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An Integrated Tool for Calculating and Reducing Institution Carbon and Nitrogen Footprints

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Abstract

The development of nitrogen footprint tools has allowed a range of entities to calculate and reduce their contribution to nitrogen pollution, but these tools represent just one aspect of environmental pollution. For example, institutions have been calculating their carbon footprints to track and manage their greenhouse gas emissions for over a decade. This article introduces an integrated tool that institutions can use to calculate, track, and manage their nitrogen and carbon footprints together. It presents the methodology for the combined tool, describes several metrics for comparing institution nitrogen and carbon footprint results, and discusses management strategies that reduce both the nitrogen and carbon footprints. The data requirements for the two tools overlap substantially, although integrating the two tools does necessitate the calculation of the carbon footprint of food. Comparison results for five institutions suggest that the institution nitrogen and carbon footprints correlate strongly, especially in the utilities and food sectors. Scenario analyses indicate benefits to both footprints from a range of utilities and food footprint reduction strategies. Integrating these two footprints into a single tool will account for a broader range of environmental impacts, reduce data entry and analysis, and promote integrated management of institutional sustainability.

Keywords: carbon footprint; energy; food; indicator; nitrogen footprint; sustainability

Introduction

Institutions of higher education provide an ideal setting to measure, analyze, and improve sustainability performance. They have the potential to make significant improvements to their sustainability given the span and impact of their overall activities and their ability to make management decisions both from the top-down (i.e., by the administration) and bottom-up (i.e., through student initiatives). Institutions of higher learning can also be used as a learning laboratory both to test sustainability strategies and to educate large populations of students about the importance of managing and reducing their environmental impact.

The interest and potential for institutions of higher education to lead in sustainability initiatives has been demonstrated by the success of the Campus Carbon Calculator™, a carbon footprint tool for institutions to track and manage their carbon footprint.[1] More than 90 percent of the colleges and universities that report their carbon footprint for the Second Nature Carbon Commitment (formerly known as the American College & University Presidents' Climate Commitment) use the Campus Carbon Calculator™.

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Integrating Environmental Footprints

Multiple footprints have been established to calculate a consumer's contribution to environmental pollution, such as the ecological footprint,[2] carbon footprint,[3] water footprint,[4] and nitrogen footprint.[5] The many footprints can be confusing to consumers, which has prompted a new interest in tools that combine footprints.[6,7]

The only environmental footprint tool currently available to institutions is for the carbon footprint. An institution-level nitrogen footprint tool has been developed, piloted, and tested by participants in a project of the Nitrogen Footprint Tool Network,[8,9] but adding a second separate footprint tracking tool would be cumbersome for institutions and would not capture any potential synergies and trade-offs between footprint management strategies. Therefore, the overarching goal of this article is to present a new integrated carbon and nitrogen footprint tool for institution-level sustainability management. These footprints were selected because they represent two important areas of environmental concern and they are the two environmental footprints for which institution-level footprint tools are already available.

Nitrogen Footprint

A nitrogen (N) footprint is a measurement of the amount of reactive nitrogen (all species of N except N_2) released to the environment as a result of an entity's resource consumption (e.g., food, utilities, transit).[5] Although it is necessary for food production and to support life, excess reactive nitrogen can cause a cascade of detrimental impacts to ecosystem and human health.[10,11] The N footprint aims to reduce the loss of reactive nitrogen through both education and the elucidation of possible management scenarios for reducing reactive nitrogen losses.

The N footprint methodology was first developed at the consumer level for the United States and the Netherlands.[5] The tool has since been applied in the United Kingdom, Germany, Austria, Japan, Australia, and Tanzania and is in development for Denmark, China, Portugal, and Taiwan.[12] A nitrogen footprint tool was then developed for a different type of entity: an institution.[8] First developed and applied at the University of Virginia, the tool accounts for nitrogen losses associated with food purchases, utilities usage, transport, fertilizer application, research animals, and agricultural activities. The N footprint includes the different forms of reactive nitrogen released from institution activities (e.g., NO_x, N_2O, total N), which are converted to and reported as the total weight of reactive nitrogen.

Carbon Footprint

The carbon (C) footprint is based on the total greenhouse gas emissions associated with a product, service, or other entity.[3,13] The C footprint typically includes the six major greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).[6] These greenhouse gases are reported together based on their global warming potential in units of carbon dioxide equivalents (CO_2e). Major sectors that emit greenhouse gases (GHG) include fossil fuel combustion, land conversion, livestock production, and crop production.[14]

The Campus Carbon Calculator™ is an institution-level C footprint tool that has been used by thousands of institutions worldwide and is the standard tool for managing institution GHG emissions in the United States.[1] The tool was originally developed in 2001 in a partnership between the University of New Hampshire Sustainability Institute and the private nonprofit Clean Air-Cool Planet (CACP). Following established best practices for carbon accounting, the C footprint is reported in three categories of scopes, which reflect how institutional decisions are capable of directly influencing carbon emissions. (See Table 1 in the Results/Discussion section for more information on scopes.)[15]

Objectives

This article presents a newly developed integrated tool that allows institutions to track and manage their carbon and nitrogen footprints together. To be released later in 2017, this tool combines the institution-level Nitrogen Footprint Tool[8] and the University of New Hampshire Sustainability Institute Carbon Management and Analysis Platform, an online platform that uses the Campus Carbon Calculator™ methodology (www.campuscarbon.com). Combining these two tools expands the ability of institutions to account for a wider range of environmental impacts.

This article presents the integrated nitrogen and carbon footprint tool for institutions; compares the nitrogen and carbon footprints of five institutions by several metrics; and identifies reduction strategies that will reduce both the nitrogen and carbon footprints.

Methods

Integrating the Nitrogen and Carbon Footprints

Combining the distinct institution-level nitrogen and carbon footprint tools requires four phases: 1.) comparing data requirements and addressing gaps, 2.) integrating the calculations, 3.) identifying how to report the results, and 4.) incorporating projections and management scenarios. The first three will be complete when the first version of the integrated tool is launched in 2017, and projections and scenarios will be incorporated in a future version of the tool. The Nitrogen Footprint Tool is being built into the existing web-based interface for the Campus Carbon Calculator™, currently called CarbonMAP.

Comparing Data Requirements

The sectors included in the carbon and nitrogen footprint calculations were compared, and any differences in the sectors were identified. For example, the sector refrigerants is part of the C footprint but not the N footprint. All sectors in each standalone footprint tool are included in the integrated tool. For any sector that was in one tool but not the other, a review was conducted to determine if that sector should be added to the other footprint tool. For example, refrigerants have a negligible nitrogen footprint so were not added to the Nitrogen Footprint Tool.

Integrating the Calculations

The methods and equations for the two footprints were aligned for consistency and comparability in the integrated tool. The calculations were aligned by first ensuring that the data input describing resource consumption (e.g., the amount of fuel consumed) was the same for the two footprints. Any conversions necessary to calculate the total resource consumption (e.g., assumptions about commuting) were also kept consistent. For most sectors, the only difference in the two footprint calculations is the emissions factors used (e.g., for utilities, transportation). However, the calculations for the carbon and nitrogen footprint do diverge for food consumption and food production because of the different pathways through which greenhouse gases and nitrogen pollution are released from these sectors. Equations for calculating the carbon and nitrogen footprints for on-site stationary combustion, public transit, purchased electricity, food production, and food consumption/wastewater are given in the Supplementary Material, which may be found online at www.liebertpub.com/sus. Complete documentation for the carbon and nitrogen footprints can be found in the user's guide for each tool.[8,16,17]

The food sector will be added to the C footprint using the N footprint methods for estimating the weight of food purchases.[8,16] Briefly, the food weights are calculated using purchase records for an entire year or for a subset of the year or locations and then scaled. Food weights can be scaled based on the percent of purchases or percent of weight represented in the subset of data. Each food product is placed in a food category based on up to three ingredients, and the weight is distributed evenly across those ingredients. Guidance for assigning food categories is provided in the Nitrogen Footprint User's Manual.[16] The carbon and nitrogen footprint calculations differ for both food production and food consumption. For food production, the C footprint is calculated by multiplying a weight of food by a greenhouse gas emissions factor,[18] whereas the N footprint has several components that are summed: virtual nitrogen (calculated by multiplying the weight of food N by a virtual N factor[5]), wasted food nitrogen, and transport emissions. For food consumption/wastewater, the C footprint is calculated by multiplying the volume of wastewater processed by a greenhouse gas emissions factor for a given wastewater treatment system, whereas the N footprint calculation multiplies the amount of food nitrogen consumed (which ultimately enters the sewage stream) by one minus the nitrogen removal rate at the local wastewater treatment facility. (See the Supplementary Material, Table S1 and Equations 5-8 for more information about the food calculations, which may be found online at www.liebertpub.com/sus.)

Identifying How to Report the Results

Because the two footprints mostly represent different environmental impacts, the footprints will be reported separately as the C footprint (units of metric tons CO_2e) and the N footprint (units of metric tons of N). It should be noted that there is one area of overlap: Nitrous oxide (N_2O) is both a greenhouse gas and a part of the N footprint. However, nitrous oxide is included in both footprints because of its contribution to the nitrogen cascade (e.g., global warming, stratospheric ozone depletion)[10] and because the two footprints are not additive and are presented separately. The geographic scale for the two footprints also differs. Greenhouse gas emis-

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sions are well mixed and contribute to global climate effects regardless of where they are emitted. Nitrogen losses can have a range of effects, from local to global, depending on the type of nitrogen released.

The carbon and nitrogen footprints are each reported on a total basis, on a per capita basis, by sector, and by scope. The results are reported as the total C footprint and total N footprint. The per capita C footprint and per capita N footprint are reported to normalize the data to each institution's population. The per capita footprints are calculated using full-time equivalents (FTE), which consider how often different populations (e.g., part-time students, full-time students, faculty, staff) are at the institution. The footprints are also presented by sector (food consumption/wastewater, food production, utilities, transport, and research and agriculture) and by scope (scope 1, 2, 3). (For more information, see Table S2 in Supplementary Material, which may be found online at www.liebertpub.com/sus.) Scope 1 includes on-site stationary combustion, fleet vehicles, and research animals; scope 2 is purchased electricity; and scope 3 includes commuting, air travel, food production, wastewater, and feed for research animals.[15] In the integrated online tool, additional comparison and normalization metrics (e.g., per gross square footage) are also available.

Comparing Preliminary Footprint Results

Although the Campus Carbon Calculator™ has been used by thousands of institutions, the Nitrogen Footprint Tool has been pilot tested by 20 institutions. Results for the carbon and nitrogen footprints are presented as a case study here for the following five institutions: Eastern Mennonite University, Dickinson College, University of New Hampshire, Colorado State University, and University of Virginia. Nitrogen footprint results were obtained from Castner et al.,[9] and carbon footprint results were obtained directly from each institution. Additional offsets (e.g., purchased Renewable Energy Credits) and non-additional offsets (e.g., sold Renewable Energy Credits) were not included in this comparison so that the sources and emissions for the carbon and nitrogen footprints could be directly compared. The calculation year is fiscal year 2014.

The total footprints were compared by sector and by scope. The footprints were also compared on a per capita basis for the total footprint, on a per capita basis by sector (utilities), and the footprint per kilogram of food purchased (food). Additional comparison metrics for the N footprint are explored in Castner et al.[19] Linear regressions between the carbon and nitrogen footprints are used to show how the two footprints relate at the institution scale, and *p* values are presented to determine if correlations are significant.

Identifying Integrated Management Strategies

The effect of management strategies on the carbon and nitrogen footprints were explored for the five institutions and are presented as case studies in this article. The management strategies analyzed were energy scenarios (purchase 25% renewable energy, improve energy efficiency by 10%, and replace all purchased electricity with renewables) and food scenarios (replace 25% of beef purchases with chicken, replace 25% of meat protein with vegetable protein, and reduce food waste by 25%). These scenarios do not include projections of changes in population because they aim to show the direct effect of specific changes in practices. However, when institutions are setting carbon and nitrogen footprint reduction goals, projections must be included.

Results and Discussion

Integrating the Nitrogen and Carbon Footprints

A review of the data inputs required for the existing carbon and nitrogen footprints identified substantial overlap in the utilities and transport sectors (Table 1). (Also see Table S3 for a complete list of data inputs, which may be found in the Supplementary Material online at www.liebertpub.com/sus.) In these sectors, the C footprint incorporates more options (e.g., more fuel types), and the N footprint is being expanded to fill in these gaps. The C footprint does not currently include a major sector of the nitrogen footprint: food. As part of this integration, the C footprint of food will be incorporated into the combined carbon and nitrogen footprint tool.

Comparing Preliminary Footprint Results

The size of the total carbon and nitrogen footprints, which range from 6,560 to 337,000 metric tons CO_2e and 11 to 444 metric tons N per year, are likely driven by the institutions' populations (Figure 1A, 1C). When footprints are compared on a per capita basis, the effects of different practices begin to emerge (Figure 1B, 1D). Across the carbon and nitrogen footprints, the two largest sectors are food and utilities. Food production makes up the largest proportion of total institution N footprints (34-78%) while it makes up a smaller proportion of total C footprints (2-17%). On the other hand, utilities are the largest contributor to the total C footprint (41-83%) and typically a smaller contributor to the total N footprint (8-52%).

The food production carbon and nitrogen footprints are driven by the types and amounts of food purchased by an institution. For example, Dickinson College has larger food footprints because nearly all students eat most meals on campus and the campus hosts summer programs that include meals in its dining services, which is not the case for the other universities in the comparison. The utilities footprints differ across institutions based on the total energy consumption and the types of fuel used. For example, the University of New Hampshire has small utilities carbon and nitrogen footprints because its energy is derived from an on-campus cogeneration facility that uses processed methane generated at the local landfill. The University of Virginia has a larger utilities footprint because its campus includes a hospital and because most of its electricity is purchased and the electricity fuel mix has a high percentage of coal.[8]

Carbon and nitrogen footprint results can also be presented by scopes, which describe how directly emissions are related to institution activities (scope 1 is the most direct; scope 3 is the least; see Figure 2). Both scope 1 and 2 contribute a large proportion of the C footprint, whereas the largest scope for the total N footprint is typically scope 3 (43-88%). This means that most carbon emissions that are currently

Table 1. A Summary Comparison of the Data Requirements for the Campus Carbon Calculator™ and Nitrogen Footprint Tool, by Scope

Scope	Data category	Carbon footprint	Nitrogen footprint
Scope 1	On-campus stationary sources	Yes	Yes[a]
	Direct transportation sources	Yes	Yes[a]
	Refrigerants & chemicals	Yes	No
	Agriculture sources	Yes[b]	Yes[b]
Scope 2	Electricity, steam, chilled water	Yes	Yes
Scope 3	Commuting	Yes	Yes[a]
	Directly financed outsourced travel; study abroad; student travel to/from home	Yes	Yes
	Solid waste	Yes	To be added
	Wastewater	Yes	Yes
	Paper	Yes	To be added
	Food purchases	To be added	Yes
Offsets	Offsets with additionality	Yes	Yes[c]
	Non-additional Renewable Energy Certificates (RECs)	Yes	To be added

[a]Additional fuel types will be added for the nitrogen footprint.
[b]Animal types will be added for the carbon footprint (research animals) and nitrogen footprint (research farms).
[c]Additional offsets may be added for the nitrogen footprint.

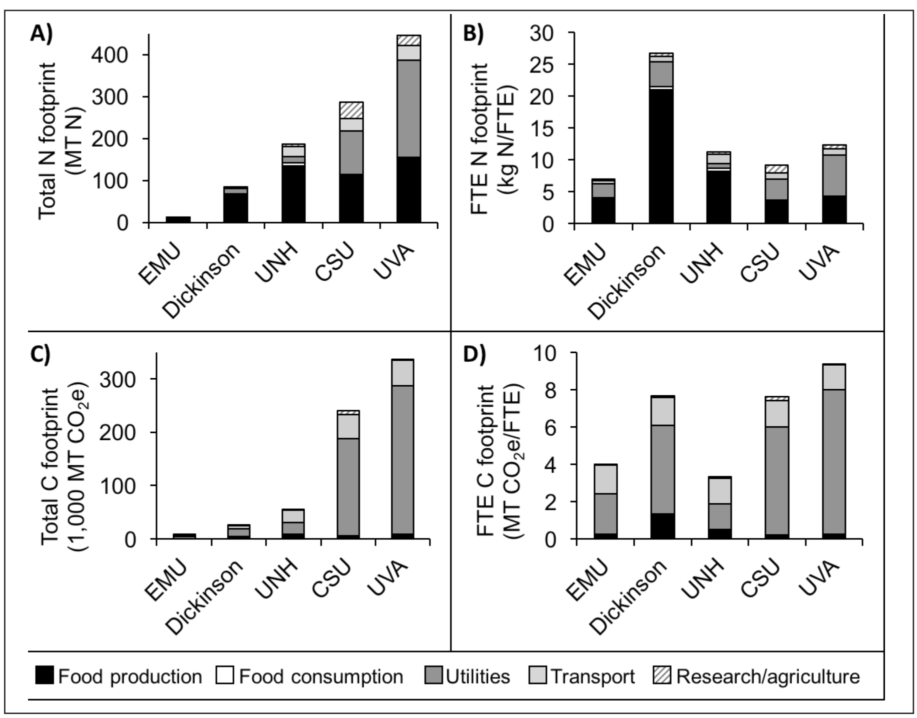

Figure 1. Institution nitrogen (N) and carbon (C) footprints by sector, shown as: **A**) the total institution N footprint, **B**) the N footprint per full-time equivalent population (FTE), **C**) the total institution C footprint, and **D**) the C footprint per FTE. Footprints are shown for: Eastern Mennonite University (EMU, population 1,648), Dickinson College (population 3,174), University of New Hampshire (UNH, population 16,548), Colorado State University (CSU, population 31,409), and University of Virginia (UVA, population 35,894).

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tracked occur closer to the institution, while most nitrogen losses occur elsewhere. Greenhouse gas emissions contribute to the global greenhouse effect regardless of where they are emitted. Conversely, nitrogen losses have more local pollution effects for most forms of nitrogen, such as local water quality and air quality effects. Given this, institutions may consider implementing two N footprint reduction goals: a goal for scope 1 (with a focus on local N pollution) and a goal for the overall N footprint. Many of the benefits from an overall nitrogen reduction goal could occur in ecosystems far removed from the institution itself, but those environmental impacts are still the responsibility of the institution.

The carbon and nitrogen footprint results of the five institutions were compared (Figure 3). The total carbon and nitrogen footprints correlate strongly ($R^2 = 0.92$, p value = 0.009; Figure 3A), which suggests they may have similar drivers. Regressions comparing each of the total footprints to gross square footage for each campus found a significant correlation ($R^2 > 0.95$, p value < 0.005), suggesting that institution size is a driving factor for the total carbon and nitrogen footprints (regressions not shown). However, the comparison of per capita carbon and nitrogen footprints was not significant ($R^2 = 0.14$, p value = 0.5; Figure 3B), likely due to differences in sector-specific institution activities. For example, Dickinson has a large food N footprint because 94 percent of students have meal plans, and a moderate per capita C footprint. On the other hand, UVA has a large C footprint due to its research facilities and fuel mix, and a moderate N footprint. Due to the differences in institution activities,

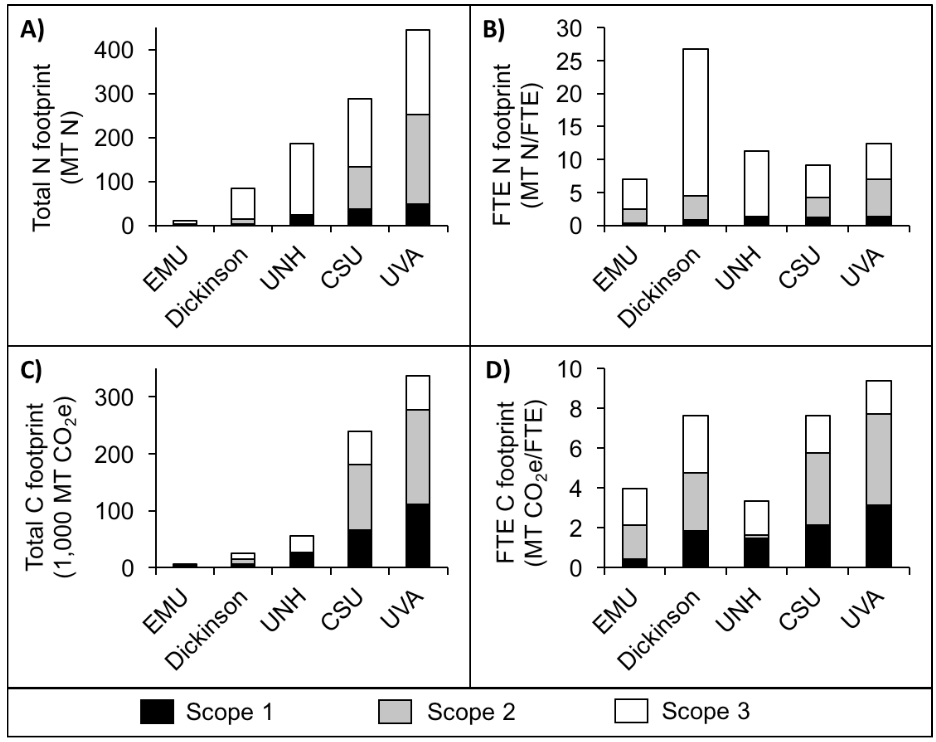

Figure 2. Institution nitrogen (N) and carbon (C) footprints by scope, shown as: **A**) the total institution N footprint, **B**) the N footprint per full-time equivalent population (FTE), **C**) the total institution C footprint, and **D**) the C footprint per FTE. Footprints are shown for: Eastern Mennonite University (EMU, population 1,648), Dickinson College (population 3,174), University of New Hampshire (UNH, population 16,548), Colorado State University (CSU, population 31,409), and University of Virginia (UVA, population 35,894).

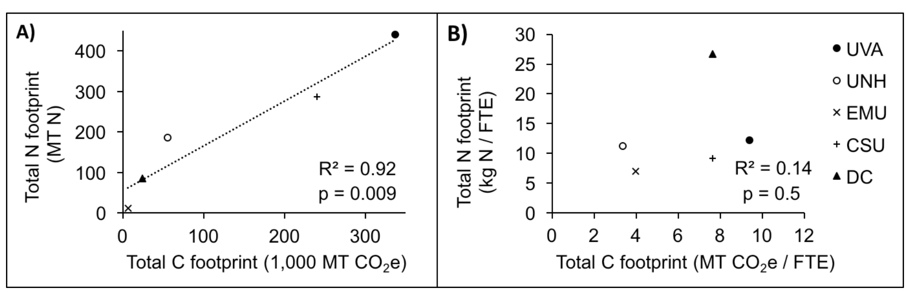

Figure 3. A comparison of institution carbon (C) and nitrogen (N) footprints in terms of: A.) the total C footprint and N footprint, and B.) the total C footprint and N footprint by full-time equivalent population (FTE). Footprints are shown for: the University of Virginia (UVA), University of New Hampshire (UNH), Eastern Mennonite University (EMU), Colorado State University (CSU), and Dickinson College (DC).

the footprints should be explored on a sector-specific basis.

A linear regression between the carbon and nitrogen footprints for per capita utilities found a significant correlation ($R^2 = 0.89$, p value = 0.02), which is likely because of the similar relative magnitude of carbon and nitrogen footprints for different fuel types (Figure 4A). The linear regression for the carbon and nitrogen food footprints per kilogram of food was also significant, which reflects the consistency in the relative impacts of different food products for the carbon and nitrogen footprints ($R^2 = 0.95$, p value = 0.005; Figure 4B).[5,17] The carbon and nitrogen footprints for other sectors (e.g., transportation) and normalizations (e.g., footprints per gross square foot) did not exhibit significant correlations.

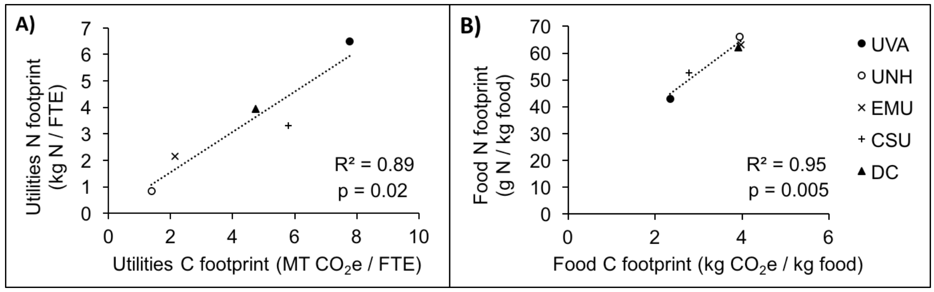

Figure 4. A sector-specific comparison of institution nitrogen (N) and carbon (C) footprints in terms of: **A**) The C and N footprint of utilities by full-time equivalent population (FTE), and **B**) the food production C and N footprints per kg of food purchased. Footprints are shown for: the University of Virginia (UVA), University of New Hampshire (UNH), Eastern Mennonite University (EMU), Colorado State University (CSU), and Dickinson College (DC).

Identifying Integrated Management Strategies

The effects of a variety of food and energy management strategies were reviewed for five institutions (Table 2). Of the food scenarios analyzed, the most impactful was replacing 25 percent of meat purchases with vegetable purchases. Within the food sector, this scenario resulted in a 16 to 21 percent reduction for the food C footprint and a 7 to 18 percent reduction for the food N footprint. However, when presented in the context of the total footprint, the reductions were just 0.4 to 4 percent for carbon and 3 to 14 percent for nitrogen. Generally, the food scenarios had a smaller impact on the total C footprint than the N footprint because food makes up a smaller percentage of the overall C footprint.

Table 2. The Range of Reductions from Food and Utilities Scenarios for Five Campus Carbon and Nitrogen Footprints

	Scenario	Carbon footprint reduction[a,b]		Nitrogen footprint reduction[a,b]	
		Within sector	For total footprint	Within sector	For total footprint
Food	Replace 25% of beef purchases with chicken	5-9%	0.1-2%	2-5%	1-3%
	Replace 25% of meat protein with vegetable protein	16-21%	0.4-4%	7-18%	3-14%
	Reduce food waste by 25%	4-5%	0.1-1%	4-5%	1-3%
Utilities	Purchase 25% renewable energy	3-21%	1-12%	1-35%	0.04-15%
	Improve energy efficiency by 10%	3-9%	1-5%	1-10%	0.04-5%
	Replace all purchased electricity with renewables	11-85%	5-49%	2-99%	0.2-46%

[a]Results are given both within the sector of interest (food, utilities) and for the total footprint.
[b]The results show the range for five institutions (UVA, UNH, EMU, CSU, and Dickinson College).

The utilities management strategies had a larger impact on both footprints. Replacing all purchased electricity with a renewable energy source has the potential for substantial reductions: 5 to 49 percent for the total C footprint and 0.2 to 46 percent for the total N footprint. However, the size of the potential reduction is determined by the percent of total electricity usage that is from purchased electricity versus on-campus stationary combustion sources.

All scenarios analyzed found reductions for both the carbon and nitrogen footprint, and other studies assessing the effects of campus sustainability initiatives on both footprints have had similar findings.[20] Energy scenarios were more effective for reducing the total C footprint, whereas the most effective strategies for the N footprint vary by institution. The energy scenarios are successful because the entire utilities footprint can be offset with renewable energy, which has a minimal carbon and nitrogen footprint.[21] The same cannot be accomplished for food purchases because all methods of food production for all types of food release both greenhouse gases and nitrogen pollution. As a result, achieving N footprint neutrality is difficult without additional offsets, such as the purchase of Renewable Energy Credits.[22] Despite this, important reductions in the food footprints can and should still be achieved by shifting toward less impactful sources of protein (e.g., chicken, vegetable protein), choosing foods from more sustainable farms, and reducing food waste.

Next Steps and Summary

The integrated carbon and nitrogen footprint tool will be publicly launched in 2017. A subsequent version of the online tool will include the ability to analyze projections and

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scenarios and perhaps even include other footprints, such as phosphorus or water. Offsets for N footprints will be explored more, especially since N footprint neutrality is not possible without offsets. Other ways of presenting the footprints will also be considered, such as linking the footprints to social and economic costs.[23]

This article presents an integrated tool that institutions can use to calculate, track, and manage both their nitrogen and carbon footprints together. The data requirements for the two tools overlap substantially, although integrating the two tools will add a calculation of the carbon footprint of food. Institution nitrogen and carbon footprints compare strongly in most sectors, and scenario analysis indicates benefits to both footprints from a range of reduction strategies. Integrating these two footprints into a single tool will account for a broader range of environmental impacts, reduce data entry and analysis, and promote integrated management of institutional sustainability.

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