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Environmental impact food labels combining carbon, nitrogen, and water footprints

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ABSTRACT

The environmental impact of the production and consumption of food is seldom depicted to consumers. The footprint of food products provides a means for consumers to compare environmental impacts across and within product groups. In this study we apply carbon, nitrogen, and water footprints in tandem and present food labels that could help inform consumers about the environmental impacts of individual food products. The footprint factors used in this study are specific to the United States, but the concept can be applied elsewhere. We propose three methods of footprint calculations: footprint weight, sustainability measures, and % daily value. We apply the three footprint calculation methods to four example labels (stars label, stoplight label, nutrition label add-on, and a detailed comparison label) that vary in design and the amount of detail provided. The stars label is simple and easily understood but provides minimal detail about the footprints. At the other end of the spectrum, the detailed comparison label gives context in relative terms (e.g., carbon emissions for equivalent distance driven) for the food product. Implementing environmental impact food labels requires additional understanding of how consumers use footprint labels, and label suitability may vary for government organizations, retail and local grocers, and farmers.

1. Introduction

Food production can negatively impact human health and the environment, and consumers are becoming increasingly conscious of the consequences of their food purchases. The food production process requires substantial inputs of land, water, fertilizer, pesticides, and energy. Conversion of natural lands to agricultural lands—especially through deforestation—leads to biodiversity loss, nutrient runoff, soil erosion, and greenhouse gas emissions. In the United States, about 80% of freshwater use (including both surface and groundwater) is directed toward irrigated agriculture (e.g., Richter, 2014), and in some parts of the country has contributed to water scarcity and inadequate environmental flows (e.g., Colorado and Bravo river basins; Hoekstra et al., 2012). The use of fertilizers can lead to nutrient losses to waterways, groundwater, and the atmosphere. Once in the environment, excess nitrogen can lead to water acidification, eutrophication, climate change, and biodiversity loss (Erisman et al., 2013; Galloway et al., 2003) as well as human health impacts (e.g., blue baby syndrome; Knobeloch et al., 2000). Agriculture also requires energy; the burning of fossil fuels for fertilizer production, mechanized farming, and transport emits greenhouse gases and pollutants such as carbon dioxide and nitrogen oxides (Burnley et al., 2010). In addition, livestock enteric fermentation is an important contributor of methane. The livestock sector of food production alone is expected to exceed humanity's sustainable contributions to global climate change and nitrogen by 2050 (Pelletier and Tyedmers, 2010; Steinfeld and Gerber, 2010; Leip et al., 2015), which necessitates the continued evaluation of current and projected food consumption trends (Deckers, 2010; González et al., 2011; Tilman and Clark, 2014).

Current food labels in the US focus on food characteristics (e.g., nutritional value, additives) and to some extent on issues such as Fair Trade, animal welfare, and food origin. Consumers

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are becoming more aware of the unintended negative impacts of food production. However, even though consumers have shown concern and understanding with respect to these issues, it has not translated into greater use of sustainability labels (Gadema and Oglethorpe, 2011; Grunert et al., 2014). The continued lack of use may result from higher prices of labeled products, credibility of the labels, availability of labeled products, a lack of understanding of what the labels represent, or other perceptions (Gadema and Oglethorpe, 2011; Grunert et al., 2014). Perhaps the clearest example of consumer interest, however, is organic food labeling (Dettmann and Dimitri, 2010). Certified by the United States Department of Agriculture, organic farming in the United States follows a specific set of practices that aim to limit environmental impacts, support animal welfare, and improve food quality. Organic food production does not use mineral fertilizer, pesticides, or genetically modified material; only if a farmer fulfills these requirements can the products be labeled as 'organic.' The number of certified organic operations in the United States has increased from about 5000 in 1990 to almost 15,000 today, and organic food makes up about 4% of total US food sales (Greene, 2013). Although some food companies and grocery stores have developed labeling schemes to help inform their consumers about sustainability beyond organic production, these labels typically focus on a specific environmental impact (e.g., greenhouse gas emissions, animal welfare).

1.1. Environmental footprints

In this study, we propose a comprehensive environmental impact food label that assesses a food product's sustainability in terms of its energy, nitrogen, and water use. Three specific metrics that can address these environmental impacts are the carbon, nitrogen, and water footprints, respectively. Taken together, these indicators provide information about how a specific food product impacts the environment during its production. The calculation methods and label designs presented in this paper could be expanded to account for other sustainability metrics (e.g., ecological footprint, pesticide use, animal welfare). However for the purposes of this paper, the carbon, nitrogen, and water footprints will be used for two reasons. First, these three footprints represent a broad range of the environmental impacts of food production. Second, peer-reviewed food production factors are already available for these three footprints. Although ecological footprint food production factors have been developed for specific cases (e.g., Kissinger, 2013), the ecological footprint overlaps with other footprints and the carbon footprint is a more direct measure of a food product's environmental impact (Blomqvist et al., 2013; Fiala, 2008). In addition, this study aims to present a framework for designing an environmental impact food label; this proposed framework can be modified to have more or fewer environmental impacts presented.

The carbon footprint of a product or service represents the greenhouse gas emissions during the lifecycle of a product or service, usually from production, use/consumption, and disposal (Röös et al., 2014). Carbon footprint calculations differ with respect to two topics: the greenhouse gases considered and the boundaries of the calculation (Edwards-Jones et al., 2009; Pandey et al., 2011). The carbon footprint is reported as a mass of total CO_2 equivalents (CO_2-eq). The other important greenhouse gases generally included in the carbon footprint are methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) (Galli et al., 2012). The system boundaries of a carbon footprint describe which stages of production are considered, and they can include different combinations of direct and indirect emissions according to life cycle assessment definitions (EC, 2013; European Food SCP RT, 2013; Pandey et al., 2011). For example, crop production would incorporate emissions related to farm vehicles, fertilizer and pesticide production, soil emissions, processing, transportation, and waste (Röös et al., 2014; Weiss and Leip, 2012).

The nitrogen footprint of a food product refers to the total amount of reactive nitrogen (all species of nitrogen except N_2) released to the environment from the production and consumption of a food product (Leach et al., 2012). The creation of reactive nitrogen as synthetic fertilizer has supported a growing population (Erisman et al., 2008). However, the related human alteration of the nitrogen cycle has led to the accumulation of excess reactive nitrogen in the environment. Once released to the environment, reactive nitrogen can contribute to a series of negative human and environmental impacts such as smog, acid rain, biodiversity loss, climate change, and eutrophication (Erisman et al., 2013; Galloway et al., 2003; Sutton et al., 2011; Vitousek et al., 2009). A food nitrogen footprint has two parts: the food consumption N footprint (i.e., the nitrogen actually embedded in the consumed food product, which is ultimately lost to the environment as human waste unless the N is converted to N_2 during sewage treatment or used as a fertilizer) and the food production N footprint (i.e., the N released to the environment during food production, such as from fertilizer runoff and processing wastes). The food consumption footprint is unique to the nitrogen footprint and is not considered for the carbon and water footprints due to its relatively small contribution and the boundaries established by the studies that calculated the carbon and water footprint factors. Food nitrogen footprint research is still developing. Xue and Landis (2010) studied nitrogen and phosphorus flows for different food products using a life cycle analysis approach to assess the eutrophication potential of different food products. Leach et al. (2012) then defined a per capita nitrogen footprint and presented a tool to allow consumers to calculate their personal N footprint. Leip et al. (2014a) determined the nitrogen food production footprint of different food products produced in the European Union.

The water footprint of a food product can be generally defined as the amount of water consumed (through evaporation and transpiration) in the production of that good. This metric has been extensively studied (Hoekstra et al., 2011; Mekonnen and Hoekstra, 2011, 2012) and is an important measurement to consider, as agriculture accounts for ~90% of consumptive freshwater use by humans (Falkenmark and Rockström, 2004). The total consumptive water footprint of a crop can be defined as the sum of its green and blue water footprints, where the green water footprint is the water from precipitation used in the production of the good and the blue water footprint is the water from irrigation used (Hoekstra et al., 2011; Hoekstra and Mekonnen, 2011; Vanham et al., 2015). When a processed good or animal-source good is the product of interest, additional water uses occur in the production chain (e.g. processing, drinking water), though these are minor in comparison to the water required for crop growth. Changes in water quality (i.e., gray water) from nutrient loading and runoff (typically reactive nitrogen) can also be included in a total water footprint. The gray water footprint, which is not included in this study, represents the amount of water required to dilute fertilizer runoff to an acceptable environmental or human health standard concentration and can be calculated using information on fertilizer application and leaching rates (Hoekstra et al., 2011).

1.2. Environmental impact food labels

Existing environmental impact food labels are limited and tend to focus on a specific impact (Röös and Tjärnemo, 2011). Food labels addressing nitrogen and water footprints have not yet been developed. Carbon labeling, however, has become more prevalent in recent years. In 2007, the British grocery company Tesco began labeling their products with carbon footprints due to household demand (Boardman, 2008; Gadema and Oglethorpe, 2011), but the project was discontinued. A similar and successful initiative by Max Burgers in Sweden was well-received and led to the sale of more vegetarian burgers (Tan et al., 2012). A survey in Sweden mirrored this outcome by finding that consumers are willing to purchase labeled products and change eating behaviors (Blomqvist, 2009). Other companies have developed or are using carbon labeling or measuring schemes, such as the Finnish Raisio and Fazer Groups, the companies involved in the Product Carbon Footprint (PCF) project in Germany, Unilever using the Cool Farming Tool, and the French Leclerc (Tuomisto et al., 2011). Although the number of large scale success stories is limited, the number of publications which survey groups on label perceptions, preferences, and usefulness is growing and potentially indicates increasing awareness and perhaps the potential for the future use and expansion of labeling (Hu et al., 2012; Sirieix et al., 2013; Zepeda et al., 2013; Chkanikova and Lehner, 2014; Festila et al., 2014; Van Loo et al., 2014). Examples of environmental impact labels include the United Kingdom Tesco grocery store carbon label, the carbon footprint stoplight label designed by Vanclay et al., 2011, and the Whole Foods environmental impact label (See Supplementary Material, Fig. S1 for examples of label designs).

Consumer confusion is a concern for environmental food labeling strategies (Grunert et al., 2014). Although consumers have reacted positively to carbon footprint labels, there are barriers that limit immediate change to food systems (Gadema and Oglethorpe, 2011; Upham et al., 2011). Röös and Tjärnemo (2011) found that consumers can be deterred from purchasing carbon-labeled products due to price concerns, food purchasing habits, product availability, limited information and marketing, distrust in the labeling system, and a lack of perceived personal benefit. To be effective, carbon footprints must be presented in a manner that puts the values in context and clearly shows the implications of personal actions with respect to greenhouse gas emissions (Schmidt, 2009).

A simple "stoplight" carbon labeling approach (i.e., green for below-average emissions, yellow for near-average, and black for above-average) resulted in small changes of purchasing patterns with a large shift only occurring when the green product was also the cheapest (Vanclay et al., 2011). A similar study in Australia found that consumers preferred and understood labels that showed carbon emissions relative to other common products and utilized simple designs, such as a traffic light color system (Sharp and Wheeler, 2013). Although the use of carbon footprint labels has limitations, dispensing this knowledge is well-received by the public and can have a greater impact with the incorporation of other measures of environmental sustainability (Tan et al., 2012).

Food labels describing the N footprint of a food product have not yet been developed, likely due to the newness of the research (Galloway et al., 2014). However, food nutrition labels all report one major component of a food nitrogen footprint: protein consumption (European Council, 1990; USFDA, 2013). Nitrogen is embedded in food as protein, which is 16% nitrogen. To determine how much nitrogen is consumed as a food product, the only piece of information needed is the food's protein content. However this food consumption N footprint typically makes up less than 20% of a food product's N footprint; the remainder is from losses during food production (Leach et al., 2012).

The water footprint of products has been well studied (see Mekonnen and Hoekstra, 2011, 2012), but there has been little done with respect to labeling. Postle et al. (2011) examined the current use of different certification and labeling schemes as related to water resource usage. They characterized water-related labeling as taking one of two main forms: (1) information on the amount of water needed to produce the good and (2) information that encourages responsible use of water. The authors ultimately recommended that a label based purely on a water footprint (#1 above) is not easily interpreted by the consumer and does not readily convey impacts. However, the second form of labeling can convey a more effective message—provided that universal standards and methodologies are put in place (Postle et al., 2011). Both of these points have been reiterated in similar studies for both water (e.g., European Food SCP RT, 2011; Segal and MacMillan, 2009) and carbon (e.g., Sharp and Wheeler, 2013) footprint labeling.

Footprints describe the impact of a product or service on the environment and are calculated for a multitude of goods and services, especially crop and livestock products. Labeling products with carbon, nitrogen, and water footprints, however, is not common. Besides limited data availability for product and service footprint factors, there is no coordinated carbon, nitrogen, and water footprint calculator or labeling system. Initial research into the integration of footprints (ecological, carbon, and water) indicated they jointly complement one another and more comprehensively described the impact of goods and services on the environment (Galli et al., 2012, 2013). The combination of the various footprints and identification of their sustainable values can help identify humanity's environmental footprint and the reductions necessary to approach sustainability (Hoekstra and Wiedmann, 2014).

1.3. Objectives

The overarching objective of this paper is to propose a flexible methodology for developing environmental impact food labels to help consumers make informed purchases. Here, we describe the methodology typically used to calculate carbon, nitrogen, and water footprints for food products and provide examples of the footprints for a range of primary food products. We present three distinct footprint calculation methodologies and four example environmental impact food label designs. An integrated carbon, nitrogen and water footprint labeling system will enhance a consumer's ability to make informed purchasing decisions based on the environmental impact of products.

2. Methods

2.1. Footprint factors

Methodologies for calculating carbon, nitrogen, and water footprints are well-established and are not the focus of this study. Instead, we compiled footprint factors from published studies that are average values for major food product categories produced using conventional production methods (carbon: Heller and Keoleian, 2014; nitrogen: Leach et al., 2012; water: Mekonnen and Hoekstra, 2011, 2012). While there is variability in the footprint factors within each food group, we use food group averages to demonstrate the various methods of presenting the footprint of a product (i.e., by weight, calorie content, and protein content) and to calculate the carbon, nitrogen, and water footprint for a healthy diet recommended by the United States Department of Agriculture (USDA, 2010). Footprint factors presented here are presented as, or as close as possible to, the cumulative footprint from the start of production to the store shelf (see Supplementary Material for more information). The footprint factors used in this study are specific to the United States, but the labeling concept can be applied elsewhere using location-specific footprint factors.

Carbon footprints for various products are reported in term of CO_2-eq (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6). The carbon footprint factors for crop products include emissions associated with fertilizer and pesticide production; farm vehicle emissions; soil emissions; and any emissions associated with harvesting, processing, and waste. These values are divided by the crop yield to determine the kg of CO_2-eq emitted per kg of product. For animal products, the footprint factor considers both the emissions from producing the animal's feed as well as emissions from producing the animal product itself (e.g., electricity usage, direct animal emissions, processing, waste). These values for animal products are similarly divided by the yield to determine a per kg carbon footprint value. Carbon footprint factors were collected from Heller and Keoleian (2014).

The food nitrogen footprint is presented as the weight of reactive nitrogen released to the environment from the consumption and production of a food product. The food consumption N footprint is calculated using the food product weight and its protein content. The food production N footprint can be calculated using virtual N factors (VNF), which describe the average amount of reactive nitrogen released to the environment per unit of nitrogen consumed by food type (Leach et al., 2012). These factors were established for conventional production in the United States, but they can be adapted to describe other food production practices (e.g., organic) or food production in other regions or countries (e.g., Pierer et al., 2014; Shibata et al., 2014). The VNF were developed with an approach in which average N losses at each stage of the food production process were determined for major food types. The food production N footprint is calculated by multiplying the food consumption N footprint by the VNF. The total food N footprint is then the sum of the food consumption and food production N footprints. Nitrogen emissions from fossil fuel combustion (e.g., fertilizer production, transport, on-farm energy use) are not considered here due to their relatively small contribution, but these emissions can be incorporated if energy use and the associated emission factors are known. There is some overlap between the carbon and nitrogen footprints with respect to N_2O emissions. However, this overlap is not addressed because N_2O makes up a very small part of the nitrogen footprint by weight (Leach et al., 2012), the footprints are calculated and presented separately, and the carbon and nitrogen footprints reflect the distinct scopes of climate change and resource efficiency, respectively (Pelletier and Leip, 2014). Nitrogen footprint factors were collected from Leach et al. (2012).

The water footprint is presented as cubic meters of water used to produce a food product. The methodology used to calculate water footprints has been established by Hoekstra et al. (2011). The water footprint (green + blue) used here is calculated as the crop water use (CWU) divided by the crop yield, where green water is that provided by precipitation and blue water through irrigation. The gray water footprint was not included in this study because it is typically small in comparison to that of blue and green, and the impact of fertilizers is already considered in the nitrogen footprint (Vanham and Bidoglio, 2013; Vanham et al., 2015). CWU can either be estimated empirically or calculated using an appropriate crop model (e.g., the FAO's CROPWAT model; FAO, 2009) and is the summation of the crop's daily evapotranspiration over the growing period. While not included here, evaporative losses during the storage and transport of irrigation water may also contribute substantially to the water footprint of a crop's production and should therefore be included in studies requiring more detailed estimates. A detailed understanding of the crop's production is required as this calculation takes into account numerous factors (e.g., crop type, location, growing season length, monthly precipitation and temperature, wind speed, soil properties) to calculate a crop's evapotranspiration (see Hoekstra et al., 2011, Box 3.8 for a full list of data requirements). For animals and animal products, the water footprint is primarily composed of the crop portion described above for feed production, but also includes drinking water and any water used in processing or cleaning an animal product. Water footprint factors were collected from Mekonnen and Hoekstra (2011, 2012).

2.2. Presenting footprints in a food label

Three calculation methods for presenting food product footprints are shown in this study: footprint weight, sustainability measures, and % daily value (Table 1). Each calculation method produces a footprint measure that can be incorporated into one of the four label designs (see below). These three calculation methods were selected to provide a range of options for presenting the footprints, to show the average impact of different foods as well as to highlight farm-specific sustainability measures, and in response to literature suggesting consumers respond better to labels that give context (e.g., Schmidt, 2009; Sharp and Wheeler, 2013).

Table 1
Three footprint calculation methods and four environmental impact label designs. The table explains how each calculation method and label design can be used together. The labels integrate carbon (C), nitrogen (N), and water (W) footprints.

	Footprint calculation methods		
	Footprint weight *(Mass-based approach)*	Sustainability measures *(% of possible sustainability measures employed)*	% Daily value *(Contribution of food footprints to reference footprint)*
Label designs			
Stars label	• Assign stars to C, N, and W footprints based on pre-determined mass ranges • Average the C, N, and W footprint stars	• Assign stars to C, N, and W footprints based on % of identified sustainability criteria met • Average the C, N, and W footprint stars	• Assign stars to C, N, and W footprints based on a food item's % daily value of a reference footprint • Average the C, N, and W footprint stars
Stoplight label	• Assign stoplight colors to C, N, and W footprints based on pre-determined mass ranges • Present individual footprints and colors	• Assign stoplight colors and rating (low, medium, high) to C, N, and W footprints based on meeting identified sustainability criteria • Present individual footprint rating (low, medium, high) and colors	• Assign stoplight colors to C, N, and W footprints based on a food item's % daily value of a reference footprint • Present individual footprint colors and % DV
Nutrition label add-on	• Report C, N, and W footprint weight	• Report C, N, and W footprint rating (low, medium, or high) based on % of sustainability criteria	• Report C, N, and W % daily value
Detailed comparison label	• Define footprints • Report C, N, and W footprint weight • Compare to footprints within and beyond food category	• Define footprints • Report C, N, and W footprint rating (low, medium, or high) based on % of sustainability criteria • Compare to footprints within and beyond food category	• Define footprints • Report C, N, and W % daily value • Compare to footprints within and beyond food category

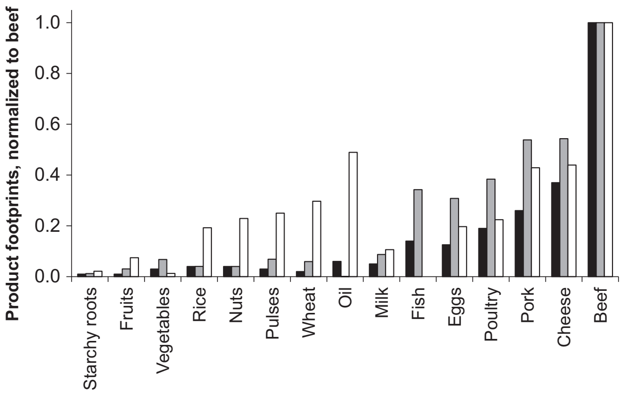

Fig. 1. Carbon footprints (black bars; kg CO_2-eq/kg food), nitrogen footprints (gray bars; g N/kg food), and water footprints (white bars; m^3 water/kg food) for major food categories, normalized to beef for comparison. See Appendix, Table A1 for data sources.

The first calculation method (footprint weight) is a mass-based technique that directly reports the footprint weight for a given product (e.g., 26 kg CO_2-eq per 1 kg beef). This is the most common method used in studies determining a footprint for a product. The footprint for a product is calculated as the weight of the food product multiplied by the appropriate footprint factor (Eq. (1)).

Eq. (1). Footprint weight calculation method. F_w is the footprint calculation as weight, w is the weight of the product, and f is the footprint factor.

$$F_w = w \times f \tag{1}$$

The second calculation method (sustainability measures) indicates how a product was produced. Sustainability measures could be a predefined range of quantitative footprint values that a given product must meet. Or, a set of sustainability practices could be compared to a particular farm's practices. We will focus here on the second option, which uses farm-specific information but does not require footprint calculations. The predefined sustainability measures might include crop rotation, riparian buffers, and rotational grazing. As more of these measures are met by a producer, the product's sustainability rating improves. The footprint for a product is calculated as the sum of sustainability measures that apply at a given farm divided by the total possible sustainability measures (Eq. (2)). Percent sustainability ranges would then be assigned; for example, if a farm employs over 50% of the possible sustainability measures, then they could have a "sustainable" rating. The total number of sustainability measures should be defined by farm type (e.g., crop, livestock).

Eq. (2). Sustainability measures calculation method. F_s is the footprint calculated as the percent of possible sustainability measures.

$$F_s = \frac{\sum \textit{Sustainability measures at farm}}{\sum \textit{All possible sustainability measures}} \tag{2}$$

The third footprint calculation method (% daily value, %DV) determines the percent of a consumer's total daily footprint used in the consumption of a given product. The % daily value is calculated on the basis of a reference (or 'sustainable') daily total footprint. We use the USDA and United States Food and Drug Administration (US FDA) percent daily value concept for daily nutrition requirements and limits (USDA, 2010). The total carbon, nitrogen, and water footprints were determined for a daily healthy diet, described below. The footprint of an individual food product can then be reported as a percent of the daily allotment from the healthy diet. Percent daily value ranges were identified, and the following color scheme was assigned to help classify the impact of a product: green (less than 5% DV), yellow (5–20% DV), and red (20% DV and greater) (see Supplementary Material for further information). A sustainable diet could be determined if sustainable per capita carbon, nitrogen, and water footprints were defined. The footprint a product is calculated as the footprint weight of a given product (see Eq. (1)) divided by the total daily footprint weight associated with a healthy diet (Eq. (3)).

Eq. (3). % Daily Value calculation method. F_{DV} is the footprint as % daily value, F_w is the footprint of a product by weight, and D_w is the total daily footprint weight associated with a healthy diet.

$$F_{DV} = \frac{F_w}{D_w} \tag{3}$$

2.3. Label designs

We present four environmental impact label designs: the stars label, the stoplight label, the nutrition label add-on, and the detailed comparison label. Each of the three footprint calculation methods described above can be used along with each of these four proposed label designs. The four label designs described below increase in complexity and level of detail.

The stars label utilizes a star rating system to describe the sustainability of a product with respect to its carbon, nitrogen, and water footprints. This label combines the three footprints into a single measure as an average of the three. The sustainability rating for the stars label ranges from 0 stars (least sustainable) to 3 stars (most sustainable).

The stoplight label utilizes a stoplight color-coding system and describes each footprint separately. This label displays one of the three footprint calculation methods. The color used to represent each footprint is based on a pre-determined range with green representing a small footprint, yellow an intermediate footprint, and red a large footprint (see Supplementary Material for more information).

The nutrition label add-on is an addition to the existing food nutrition label, with a section added to display one of the three footprint calculation methods described above. The %DV footprint could be seamlessly integrated into the US FDA nutrition label, which already provides nutrition information as %DV. In Europe, where nutrition information is given as mass per 100 g or 100 ml of product, the weight footprint calculation method would be easier to integrate. The nutrition label add-on design provides information about the product related to its environmental impact in the same location consumers would look to for dietary information.

Lastly, the fourth label design (the detailed comparison label) provides the most information about a product's footprints with additional comparisons to other food and non-food products and services. For each product, the carbon, nitrogen, and water footprints are provided. The product footprint is then compared both to other similar food products (e.g., chicken vs. beef) as well as to other unrelated products or activities which serve to put the footprint values into perspective for the average consumer (e.g., describing a product's carbon footprint in terms of distance driven).

2.4. Calculation method examples and label designs

We present an example of each of the three calculation methods. We show all four label designs using calculation method 3: percent daily value. This calculation method was selected for the label designs because it provides the footprint information to consumers in a format that shows relative comparisons across and within food product categories. However, it should be noted that the four label designs can be developed using each of the three calculation methods. See the Supplementary Material for further details on the calculation and results of the USDA healthy diet and percent daily value calculations.

3. Results and Discussion

3.1. Footprint factors

Carbon, nitrogen, and water footprint values per kg product were compiled from the literature and are presented for wheat, rice, fruits, pulses, starchy roots, vegetables, nuts, oil, eggs, milk, cheese, fish/seafood, chicken, pork, and beef (Fig. 1, Appendix Table A1). These values were used to calculate each of the three footprints per 1000 kcal and per kg protein. In most cases, the footprints were greatest for meat products. Beef had the largest carbon, nitrogen, and water footprints per kg product while starchy roots had the smallest carbon footprint, oil had the smallest nitrogen footprint, and vegetables had the smallest water footprint. In some instances, the calculated footprint in terms of 1000 kcal or kg protein was high for products with low protein or caloric contents (see Appendix, Table A1). For example, the footprint factors for vegetables and fruits per kg protein are much higher than the per kg product factors due to the very low protein content of vegetables and fruits (Pierer et al., 2014). The ranking of products for each of the three footprints varied (Fig. 1), indicating that while one product may appear favorable in terms of one footprint, it may appear less sustainable with respect to the two other footprints. For example, oil has the smallest nitrogen footprint but one of the largest water footprints. With tradeoffs among footprints, an integrated and comprehensive label is important to help inform consumers when making a product decision. A more complete environmental impact food label should also include animal welfare (when relevant), fair trade, land use, pesticides, biodiversity, waste, and other sustainability indicators.

3.2. Presenting footprints in a food label

The proposed footprint calculations and label designs provide a range of options regarding the amount and types of information presented to consumers. Different labels could be more useful for a particular product audience, but for wider use and consistency, a single labeling scheme would be preferable. The labels shown in this study are simply representative of possible designs. Label components can be combined or used interchangeably. For example, the stoplight label's coloring system may be applied to all four label designs, provided that color boundaries are well-defined. It is feasible to incorporate product comparisons on all four labels, as this feature may greatly aid consumer decision-making (e.g., Schmidt, 2009; Sharp and Wheeler, 2013). Label developers should carefully consider the most effective type of information and method of communication to reach their target consumers.

The footprint weight calculation method provides information to consumers in the most direct form (Table 2). However, consumers must then interpret what the footprint weight means. Without any context or comparisons, most consumers will not know, for example, the impact of 1 kg of CO_2-eq on the environment. Comparisons within and across food products are clear with this calculation method. However, the units for the carbon (CO_2-eq), nitrogen (weight of reactive N), and water (m^3 water) footprints are distinct and limit the ability to compare across footprints in their typical units. This method groups food products together and therefore does not consider the effects of any sustainable farming practices implemented by a specific producer.

The sustainability measures calculation method requires that clear and comprehensive sustainability criteria be defined (Tonsor and Shupp, 2009). The major strength of this approach is that it gives farmers credit for specific practices employed to reduce environmental impacts. This label is therefore effective for comparing within food categories. However, comparisons across food product categories for a product's overall environmental impact could be confusing because this label is based on specific farming practices rather than quantified environmental impacts. This means that a product with a large nitrogen footprint could have a better sustainability rating than a product with a small nitrogen footprint due to the number of sustainability initiatives implemented at the farms. However, as mentioned above, a labeling system combining quantitative and qualitative criteria could be developed to increase the accuracy of the message that the label conveys to the consumer.

The % daily value calculation method is a quantitative approach that translates the footprint weight into a form that helps provide context to users. To have a more sustainable diet, consumers are encouraged to stay below (not meet or exceed) the 100% daily value for each footprint. This approach gives consumers a sense of the magnitude of a given product's footprint within the scope of a healthy/sustainable daily footprint. The diet used for demonstration purposes in this paper is not necessarily a sustainable diet; it is a healthy diet recommended by the USDA (Fig. 2). A healthy diet was used rather than a sustainable diet because a sustainable diet has not yet been clearly defined (Garnett, 2014; Tilman and Clark, 2014; Vanham et al., 2013; Westhoek et al., 2014). For this calculation method to be more effective, an average or optimum sustainable diet should be defined and used as a reference daily footprint. Alternatively, the reference footprint values could be derived from global (or regional) planetary boundary considerations (de Vries et al., 2013; Rockström et al., 2009; Steffen et al., 2015). These would provide independent estimates of maximum daily footprints per person. However, using a reference footprint based solely on planetary boundary considerations could yield a diet that does not meet minimum nutritional requirements. The healthy diet is a reasonable approximation to use for now because any recommended diet must also meet human nutritional needs, but it could be refined in the future to better link to planetary

Table 2
Comparing three footprint calculation methods: (1) footprint weight, (2) sustainability measures, and (3) % daily value.

	(1) Footprint weight	(2) Sustainability measures	(3) % daily value
Data type	Quantitative	Qualitative	Quantitative
Units	• kg CO_2-eq • Grams reactive N • m^3 water	% of possible sustainability measures	% daily value
Comparisons within food category?	Yes	No	Yes
Comparisons across food categories?	Yes	No	Yes
Farm-specific?	Not typically	Yes	Not typically
Provides context for footprint?	No	Yes	Yes
User-friendliness	Low	High	Medium

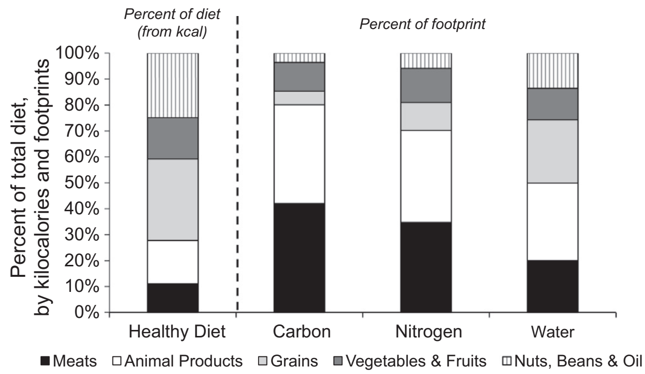

Fig. 2. Healthy diet components by food group: Contribution of each food group to a healthy diet (on a kilocalorie basis) and to the total daily allotments for the three footprints (carbon, nitrogen, and water). Daily footprint allotments are calculated using the healthy diet components (see Supplementary Material) and the respective footprint factors by food group (see Supplementary Material, Table S3).

boundaries. Similar to the footprint weight calculation method, the % daily value method also groups food products together and therefore does not give individual farmers credit for sustainability practices.

3.3. Label designs

The four label designs presented in this paper are given as examples of how environmental impact food labels could be designed (Fig. 3). They provide a range of detail and context for consumers. These labels are also easily modified and may be changed to include more or less detail, depending on the prospective audience and the goals of the retailer.

The stars label is the simplest label design. It presents an average sustainability rating, which can range from 0 stars (least sustainable) to 3 stars (most sustainable). Both a benefit and drawback of this label is that it combines the carbon, nitrogen, and water footprints into a single label. This label is the easiest to understand, but it does not give consumers information on specific environmental impacts. This label is better at comparing across food categories than within food categories due to the label's relatively low resolution (e.g., 0–3 stars).

The stoplight label shows each of the three footprints and color-codes each of the footprints based on its sustainability rating or value range. This label allows consumers interested in a particular environmental impact (e.g., climate change) to see the related footprint. The color scheme aids in presenting the information in a user-friendly format. Despite this, the level of detail may still be too complex due to the amount of information presented. This label allows users to compare across and within food product categories when additional information (e.g., % daily value) is included on the label.

The nutrition label add-on attaches the footprint results to the existing US FDA food nutrition label. To be consistent with the food nutrition label, the % daily value calculation can be used; however the other calculation methods (footprint weight, sustainability measures) could also be used. This approach allows consumers to compare within and across food categories when a quantitative calculation method is used. Incorporating the footprint label into existing nutrition labels reduces the number of labels on a food product. It also provides the footprint information in a setting and context that is already familiar to many consumers. Given the infrequent updates to the food nutrition label and the formal steps required for any changes, it is unlikely that this approach would be feasible in the short term. However, if a clear need for environmental impact food labels is demonstrated, then this update to the existing national food nutrition label could be proposed in the next round of updates.

The detailed comparison label translates each of the three footprints into more familiar metrics, which could help improve consumer understanding of the magnitude of the food product's impact on the environment. For example, the carbon footprint weight can be translated into the emissions associated with driving a certain distance. In addition, this label shows the footprints of similar food products (e.g., other meat products) to show how a given product compares and to help consumers choose a comparable product with a lower environmental impact. This design was developed due to indications in the literature that consumers are more likely to change food purchases if the environmental impacts are put into context and clearly communicated (e.g., Schmidt, 2009; Sharp and Wheeler, 2013). This label displays very detailed information that could make it difficult for consumers to understand. Graphics would help improve this label.

On any of these proposed label designs, a QR code could be incorporated. QR codes could link to a website that provides more detailed information about a food product and background information on the methods and criteria applied. QR codes could even allow a consumer to add a food product to a virtual shopping cart that would then calculate that consumer's footprints for all products purchased.

The type of calculation method and label design selected should consider consumer goals. For example, is the consumer going to the store to buy a specific product such as chicken? If so, then an approach that considers sustainable farming practices and compares within a given food product category would be most effective. Or, is the consumer trying to reduce the overall environmental impact associated with their purchases? If so, then a quantitative label that compares across food products would be more useful.

3.4. Putting labels into practice

Environmental impact food labels can be put into practice through a variety of avenues, including by a government, a certification organization, a food provider, a grocery store, or an individual producer.

At the government level, an environmental impact food label could be incorporated into existing nutrition food labels. The nutrition label add-on design shows how environmental footprints could be appended to the US FDA nutrition food label. Establishing a national environmental impact food label would require the development of a consistent set of standards that has to pass several official bodies, depending on the scope and level of detail. If comparisons are to be made between food product groups, a large database of environmental impact factors calculated using consistent methods would be sufficient. This would likely require further research beyond currently available environmental impact footprint factors—especially if farmers were to be given "credit" for sustainability practices. Comparisons between different brands, products, and regional suppliers would require the collection of quantitative data from farms. Confirmation and certification of the calculation process and resulting factors would also be necessary to establish consumer confidence. This approach would be difficult, expensive, and time-consuming to implement on such a broad scale. However, instituting environmental impact food labels at the national level would ensure broad dissemination and impact.

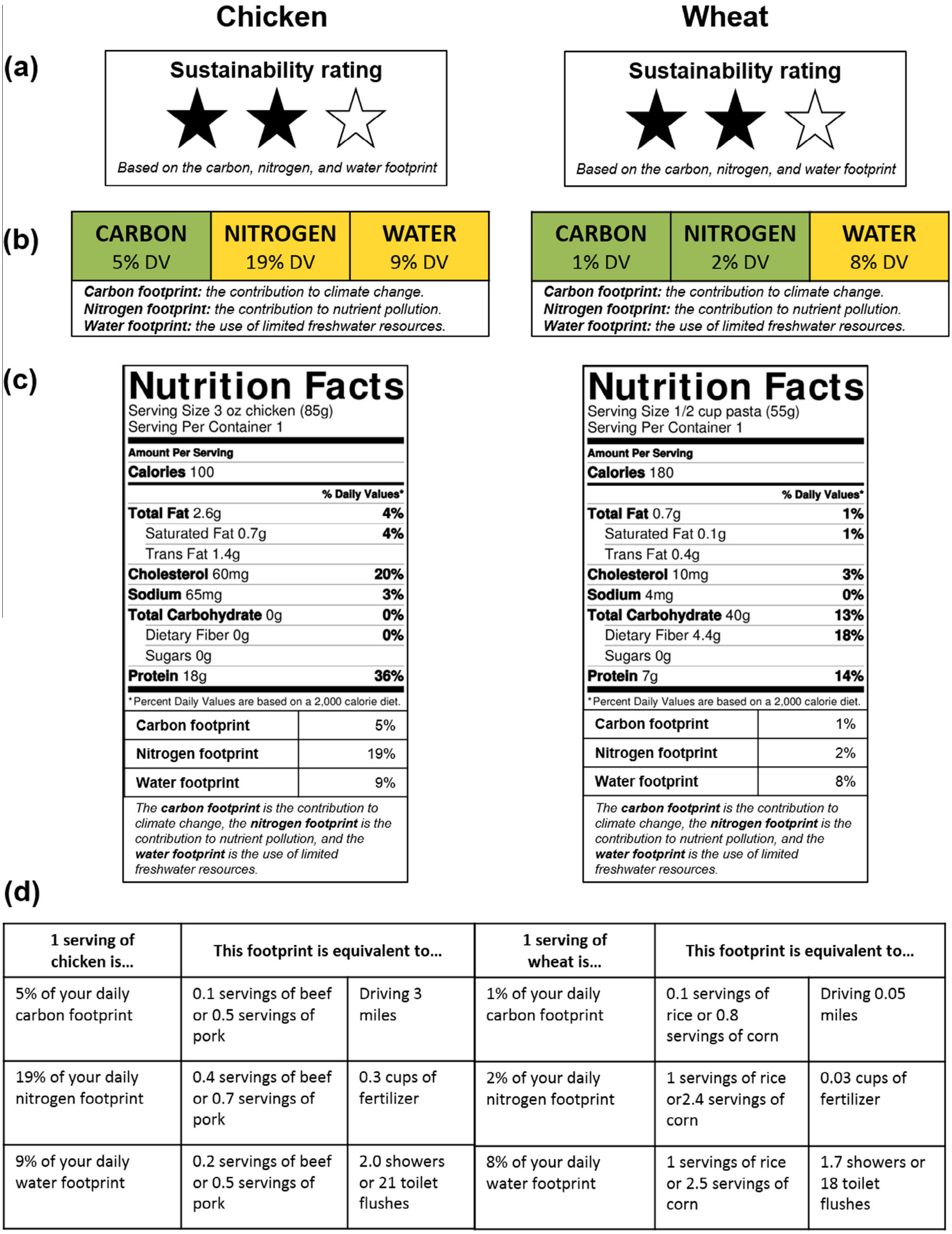

Fig. 3. Four proposed environmental impact food label designs showing the carbon, nitrogen, and water footprints of chicken and wheat. The three designs are: (a) stars label, (b) stoplight label, (c) US FDA nutrition label add-on, and (d) detailed comparison label. The % daily value calculation method was used for all label designs in this demonstration, but other calculation methods could be used.

Certification organizations (e.g., the European Union, USDA) are responsible for developing, implementing, and overseeing the organic food label. Official certification institutes deal with compliance. This design could be a structure for an environmental impact food label. Criteria for the environmental impact label (e.g., the use of footprints) could be officially set by a government and then implemented by independent organizations, the grocery stores, or individual producers. Because such a method would require the establishment of official standards for compliance, this approach would also be difficult, expensive, and time-consuming to implement.

A national food provider or grocery store chain could also accomplish large-scale implementation of environmental impact food labels that could cover a broad range of products, brands, and food production methods. Similar to implementation at a government level, this approach would also be expensive and would likely require additional research and the establishment of large databases. Labeling at this scale would require retailers to provide consistent labeling for all products (Nilsson et al., 2006). Whether or not companies decide on such investments depends on customers' 'willingness to pay' for products with a higher sustainability score. This in turn depends largely on the societal awareness of these issues and the availability of data and tools to effectively communicate these topics (Galloway et al., 2014; Leach et al., 2012; Leip et al., 2014b). The UK-based grocery store Tesco did implement a carbon footprint labeling system that was ultimately discontinued due to the amount of work required (Tan et al., 2012). However, other national food providers and grocery stores, such as Walmart and Whole Foods, are currently developing broad environmental impact food labels (see respective websites).

Small grocery stores have a more limited product list, which could make implementing an environmental impact food label more feasible. Grocery stores with a consumer base already interested in sustainability could especially benefit from such a program. In addition, grocery stores that partner with local producers could develop labels that specifically reflect the local producers' sustainability practices. At this level, there would likely be less certification and new research necessary, which could make this approach less time-intensive and less expensive.

Finally, environmental impact food labels could be used by individual producers. The producers that would most benefit would be farmers using sustainability practices and who have a consumer base interested in the environmental impact of their food purchases. Using a footprint label could help producers attract new customers. However, research or new calculations would be necessary to determine an individual farm's footprint factors. In addition, certification and quality assurance could be more limited at this individual level.

Regardless of the implementation level, labels must use consistent methods in terms of the system boundaries included, parameters used in calculations, and how impact is divided among processed products (e.g. economic versus mass allocation). Consistent methods are essential to allow comparisons among food products within an impact category.

Before the labels could be put into practice, the readability and uniform presentation of each of the labels would need to be considered. For example, the detailed comparison label would be too large to appear on smaller packages, and a scaled version of this label would likely be necessary. One advantage of the stars label is its simple design and readability, which would be immediately usable across a range of product sizes.

3.5. Other applications

An integrated environmental footprint label has a range of further applications, especially if put into practice by one or more of the abovementioned entities. In our study we analyzed the footprints of primary product groups with just one ingredient (e.g., beef, rice). The footprints of multi-ingredient products could be calculated by combining the footprints of the multiple ingredients involved in production and accounting for additional processing (Huang et al., 2014; Jensen and Arlbjørn, 2014; Pirog and Benjamin, 2005). The number of ingredients and the complexity of the production method are the primary constraints on determining the footprints of a multi-ingredient product. Other sustainability indicators could be incorporated into the food labels presented in this study, such as the ecological footprint (Rees, 1992; Wackernagel and Rees, 1996) or other similar indicators of sustainability (Čuček et al., 2012). The concept of using integrated environmental footprint labels can be expanded to non-food items. An environmental footprint label could be developed for any item produced and sold in retail stores, such as electronics, clothing, and furniture as demonstrated for carbon by Berners-Lee (2010).

4. Conclusions

Environmental impact food labels can help consumers compare across and within food product types and make more sustainable and environmentally-conscious decisions. We proposed three footprint calculation methods and four food label designs that integrate carbon, nitrogen, and water footprints. The labels vary in both design and the amount of detail presented. The purpose of this paper was not to identify the best label, but rather to provide options that include multiple environmental impacts. Regardless of the label selected, an environmental impact labeling strategy will be more effective if a single, integrated label is used across a broad range of food products and retailers. The incorporation of footprint labels onto food products could both increase public awareness of the environmental impacts associated with food production as well as support producers who provide sustainable products.

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Appendix A

See Table A.1.

Table A.1
Carbon, nitrogen, and water footprint factors for major food categories reported per kg product, per 1000 kcal, and per kg protein. References for original footprint factors (per kg product) denoted with superscript letters.

	Carbon			Nitrogen			Water		
	kg CO_2-eq/kg product[a]	kg CO_2-eq/ 1000 kcal[*]	kg CO_2-eq/ kg protein[*]	g N lost/kg product[b]	g N lost/ 1000 kcal[*]	g N lost/kg protein[*]	m^3/kg product[c]	m^3/ 1000 kcal[*]	m^3/kg protein[*]
Vegetable products									
Wheat	0.58	0.1	3.5	13.9	3.7	112	2.0	0.5	15.8
Rice	1.14	0.8	35.7	9.4	2.6	112	1.3	0.4	15.1
Fruits	0.36	0.7	59.7	7.1	12.4	1056	0.5	0.9	73.1
Pulses	0.78	0.1	1.6	16.1	4.4	64	1.7	0.5	6.6
Starchy roots	0.21	0.2	7.7	2.8	3.7	128	0.1	0.2	6.4
Vegetables	0.73	5.8	138.6	15.8	44.1	1056	0.1	0.2	5.6
Nuts	1.17	0.4	13.7	9.3	1.8	64	1.5	0.3	10.4
Oil	1.63	0.6	0.0	0.0	0.0	0	3.2	0.4	0.0
Animal products									
Poultry	5.05	1.2	6.7	89.8	74.8	432	1.5	1.2	7.1
Pork	6.87	2.1	13.3	126.0	94.0	608	2.8	2.1	13.7
Beef	26.45	11.4	78.9	234.0	160.1	1104	6.6	4.5	31.1
Milk	1.34	2.6	36.7	20.4	40.9	576	0.7	1.4	19.8
Cheese	9.78	2.3	36.2	127.1	36.7	576	2.9	0.8	13.1
Eggs	3.54	1.4	17.7	72.1	49.7	608	1.3	0.9	11.0
Fish	3.83	1.9	11.2	80.1	72.0	416	X[**]	X[**]	X[**]

[a] Heller and Keoleian (2014).
[b] Updated from Leach et al. (2012).
[c] Mekonnen and Hoekstra (2011, 2012).
[*] Conversion factors derived from the U.S. Department of Agriculture National Nutrient Database for Standard Reference were used to convert footprint factors from per kg product to per 1000 kcal and per kg protein; see Supplementary Material.
[**] Data unavailable.

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodpol.2016.03.006.

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