramatically since the transition to large-scale mechanization around 1950s and are predicted to continue to rise into and beyond 2030 (Figure 8). Energy density, however, is not proportional to GHG emissions. A study by Martin *et al*. (2014) finds that energy-dense sweets are among the lowest emitters of GHG while similarly energy-dense meats are among the highest emitters (Figure 9). Meat production is expected to double from 229 million tonnes in 1999-2001 to 465 million tonnes in 2050 (McMichael *et al*., 2007). The global trend of increasing GHG emissions could lead to unpredictable weather that could heavily impact crop production (Klein *et al*., 2014).

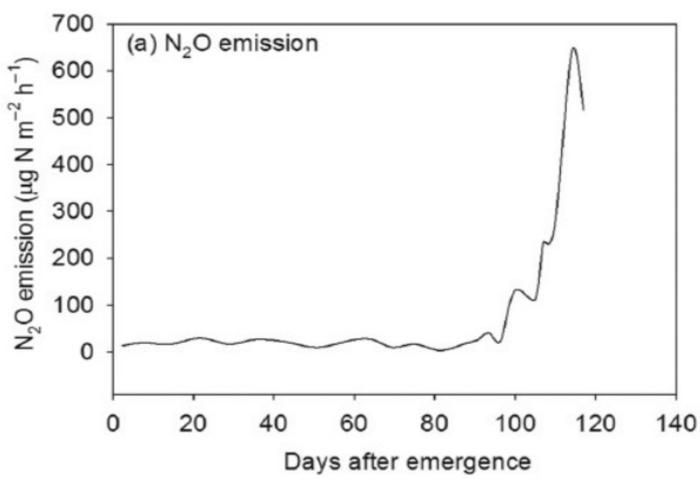

Figure 7: Typical nitrous oxide soil emissions from soybean ecosystems. The spike beginning at ~85 days signifies pod-filling stage through harvest when the plan begins decomposition (Uchida and Akiyama, 2013).

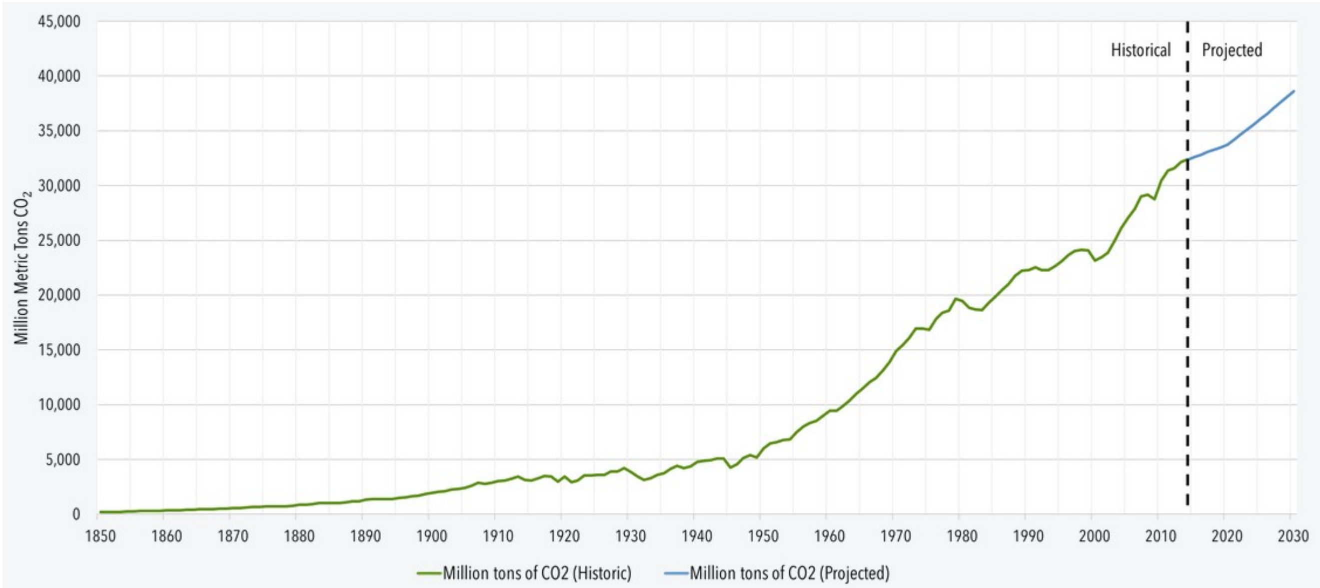

Figure 8: Carbon dioxide emissions measured from 1850 to 2014, and projected to 2030 (Center for Climate and Energy Solutions, 2017).

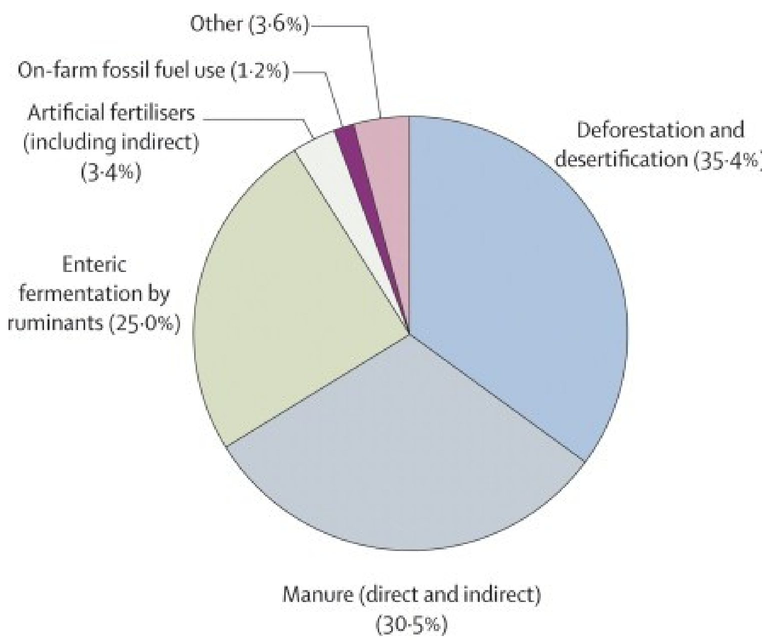

Figure 9: Proportions of GHG emissions from different parts of livestock production (McMichael et al., 2007).

Water

Nearly a third of the global population now lives in areas that suffer from freshwater scarcity (Jalava *et al*., 2014). Agriculture alone accounts for more than 70% of the total global freshwater consumption (Clark and Tilman, 2017; Jalava *et al*., 2014). Nearly 70% of the total agricultural water consumption is used in crop irrigation of which corn, soy, and forage crops are the biggest users (Figure 10) (Compton *et al*., 2018; Maupin *et al*., 2014; Smil, 2004). It is further estimated that 40% of the water intended for agricultural use is lost to surface run-off and leakage (Food and Agriculture Organization of the United Nations, 2012). Furthermore, water is heavily used in processing and refining raw food items. Water is used for cleaning and disinfecting raw ingredients. It is also used in process streams to facilitate the transportation and separation of food (Klemeš *et al*., 2008; van der Goot *et al*., 2016). Refining foods uses and wastes additional water. Many food manufactures use dehydrated fractional ingredients to ensure the consistency and purity of their product (van der Goot *et al*., 2016). Water is then necessarily added back to the ingredients to reach the desired moisture level creating ever increasing fresh water demand. Energy-dense foods such as sugars tend to use large amounts of fresh water and generate large amounts of wastewater throughout production. According to one study, a factory processing 10,000 tonnes of beets for sugar will use 2500-4000 m^3 of freshwater and generate even more wastewater through processing and dehydration (Klemeš *et al*., 2008). Although industry specific water usage data is limited, it is estimated that food processing generates 1.4 billion liters of wastewater annually (Compton *et al*., 2018). According to Compton *et al*. (2018) there are two types of wastewater that can be generated – organic and chemical (Compton *et al*., 2018). Organic wastewater contains the otherwise eatable by-products of food processing. While organic wastewater is not toxic, it can introduce excess nutrients into ecosystems if left untreated. Conversely, chemical wastewater is often toxic and is a direct threat to ecosystems (Compton *et al*., 2018). Although water use efficiency has been increased by agricultural techniques, genetic modification, and wastewater management, the population growth rate paired with the threat of climate change negates any reduction in total freshwater usage (Jalava *et al*., 2014).

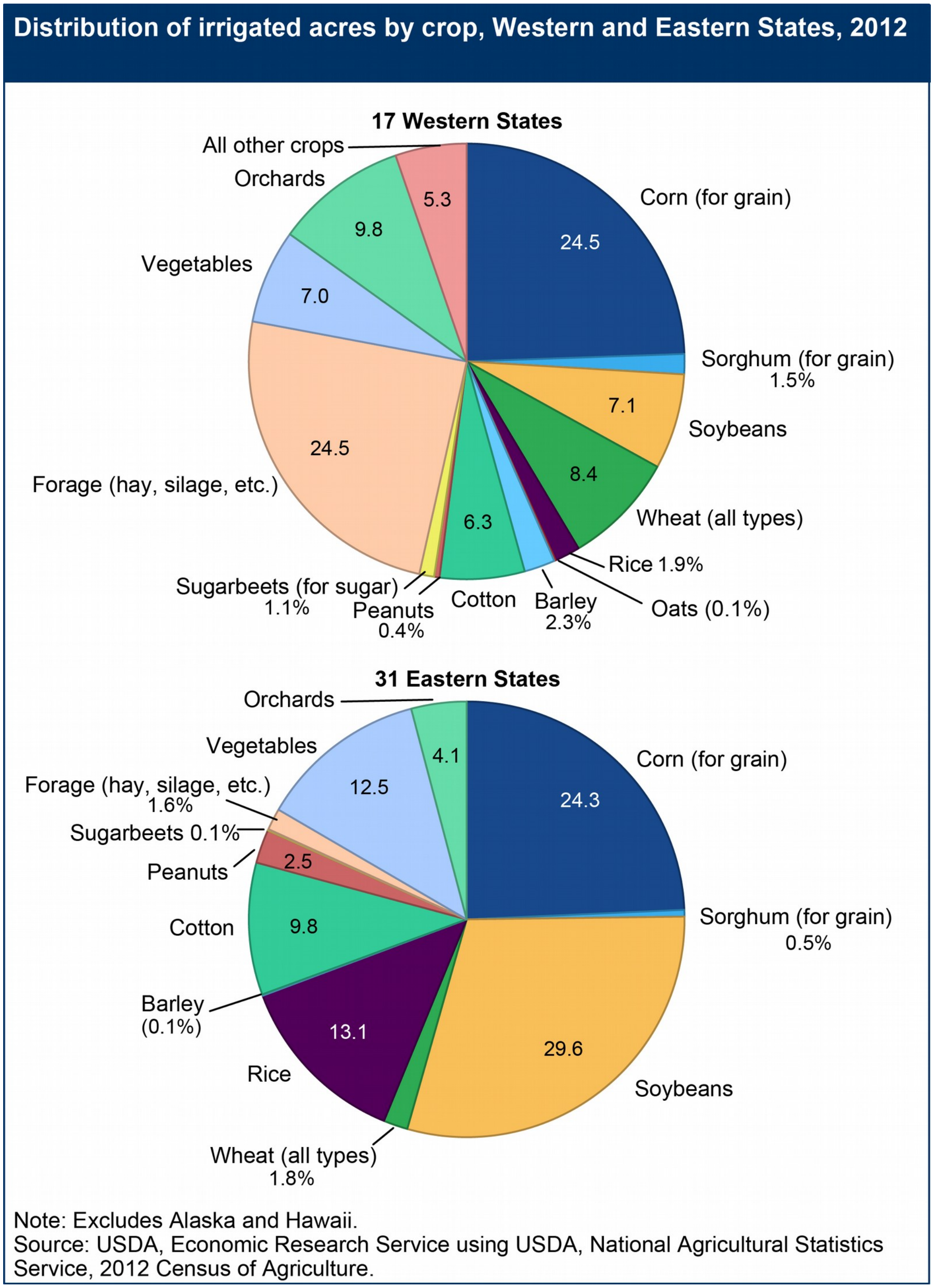

Figure 10: Relative distribution of 2012 harvested irrigated acres for Western and Eastern States, by major crop category (USDA Economic Research Service, 2012).

Energy

Every step in agriculture requires energy input and consumes 30% of the available global energy (Food and Agriculture Organization of the United Nations, 2012). The FAO describes two energy input categories – direct and indirect. Direct energy sources include electricity, mechanical power, and fuels. Indirect energy sources include the energy required to manufacture inputs that supply the agricultural system including agrochemicals (Food and Agriculture Organization of the United Nations, 2012).

Commodity crops corn, soy, and wheat are commonly used in the production of refined energy-dense foods including livestock. The conversion efficiency of crops into animal protein ranges from 3% for pork to 17% for eggs. (Milo, 2016). However, the conversion efficiency of commodity crops into refined food items has not been well studied. One study claims the production of 1kg of breakfast cereal, an energy-dense refined food, requires an energy input of 15,675 kcal, but only provides 3,600 kcal of energy to the consumer (Pimentel and Pimentel, 1985). Similarly, cane sugar, which is 20% sugar content, requires an energy input equivalent to the final product, crystalline sugar's energy availability. The energy input for lower sugar content beets (17% sugar content) is even greater than cane sugar for the same return resulting in a net loss of energy to production (Table 5) (Pimentel and Pimentel, 1985). High-fructose corn syrup (HFCS) has largely replaced roughly 40% of cane and beet sugars as a lower cost alternative (Figure 11) (Parker *et al*., 2010). The production of HFCS requires a two step process. The initial step uses the same energy-intensive processes used to produce breakfast cereal – milling, wetting, drying – to extract starch (Figure 12) (Buck, 2001). The second step requires chemical and enzymatic hydrolysis of the extracted corn starch (Figure 13) (Parker *et al*., 2010). The processing of corn into starch alone uses 15% of the total energy used by the food products industry (Klemeš *et al*., 2008). A large percentage of this energy is used in the heating and drying of the corn to remove the excess water introduced during processing (van der Goot *et al*., 2016). Further, the milling of grain and oilseed in the U.S. uses over 16 billion kWh of electricity mostly in the machine driven systems and over 110 billion ft^3 of natural gas mostly in boilers to produce steam nearly tying it with meat production (Compton *et al*., 2018). The refinement of raw food crops into refined products is a large, uncapped energy sink.

Table 5: Energy inputs for processing cane and beet into crystalline sugar product, raw grain into breakfast cereal, and corn into HFCS. Adapted from Pimentel and Pimentel (1985).

Product	Processing Energy (kcal/kg)	Food-energy Value (kcal/kg)
Beet sugar (assumes 17% sugar in beets)	5,660	3,850
Cane sugar (assumes 20% sugar in cane)	3,380	3,850
Breakfast Cereal	15,675	3,600
HFCS	-	2,810

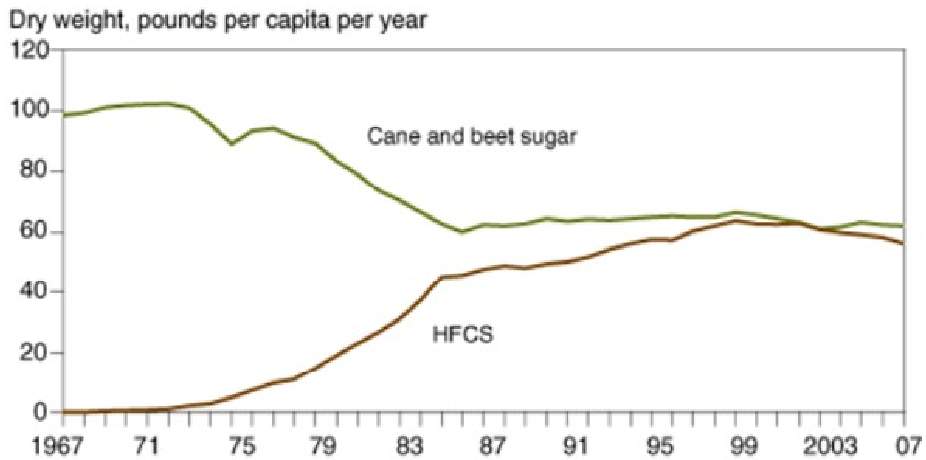

Figure 11: The increased use of HFCS in U.S. food production. HFCS has replaced roughly 40% of cane and beet derived sugars (Parker et al., 2010).

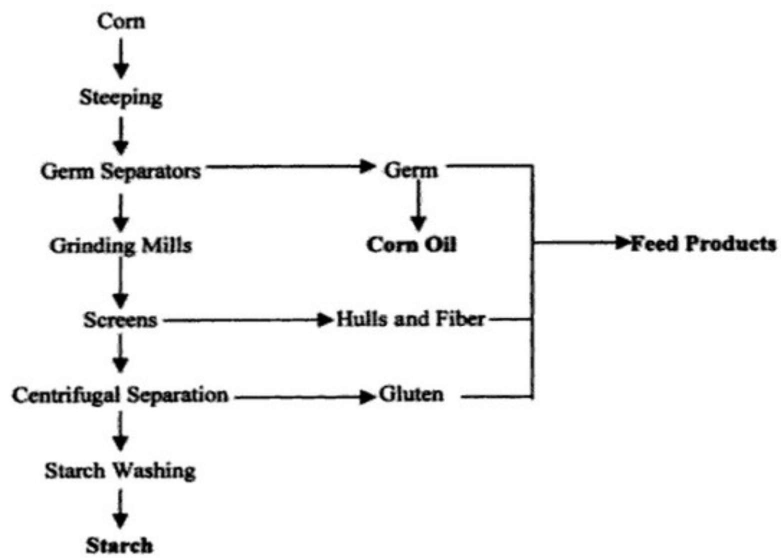

Figure 12: Wet-milling process flowchart showing the first stage of HFCS production from raw (dried) corn (Buck, 2001).

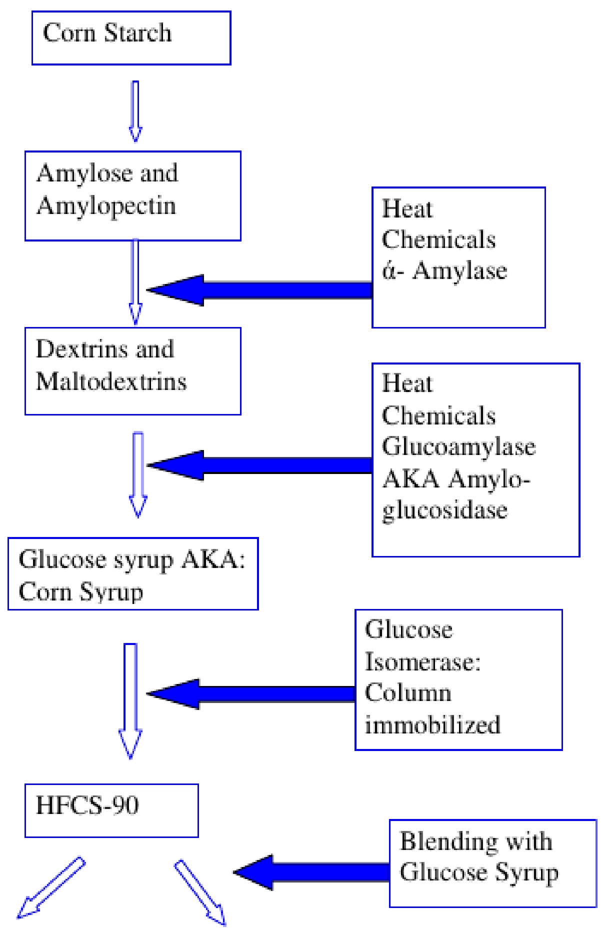

Figure 13: Chemical and enzymatic hydrolysis process flowchart showing the final stage of HFCS production from corn starch (Parker et al., 2010).

Transportation

Nearly 15% of agricultural energy is consumed by transportation (Martin *et al.*, 2014). Transportation efforts are proportional to the weight and volume of a food. Raw agricultural products are greater than 80% water by volume. The process of creating an energy-dense food typically involves the removal of water and resulting concentration of energy/nutrients in the food (Pérez-Escamilla *et al.*, 2012). The energy input required to dehydrate and process raw food items is often offset by the energy savings associated with transportation (Pimentel and Pimentel, 1985). Additional energy savings are available due to reduced packaging and storage requirements. Refined sugars and fats are easier to transport and store when compared to fresh foods which reduced the end cost to consumers per unit calorie (Drewnowski, 2004). On a per calorie basis, the reduction of GHG associated with transportation of sweets relative to fresh fruit and vegetables is greater than 80% (Martin *et al.*, 2014).

Land Use

More than one-third of the world's land surface is used by global food production (Hallström *et al.*, 2015). When food is refined, there is a net loss of energy. This is greatest for meat production which has the aforementioned protein conversion efficiency as low as 3% (Milo, 2016). Many agricultural advancements have targeted enhancing per acre crop yield including synthetic fertilizers, agrochemicals, and genetic modification. However, agriculture is still considered to be a driver for more than 80% of global deforestation (Baroni *et al.*, 2006; Hallström *et al.*, 2015). Monocropping and intensification further drive the degradation of arable land. Soil degradation falls into two categories – physical or chemical (Maredia and Pingali, 2001). Deforestation exposes unconsolidated soils to wind and water erosion. Soil naturally replenishes at a rate of about 0.8 mm $year^{-1}$, but agriculture drives a loss of nearly 18 mm $year^{-1}$ resulting in a yearly soil deficit of over 17 mm (McLaughlin and Mineau, 1995). Sugar cane and sugar beet, each providing half of the U.S. sugar production, cause significant soil erosion. In Florida, where the climate is favorable for sugar cane production, the land in the Everglades Agricultural Area has subsided 6 feet since 1920 (Mann, 2017). Irrigation and chemical usage leads to "waterlogging, salinisation, loss of nutrient and/or organic matter, acidification, and pollution/toxicity" of the soil (Maredia and Pingali, 2001). It is estimated that such soil degradation accounts for a 5 to 7 million ha per year reduction in arable farm land (Maredia and Pingali, 2001).

Agrochemicals

Fertilizers

Intensification of crops rapidly depletes the available nutrients in soil. Both natural and manufactured fertilizers are used to replenish soil nutrient stocks. These fertilizers introduce persistent toxins and negatively alter the soil chemistry, subsequently reducing or even halting crop production (Maredia and Pingali, 2001). However, the impacts of fertilizer application extend beyond the fields. Nitrogen and phosphate, two main ingredients in commercial fertilizers, are both water soluble and mobile. If applied in excess of what the intended crop can use, these nutrients will lead to excess algal growth in downstream water bodies (United States Environmental Protection Agency, 2015). Synthetic fertilizers from corn operations alone contribute to an 8,500 square mile dead zone in the Gulf of Mexico (Klein *et al*., 2014). Further, excess nitrogen can also promote the release of nitrous oxides, a greenhouse gas, from soils (United States Environmental Protection Agency, 2015). Fertilizer use initially spiked during the 'green revolution' of the 1960s in response to food shortages and has remained high (Figure 14) (Food and Agriculture Organization of the United Nations, 2012; United States Environmental Protection Agency, 2015). Corn crop alone accounts for greater than 40% of the total fertilizer application, in part because of the volume in which it is grown, but also because it requires more fertilizer than other crops, for example, soybeans (United States Environmental Protection Agency, 2015). As the demand for corn-derived products increases, so too will the demand for commercial fertilizers. The FAO estimates that fertilizer application will increase by a minimum of 17% with anticipated advances in genetic modification, but up to 40% as a baseline between 2002 and 2030 (Figure 15) (Selman and Greenhalgh, 2010).

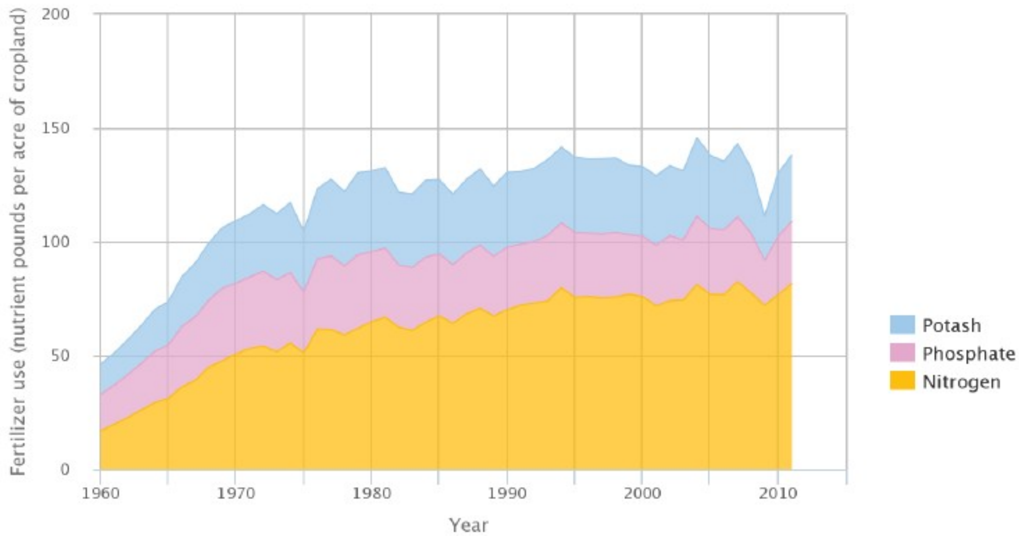

Figure 14: Commercial fertilizer use in the U.S. between 1960 and 2011 (United States Environmental Protection Agency, 2015).

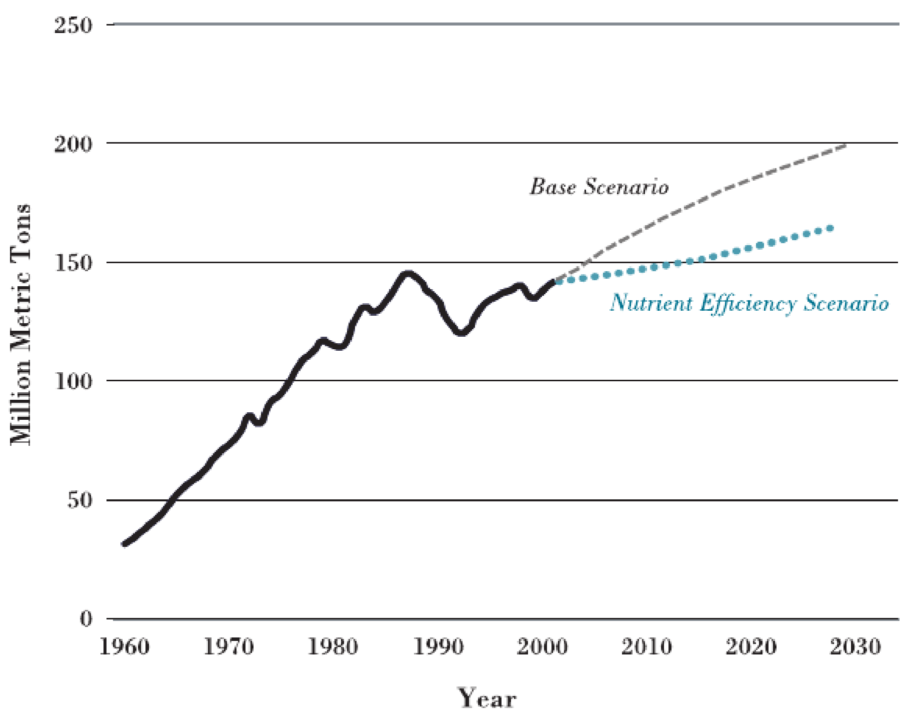

Figure 15: Past and projected global use of agricultural fertilizer. Nutrient efficient scenario is based on anticipated crop enhancements from genetic engineering; base scenario applies current agriculture methods adjusted for predicted population growth to 2030 (Selman and Greenhalgh, 2010).

Pesticides

Pesticide usage grew by a factor of 32 between 1950 and 1986 (Food and Agriculture Organization of the United Nations, 2012). The introduction of mechanization in part changed the limiting factor of crop yield from labor to pests and soil fertility, both of which are mitigated through the use of agrochemicals (Binswanger, 1986). It is estimated, however, that 99.9% of pesticide application does not reach its intended target and remains free to impact the unintended environment (Maredia and Pingali, 2001). Excess pesticides have severe health consequences both directly and indirectly to humans. A study in the Philippines measured the true cost of pesticide application in terms of healthcare costs and found that the cost of exposure to the farmer and the increased yield ultimately resulted in a net loss of productivity(Maredia and Pingali, 2001). The net losses from pesticide application extend beyond the field. Several other industries are impacted by the use of pesticides including those relying on honeybees, livestock, fish, and other wildlife (Maredia and Pingali, 2001). About 415 of the pests targeted by pesticides have developed resistances resulting in increased application of pesticides to maintain effectiveness (Pimentel and Pimentel, 1985). Because synthetic agrochemical manufacturing is an energy intensive process, increased application results in exacerbated environmental issues associated with energy as noted previously. (Clark and Tilman, 2017; Food and Agriculture Organization of the United Nations, 2012).

Biodiversity

Impacts of hybridizing and genetic modification

A major concern about crop intensification is the loss of biodiversity. High yield crops are a product of deliberately narrowing the genetic diversity to a single lineage of crop to meet specific needs, including pest resistance, water requirements, and productivity (Maredia and Pingali, 2001). The recent wide-spread acceptance of genetic modification has raised concerns regarding altered biodiversity of natural predatory and parasite species (O'Callaghan *et al*., 2005), soil biota and processes (Dunfield and Germida, 2004; Motavalli *et al*., 2004; O'Callaghan *et al*., 2005), and weedy species and other wild taxa (Conner *et al*., 2003; Ellstrand, 2003; Raybould and Gray, 1993). However, a more recent literature review by Carpenter (2011) finds the impacts on biodiversity at a large scale to be relatively small, citing the achievements of transgenic crops, including the reduction of arable land loss due to increased productivity and resource use efficiency under more sustainable growing methods. However, there are concerns about the potential for cross-breeding between transgenic and native plants and the long term impacts of transgenic crops on wild species and processes.

Impacts of agrochemicals

Simply put, the goal of pesticides is to selectively "kill something somewhere" and, by that definition, affect biodiversity (McLaughlin and Mineau, 1995). Pesticides that are selective eradicate a single species of plant, insect, fungus, or other. This impacts not only the targeted species, but any that rely on it. Often pesticide application is imprecise and/or it is mobile through soil, wind, or water. The most quantifiable negative impact of intensive farming is loss of habitat due to land use change, often leading to the population decline of several species, particularly insects and birds (Jacobsen *et al*., 2013; McLaughlin and Mineau, 1995). Birds are useful indicators of environmental health. Many bird populations in arable landscapes in the UK have experienced declines of up to 87% over a 28 year study period attributed to agrochemical application and loss of habitat (Stoate *et al*., 2001). Additionally, fertilizer application diminishes the biological activity of several ecosystems. Important soil microbes are eradicated by inorganic fertilizers and pesticides (McLaughlin and Mineau, 1995; Stoate *et al*., 2001). Important aquatic breeding grounds are hindered by eutrophication from nutrient run-off. One study found the common herbicide, Roundup (glyphosate), to nearly eradicate the tadpoles of several frog species demonstrating the toxicity of pesticides on ecosystems beyond crop fields

(Relyea, 2005). Persistent application of fertilizers and pesticides results in soils becoming saturated with salts and toxins, respectively (Maredia and Pingali, 2001). This leaves fields and their surroundings uninhabitable by both cultivated and native flora and fauna.

Obesity Trends

The prevalence of obesity globally has steadily risen over the last 100 years (Keith *et al*., 2006). According to the most recently released data brief from the National Health and Nutrition Examination Survey, the prevalence of obesity in the United States has accelerated even over a short 15 year period (Figure 16) (Hales *et al*., 2017). Many studies attempt to identify the root cause of obesity including sleep deprivation (Beccuti and Pannain, 2011; Gangwisch *et al*., 2005; Keith *et al*., 2006), farm subsidies (Alston *et al*., 2008; Elinder, 2005), dietary shifts (Cavadini *et al*., 2000), beverage consumption (Cavadini *et al*., 2000; Malik *et al*., 2006), poverty and education (Drewnowski and Darmon, 2005; Drewnowski and Specter, 2004), media consumption (Dixon *et al*., 2007), and others. In a 2006 paper, Keith *et al*., consider the holistic impact of the combination of putative lifestyle factors, coupled with reduced physical activity and food marketing practices (Figure 17). Ultimately, the underlying cause of obesity, regardless of other parallel behaviors, is an imbalance between energy intake and energy expenditure (Mann, 2017). This following sections will explore the implications of an energy-dense food environment and the impacts of obesity prevalence.

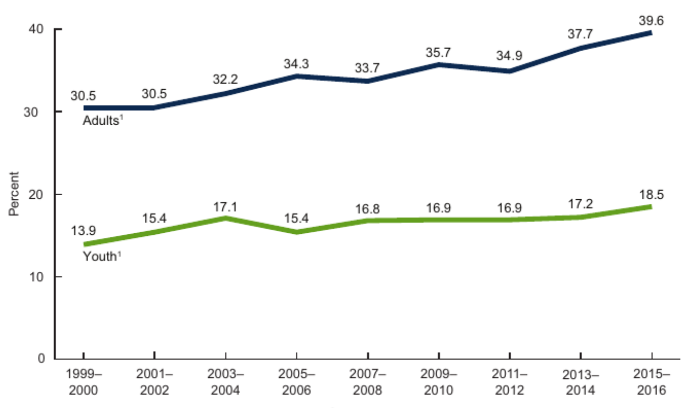

Figure 16: Yearly adult (age 20+) and youth (age 2-19) obesity trends between 1999 and 2016 (Hales et al., 2017).

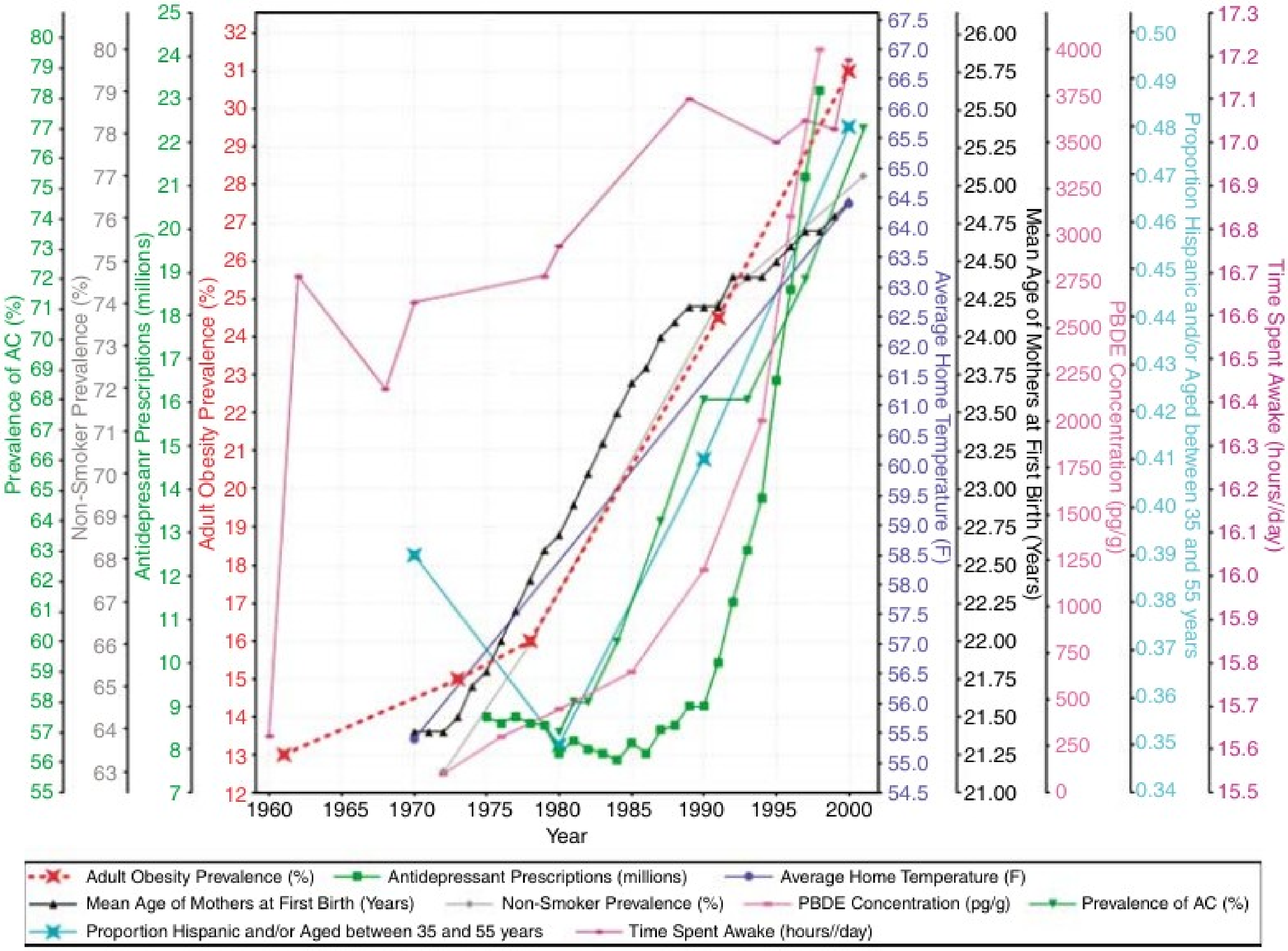

Figure 17: Secular changes in select factors that may be key indicators of increasing obesity trend (Keith et al., 2006).

Food affordability, availability, and composition

The costs of food have decreased dramatically since the adoption of the above discussed agricultural techniques. Since 1950, the prices of food adjusted for inflation have decreased by 54% for livestock, 72% for field crops, 23-28% for fruits and vegetables (Alston *et al*., 2008). These prices are driven by a sharp increase in supply. Lower costs combined with food energy abundance has shifted nations from undernourished to over-nourished – an issue equally as threatening to life-expectancy (McMichael *et al*., 2007). Forty percent of the prevalence of obesity in the United States over the last 25 years can be attributed to reduced food costs, particularly those high in processed fats and sugars

(McMichael *et al*., 2007). Cheap commodity crops in excess has led to creative processing techniques to make new unique products. Corn can be processed into HFCS, soy can be processed into soybean oil, and wheat can be processed into fiber poor cereals. The result of processing foods is an increase in the energy density of the final product through mechanism described previously. On a per-calorie basis, energy-dense foods cost less than their energy-dilute counterparts. (Figure 18) (Drewnowski, 2004; Drewnowski and Darmon, 2005). Cheap, energy-dense foods have been shown to be a leading contributor to the global obesity trend (Drewnowski, 2004). Meanwhile, this trend is also contributing to environmental pressures.

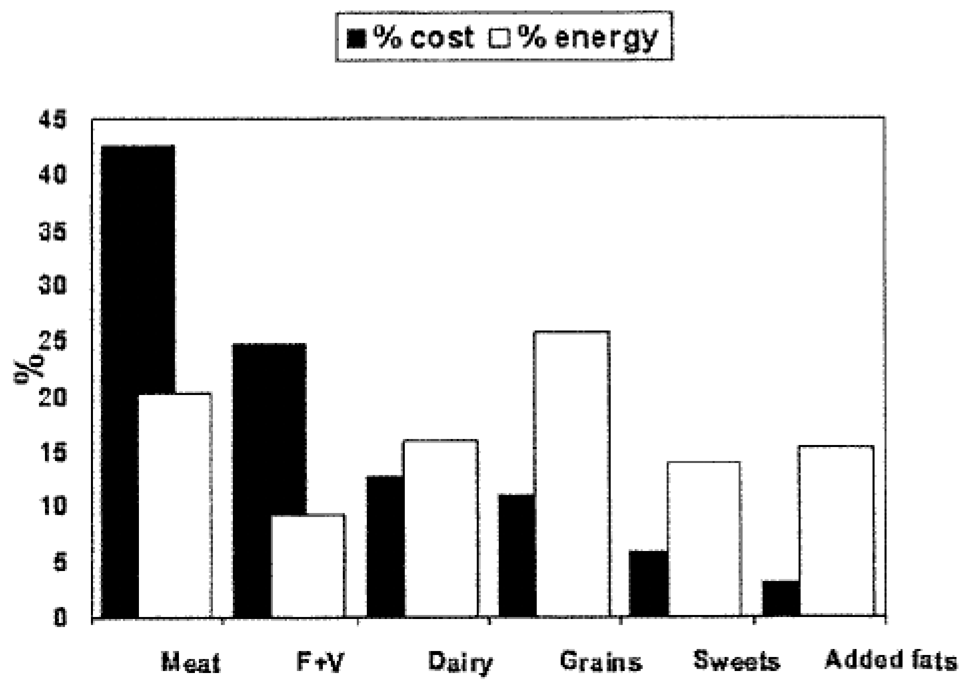

Figure 18: Dietary energy contribution relative to dietary costs of six major food groups. Energy-dense sweets and added fats contribute a relatively high percentage of dietary energy at a relatively low cost (Drewnowski and Darmon, 2005).

Environmental impacts of obesity

The costs of obesity on health are profound, and are frequently explored in research. The costs of obesity on the environment, however, are not. Of the research that is available, most focuses on the indirect environmental impacts of obesity through food choice (Baroni *et al*., 2006; Hallström *et al*., 2015; Heller *et al*., 2018; Heller and Keoleian, 2015) rather than the direct impacts. As of 2005, the total biomass of adult humans was 287 million tonnes, 15 million tonnes in excess of a healthy weight population. (Walpole *et al*., 2012). The 5% excess in human biomass contributes to greenhouse gas emissions through increasing agricultural emissions, transporation emissions, and waste (Figure 19) (Michaelowa and Dransfeld, 2008).

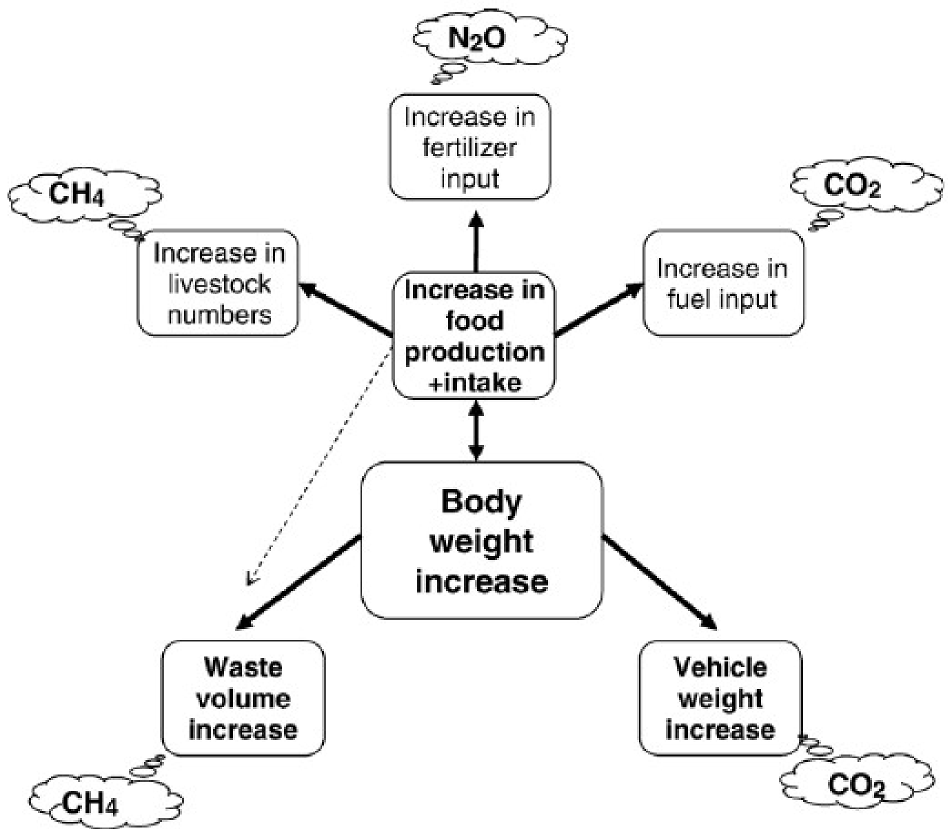

Figure 19: Greenhouse gas emission impacts of increased human biomass (Michaelowa and Dransfeld, 2008).

Metabolic Homeostasis

It is estimated that obese individuals consume about 8% more food energy in order to maintain their daily metabolic rate and up to 35% more for activities that a non-obese individual (Squalli, 2017).

On average, an obese population will require 19% more food energy than a population of healthy weight (Mann, 2017). With over 68% of the U.S. population classified as overweight, the demand on agricultural products (raw and processed) is directly proportional to the demand for additional food energy. This creates a cycle in which agriculture and obesity promote one another, amplifying the environmental consequences of additional food production.

Transportation

In addition to a higher rate of food consumption, obesity increases demands on transportation. Similar to an increase in food energy to maintain an increase in weight, so does transportation energy increase with an increase in weight. Obesity decreases physical activity and personal mobility (Mann, 2017). This both leads to an increased use of motor vehicles and an increase load on such motor vehicles. (Mann, 2017). A study by Tom *et al*. (2014) calculated the weight gained in the United States from 1970 to 2010 to be 5 to 6 kg per person for a total of 3.6 billion kilograms of excess weight. Although the United States only hosts 6% of the global population, it has 34% of the global biomass due to obesity (Mann, 2017). It turns out that this excess weight cost 205 billion liters of excess fuel usage for passenger vehicles, airplanes, and transit vehicles between 1970 and 2010 (Figure 20) (Tom *et al*., 2014). Nearly 1.4% of the total fuel used in 2010 was to transport excess weight. A previous study focused strictly on aviation transportation found similar results of up to 2.4% excess fuel consumption attributed to the transport of overweight passengers (Dannenberg *et al*., 2004). Greater reliance on vehicular transportation contributes to greater energy costs and GHG emissions. Squalli (2017) estimates that obesity rates must remain at or below 33.7% to maintain current CO_2 emissions and at or below 22.5% to maintain current N_2O emissions (Figure 21). However, as of 2011 only two states fall below the 22.5% obesity rate meaning the N_2O emissions will continue to rise (Squalli, 2017).

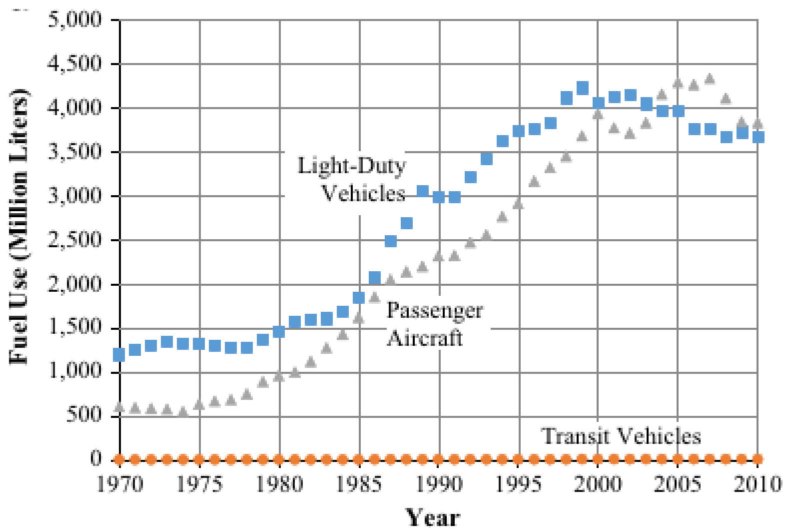

Figure 20: Annual fuel use due to excess passenger weight for light-duty vehicles, passenger aircraft, and transit vehicles (Tom et al., 2014).

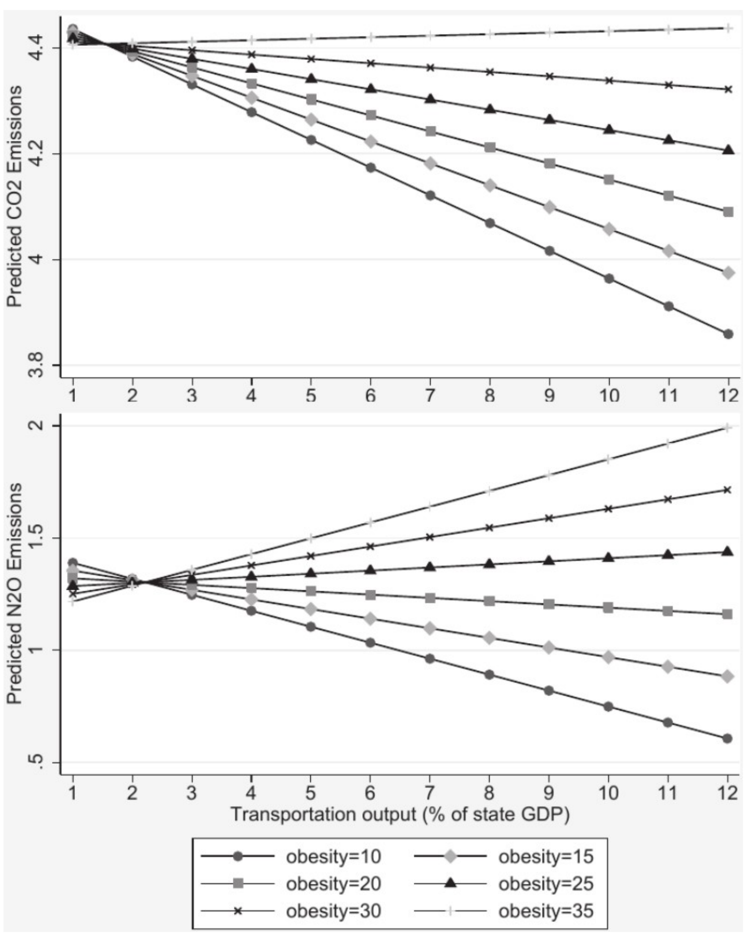

Figure 21: Predictive margins plots of the effects of transportation on predicted log CO_2 and N_2O emissions for six levels of obesity (%). (Squalli, 2017).

Conclusion

Fueled by efforts to improve food security for a growing population much attention has been given to boosting agricultural output over the last 80 years. The U.S. has been witness to crop hybridization, pesticide and fertilizer synthesis, mechanization, and even gene manipulation in the effort to increase crop yields. Fortunately, for the sake of food security, we have been successful. Less fortunately, the environment and our health has paid the toll for the large-scale transition to high-tech agriculture. We are just starting to recognize many of the implications agriculture has on the environment.

Agriculture alone accounts for 30% of greenhouse gas emissions, the leading driver of climate change. There is no single source of GHG emissions, making the fix difficult. Inputs of fertilizer, transport of food, soil degradation, food processing, and livestock all contribute. Further, nearly 70% of global freshwater and 30% of global energy is used in the growing, harvesting, and processing of food. Unfortunately, little progress is being made to optimize agriculture for a smaller environmental footprint.

The U.S. food market now actively provides nearly double the recommended calorie intake per capita. This excess has led to nearly two-thirds of the U.S. population being labeled as overweight, one-third of whom are considered obese. Excess weight has social, economic, and health implications. It also heavily impacts the environment. Obesity accounts for higher food consumption rates, greater greenhouse gas emissions, and more fuel-powered transportation.

The excess production of commodity crops has created a market for highly processed ‘junk food’ and livestock. The transformation from raw to refined foods produces significant waste in terms of both production energy costs and energy losses due to refining; that is, converting corn into meat or into high-fructose corn syrup. Strong policy is needed to regulate the environmental impacts of agricultural trends employed to meet the needs of a population growing in number and weight. The sooner we recognize the inefficiencies of producing and consuming an energy-dense diet, the healthier will be our person and our environment.

There has been a recent focus on mitigating obesity through education. This has proven ineffective because lifestyle education is difficult to practice in a food system saturated by cheap, energy-dense ‘junk foods.’ Instead, our health and food system will benefit from environmentally-driven agricultural policies that limit over-production, energy consumption, water waste, and agrochemical application. Without cheap, excess commodity crops, the production of energy-dense foods will be reduced. To do this, farm subsidies must shift to support sustainable farms growing non-commodity crops. This would help to maintain food affordability, but shift the savings at the consumer level from ‘junk foods’ to a nutritionally diverse diet.

The major health problems associated with an energy-dense diet will not disappear with one simple solution. We must consider not only economics, public health, and society, but also the environment in the food system web. Obesity is a marker of a broken system that must be revised now in order to reduce obesity-related health care costs, deaths, and environmental degradation.

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