

Integrating Nutritional Benefits and Impacts in a Life Cycle Assessment Framework: A US Dairy Consumption Case Study

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ABSTRACT

Although essential to understand the overall health impact of a food or diet, nutrition is not usually considered in food-related life cycle assessments (LCAs). As a case study to demonstrate comparing environmental and nutritional health impacts we investigate United States dairy consumption. Nutritional impacts, interpreted from disease burden epidemiology, are compared to health impacts from more traditional impacts (e.g. due to exposure to particulate matter emissions across the life cycle) considered in LCAs. After accounting for the present consumption, data relating dairy intake to public health suggest that low-fat milk leads to nutritional benefits up to one additional daily serving in the American diet. We demonstrate the importance of considering the whole-diet and nutritional trade-offs. The estimated health impacts of various dietary scenarios may be of comparable magnitude to environmental impacts suggesting the need for investigating the balance between dietary public health advantages and disadvantages in comparison to environmental impacts.

Keywords: dairy, dietary guidelines, LCA, nutrition

1. Introduction

Dietary guidelines, for instance suggested by the United States government, focus on improving health through dietary nutrition and do not consider environmental impacts occurring throughout the life cycle of the recommended diet (van Dooren et al., 2014). On the other hand, food-related Life Cycle Assessments (LCAs) assessing environmental and public health, tend to neglect nutritional advantages and disadvantages (Heller et al., 2013). In general, the assessment of emissions and nutrient intake is based on a functional unit relevant to the study question and the food system of interest. The selection of the functional unit is extremely important in LCA—specifically within food LCAs this point cannot be further emphasized, as it may change results when comparing two various food items or diets on different bases. Historically, there has been a large number of functional units based food LCAs (e.g. based on mass or volume of a single food type, quality corrected mass, a single nutrient, a full nutrient profile). Food oriented studies have mostly focused on environmental efficiency in crop or food production, for instance, how to decrease environmental impacts per unit output. (e.g. Garnett, 2013). In order to consider questions of impacts and benefits of dietary choices, i.e. consuming one food over another, assessment must be conducted in the context of the overall diet. These consumption oriented approaches (based e.g. on serving size, or full dietary or meal nutrients) are of growing interest as a means of informing consumer choices and policy decisions that affect dietary recommendations (e.g. Vieux et al, 2013).

Table 1 summarizes approaches to add nutritional impacts into environmental impact assessments the domain of application and limitations of each method, leading to the following statements: All present methods are impact oriented and do not enable a comparison of impacts with nutritional benefits. Several indices are themselves based on the contribution of the food to recommended nutrient intakes rather than based on epidemiological measures of health benefits and impacts. We expect in general when "quality" adjustments made including nutritional aspects, assessed impacts are reduced for items having positive nutritional benefits such as milk, fruit vegetables. This supports our thinking that if we can get to a better assessment of health benefits for products like milk then environmental impact in terms of expected negative human health impacts will be more balanced. However, trying to force various benefits and impacts associated to nutrition in the basis for comparison (the traditional functional unit) does not provide a clear view of the benefit of "positive" nutritional components versus the impact of "negative" nutritional components.

There is therefore a need to consider health benefits and impacts of nutrition in a parallel way to the latest quantitative development of the global burden of disease to incorporate diet-related risk factors, and consider Disability Adjusted Life Years as a basis for an improved index.

Table 1. Summary Table of Identified Approaches to Incorporating Nutrition in Environmental Impact Assessment

Approach	Domain of application	Limitation / needs	Features of interest for framework
a) Functional unit approaches			
Mass- or volume-based e.g. per kg or per liter	Internal (production oriented) assessments; identifying hotspots, evaluating abatement scenarios	Not appropriate for comparisons of different foods	Intermediary calculation step
Quality corrected mass e.g. per kg FPCM	Normalizing product quality across different production practices; evaluating scenarios that affect product quality	Limited to simple nutritional quality assessments that can be related to a mass unit; not appropriate for comparison of disparate foods	Reconsideration of FPCM and impacts of allocated cream in overall diet scenarios
Single nutritional aspect, e.g. per g protein	Evaluating single nutritional dimensions across foods with related functions	Limited complexity; does not capture other nutritional differences	Impact and benefit of single nutrient could be estimated separately
Nutrient profile e.g. per index unit value	More complete nutritional picture; may be valuable in comparing foods	Negative impacts not adapted for functional unit; most current indices based on dietary recommendations rather than health outcome	Would be of interest to create a DALY weighted nutrient profile
Approach	Domain of application	Limitation / needs	Features of interest for framework & next steps
b) Consumption oriented approaches			
Serving size per serving size	Normalizes based on typical consumption quantities; can be used as a consumption-based unit for comparing individual food items, provided that health effects of nutrients are also considered	Does not link with nutrition or health; inconsistent definitions of servings	Testing scenario of one additional serving of milk
Diet-based for overall diet	Basis for consumption oriented assessment	Requires parallel assessment of nutritional quality/health; no basis to evaluate trade-offs	Basis for comparison framework at diet level
Equivalent nutrition diet for overall equivalent diet	Sound basis for comparing environmental impact of similar diets	Limited to nutritionally equivalent diets; definition of “nutritional equivalence” may be limited	Useful in considering isocaloric dietary substitution scenarios
Diet-level nutrient profile e.g. per index unit value of overall diet	May offer a comprehensive nutritional basis for diet comparisons	Negative impacts not adapted for functional unit; most current indices based on dietary recommendations rather than health outcome	Will be used as a comparative approach

To address these needs, we aim in this paper to 1) present a preliminary framework to show separately environmental and nutritional impacts together on a comparable scale, starting from serving size, 2) build on global burden of disease information and use of the DALY to compare human health impacts and benefits of nutrition, 3) provide a dairy case study to demonstrate the framework and analyze population-scale health effects of dietary changes.

2. Methods

2.1. Framework for comparing impacts and nutritional benefits of food

In an effort to bridge this research gap we build a preliminary framework and implement a dairy case study. Figure 1 schematically outlines the LCA framework to begin harmonizing nutritional and environmental impacts, where different food items within various diets may be associated with numerous environmental emission types which may influence population-scale health. Likewise, considered nutrients within those food items contribute to the nutrient index (i.e. nutrients consumed) and may also lead to various population-scale health impacts and benefits. To express human disease burden, many LCAs use the Disability Adjusted Life Year (DALY) (ILCD, 2010). Recently this metric has also been applied to quantify nutrition-based health impacts. For example, Murray et al. (2013) found that amongst a variety of health indicators and risk factors (e.g., smoking, violence, pollution etc.) inadequate diet generally accounts for 26% of deaths in the United States and 14% of DALYs. Benefiting from the implementation of the DALY metric in public health nutrition research and population-scale epidemiological evidence on minimum dietary risks, we build on work by Murray et al. (2013) and Lim et al. (2012) who performed large-scale epidemiological literature reviews on disease burden associated with specific food categories and nutrients, referring to both positive and negative health outcomes as nutritional impacts. Overall this approach offers an interesting possibility to compare nutritional benefits and impacts consistently with environmental impacts on human health.

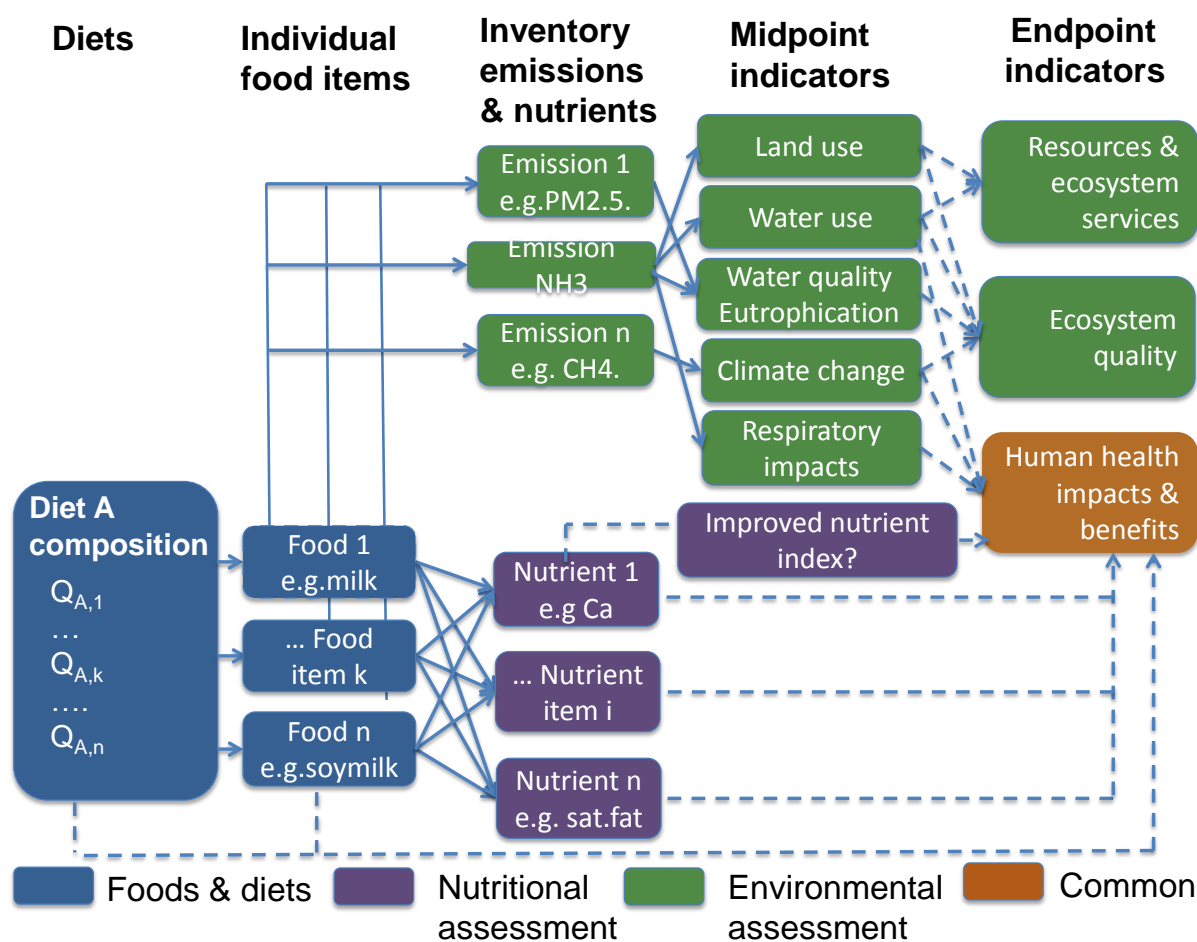


Figure 1. Framework to combine nutritional and environmental assessments. Dashed lines represent links that are useful to interpret midpoint categories, but whose quantification is also associated with a higher degree of uncertainty.

2.2. Dairy case study

a) Functional unit and scope

To test the LCA framework, which includes both nutrition and environmental impacts, we study a dairy case study. The Dietary Guidelines for Americans (USDA, 2010) recommends adult Americans consume 3 daily servings (≈ 740 g/day total) of low-fat or fat-free dairy products, close to doubling current consumption (USDA ERS, 2012). Previously performed LCAs (e.g. Thoma et al., 2013, Asselin-Balençon et al., 2013) have quantified various environmental impacts of dairy production in the US. Entirely missing from these LCAs, however, are the use phase nutritional impacts or benefits on human health due to dairy consumption. Building on the literature review from Heller et al., (2013), this research aims to incorporate nutrition related health effects of dairy into an LCA framework to compare them consistently with environmental impacts. We use the serving size as a common functional unit when combining nutritional and environmental impacts within LCA. This allows easy comparison with recommended dietary guidelines, based on serving sizes, and can also be easily converted to mass or volume, as well as to a corresponding nutritional intake or dietary function (e.g. calcium intake). We consider epidemiologically-based estimations of dairy's contribution to the global burden of disease and caloric intake to evaluate the health impacts due to nutritional components. For environmental impact, we focus on greenhouse gas (GHG) emissions and human health impacts of particulate matter (PM). We select these two impact categories because of their high relevance, and they have been extensively studied in relation to the dairy industry by Thoma et al. 2013 and Henderson et al. 2013. Additionally, human health effects of PM have also been assessed through various epidemiological studies (Pelucchi et al., 2009) and can thus be compared with nutritional impacts.

b) Defining the American diet and dietary context

In order to understand how a shift in dairy consumption may affect overall nutritional intake, we must first define the current "average" diet in the US. We assess two available datasets: The National Health and Nutrition Examination Survey (NHANES) and the USDA-maintained Loss Adjusted Food Availability (LAFA) data series (USDA ERS 2012). Survey-based approaches, like NHANES, are known to under-report food intakes; they are also comprised of as-consumed (e.g., processed) food items, with no consideration of the life cycle of a food item e.g. from the commodity or ingredient level. LAFA, on the other hand, measures the use of food commodities (e.g., wheat) by tracking the US marketplace. Generally, the available supply is the difference between the sum of production, imports and beginning stocks, and the sum of non-food use (e.g. industrial uses), exports, and ending stocks for a given calendar year. In the LAFA series, the available supplies for over two hundred commodities are adjusted by percent loss assumptions, for instance plate waste and food spoilage in order to account for various processes effecting food loss along the chain farm to retail. Availability adjusted for loss can serve as a useful proxy for per capita food consumption in the US. While LAFA data is presented at the food commodity level (i.e., raw farm products like wheat and corn rather than consumables like bread or tortilla chips), this level is far more manageable from the environmental impact perspective; LAFA data also allows to account for supply chain losses, which contribute to environmental impact but are not consumed (and therefore do not contribute to nutritional health effects). Therefore, we propose using a recent 2010 LAFA data series to define average US food consumption (the background average US diet) within this proof-of-concept case study. These data are available both on a weight and on a food pattern equivalent basis, permitting consistent connection between environmental impact and nutritional data.

c) Scenarios

In general, it is important to consider the nutritional and health effects from consumption of a single food item within the full dietary context. From average diet information we find that the average US adult diet includes 1.5 cup equivalents (with around 245 grams of milk per cup) of dairy consumed per person per day, about half the recommended value. To investigate the shift from average consumption to recommended consumption we evaluate three dietary scenarios. These are hypothetical examples to implement this framework; unfortunate-

ly there is limited data available to predict actual dietary changes. Starting from the average diet (scenario 0) at population-scale we investigate the effects if people generally will (Figure 2):

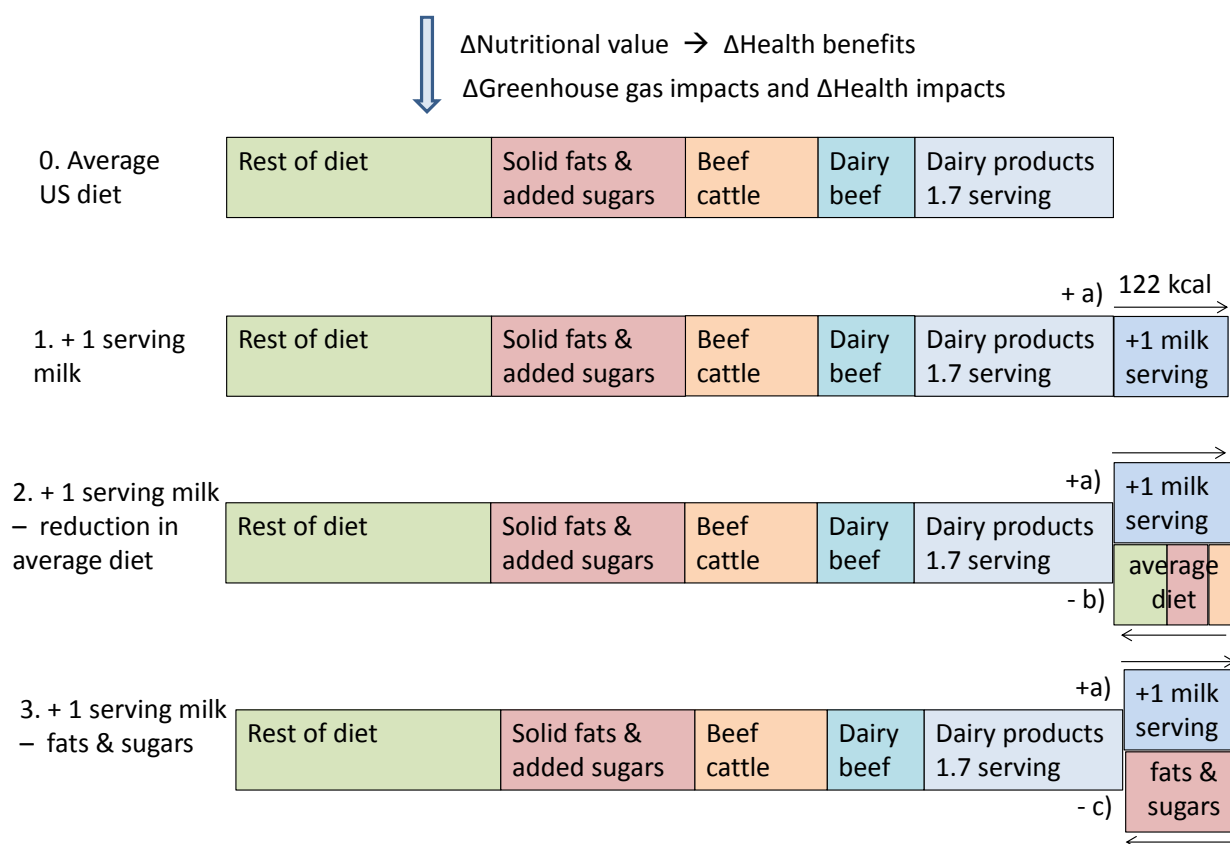


Figure 2. Scenario schematic: Changes in nutritional/health benefits and environmental impacts (greenhouse gas, example) associated with one additional serving of milk within the diet.

1. Add an additional serving (1 cup) of “2% milk,” that is fluid milk containing 2% fat, (per capita per day) to the diet, with no change to the rest of the diet; i.e., this scenario would result in an increased caloric intake over the average diet baseline.
2. Add an additional serving of 2% milk while subtracting an equal caloric quantity from the overall average diet. Thus, the 1 cup of milk would be added to a diet that is proportionally reduced by ~122 kcals (the energy content in 1 cup of 2% milk). The resulting diet would be iso-caloric with the average diet baseline.
3. Add an additional 1 cup of 2% milk while subtracting an equal caloric quantity of “empty calorie” foods. This will likely be a proportional representation from the Dietary Guidelines’ “solid fats and added sugars” category. The resulting diet would be iso-caloric with the average diet baseline.

We use these specific scenario decisions based on the following logic: In response to dissemination of dietary guidelines, consumers may acknowledge the governmental recommendation for increasing lower-fat dairy consumption, and chose to supplement their diet with a low-fat milk product (here considered 2% fat, because it is the most commonly consumed lower fat form of milk). This dietary change: 1) may not result in compensatory removal of equivalent calories from the rest of the diet (e.g. Duffy and Popkin 2007); 2) may result in compensatory removal of calories resulting in an a diet approximately iso-caloric to before dairy supplementation; 3) may result in removal of other beverages such as sodas from the diet (e.g. Cavadini et al. 2000).

3. Results compilation and case study

3.1. Nutrition-oriented assessment and relation to health

To assess nutrition-related health impacts, we use a global burden of disease (GBD) approach, building off of Murray et al. (2013) and Lim et al. (2012). Specifically, we build on the risk ratios from the GBD sources and minimum risk thresholds to extend nutrition-oriented work that associates nutritional/dietary benefits and risks with DALYs.

The benefits associated with increasing dairy consumption are dependent on the status-quo consumption or dairy products. Within the GBD risk framework, there are no additional health benefits to increase servings above the consumption threshold corresponding to the reported *minimum risk level*. Given the adult population (19+ yrs) in NHANES 2009-2010 had a reported milk intake of 0.87 cup per day (unpublished data), we can calculate the increase in amount of milk to reach the milk consumption threshold corresponding to the minimal risk level according to Lim, et al (2012). Assuming we standardize milk to 2% reduced fat milk with 236 g/cup, we estimate that currently American adults are consuming 205 g milk/day (the product of 0.87 cup and 236 g/cup). With a reported minimum risk threshold level of 450 g/day, we can deduce that adult Americans would need to consume *an additional* 245 g milk per day on average, which is about 1.04 cups (245 g milk/236 g per cup), to reach the minimal risk level outlined in Lim et al., (2012).

As a comparative exploration, we perform the same calculation based on nutrients instead of dairy or milk as a whole-food. The reported minimal risk for calcium intake is 1200 mg/day. Assuming a non-dairy calcium intake of about 385 mg/day (Fulgoni et al. 2011) and calcium from dairy as 516 mg calcium (1.72 cup equivalents of all dairy products from NHANES 2009-2010 with each cup equivalent having approximately 300 mg of calcium) we deduce we need an additional 299 mg calcium/day ($1200-385-516=299$) to achieve the minimal risk level outlined in Lim et al., (2012). Again, this corresponds to about one cup of 2% milk.

It appears Murray, et al., (2013) used ounces of weight rather than fluid ounces for their calculation for impact of milk (226.8g/8 oz=28.35g). To keep units similar to relative risks we can perform similar calculations; based on these relative risks, the change in milk in cup equivalents is 0.96 cup eq of 2% milk, which again corresponds to about one cup.

These different preliminary calculations suggest that an increase of *one serving of milk* will maximize health benefits for the primary dairy-related risk categories. Increases above this level would increase impacts without additional benefits in these categories. Further research will be needed to define minimal risks for other health categories (e.g., bone health, blood pressure).

3.2. Quantification of greenhouse gas emissions

Detailed results from the Innovation Center sponsored milk LCA studies (Thoma et al. 2013; Henderson et al. 2013) are used to estimate greenhouse gas emissions from the life cycle of fluid milk production. Additionally, to broadly estimate GHG emissions from the general diet we generate a dataset of 250 data points aggregated from a variety of published studies on greenhouse gas emissions from the production of specific foods in specific places. Where multiple emission factors exist in the dataset for the same food, an average is taken. For foods without specific data points, proxies are formed by averaging related foods. Several limitations exist in using this dataset: many studies are not specific to US production scenarios; significant variability can exist between studies of the same food; transport and other variables are not treated in a consistent fashion across studies. Still, the dataset is useful for a pilot level study; it captures most of the important foods in the LAFA dataset and is the most reasonable collection of data current available.

3.3. Quantification of Particulate Matter (respiratory inorganics) emissions and related impacts

The largest contributors in typical food and agricultural systems to respiratory inorganic impacts are particulate matter (PM) from internal combustion engines (i.e., tractor use, transportation) and ammonia emissions (a PM precursor), primarily from manure storage and handling. The Comprehensive LCA of Fluid Milk (Henderson et al. 2013) models these emissions (and impacts) related to PM for the US milk production chain, and will thus be used in this case study. Since most published LCA studies on foods do not report these emissions or im-

pacts, we propose the following approach to provide a first order estimate of the PM associated with producing the average US diet. The majority of PM from food systems comes from direct ammonia emissions during agricultural production (generating secondary PM) and from tractor usage and from transportation (primary and secondary PM). A preliminary study carried out on the 4000 Ecoinvent processes shows that PM from all sectors can be interpolated from correlations between PM and greenhouse gas emissions (GHGE), with specific coefficients for agriculture production and for transportation. We estimate the proportion of GHGE from the production of individual food types using studies that report the contribution of field emissions, tractors and transportation to various food group GHGE (Weber and Matthews 2008; Hoolohan et al. 2013; Meier and Christen 2013). These studies will be combined with the Ecoinvent derived correlation to estimate direct emissions of PM_{2.5} (so-called primary PM) as well as emissions of precursors (NH₃, NO_x, SO₂) of secondary PM (this important PM precursor for the average diet).

As described by Fantke et al. (2014), a starting point to determine the human health impacts associated with primary and secondary particulate is the effort of an earlier UNEP/SETAC working group that has designed a framework and proposed a set of default human intake fractions (iF) associated with PM emissions for use in LCIA (Humbert et al. 2011). This effort was consistent with other consensus building actions in the frame of comparative chemical assessments. However, this effort is limited to the part of the impact pathway from emissions to concentration and human intake, but does not cover the part from human intake to finally health effects. This will be complemented according to the latest recommendations of the LCIA guidance task force for PM related health impacts based on dose-response from the 2010 global burden of disease (Lim et al. 2012; Murray et al. 2013) as well as calculations based on the American Cancer Society Study of Particulate Air Pollution and Mortality (Gronlund et al. 2013; Pope III et al. 2002). Since nutrition impacts and benefits will also be mostly based on the 2010 burden of disease, this will ensure a good consistency between environmental impacts and nutrition.

3.4. Overall trade-offs

With considering only one serving additional in each dietary scenario, preliminary results show the following tendencies. The increase in calories may dominate, generating important additional impacts. In the iso-caloric scenario 2, the nutritional benefit of milk becomes important and will counter balance the human health impacts of PM over the life cycle. Dietary scenario 3 provides the most substantial nutritional advantage by also reducing the nutritional impacts of added sugar. We finally analyze the trade-offs between human health and global warming impacts for each scenario.

4. Discussion

Considering the present US consumption, and limited epidemiological data on disease burden, our results suggests that lower-fat milk leads to nutritional benefits up to one additional serving. Nutrition is a complex issue and we do not attempt to cover all intricacies in this case study. For example we do not consider non-nutritional health impacts such as social/cultural issues with dietary changes, or other health related issues such as bowel motility or indigestion related to lactose intolerance. We also do not consider possible variations in health impacts for different age groups (i.e. a health advantage of consuming dairy may be more measurable for children and teenagers than for elderly populations) and consider the general order of magnitude of potential impacts at the population scale and not the health impacts for a given individual. We also do not consider at this stage other potential benefits of dairy products on other risk areas such as bone health and blood pressure, whereas the Lim et al. (2012) and Murray et al (2013) studies consider only carcinogenic risks (e.g. balancing associations of dairy consumption with decreased risk of colorectal cancer and increased risk of prostate cancer).

It is important as population grows and food and environmental resources become strained that research continues on harmonizing nutritional and environmental public health impacts of foods and diets. This study assesses epidemiological data on disease burden in relation to one food group (dairy) and one associated nutrient (calcium) in the context of governmental dietary regulations and LCA. This type of analysis may help regulators in selection of dietary guidelines and promote holistic consideration of both the environment and the direct nutritional implications. Our findings emphasize a clear need for more research on dietary choices and for understanding whether or not shifts in the diet are compensated for by other food groups. Generally the framework we

present provides the groundwork for considering both the nutritional and environmental impacts of a specific food, and for also considering the entire dietary context, which we find essential.

5. Conclusion

In all, this work suggests that in order to optimize public health dietary recommendations, nutritional impacts and benefits should be considered with respect to the entire diet as well as the food's life cycle. This work provides a stepping-stone for consistently incorporating nutritional effects into an LCA framework.

Accounting for the nutritional function of food is a perennial problem in assessing the environmental impact of food production in the LCA framework. The review presented here outlines a functional unit approach that also includes dietary context. We propose a novel framework for bringing environmental and nutritional aspects of food together using the global burden of disease approach to evaluating risk factors using the DALY metric. This approach allows expression of behavioral choices such as diet composition in terms of the associated disease risks. Under such a framework, nutritional and environmental health impacts of a dietary change may be evaluated in equivalent units, permitting a quantitative estimate of the complements and trade-offs between nutrition and environment. Regarding the limited epidemiological data relating food items to possible health impacts, these preliminary investigations do not offer exact calculations or the health risks for a given individual, but instead should be considered as an indication of the importance of balancing nutritional and environmental health impacts, as these may lead to contradicting conclusions depending on the population-scale dietary context.

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