The Effects of American Diets on Food System Energy Use

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Introduction

U.S. food-related energy use was about 14 quadrillion British thermal units (Btu) in 2002 (Canning et.al. 2010). This level is roughly equal to all energy use (food and nonfood related) for India in 2002, the world's 6th leading primary energy consumer that year, and exceeded that years combined energy budgets of all African nations (U.S. Department of Energy, Energy Information Administration, 2016). In turn, energy costs have represented a substantial and highly variable share of food costs, growing from 3.5 cents of each dollar spent in U.S. grocery stores in 1998 up to 7.5 cents in 2008, and down to 5.7 cents in 2013 (U.S. Department of Agriculture, Economic Research Service, 2016). This large intersection of food and energy commodity markets portend a strong relationship between nutrition promotion and resource use.

Background

Energy in the U.S. Food System

Among the few U.S. and numerous international studies of food-related energy use using the environmental input-output (EIO) method,[1] two closely related studies 36 years apart applied the EIO framework to the latest U.S. benchmark input-output accounts in order to assess energy use linked to all domestic food expenditures. Hirst (1974) found that 12 percent of the 1963 U.S. energy budget was attributed to the food system, with household energy use making up the largest portion of this total. The U.S. food system studied by Hirst produced 13.7 percent of total 1963 U.S. gross domestic product (GDP), whereas the 2002 food system studied by Canning et al. (2010) produced 8.7 percent of 2002 GDP.[2] Although the food economy share of GDP fell by

[1] A review of several studies using the EIO method other types of life cycle assessments (discussed below) is found in Heller, Keoleian, and Willett (2013).

[2] Based on 1963 and 2002 GDP data reported in U.S. Bureau of Economic Analysis, "Table 1.1.5 (line 1)," and "Table 2.4.5 (lines 26 and 82)" www.bea.gov/iTable/index_nipa.cfm (accessed November 18, 2015).

more than a third between the two study periods, Canning et al. (2010) found a one-fifth increase in the food system's share of the national energy budget to 14.4 percent in 2002. About half of the growth in food-related energy use between 1997 and 2002 was explained by a shift from human labor toward a greater reliance on energy services. Per capita food availability growth and population growth each accounted for one-quarter of the increase. Limitations of both the Hirst, and the Canning et al. studies are (1) neither study examines energy use by U.S. region, and therefore they are not able to distinguish between fossil fuel and non-fossil fuel use, and (2) only one (Hirst) or two (Canning et al.) years are studied in these reports, and this does not allow for statistical analysis of energy markets over an extended period.

A different analytical approach to measuring food-system energy use which is outside of the economic accounting structures of EIO analysis is known as process-based life cycle assessment, or process-based LCA. Whereas the boundary of analysis for the EIO approach is the entire domestic economy, a process-based LCA study will typically identify a more narrow boundary comprising of the salient domestic processes within the food system life cycle. Within these boundaries a piecemeal approach to compiling primary and secondary data sources for measuring direct energy use is carried out, and often involves making informed assumptions about the application of more narrowly defined data to processes outside of its own boundary definitions. If the boundaries are carefully defined and reliable data sources are available, results from applying the EIO and process-based LCA methods to the same research question should converge. Two studies using a process-based LCA approach, Heller and Keoleian (2000) and Pimentel et al. (2008), ask a similar research question, but their results differ.

Heller and Keoleian (2000) use data from the mid-1990s and find that the U.S. food system used 10.2 quadrillion Btu, or roughly 11 percent of the average mid-1990s annual U.S.

energy budget. This study found that household operations accounted for the largest share of total food-related energy flows and the combined energy flows through food processing and packaging industries are similar to the 1997 figures in Canning et al. (2010). Heller and Keoleian (2000) attribute greater energy flows to the farm and farm input industries than Canning et al. (2010) and lower flows through the foodservice and food retailing industries. Aside from the two studies using different data sources and covering different time periods, their definitions of supply chain stages are also different. For example, transportation-related energy flows represent the combined flows through the commercial freight industry and household food related travel in Heller and Keoleian (2000)'s work, whereas Canning et al. (2010) treat the latter as part of household-related energy flows.

Another process-based LCA study by Pimentel et al. (2008) use data from the mid-2000s and report that total food-related energy flows through the U.S. food system represented 19 percent of the national energy budget. Although this figure is somewhat higher than Canning et al.'s (2010) 2002 estimates, the combined results from the four studies suggest a finding that the food system was demanding a similar share of the national energy budget in the early 1960s and the late 1990s, and was gaining share of the national energy budget from the late 1990s into the first decade of the 2000s. These two process-based LCA studies also do not extend their analysis out to U.S. regions in order to more accurately measure the specific fuel sources (e.g., fossil vs non-fossil fuels) used by the U.S. food system, and they also are single period studies. Further, since no economic markets are defined by this approach, price and quantity information linked to specific energy market transactions are not compiled.

Sustainable Diets

Rather than focus solely on energy use in the food system, a number of studies have assessed the environmental impacts and sustainability of dietary choices. As defined by the Food and Agricultural Organization of the United Nations,

> "Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources." (2010, p. 7)

While environmental impacts depend on where (i.e. locally, domestically, internationally) and how (i.e. conventionally, organically) foods are produced (Baroni, Cenci, Tettamanti, & Berati, 2007; Saxe et al., 2013), a common approach to assess sustainability is to focus on specific food products. This line of research typically finds that animal-based products, such as meat or dairy, are more resource-intensive (Carlsson-Kanyama & Gonzalez, 2009; Eshel & Martin, 2006; Macdiarmid et al., 2012; Saxe, Larsen, & Mogensen, 2013; Tukker et al., 2011; Wallen, Brandt, & Wennersten, 2004; Vieux, Soler, Touazi, & Darmon, 2013). However, Carlsson-Kanyama, Ekstrom, and Shanahan (2003) find variation in energy embodied in different food products, even products that fall into the same food category. For example, energy inputs for meat ranges from 35 megajoules (MJ)[3] per kg for chicken up to 75 MJ per kg for beef in Sweden. By comparison, the energy inputs for vegetables range from 2.7 to 66 MJ per kg and sweets can range from 18 to 44 MJ per kg.

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[3] 1 megajoule = 1×10^6 Joules and 1 Joule = 9.4782×10^{-4} Btu.

However, focusing solely on energy use may not accurately depict environmental impacts. As such greenhouse gases (GHG) are another frequently used metric to assess sustainability. For example, energy derived from the burning of fossil fuels to generate electricity emits carbon dioxide (CO_2) into the atmosphere and contributes to climate change. Eshel and Marin (2006) consider the energy and GHG emissions associated with the average U.S. diet and 4 hypothetical, isocaloric diets by decomposing the diets into the animal-based and plant-based components. They find that omnivorous diets containing fish or poultry and a lacto-ovo vegetarian diet are associated with less emissions than the average U.S. diet. Another study by Marlow et al. (2009) considers multiple environmental metrics. The authors compare an omnivorous diet to a lacto-ovo vegetarian diet in California and find the non-vegetarian diet uses more fertilizer, water, primary energy, and pesticides by factors of 13, 2.9, 2.5, and 1.4, respectively.

Others extend the scope of their research beyond environmental impacts to include another element of sustainable diets: human health. There are studies exploring both the environmental and health impacts (Eshel et al., 2014) of omnivorous diets in the United States (Heller & Keoleian, 2015; Tom, Fischbeck, & Hendrickson, 2015), the United Kingdom (Macdiarmid et al., 2012), Sweden (Wallen et al. (2004), France (Vieux et al., 2013), Denmark (Saxe et al., 2013), across Europe (Tukker et al., 2011), and on a global scale (Tilman & Clark, 2014). In this line of research, healthy diets are typically characterized as diverse diets with reduced meat consumption and increased fruit and vegetable consumption (Macdiaramid et al., 2012; Saxe et al., 2013). While results are mixed due to the data sources, types of models, units of measurement, and definitions of healthy, these studies largely find that healthier diets are associated with fewer environmental impacts.

Macdiarmid et al. (2012) use a linear programming diet model to identify healthy diet outcomes in the UK. They find that GHG emissions may decrease 36 to 90 percent when shifting to a healthier diet. Using a consequential life-cycle assessment approach in Denmark, Saxe et al. (2013) also find that the healthy diet decreases GHG emissions, but by 27 percent. The healthier diet scenarios evaluated using an environmentally extended input-output model across Europe by Tukker et al. (2011) moderately lessen (by 8%) the aggregated environmental impacts of food. On a global scale, Tilman and Clark (2014) report that environmental impacts such as GHG emissions, land clearing, and species extinction could be reduced with alternative diets by comparing life cycle assessments.

Two recent U.S. studies look at the GHG emissions associated with healthy diets, as defined by the 2010 Dietary Guidelines for Americans (DGA), and rely on USDA's Loss-Adjusted Food Availability Data as a proxy for food consumption (Heller and Keoleian, 2015; Tom et al., 2015). Both Heller and Keoleian (2015) and Tom et al. (2015) rely on LCA data from the literature. The authors observe a 1 percent decrease in GHG emissions when eating healthy and reducing calories to the recommended level of 2,000 calories per person per day. In Tom et al.'s (2015) dietary scenario that meets the 2010 DGA in composition and caloric intake, energy use increases from the baseline by 38 percent and GHGs increase by 6 percent. Vieux et al. (2013) also find that a healthy diet increases GHG emissions by 9 percent for men and 22 percent for women. Alternatively, Wallen et al. (2004) find a negligible effect on energy use, and thus, GHG emissions given a shift to a healthier diet. Their estimates rely on energy data on food products from multiple sources, primarily relying on existing LCAs. In each of these studies, costs of alternative diets are not considered.

These empirical studies at the intersection of diet, fossil fuel consumption, and the environment provide several insights that can help inform important policy issues. Where findings cover similar time periods and measure overlapping outcomes, they produce mostly reinforcing results. However, the combined insights of these studies still create an incomplete accounting of where fossil fuels are used throughout the agri-foodchain over time and what the alternative diets will cost.

To address this gap in the empirical research, this paper explores how shifting to a healthier diet, as defined by the 2010 Dietary Guidelines for Americans, affects energy use in the U.S. food system. In other words, we inform the issue of whether nutrition policy compliments or competes with the sustainable use of energy resources.

The Dietary Guidelines for Americans (DGA) are published every five years by USDA and the Department of Health and Human Services. The DGA aim to improve the health and well-being of Americans by providing dietary recommendations informed by current nutrition science for Americans age 2 and above. Adhering to the DGA and engaging in physical activity can help Americans manage their weight and reduce their risk of chronic diseases.

We begin with the hypothesis that increasing the number of Americans following the 2010 DGA would decrease the energy embodied in our diets. For this to hold, current diets must be more energy intensive than the diets resulting from all Americans aligning their food consumption with the DGA. For the likelihood of diet outcomes to be objectively determined, evidence of the statistical probabilities for alternative healthy diet outcomes is required. Since this is beyond the scope of the data and models available for this research, our approach is to employ a mathematical programming model that determines the minimum required change from current diets that is necessary to meet the DGA under alternative scenario assumptions, and apply a transparent ad hoc probability-based assessment of the likelihood of the different scenario outcomes.

Methods

Mathematical optimization

This study uses the newly compiled Food Environment Data System (FEDS). FEDS is a system of national environmental economic accounts which is organized into a food system life-cycle framework. To compile FEDS for the years 1993 to 2012, the starting point is the ERS Food Dollar accounts (Canning, 2011), which is compiled primarily from two main data sources; Benchmark Input-Output (IO) accounts published in 5-year intervals by the Bureau of Economic Analysis (BEA) and annual input-output tables (1993 to 2012) published by the Bureau of Labor Statistics (BLS). The ERS food dollar accounts reconfigure the IO accounting structure to better represent salient attributes of the U.S. food system and incorporates other primary data sources into the estimation process. A detailed documentation of the first edition food dollar accounts is reported in a separate ERS report (Canning, 2011) and updates and changes to these accounts are reported in the online documentation to the Food Dollar data product (U.S. Department of Agriculture, Economic Research Service, 2016).

FEDS then yields a complete accounting of all food-related energy market transactions throughout the domestic economy, broken out by supply chain stage and energy commodity. For the benchmark years 2007-2008 considered in this study, there are 84 final demand categories (see the Appendix Table A.1). These final demand categories represent food and beverage expenditures, so $\mathbf{y}_e$ is a vector of annual expenditure totals across all agri-food stages where e is the set of all expenditure categories {1,…,84} and $\boldsymbol{\xi}_e$ represents the vector of embodied energy by each of these 84 commodities purchased.

To carry out the diet analysis, we must translate what Americans are buying into what they are eating. We link the 84 final demand categories from the FEDS to the grams of foods and beverage items consumed through the matrix $\mathbf{Q}_{e,f}$ where f = food items = {1,…,4067}. Another way to describe the matrix $\mathbf{Q}_{e,f}$ is that it is the set of all food and beverage items as consumed, organized into the commodity groups as purchased. The number of columns equals the number of food and beverage products consumed by all Americans ages 2 and above, and the number of rows equals the number of consumer food and beverage commodity groups as purchased. For example, whole milk maps 100% to the dairy commodity, so it is vector of all zeros except for the cell that intercepts the fresh whole milk commodity (e=16). Another example would be shrimp stir fry which maps to the commodities shellfish (15), oil (24), and vegetables (31) based on the proportions of these ingredients used in the meal. For the diet analysis, we are only concerned with food items consumed, so we can collapse the rows in the $\mathbf{Q}_{e,f}$ matrix; $\mathbf{q}_f^0 = (\mathbf{i}' \times \mathbf{Q}_{e,f})' =$ baseline diet column vector, indexed by food items.

Let $\mathbf{N}_{n,f}$ represent a matrix populated with conversion factors that transform grams as consumed for each food and beverage product into units corresponding to all specific dietary requirements in the DGA; n = nutritional attributes = {1,…,49}. A list of these nutritional attributes is provided in Appendix Table A.3. For example, the **N** matrix will transform grams of a fresh apple reported in the $\mathbf{q}_f^0$ vector into calories[4], cup equivalents of fruits, and many other nutrition metrics. Next, let $\mathbf{n}^G$ and $\mathbf{n}^L$ represent the nutrition goal and nutrition limit matrices, reporting the dietary goals and dietary limits of each age/gender cohort across all nutrition metrics. These are the complete 2010 DGA metrics, subsets of which only specify (i) goals (lower bound), (ii) limits (upper bound), or (iii) both goals and limits. Then for any diet outcome,

[4] In our work, 1 calorie refers to a kilocalorie, or food calorie, equivalent to 4,184 Joules.

$\mathbf{q}_f^i$ to be in alignment with the DGA the following two conditions must hold: $(\mathbf{q}_f^i \times \mathbf{N}) \geq \mathbf{n}^G$ and $(\mathbf{q}_f^i \times \mathbf{N}) \leq \mathbf{n}^L$. Simply put, these two inequality expressions state that for each cohorts average observed diet represented in $\mathbf{q}_f^i$, the embodied nutrients of all items consumed as measured by multiplying by $\mathbf{N}_{n,f}$ (nutrient conversion matrix) must at least meet all nutrition goals ($\mathbf{n}^G$), but not exceed nutrition limits ($\mathbf{n}^L$).

To get Btu per gram for each food and beverage item consumed, we rely on the grams consumed by expenditure group represented by $\mathbf{q}_e^0 = (\mathbf{Q}_{e,f} \times \mathbf{i})$ and divide each element in $\boldsymbol{\xi}_e$ by the corresponding element in $\mathbf{q}_e^0$. Then, we map this Btu per gram back to each food item using the proportions of commodities from $\mathbf{Q}_{e,f}$. This results in $\boldsymbol{\xi}_f$. In the same way, to get dollars per gram for each food item, we use the same process, but use $\mathbf{y}_e$ in place of $\boldsymbol{\xi}_e$ resulting in $(\mathbf{pq})_f$.

If $\mathbf{q}_f^0$ represents annual average current diets (baseline) of all Americans ages 2 and above and distinguished by age/gender cohort groupings (see Appendix Table A.3), we seek a similar diet outcome, $\mathbf{q}_f^1$, which is as close as possible to $\mathbf{q}_f^0$ while also meeting the DGA. We run the model for all cohorts, k = {1,...,16}, but this superscript is left out for clarity. The basic model is stated as:

1) $$Min_\Delta = \sum \left\{ (\boldsymbol{\omega}^{-1})' \times \left(\mathbf{q}_f^1 - \mathbf{q}_f^0 \right) \right\}^2$$

$subject\ to$

2)

a) $\mathbf{q}_f^0 \times \mathbf{N}_{\mathrm{n,f}} \geq \mathbf{n}^{\mathrm{G}}$ (DGA goal constraints),

b) $\mathbf{q}_f^0 \times \mathbf{N}_{\mathrm{n,f}} \leq \mathbf{n}^{\mathrm{L}}$ (DGA limit constraints),

c) $\mathbf{q}_f^0, \mathbf{q}_0^1 \geq 0$ (non-negative consumption constraint),

d) $\{ (\mathbf{pq})_{\mathrm{f}}' \times \mathbf{q}_f^1 \} \leq \{ (\mathbf{pq})_{\mathrm{f}}' \times \mathbf{q}_f^0 \}$ (budget limit constraint)

where $\mathbf{q}_f^i$ is a quantity vector of a food or beverage item and $(\mathbf{pq})_{\mathrm{f}}$ is the wholesale price of an item. The model specifies a weighted least square objective function (Equation 1) where the vector $\boldsymbol{\omega}$ represents weights applied as a penalty for each unit of deviation between $\mathbf{q}_f^1$ and $\mathbf{q}_f^0$. If our hypothesis were that baseline diets align with the DGA, using the vector of variance terms for $\mathbf{q}_f^0$ as our weights makes (Equation 1) a constrained maximum likelihood model (Canning, 2014). However, our assumption is that the baseline diet is not fully in alignment with the DGA and we are seeking instead to minimize the mean absolute percentage difference between healthy and baseline diets, so we set the weight vector equal to $\mathbf{q}_f^0$. The complete constraint sets are stated in Equations 2.a to 2.d.

An extension of the baseline model changes the objective function for a new diet $\mathbf{q}_f^2$ that meets the DGA with minimum use of fossil fuels:

3) $$Min_{\boldsymbol{\xi}} = \sum_f \{(\boldsymbol{\xi}_f)' \times \mathbf{q}_f^2\}$$

Data

To compile the model data, we follow a methodology similar to the *Thrifty Food Plan, 2006* (Carlson, Lino, Juan, Hanson, & Basiotis, 2007). First, data from What We Eat in America (WWEIA), the dietary intake component of the 2007-2008 National Health and Nutrition

Examination Survey (NHANES), characterize a baseline American diet ($\mathbf{q}_f^0$). NHANES is a nationally representative survey that is done in two-year cycles. The 2007-2008 data correspond with the 2007 BEA benchmark accounts, the most recent data that characterizes the U.S. economy by detailed sector, used in FEDS.

We use only Day 1 of the NHANES data because of underreporting in Day 2(Todd, Mancino, & Lin, 2010), different reporting modes, and possible survey fatigue. We weight the NHANES data by the reported sample weights for Day 1 to represent the U.S. population's food consumption for 16 age-gender cohorts of our analysis, defined by the American Community Survey (see Appendix Table 2). The 2010 DGA contain only nutrition information for those 2 years old and above, so we restrict the sample size which results in 8,528 participants[5]. In our sample, there are 4,067 unique food or beverage items consumed ($\mathbf{q}_f^0$). The Baseline Diet is the grams of food or beverages consumed by each cohort as reported in NHANES meaning there is a $\mathbf{q}_f^0$ for each cohort. We confirm our baseline diets to the WWEIA and Food Patterns Equivalents Database (FPED) data tables to ensure the weighting of the sample is correct (U.S. Department of Agriculture, Agricultural Research Service, 2010a; U.S. Department of Agriculture, Agricultural Research Service, 2010b).

The **N** matrix is comprised of calories, Food Patterns components, and nutrients. First, data on nutrient content of the food and beverage items are retrieved directly from NHANES[6]. The nutrients selected come from Appendix 5 of the 2010 DGA and we convert the data to nutrient per 1 gram of food item. Secondly, the USDA Food Patterns recommend daily consumption of food groups, or Food Patterns (FP) components, such as dark-green vegetables

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[5] One participant in the sample did not report eating anything, so this participant was excluded. We are trying to characterize average diets and eating nothing over time would not be enough for survival.

[6] Nutrient data on Day 1 consumption comes from the NHANES dr1iff_e file.

or whole grains. We use the Food Patterns Equivalents Database (FPED) which converts the food and beverage items from NHANES to the FP components. FP components are reported in either cup equivalents, ounce equivalents, teaspoons, grams, or number of alcohol drinks. "An equivalent is an amount considered nutritionally equal to 1 cup in the vegetable, fruit, or dairy components or 1 ounce in the grains or protein components" (National Collaboration for Childhood Obesity Research, n.d.). For example, 1 to 2 oz. of natural cheese and 245 grams of fluid milk are both equal to one cup equivalent (Bowman et al., 2013). With the normalized units, the FPED allows us to make nutritional comparisons across food items that are in different forms. This database also allows us to compare dietary intake data to the 2010 DGA. We use the FPED 2007-2008 corresponding to Day 1 of the 2007-2008 cycle of NHANES[7] which converts all of the USDA food codes reported in our sample to FP components. Then, we convert these data to FP components per gram of food or beverage consumed by cohort. Together, the nutrient content from NHANES and the FP components from FPED form **N**.

To model primary energy[8] embodied in diets, we link the NHANES data to the commodity groups from FEDS ($\mathbf{Q}_{e,f}$) described in the theoretical model. Similar mapping is done by Volpe, Okrent, & Leibtag (2013) to link 2003-2004 NHANES data with the 52 Quarterly Food-at-Home Price Database groups to estimate a Healthy Eating Index score, another measure of dietary quality.

To resolve any uncertainty in the manual mapping process, the grams mapped to the initial 74 categories from FEDS are aggregated to 38 commodities. Therefore, we calculate 38 energy pathways with unique Btu/gram ratios. We map these Btu/gram ratios back out to the

[7] Food Patterns component data on Day 1 consumption comes from the FPED dr1iff file.
[8] In this report, since we consider both primary energy (Btu) and food energy (calories), we reference their respective units instead of energy to avoid confusion.

original food item in the proportion of ingredients in each particular food item. This mapping results in embodied Btu for each food or beverage item in our baseline diet from NHANES ($\boldsymbol{\xi}^f$). There are 1,672 unique Btu ratios associated with these food items. Just as we can trace Btu back to each food item, we can also do this with dollars. The cost is the weighted average based on the commodity makeup of the food or beverage ($(\mathbf{pq})_f$. This cost is not reflective of an item's price on may pay at a retail store, rather its wholesale price.[9]

Now, with the input data compiled, we shift our focus to the model constraints ($\mathbf{n}^G$ and $\mathbf{n}^L$). All of the constraints are weighted based on the age and gender demographics of NHANES Day 1 participants. First, we assume a moderately active activity level for caloric needs which we allow to vary by 5 percent above or below the target to give the model flexibility (Appendix 6, 2010 DGA). Secondly, we include the FP components as constraints; the subcomponents are selected for grains, vegetables, and protein foods (Appendix 7, 2010 DGA). Daily alcohol limits are also included and are set at zero for those under the legal drinking age. Lastly, we impose thirty-three nutritional targets as constraints from Appendix 5 of the 2010 DGA, supplemented by Tolerable Upper Intake Levels (UL) when necessary (Institute of Medicine, n.d.). A complete list the constraints is available in Appendix Table 3. We use combinations of these constraints in the modeling and label them by numeric sets shown in Table 1. Examining different constraint sets allows us to test a range of scenarios and definitions of a healthy diet. First, though, we compare the Baseline Diet to the 2010 DGA to see how the current U.S. consumption rates.

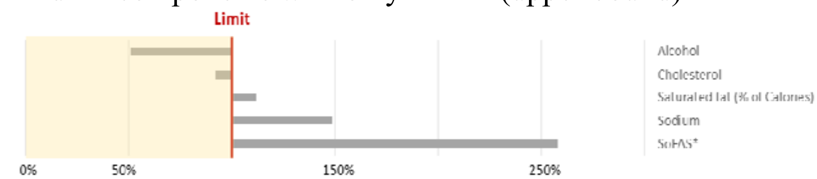
Assessment of the Baseline Diet shows that current consumption in the United States is not in line with the 2010 DGA. Figures 1 to 3 shows all of the constraints and where the

[9] Wholesale prices are used to avoid having the model trade-off between lower price margins for food at home versus away from home. This approach assumes the share consumed home verses away do not change.

baseline falls relative to these constraints. The area shaded in yellow is recommended; consumption should be at or above the goal (lower bound) and below the limit (upper bound). Baseline consumption is over three of the five limits, under 14 of the 23 goals, and misses the mark on six of 20 constraints with a goal and a limit.

Figure 1

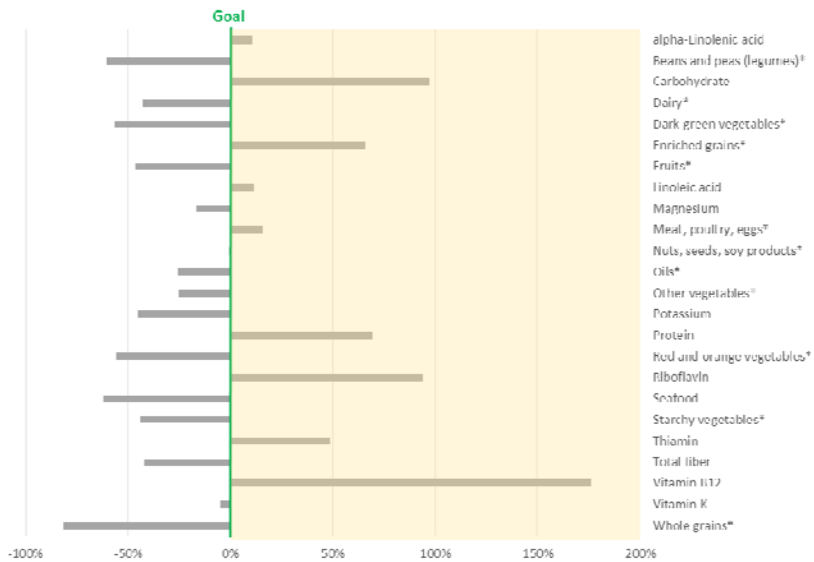
Nutrient and FP components with only a limit (upper bound)



Note. FP components are indicated with an asterisk (*).

Figure 2

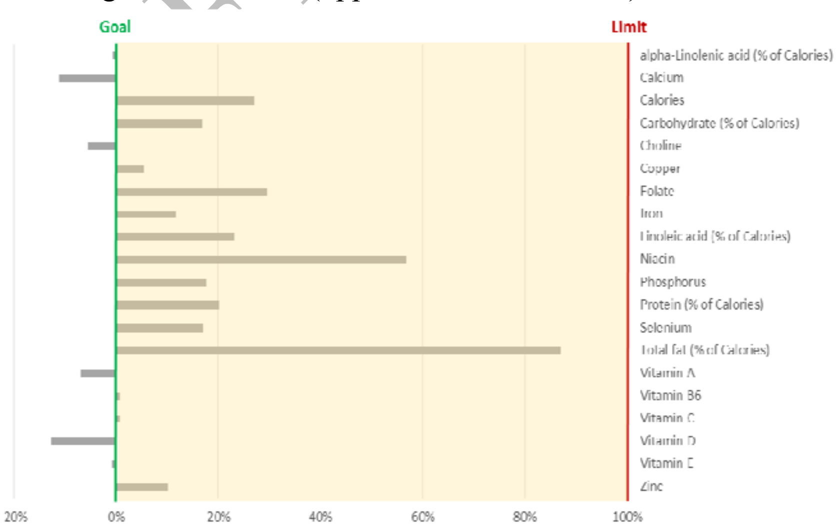
Nutrient and FP components with only a goal (lower bound)



Note. FP components are indicated with an asterisk (*).

Figure 3

Nutrients with a goal and a limit (upper and lower bounds)

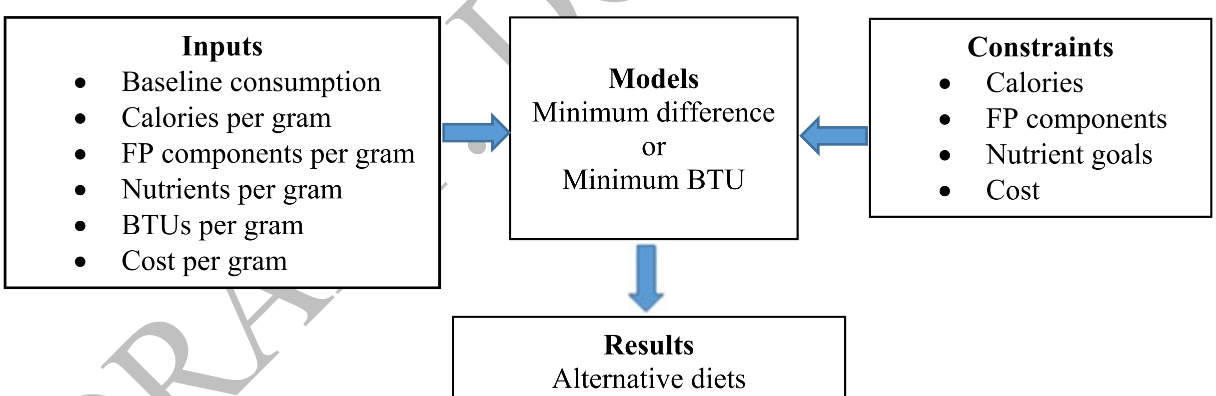


Note. There are no FP components with both a goal and a limit.

We run many iterations of the two mathematical models. We allow the models to choose between the 4,067 foods or beverages consumed in the Baseline Diet. We use the General Algebraic Modeling System (GAMS) with the solver CONOPT3 since the objective functions are quadratic and the constraints are both linear and non-linear. The models are run for each of the cohorts separately.

There are two objective functions, or ways one could choose a healthy diet. In the first model (Equation 1), the objective is to minimize the changes one would have to make from baseline consumption patterns; in other words, it is the shortest route to eat healthy. The second model's objective is to minimize Btu while still shifting to a healthy diet (Equation 3). In this case, we allow greater changes from the Baseline Diet. Figure 4 presents a diagram of the models with the inputs and constraints which are formally stated above.

Figure 4
Mathematical models diagram



Results

We obtain an optimal solution for each model and all of the constraints included are met. We present findings for the total population. Figures 5 and 6 compare the results from both models using two metrics: Btu and cost. Table 1 indicates which constraints make up each constraint set used in the modeling. These combinations can be thought of as different definitions of healthy diets. The results indicate which diets use more Btu or are more costly.

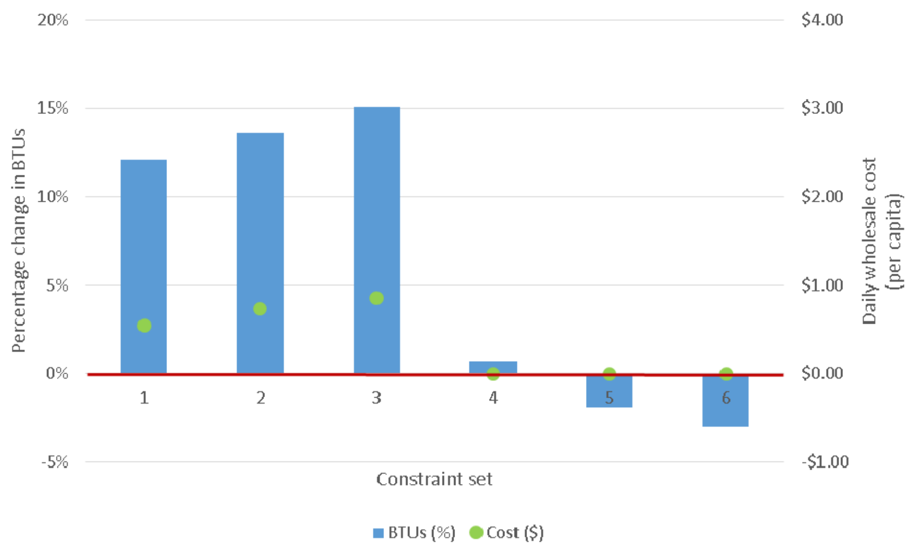
Table 1
Constraint sets defined over dietary and cost constraints

	Constraint set					
	1	**2**	**3**	**4**	**5**	**6**
Calories	x	x	x	x	x	x
USDA Food Patterns	x		x	x		x
Nutrition targets		x	x		x	x
Cost				x	x	x

Figure 5 summarizes results for the minimum difference model under the 6 constraint sets. When only combinations of dietary constraints are considered, both Btu and cost increase from the baseline levels. Constraint Set 3 produces substantial increase in both metrics; Btu increase 15 percent while wholesale cost increases 86 cents per capita per day. Therefore, making minimal shifts to eat healthy, without regard to cost, will require more Btu. Btu also increase with Constraint Set 4. Btu may be reduced when keeping dietary costs the same, but only when applying Constraint Sets 5 and 6. Although Constraint Set 6 reduces Btu by only 3 percent, this is equivalent to taking 3.7 million cars off the road, in terms of the Btu in gasoline[10].

[10] This was calculated by multiplying the Btu embodied in the Baseline Diet by the percentage change. Then, we divide by 120,476, the Btu is a gallon of gasoline (U.S. Department of Energy, Energy Information Administration, 2015). Next, we multiply by 25.2, the average miles per gallon reported for October 2015 (University of Michigan, 2016). Finally, we divide by 13,472, the total average annual miles drive in the U.S. (U.S. Department of Transportation, 2015).

Figure 5
Minimum difference model results relative to Baseline Diet

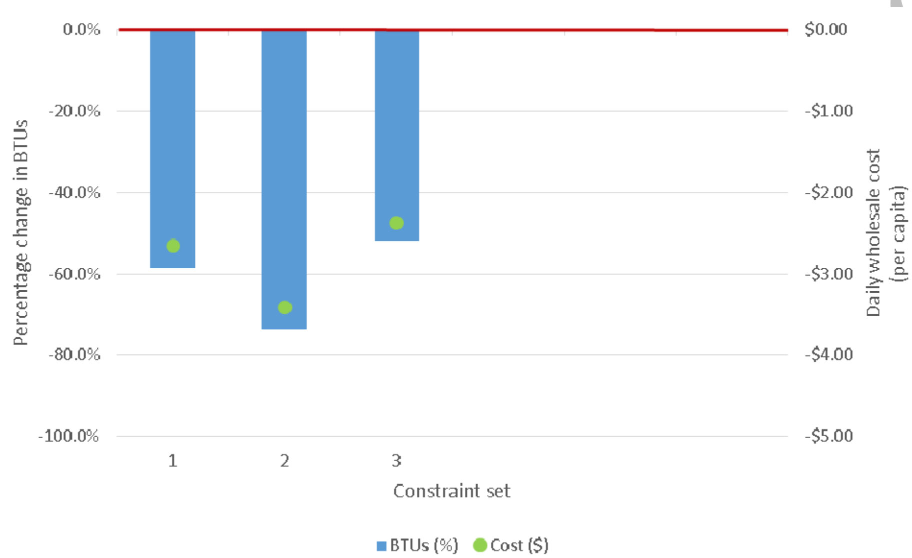


The results show that nutrition targets are important constraints to consider in addition to the FP components. The FP are designed to meet nutritional requirements if the nutrient-dense forms of the food items are consumed (Britten, Cleveland, Koegel, Kuczynski, & Nickols-Richardson, 2012). Nutrient density implies that a food item is consumed in a way that efficiently provides nutrients while minimizing extra calories from solid fats, refined starches, added sugars or sodium (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010, p.5). However, the most nutrient dense forms of food are not the foods chosen by most Americans (Britten et al. 2012) which our data confirm. For example, in Constraint Set 1, with only the calorie and FP component constraints, we discover that the cohorts were not meeting nutrient goals or limits. For example, sodium is still being over-consumed by 1536 mg, or 69 percent above the daily recommended maximum.

Figure 6 shows the results for the model that minimizes Btu embodied in diets. In this model, Constraint Sets 4-6 are not included since costs decrease when only considering dietary constraints; the cost constraint would be redundant. Wholesale costs decrease by $2.38 to $3.41

per person per day and Btu decrease from between 52 and 74 percent compared to the Baseline Diet. The minimum Btu model with Constraint Set 2 is the most efficient diet of all in terms of Btu and also the lowest-cost. Reducing Btu by 74 percent to 2.06 quadrillion Btu is equivalent to taking 90 million, or more than one-third, of the cars off the road in the U.S., measured by Btu in average gasoline consumption[11].

Figure 6
Minimum Btu model results relative to Baseline Diet



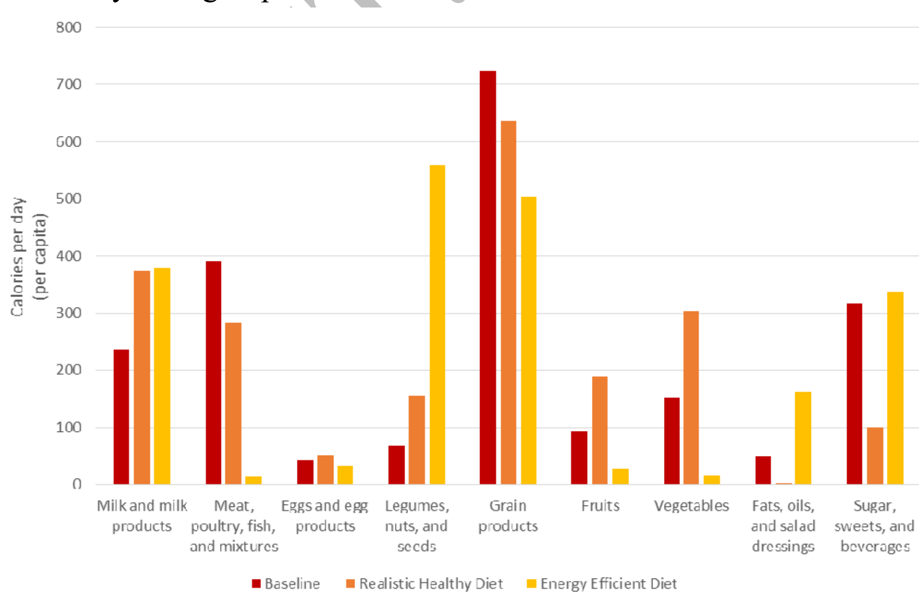
We report detailed model results of the minimum difference model with Constraint Set 6 (all dietary constraints and a budget constraint) and refer to it as the Realistic Healthy Diet. This is the most restrictive model because it assures caloric and nutritional targets are met, forces individuals to eat a diverse, omnivorous diet due to the FP components, and also maintains the daily wholesale budget of $4.65. Because this model minimizes the change from the Baseline Diet and many of the same food items are chosen, it is the most realistic dietary change that we model. This model results in 2,541 distinct food items being consumed.

[11] Calculated same as in footnote 20, except with a 74 percent change. There were 255.8 million registered highway vehicles in 2013 (U.S. Department of Transportation, Bureau of Transportation Statistics, n.d.).

We also report the results of the minimum energy model with Constraint Set 2 which we refer to as the Energy Efficient Diet[12]. This model has the flexibility to make more than a minimal change and is not restricted by the FP components, if the nutrition targets are met. This means that any food items in Day 1 of the NHANES data can be selected if caloric and nutritional needs are met. There are 85 distinct food items consumed in this diet.

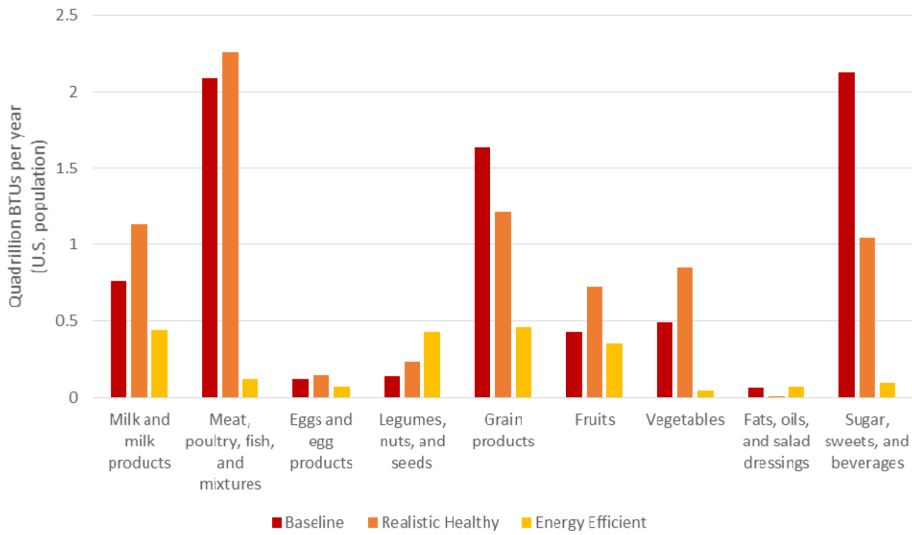
We report the results of the Realistic Healthy Diet and the Energy Efficient Diet relative to the Baseline Diet by food group. Figure 7 and 8 present the results in calories and Btu, respectively. We aggregate foods into ten food groups by the first digit of the USDA food code (see Appendix B in U.S. Department of Agriculture, Agricultural Research Service, Food Surveys Research Group, 2010b). In the Baseline Diet, the most calories come from grain products. While grain products account for 724 calories, or 35 percent of the total, they only account for 21 percent of Btu. The largest contributor to Btu is meat, poultry, fish, and mixtures in the Baseline Diet with 2.09 quadrillion Btu, or 27 percent of the total.

Figure 7
Calories by food group



[12] Energy means embodied Btu in this case.

Figure 8
Btu by food group



In the Realistic Healthy Diet, although calories from grain products are reduced to 636 calories, grain products are still the largest contributor to total caloric intake at 30 percent. However, grain products contribute a lesser share of 16 percent to total embodied Btu (1.22 quadrillion Btu). Similar to the Baseline Diet, the most Btu embodied in the Realistic Healthy Diet come from meat, poultry, fish, and mixtures. Meat, poultry, fish, and mixtures represent 30 percent of total Btu while only supplying 284 calories, or 14 percent of the total calories.

The Energy Efficient Diet results in a different ranking of food groups. Legumes, seeds, and nuts is the largest contributor to calories with 558 (27 percent of the total), followed closely by grain products with 503 calories (25 percent of the total). Grain products contribute 0.46 quadrillion Btu, or 22 percent of total Btu. 'Legumes, nuts, and seeds', and 'milk and milk products' categories each contribute 21 percent of embodied Btu in the diet.

When looking at the detailed food items in the Energy Efficient Diet, the model chooses much less variety, but more nutrient-dense items. Even if an item does not have the lowest Btu/gram, it may be able to meet more nutrient goals and thus, be favored by the model. The

Energy Efficient Diet is a pescatarian diet, meaning the model did not choose any meat or poultry items.

It may be counterintuitive that calories from milk and milk products increase in the Energy Efficient Diet while the Btu decrease relative to the Baseline Diet. We see this relationship because dietary composition changes both in terms of food groups as well composition of food items within the food groups selected. The results indicate that, in the Energy Efficient Diet, the product mix of milk and milk products is less energy intensive than in the Baseline Diet.

This highlights the importance of interpreting the results correctly. The models choose a different product mix, not just different quantities. To provide another example, the item most-consumed on a caloric basis in the fruits category is a banana in both the Baseline Diet and the Realistic Healthy Diet. In the Energy Efficient Diet, the most consumed fruit is an avocado. This does not mean that the avocado is the most efficiently produced fruit. Rather, it means that the avocado is an efficient source of nutrients, as a part of a total diet that conforms with the 2010 DGAs.

Another way to examine a shift to the Realistic Healthy and Energy Efficient Diets is percentage change from the Baseline Diet. Table 2 gives the percentage change from the Baseline Diet in calories and Btu. Overall, substantial changes in each food category is required in both the Realistic Healthy Diet and the Energy Efficient Diet.

Table 2

Percent change from Baseline Diet

	Realistic Healthy		Energy Efficient	
	Calories	BTUs	Calories	BTUs
Milk and milk products	59%	49%	62%	-42%
Meat, poultry, fish, and mixtures	-27%	8%	-96%	-95%
Eggs and egg products	19%	22%	-20%	-41%
Legumes, nuts, and seeds	131%	69%	728%	212%
Grain products	-12%	-26%	-31%	-72%
Fruits	100%	68%	-71%	-19%
Vegetables	101%	73%	-89%	-92%
Fats, oils, and salad dressings	-99%	-94%	233%	11%
Sugar, sweets, and beverages	-68%	-51%	7%	-96%

If shifting from the Baseline to the Realistic Healthy Diet, the largest increase (131 percent) is required in legumes, nuts, and seeds whereas the largest reduction in calories is 99 percent in the fats, oils, and salad dressing category. If shifting to the Energy Efficient Diet, legumes, nuts, and seeds need to again increase the most; this time by 728 percent. Foods that fall in the meat, poultry, fish, and mixtures category are reduced by 96 percent, the largest decrase in the Energy Efficient Diet. These results indicate that legumes, nuts, and seeds are an important source of nutrients that Americans are not currently consuming in sufficient quantities.

When looking at percentage change of Btu relative to the Baseline Diet, vegetables increase most in the Realistic Healthy Diet (73 percent) while legumes, nuts, and seeds increase most in the Energy Efficient Diets (212 percent). This results from under consumption in these food categories. The largest reduction in Btu is 94 percent in fats, oils, and salad dressings in the Realistic Healthy Diet whereas the largest reduction in Btu in the Energy Efficient Diet is in sugar, sweets, and beverages, by 96 percent.

Recalling our hypothesis that Btu reductions are more likely under healthy diet outcomes, such assessments are possible under the following conditions:

i. More Americans would adopt the Realistic Healthy Diet than other healthy diets

ii. The range of possible healthy diets are normally distributed from low to high Btu outcomes

iii. Virtually all Americans adopt diets within 4 standard deviations of the most common diet

Under these assumptions, the Z-statistic for the Baseline Diet outcome is 0.17, implying Pr(Z < Baseline) = 0.57.[13] Although we cannot assign a likelihood to the prospect of all Americans aligning their diets with all of the dietary guidelines for Americans, if this were to happen our best estimate for the distribution of diet outcomes is that nearly 60 percent, or roughly 3 in 5 consumers will choose diets that conform to Dietary Guidelines and reduce food system Btu requirements. Overall this would reduce food system energy use by 3 percent. Therefore, our hypothesis that energy embodied in the U.S. food system would decrease if Americans shifted to a healthy diet is supported.

In their paper, Barosh, Friel, Engelhardt, and Chan (2014) find the diet that is both healthy and sustainable more expensive, between 9 and 48 percent of weekly income for the lowest-income to the highest-income households, respectively. However, our results show that a healthy diet that also reduces Btu may have the same wholesale cost as the Baseline Diet, or be even less expensive. One assumption of our modeling is that there is no price response from changes in demand.

Another result worth highlighting is that all of the alternative diets include animal products suggesting that animal products may be part of a healthy and energy efficient diet. The healthy diets including meat, poultry, fish, and mixtures may reduce Btu compared to the Baseline Diet, depending on the amount and type of food item. While the Energy Efficient Diet,

[13] Measured as $Z = (X-\mu)/\sigma$, X is the baseline diet, μ is the realistic healthy diet, and σ is 0.25*(minBtu - realistic), where 'realistic' is shorthand for realistic healthy diet and 'minBtu' is shorthand for energy efficient diet.

the diet which reduces Btu the most, does not include meat and poultry, it does include fish and dairy products.

Even if less energy intensive diets exist, there are many challenges surrounding dietary change (Clonan & Holdsworth, 2012). Americans make dietary choices based on tastes, preferences, habits, culture, convenience, and price, among other things. However, since dietary choices are made daily, there is potential that dietary change may be easier than other consumption changes. Consumption decisions on durable goods such as transportation or housing are made much less frequently.

There are limitations in this section. As mentioned, underreporting in NHANES is documented (Archer, Hand, & Blair, 2013), so we acknowledge that the Baseline Diet is likely the lower-bound of consumption. Therefore, the Btu embodied in the Baseline Diet and the Btu savings by switching to one of the alternative diets may be underestimated. Additionally, we assume that each of the items or ingredients mapped to the linear combinations of 38 energy pathways, and this limits the measured variation in Btu/gram across different diet choices. Also, the assumptions imposed to estimate the likelihood of individuals choosing among possible healthy diet outcomes are ad-hoc and further research is needed to determine whether such assumptions are realistic. Finally, our scenario that all Americans will shift to a healthier diet is hypothetical.

Summary

The findings from this research can be used to inform discussion and evaluate proposed policies at the intersection of health, diet, energy, and environmental issues. American diets are diverse and the pathways that individuals might follow in order to align their diets with Dietary Guidelines for Americans are difficult to predict. Our research indicates that a moderate Btu reduction of 3 percent is the most likely of many possible outcomes when shifting to a healthier diet—we denote this the Realistic Healthy Diet. Other diet outcomes are possible, some with substantial Btu reductions (52 to 74 percent) and others with moderate Btu increases of 1 to 15 percent. In the Realistic Healthy Diet, calories from grain products are reduced relative to the Baseline Diet, but grain products are still the largest contributor to total caloric intake at 30 percent. However, grain products contribute a lesser share to total embodied Btu. Similar to the Baseline Diet, the most Btu embodied in the Realistic Healthy Diet come from meat, poultry, fish, and mixtures, representing 30 percent of total Btu while only supplying 284 calories, or 14 percent of the total calories. We cannot assign a likelihood to the prospect of all Americans aligning their diets with all of the DGA. If realized, the best estimate for the distribution of diet outcomes is that nearly 60 percent, or roughly 3 in 5 healthy diet outcomes will lead to reduced food system Btu requirements. Overall, this would reduce food system energy use by 3 percent, or equivalent to the annual gasoline consumption of 3.7 million U.S. vehicles.

Future research could consider other sustainability metrics in addition to energy use. For example, water, land, and other greenhouse gases also have major roles in the U.S. food system. Food system water withdrawals, soil erosion, and other greenhouse gas emissions are also likely to change under alternative U.S. diet outcomes. Each of these important natural resources and production byproducts are the subject of many current and proposed federal policies. Just as it would be considered incomplete to study only one of the many dietary recommendations in the Dietary Guidelines for Americans, the same can be said for a consideration of only one of the metrics of food system sustainability.

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Appendix

Appendix Table 1--Benchmark Year and Annual Food Related Final Demand Categories

fd0_Benchmark	Representative Products in Category	fd0_Annual
01	Rice and Packaged Rice Products	07
02	Flour, Cornmeal, Malt, Dry and Refrig/Frozen Flour Mixes (biscuts pancakes cakes etc) Made in Mill	07
03	Breakfast Cereals and Oatmeal	07
04	Macoroni and Noodle Products with Other Ingredients and Nationality Foods (not canned or frozen)	10
05	Noodle Pasta and Dry Soup Mixes with Other Ingredients Plus Fresh Pasta and Packaged Unpopped Popcorn	04
06	Popcorn Wild Rice (not canned or processed)	01
07	Grits and Soyflour	07
08	Dry Pasta Dry Noodles and Flour Mixes from Purchased Flour	08
09	Bread Rolls Cakes Pies Pastries (Including Frozen)	08
10	Cookies Crackers Biscutts Wafers Tortillas (Except Frozen)	08
11	Beef and Veal (fresh or frozen/not processed canned or sausage)	12
12	Pork (fresh or frozen/not canned or sausage)	12
13	Boxed Cooked and Processed (lunch) Meats plus Lamb & Other Meats (incl.game)	03
13	Boxed Cooked and Processed (lunch) Meats plus Lamb & Other Meats (incl.game)	12
14	Fresh Frozen or Processed Poultry (except soups)	12
15	Fresh Frozen or Prepared Fish & Shellfish (incl. caned and soups)	02
15	Fresh Frozen or Prepared Fish & Shellfish (incl. caned and soups)	03
15	Fresh Frozen or Prepared Fish & Shellfish (incl. caned and soups)	13
16	Fresh Milk	11
17	Natural and Processed Cheese	11
18	Dry Condensed and Evaporated Dairy	11
19	Ice-cream Custards Frozen Yogurt Sherbets Frozen Pudding	11
20	Cottage Cheese Yogurt Milk Substitutes Sour Cream Butter Milk Eggnog	11
21	Shell Eggs	02
22	Dried Frozen or Liquid Eggs	04
23	Corn Oils	07
24	Margerine Shortning Oilseed Oils	07
25	Peanut Butter	04
26	Mayonnaise Salad Dressings Sandwich Spreeds	04
27	Oilseed Oils and Other Oilseed Products	07
28	Butter and Butter Oils	11
29	Lard and Other Animal Oils	12
30	Fresh Fruits	01
31	Fresh Vegetables	01
32	Mushrooms and other Vegetables Grown Under Cover	01
33	Fresh Herbs and Spices	01
34	Fruit Flours made in Grain Mills	07
35	Frozen Fruits and Vegetables	10
36	Canned or Dried & Dehydrated Fruits or Vegetables	10
37	Processed Vegetables and Fruits Packaged with Other Products (e.g., noodles)	04
38	Dry Beans and Peas (not canned)	01
39	Corn Sweetners (e.g., Karo syrup & sugar substitutes)	07
40	Sugar and Chocolate Products, Non-Chocolate Bars Gums and Candies	09
41	Jams Jellies and Preserves	10
42	Desert Mixes Sweetning Syrups Frostings	04
43	Almonds and Other Fresh Tree Nuts	01
44	Fresh Peanuts	01
45	Granola	07
46	Frozen Diners, Nationality Foods, Other Frozen Specialties (excl seafood)	10
47	Catsup and Other Tomato Sauces (eg spaghetti sauce)	10
48	Pickles and Pickled Products	10
49	Canned Soups and Stews (excl. frozen or seafood) and Dry Soup Mixes	10
50	Dry and Canned Milk plus Dairy Substitutes	11
51	Nuts and Seeds	04
52	Chips and Pretzels	04
53	Vinigar Condiments Sauces (excl. tomato based) Semi-Solid Dressings and Spices	04
54	Baking Powder and Yeast	04
55	Refrigerated Lunches	04
56	Refrigerated Pizza (Fresh, not frozen)	04
57	Bagged Salads	04
58	Value Added Fresh Vegetables	04
59	Fresh-cut Fruits	04
60	Fresh Tofu	04
61	Coffee Tea and Related Beverage Materials	04
61	Coffee Tea and Related Beverage Materials	14
62	Soft Drinks and Ice	14
63	Bottled Water	14
64	Frozen and Canned Fruit Drinks	10
65	Frozen and Canned Vegetable Drinks	10
66	Spirits Flavorings and Cocktail Mixes	04
66	Spirits Flavorings and Cocktail Mixes	14
67	Wine and Brandy	14
68	Beer	14
69	Food on Farm, Vegetables	01
70	Food on Farm, Fruits and Tree Nuts	01
71	Food on Farm, Dairy	02
72	Food on Farm, Beef	02
73	Food on Farm, Meats except Beef and Poultry	02
74	Salt, Fatty Acids, and Organic Chemical Food Flavorings	05
74	Salt, Fatty Acids, and Organic Chemical Food Flavorings	06
75	Household: Natural Gas	15
76	Household: Electricity	16
77	Household: Petro for Cooking	17
78	Household: Appliances	18
79	Household: Kitchen Equipment	19
80	Household: Motor Vehicles and Parts	20
81	Household: Auto Repair and Leasing	20
82	Household: Auto Insurance	20
83	Household: Auto Fuels Lubricants and Fluids	21
84	All Other Final Demand	22

Appendix Table A.2. Cohorts defined by age and gender

Cohort	Age	Gender	n
1	2-5	Male	455
2	2-5	Female	377
3	6-11	Male	550
4	6-11	Female	571
5	12-17	Male	460
6	12-17	Female	426
7	18-24	Male	351
8	18-24	Female	345
9	25-44	Male	862
10	25-44	Female	893
11	45-54	Male	462
12	45-54	Female	461
13	55-64	Male	445
14	55-64	Female	474
15	65+	Male	688
16	65+	Female	708
			8528

Appendix Table A.3. Model constraints with sources and units

	Lower bound source	Upper bound source	Unit
Calories			
Calories	2010 DGA, Appendix 6; authors' calculations	2010 DGA; authors' calculations	Calories
USDA Food Patterns			
Alcohol	N/A	2010 DGA for adults of legal drinking age	number of drinks*
Beans and peas (legumes)	2010 DGA, Appendix 7	N/A	cup equivalents
Dairy	2010 DGA, Appendix 7	N/A	cup equivalents
Dark-green vegetables	2010 DGA, Appendix 7	N/A	cup equivalents
Enriched grains	2010 DGA, Appendix 7	N/A	ounce equivalents
Fruits	2010 DGA, Appendix 7	N/A	cup equivalents
Meat, poultry, eggs	2010 DGA, Appendix 7	N/A	ounce equivalents
Nuts, seeds, soy products	2010 DGA, Appendix 7	N/A	ounce equivalents
Oils	2010 DGA, Appendix 7	N/A	grams
Other vegetables	2010 DGA, Appendix 7	N/A	cup equivalents
Red and orange vegetables	2010 DGA, Appendix 7	N/A	cup equivalents
Seafood	2010 DGA, Appendix 7	N/A	ounce equivalents
SoFAS (solid fats + added sugars)	N/A	2010 DGA, Appendix 7	Calories
Starchy vegetables	2010 DGA, Appendix 7	N/A	cup equivalents
Whole grains	2010 DGA, Appendix 7	N/A	ounce equivalents
Nutrient targets			
alpha-Linolenic acid	2010 DGA, Appendix 5	N/A	grams
alpha-Linolenic acid (% of Calories)	2010 DGA, Appendix 5; authors' calculations	2010 DGA, Appendix 5; authors' calculations	Calories
Calcium	2010 DGA, Appendix 5	DRIs, UL	mg
Carbohydrate	2010 DGA, Appendix 5	N/A	grams
Carbohydrate (% of Calories)	2010 DGA, Appendix 5; authors' calculations	2010 DGA, Appendix 5; authors' calculations	Calories
Cholesterol	N/A	2010 DGA, Appendix 5	mg
Choline	2010 DGA, Appendix 5	DRIs, UL	mg
Copper	2010 DGA, Appendix 5	DRIs, UL	mcg
Folate	2010 DGA, Appendix 5	DRIs, UL	mcg_DFE
Iron	2010 DGA, Appendix 5	DRIs, UL	mg
Linoleic acid	2010 DGA, Appendix 5	N/A	grams
Linoleic acid (% of Calories)	2010 DGA, Appendix 5; authors' calculations	2010 DGA, Appendix 5; authors' calculations	Calories
Magnesium	2010 DGA, Appendix 5	N/A	mg
Niacin	2010 DGA, Appendix 5	DRIs, UL	mg
Phosphorus	2010 DGA, Appendix 5	DRIs, UL	mg
Potassium	2010 DGA, Appendix 5	N/A	mg
Protein	2010 DGA, Appendix 5	N/A	grams
Protein (% of Calories)	2010 DGA, Appendix 5; authors' calculations	2010 DGA, Appendix 5; authors' calculations	Calories
Riboflavin	2010 DGA, Appendix 5	N/A	mg
Saturated fat (% of Calories)	2010 DGA, Appendix 5; authors' calculations	2010 DGA, Appendix 5; authors' calculations	Calories
Selenium	2010 DGA, Appendix 5	DRIs, UL	mcg
Sodium	N/A	2010 DGA, Appendix 5	mg
Thiamin	2010 DGA, Appendix 5	N/A	mg
Total fat (% of Calories)	2010 DGA, Appendix 5; authors' calculations	2010 DGA, Appendix 5; authors' calculations	Calories
Total fiber	2010 DGA, Appendix 5	N/A	grams
Vitamin A	2010 DGA, Appendix 5	DRIs, UL	mcg_RAE
Vitamin B12	2010 DGA, Appendix 5	N/A	mcg
Vitamin B6	2010 DGA, Appendix 5	DRIs, UL	mg
Vitamin C	2010 DGA, Appendix 5	DRIs, UL	mg
Vitamin D	2010 DGA, Appendix 5	DRIs, UL	mcg
Vitamin E	2010 DGA, Appendix 5	DRIs, UL	mg_AT
Vitamin K	2010 DGA, Appendix 5	N/A	mcg
Zinc	2010 DGA, Appendix 5	DRIs, UL	mg
Budget			
Cost	N/A	IO model	dollars

Note. 2010 DGA refers to the Dietary Guidelines for Americans (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010).
DRIs refers to the Dietary Reference Intakes and UL refers to the Tolerable Upper Intake Level (Institute of Medicine, n.d.).