

# HOW TO CALCULATE YOUR INSTITUTION'S NITROGEN FOOTPRINT



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User's Manual

Allison M. Leach, Ariel N. Majidi, James N. Galloway,  
Andrew J. Greene, Lia Cattaneo

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## Summary

Nitrogen is an important component in the atmosphere, hydrosphere, and biosphere. While necessary to life, reactive nitrogen (Nr; all forms of N except N<sub>2</sub>) can be detrimental to both ecosystem and human health when present in excessive amounts. Different forms of reactive nitrogen contribute to smog and reduced air quality, acid deposition, aquatic dead zones and reduced drinking water quality, biodiversity loss, global warming, and more. Creating and analyzing your institution's nitrogen footprint (N footprint) will help to reduce its overall environmental impact and improve its sustainability. As the name suggests, "How to Calculate Your Institution's Nitrogen Footprint" is a user manual for institutional stakeholders to complete an N footprint for their institution. This manual is accompanied by the Microsoft Excel-based *Nitrogen Footprint Model Template*. Once you have calculated your institution's N footprint, you can use it to track the footprint, set targets, run scenarios, develop a nitrogen management plan, and use it as a general tool to raise awareness of N issues.

## For more information, please contact:

Elizabeth Castner

Email: eac6e@virginia.edu

University of Virginia, Department of Environmental Sciences

291 McCormick Road, PO Box 400123, Charlottesville, Virginia 22904

Phone: 434-924-0569

Allison M. Leach

Email: aml4x@virginia.edu

University of New Hampshire, Natural Resources & Earth Systems Science

Nesmith Hall, Durham, NH 03824

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## **1. Introduction**

### 1.1. What this manual provides

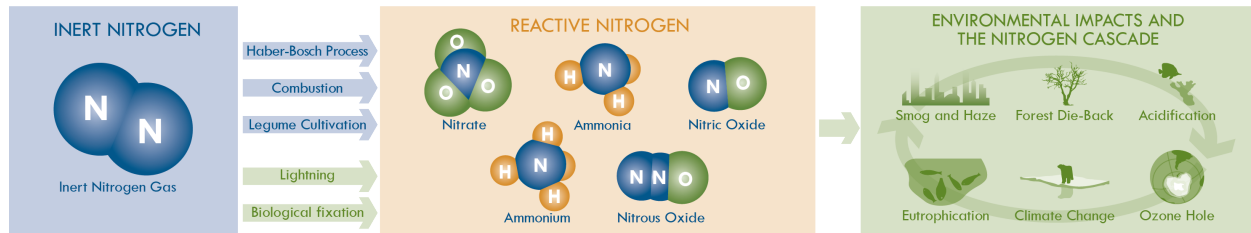
In this manual, we present an adaptable institution-level nitrogen footprint model that will help an institution to calculate its nitrogen footprint for one year, and assess means for reducing this footprint. We provide:

1. Methods for calculating an institutional nitrogen footprint (Section 2);
2. A spreadsheet template in which an institution's N footprint can be calculated (separate attachment);
3. Suggestions for scenarios and projections to be run (Sections 3 and 4); and
4. Suggestions of what to do with the results (Section 5).

The University of Virginia (UVA) calculated its N footprint for 2010 (Leach et al. 2013), and it will to be used as a case study and an example throughout this manual.

### 1.2. Why is nitrogen important?

Nitrogen (N) is one of the key elements necessary for life. Most of the nitrogen on earth is in the form of  $N_2$ , which is unreactive and makes up most of the atmosphere (~78%). However, this supply of nitrogen is unavailable to the vast majority of living organisms (Galloway et al. 2003). In order to be usable to living organisms, the strong triple bond between the N atoms in  $N_2$  must be broken in high-temperature processes or by a small number of specialized N-fixing microbes (Figure 1). These processes create reactive nitrogen (Nr), which includes all forms of N except  $N_2$  (e.g.,  $NH_3$ ,  $NH_4^+$ ,  $NO_x$ ,  $HNO_3$ ,  $N_2O$ ,  $NO_3^-$ , urea, amines, proteins, and nucleic acids). Humans consume nitrogen in the form of protein.



**Figure 1.** The conversion of inert nitrogen ( $N_2$ ) to reactive nitrogen species and several of the potential environmental impacts resulting from excess reactive nitrogen in the environment.

Once in the environment, Nr can contribute to a variety of environmental and human health problems. Effects of excess Nr include production of ground-level ozone (a pollutant that contributes to smog), biodiversity loss, acid rain, stream and lake acidification, low oxygen levels and eutrophication in bodies of water, habitat degradation, degradation the ozone layer, and global climate change. Additionally, a single molecule of Nr may cause each of these effects in sequence before that molecule is converted back to the unreactive form. This concept is called ‘the Nitrogen Cascade’ (Galloway et al. 2003).

Both natural and human-caused processes can create Nr. In nature, specialized microbes accomplish most of the conversion of  $N_2$  to Nr. Lightning also produces a small amount of Nr through the high temperatures it generates. There are three primary anthropogenic, or man-made, mechanisms for Nr creation:

- (1) the Haber-Bosch process, which is an industrial process;
- (2) the cultivation of legumes, which have a symbiotic relationship with the specialized microbes that create Nr; and
- (3) the combustion of fuels, which generates high temperatures to create Nr.

The first two support food production: Nr is an important component to fertilizers and is necessary for the food production process. However, essentially all of the Nr used in food production is lost to the environment, ~80% prior to human consumption (e.g., fertilizer runoff,

manure losses, food waste, etc.; this is also referred to as “virtual nitrogen”) and 20% following human consumption (e.g., human waste). The third mechanism (combustion of fuels) produces energy and, in the process, all of the Nr formed is lost to the environment. Globally, these anthropogenic sources of Nr are at least twice as large as natural terrestrial sources (Galloway et al. 2008; Vitousek et al. 2013). This means that humans are creating more than two times as much Nr as nature. This dominance is so great that human interference with the nitrogen cycle was recently identified as one of three global issues where the rate of change has crossed the so called ‘Planetary Boundary’ and cannot continue without significantly impacting the Earth-system (Rockström et al. 2009).

### 1.3. The Nitrogen Footprint

A Nitrogen Footprint (N Footprint) quantifies the amount of reactive N released to the environment as a result of an entity’s (e.g., individual, institution) resource consumption (Leach et al. 2012). The major sectors of resource consumption included are energy (e.g., transport, utilities) and food (e.g., consumption, production). The extensive and detrimental effects of reactive nitrogen indicate the importance of managing nitrogen efficiently to reduce its loss to and impact on the environment. A first step in managing Nr is determining the current impact from an entity through a nitrogen footprint assessment. After determining its N footprint, that entity can then take steps to manage and reduce it.

### 1.4. The role of the institution

Institutions (e.g., universities) have far-reaching impacts through activities like education and research; however, their activities can also negatively impact the environment. The growing

awareness of sustainability has prompted many educational institutions to assess their environmental impact. The American College and University Presidents' Climate Commitment (ACUPCC), an initiative launched in 2007 to encourage top administrators to pledge to reduce their institution's carbon emissions, requires signatory colleges and universities to calculate their carbon footprint and set a reduction target. Over six hundred institutions have signed the American College and University Presidents' Climate Commitment (ACUPCC) and many non-signatories have implemented similar measures (American College and University Presidents' Climate Commitment 2013). The response of educational institutions to the ACUPCC has indicated their strong interest in sustainability. However, the ACUPCC focuses on greenhouse gases and therefore only considers one type of Nr, the greenhouse gas nitrous oxide (N<sub>2</sub>O), which is largely combustion-generated and only one facet of the Nr losses incurred by institutions.

Institutions interested in obtaining a broader understanding of their environmental impact and improving their sustainability should also calculate and reduce their nitrogen footprint. A nitrogen footprint analysis will assist institutions with assessing their current level of sustainability; creating projections of future footprints; assessing the impact of different footprint management strategies; and developing short- and long-term reduction goals. The tool is also useful for raising awareness of N issues.

The currently available N footprint tool is focused on universities. Future adaptations of the tool will consider secondary schools, businesses, and communities, all of which would also benefit from calculating their N footprint.

### 1.5. Activities that contribute to an institution's nitrogen footprint.

Many activities affect an institution's nitrogen footprint. The following are a few that will be covered in this manual, along with a brief description of how it contributes to the N footprint:

- **Food consumption and production:** The use of nitrogen fertilizers in crop production, the transportation of food, the amount and type of food consumed, food waste management, and food and human waste contribute to the loss of reactive nitrogen to the environment.
- **Utilities:** The burning of fuels emits reactive nitrogen into the atmosphere.
- **Transportation:** The burning of fuels emits reactive nitrogen into the atmosphere.
- **Research animals:** The production of feed, excretion of waste, and incineration of carcasses contribute to the loss of reactive nitrogen to the environment.
- **Fertilizer:** Nitrogen-containing fertilizer is used in landscaping, little of which is taken up by the plants. The Nr not taken up by the vegetation is lost to the environment.

The nitrogen and carbon footprint have significant overlap in the energy sector (i.e., utilities and transportation). Therefore, many reduction strategies for carbon footprint reduction (e.g., increases in energy efficiency and conservation; increases in renewable energy) will also result in a decrease the N footprint (see Section 5.2 for more information). The same overlap is not seen in the food sector.

### 1.6. Nitrogen footprint versus nitrogen budget

Calculating a nitrogen footprint is different than calculating a nitrogen budget. The primary difference between a nitrogen footprint and a nitrogen budget is that the former only accounts for anthropogenic sources of Nr, whereas the latter incorporates natural sources as well. A nitrogen footprint focuses on the Nr released to the environment as a result of an entity's

activities; it includes only Nr from anthropogenic sources. A nitrogen budget, on the other hand, considers the flow of all Nr through a given system, including natural processes (e.g., biological nitrogen fixation, Nr deposition) that are not necessarily the responsibility of the institution (Savanick et al. 2007; Leach et al. 2013). Although a nitrogen budget provides important information about an institution's activities, it does not show as directly the amount of nitrogen flow into the environment for which an institution is responsible — or highlight the opportunity to reduce it. If an institution has already calculated its nitrogen budget it will be easier to calculate its nitrogen footprint.

#### 1.7. Estimated project time commitment and costs

The time required for the N footprint calculation will depend on the availability and quality of the data. The calculations require data from many different sources, and therefore typically require input and information from different departments at an institution. More time may be necessary for schools with less data documentation. However, the model can be adapted for use by institutions with varying levels of data availability.

The only cost associated with calculating an institution's N footprint is personnel time, which could be paid or voluntary depending on your institution's preference. We estimate that for an institution the size of UVA, about two months full-time personnel time for one person will be required to complete the N footprint data collection, calculation, and projection/scenario analysis.

## **2. Methods**

### 2.1. How to use this manual and associated data template

This manual and the associated data template work together to help your institution calculate its N footprint. This manual is presented in the same order as the tabs in the data template spreadsheet and should be used as a reference for understanding the template requirements.

#### **Cell Colors**

In the template, all cells in **orange** have data requirements whose values should be entered in the current cell; cells in **blue** have data requirements whose values should be entered elsewhere. **When you click on a blue cell, refer to the formula bar at the top of the spreadsheet** (see Figure 3). The formula bar will say something other than what is written in the cell; for example, `= 'Data Inputs'!E38`. In this case, the data should be entered in cell E38 in the **Data Inputs** tab. Values in the blue cells will read “0” until the linked data has been entered.

***Figure 2.** Explanation of different types of data inputs. There are two types of data inputs; those to be entered in the current tab (noted in orange in the data template) and those to be entered elsewhere (noted in blue in the data template). Within each of these categories, there may be optional and required inputs, indicated in the template by the label “**Optional**”. These distinctions are listed in a key at the top of each tab.*

E10

fx

=Data Inputs!E38

A

B

C

D

E

F

G

H

I

1

Fertilizer

Key for cell colors: 

Enter data here

2

On this worksheet: Calculations for the nitrogen released from applied fertilizer.

3

4

5

6

7

8

9

10

11

12

13

Section	Model Calculation
Worksheet	Fertilizer
Category	Type
	Amount Nitrogen
	Fertilizer Uptake Factor
	N released
	N released
	lb
	%
	Optional
(In this row, insert source number as listed in Reference Tab)	9
Fertilizer	Synthetic
*Add all additional fertilizer types and amounts.	

0 Total N Released

**Figure 3. Fertilizer tab**, showing necessary data inputs. Clicking on formulas for blue cells show where the value should be entered. Go to the cell indicated to edit. Orange cells indicate that the data can be entered directly on the current sheet.

## Optional Data Inputs

Unless otherwise noted, all data inputs are required. Optional data inputs are indicated as such in the template. In Figure 3, the fertilizer uptake factor (column E) is optional, while the other data inputs are required. In Figure 3, only one type of fertilizer is included, but additional types may be added as subsequent rows.

## Adding Rows

In many cases, additional inputs can be added to customize the template. In order to do this:

1. Insert a row below the last input on the list
2. Highlight the cells in the row for the last input and “drag down” the formulas.
3. If the addition requires additional data to be entered elsewhere (e.g., new **Data Inputs** data), be sure to add the appropriate rows in those tabs as well. For example, if a new type of fertilizer were added, a new Fertilizer Uptake Factor would also have to be added. Go to the **Data Inputs** tab and insert a row under Fertilizer, and fill out the required

information in the new row. Finally, return to the original Fertilizer addition and ensure that the linked cell is directed to the new Fertilizer Uptake Factor in the ***Data Inputs*** tab.

### **Non-input Cells**

Cells not highlighted for data input will either contain data pulled from elsewhere in the data template or will contain formulas. If you would like to view the formula for a certain cell, click on the cell and the formula will appear in the formula bar line above the spreadsheet. Any cell with a formula must remain intact or serious calculation errors will occur. These cells are not currently in a “locked” form. **THEREFORE, PLEASE DO NOT CHANGE OR DELETE ANY FORMULAS.**

Values in these cells will read “0” until all data required to calculate the value has been populated.

### **References**

References are numbered in the ***References*** tab. These references should be changed for your institution, as applicable. In most tabs, there is a row in which to enter the reference number corresponding to the data in that column, respectively. In the ***Data Inputs*** tab, the references are indicated in a column to the right of the data.

To begin, the map on the ***Intro*** tab will walk you through the data requirement categories in order. More detailed information about each category can be found in the relevant section of this manual. **You will be able to work with the developers if/when your institution’s practices require customization of the model.**

## 2.2. Defining the boundaries of the system

An important step of any modeled calculation is identifying the bounds of the system. In the case of an institution, the system can include levels such as:

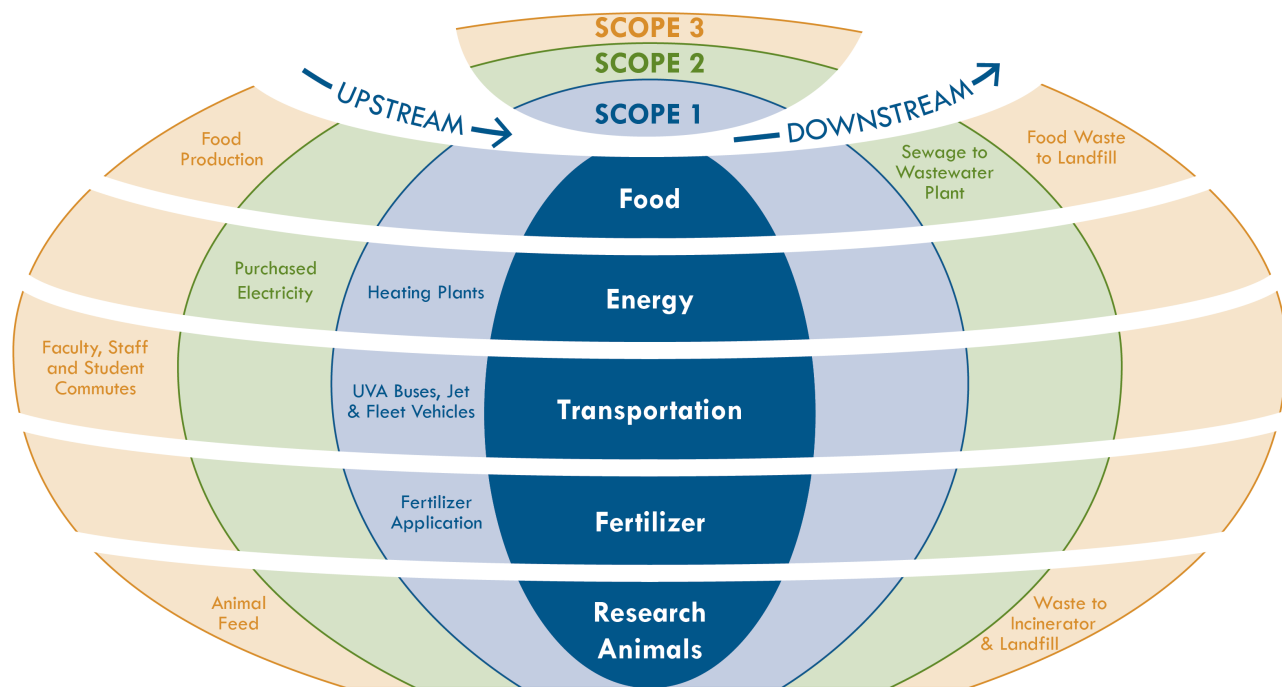
- Activities and consumption within the geographic boundaries of an institution or
- Activities and consumption that support the institution but occur elsewhere, such as food production.

The default footprint system bounds include all sectors considered in the UVA model, shown graphically in Figures 4 and 5. If you would like to make changes to the system bounds for your institutions, please contact the model developers.

The different levels of nitrogen losses can be categorized by scope. The scope concept was established for carbon footprint calculations and identifies where footprint losses occur relative to the entity of interest. When applied to the nitrogen footprint concept, the three scope levels encompass the following components:

1. *Scope 1*: Nitrogen losses that occur within the institution's geographical presence (e.g., fertilizer application) and from any institution-owned equipment (e.g., institutional vehicles). This scope level only includes Nr lost within the bounds of an institution or from institution-owned equipment.
2. *Scope 2*: Nitrogen losses from utility-linked indirect emissions (e.g., purchased electricity) or from other facilities directly connected to institution activity (e.g., sewage treatment).
3. *Scope 3*: Nitrogen losses from other indirect consequences of institutional activities and consumption patterns (e.g., commuting, food production).

The default situation used in the N footprint calculations includes all three scopes.

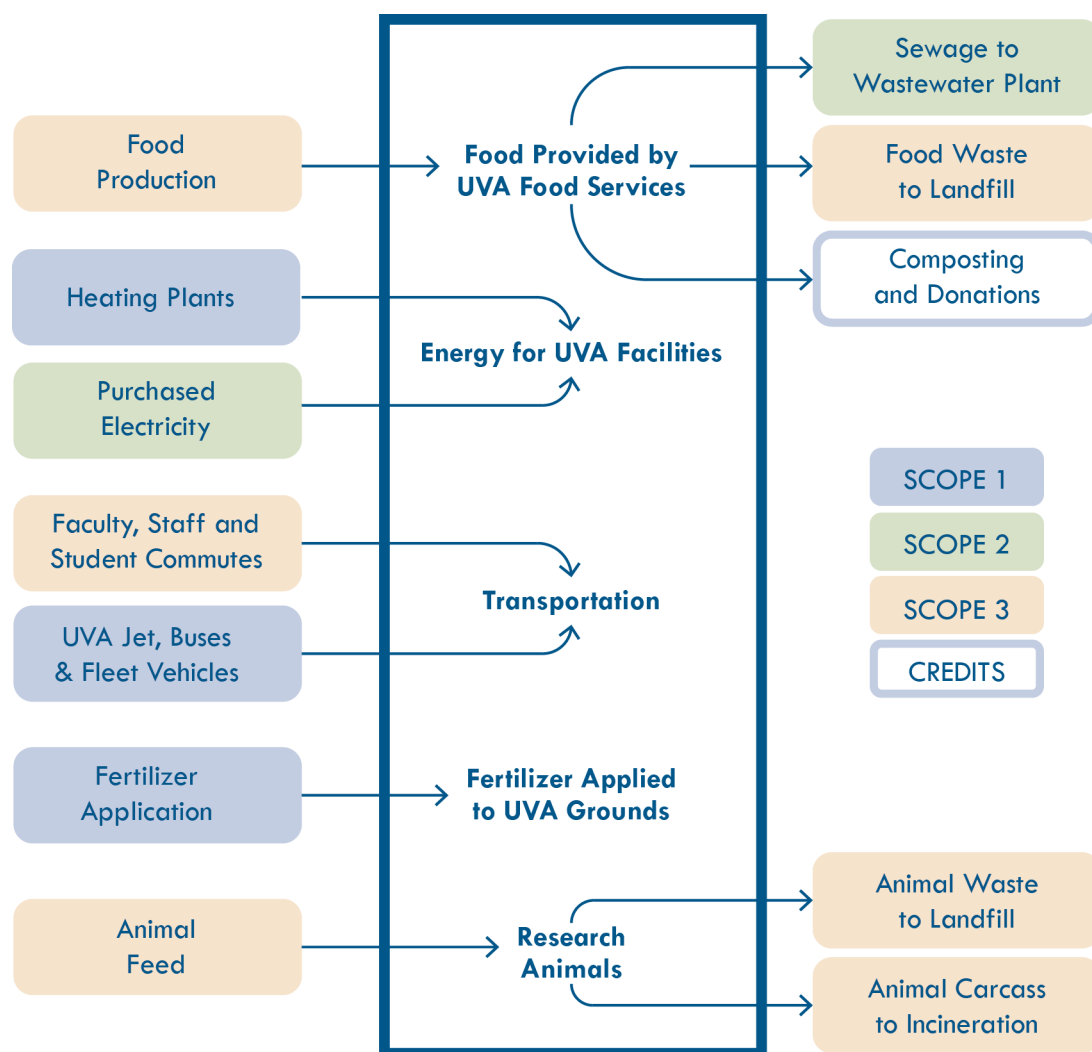


**Figure 4.** System boundaries for the institution-level nitrogen footprint with sector components depicted by scope level. Scope 1 includes all losses that occur within the geographical bounds of the institution and from institution-owned equipment. Scope 2 includes losses from utility-linked indirect emissions or from other facilities directly connected to institution activity. Scope 3 includes losses from other indirect consequences of institutional activities and consumption patterns. The center dark blue oval reports the nitrogen footprint sectors, and both upstream and downstream nitrogen losses for each sector are shown.

Figure 4 lays out these scopes, which are different levels or categories of emissions. For the N footprint, scopes are categorized based on the ownership or control of the N-releasing source (GHG Protocol). In the N footprint, scopes range from 1 (i.e., Nr released from an institution's property and equipment) to 3 (i.e., Nr released upstream from purchased goods) (See Figure 4). As the scope level increases from 1 to 3, the amount of data required to perform the calculations generally increases. It is important to note that scopes do not build on themselves. Rather, each scope represents a distinct set of activities and the associated N losses to the environment.

If an institution has already used scopes when calculating its carbon footprint, then the same scope definitions could be used for the N footprint. **The model developers should be consulted regarding any alterations to the scope or system definitions for a specific institution.**

Scopes will be referred to throughout the manual as we explain the data requirements necessary for calculating an institutional nitrogen footprint. Figure 5 shows the components of each scope as included in the UVA nitrogen footprint.



**Figure 5.** Components of the University of Virginia (UVA) nitrogen footprint broken down by sector and scope level. The outlined box represents the geographical confines of UVA. Scope levels are defined above.

### 2.3. Data requirements

The table below lists the major data requirements for each of the data categories. If a data set is unavailable at your institution, it may be possible to calculate that sector's N footprint using alternative data from the UVA data set. In the data template, UVA data is generally made available as a default value.

**Table 1.** Major data requirements for each data category. See Appendix A for further details.

<b>Data category (Section of Manual)</b>	<b>Data requirement</b>	<b>Suggested Contacts for Data Collection</b>
<b>Utilities</b> (Section 2.4)	<ul style="list-style-type: none"> <li>Amount of fuel used for electricity and heating by fuel type</li> <li>Fuel type breakdown for purchased power</li> <li>Regional NO<sub>x</sub> and N<sub>2</sub>O emission factors*</li> </ul>	Energy Manager, Director of Facilities, Fuels Purchaser
<b>Transportation</b> (Section 2.5)	<ul style="list-style-type: none"> <li>Records of public transport (institution shuttles, buses, etc.) fuel usage volume, fuel type and vehicle type</li> <li>Number of commuters traveling by car and bus</li> <li>Average number of trips/year and miles/trip for commuters traveling by car and bus</li> <li>NO<sub>x</sub> and N<sub>2</sub>O emission factors by fuel type**</li> </ul>	Director of Transportation, Human Resources (for commuting), University Travel Office
<b>Fertilizer</b> (Section 2.6)	<ul style="list-style-type: none"> <li>Amount of N fertilizer used</li> </ul>	Grounds Management
<b>Food production</b> (Section 2.7.1)	<ul style="list-style-type: none"> <li>Food purchases – see Section 2.7.1 for detailed calculation methods and associated data requirements. Depending on the calculation method chosen (see section 2.7), this could also include number of meals served, types of meals served, and population served.</li> </ul>	Dining Services

<b>Food factors</b> (Section 2.7.2)	<ul style="list-style-type: none"> <li>• Average miles traveled by food products*</li> <li>• Average food waste*</li> <li>• Protein contents**</li> <li>• Virtual nitrogen factors**</li> </ul>	Dining Services
<b>Food recycling</b> (Section 2.7.3)	<ul style="list-style-type: none"> <li>• Mass or percent of food sent to recycling (compost, donations, etc.)</li> </ul>	Dining Services, Sustainability Coordinator,
<b>Food consumption</b> (Section 2.7.4)	<ul style="list-style-type: none"> <li>• Percent nitrogen denitrification (i.e., Nr that is converted back to N<sub>2</sub>) at wastewater treatment facility</li> </ul>	Waste water treatment facility
<b>Research Animals</b> (Section 2.8)	<ul style="list-style-type: none"> <li>• Research animal count by animal type</li> <li>• Animal diet breakdown by food type</li> <li>• Information on animal carcass disposal (e.g., incineration)</li> <li>• Daily protein requirements for each animal*</li> </ul>	
<b>Projections and Scenarios</b> (Section 4)	<ul style="list-style-type: none"> <li>• Total population count (or best estimate if population is dynamic)</li> <li>• Planned changes to the institution's N and/or other resource consumption (e.g., water, energy, food)</li> <li>• Planned construction and associated energy consumption increases. If these include additional alternative fuel types, the NO<sub>x</sub> and N<sub>2</sub>O emission factors would also be necessary.</li> </ul>	Institutional Research and Assessment, Human Resources, Registrar

\* *Optional data inputs for improved accuracy*

\*\* *Default data inputs included in the calculations; however, these can be changed if you have data that may be more representative than those used in the UVA nitrogen footprint.*

## 2.4. Calculations: Utilities

Fossil fuel combustion due to energy usage emits nitrogen in the forms of NO<sub>x</sub> and N<sub>2</sub>O.

Utilities that produce electricity or steam for heating and cooling release these two forms of reactive nitrogen. The utilities used at an institution may include self-generated and/or purchased utilities. Self-generated and/or purchased renewable energy may be added if emissions factors are known.

There are two pathways that may be considered when calculating the utilities nitrogen footprint: (1) use energy consumption data and the associated emission factors or (2) use direct estimates of nitrogen emissions as reported in permits (e.g., a Title V permit to the Virginia Department of Environmental Quality).

The energy component of the nitrogen footprint will be easier to calculate if your institution has already calculated its carbon footprint (see Section 5.2.), as much of the data needed will already be available. **See Table 1 in Appendix A for detailed data requirements.**

Emissions factors for commonly used fuels and energy sources by electric utility plants and by on-site plants are included in the model. Guidelines for finding and adding other emissions factors are listed in **Appendix B**.

## 2.5. Calculations: Transportation

Nitrogen is emitted due to any fossil fuel combustion associated with transportation (e.g., fleet vehicles, work travel such as an institution jet, commuting). The emissions associated with your institution's N footprint depend on the system bounds determined in section 2.1. Two levels of transport that should be considered are institution-specific vehicles and/or commuting members of the institution's population. For each type of transport considered, data must be collected on the fuel type (e.g., gasoline, diesel, biodiesel), fuel amount, and vehicle efficiency (see template tab ***Transportation***; data requirements listed below). The nitrogen emissions are then calculated using the total fuel volume used, average fuel efficiency, and N<sub>2</sub>O and NO<sub>x</sub> emission factors (US DOT 2000; Kazas 2011; Eastern Research Group, Inc., 2007; US EPA 1995b).

The nitrogen footprint for commuting should consider the number of commuting

individuals (faculty, staff, and students), vehicle types, average fuel efficiencies, and the average number of trips and distance traveled by each commuter type per year (USDOT 2000). Fuel efficiencies and nitrogen emission factors can then be used to determine the total nitrogen released due to commuting (USDOT 2000; US EPA 1995b). Data for commuting calculations may be readily available if an institution has calculated its carbon footprint previously. **See Table 2 in Appendix A for detailed data requirements.**

## 2.6. Calculations: Fertilizer

Fertilizer is often applied to lawns, shrubs, and trees, with lawns generally being the largest receptor. During landscaping only a small percentage (~30%) of that fertilizer is retained by plants on a multi-year basis (mostly trees); the other 70% enters the environment (Wuest & Cassman 1992). The total amount of nitrogen applied as fertilizer should be reported. The average amount of nitrogen taken up by vegetation will be subtracted from the reported fertilizer application figure to determine the nitrogen actually released to the environment. **See Table 3 in Appendix A for detailed data requirements.**

## 2.7. Calculations: Food

The calculation of nitrogen released as a result of food served and consumed at an institution can be calculated in a few different ways. The amount of data required depends on the calculation method chosen. The template includes five distinct calculation methods (tab ***Food - Calculation 1, 2***, etc.), and each is described in detail in the next section. These calculation methods are progressively more data-intensive and offer the user options depending on data availability. **Only one food calculation method can be selected.**

## Choosing a Calculation Method

- **Calculation 1** uses the number of meals served at the institution in a given year, using average meal data from UVA. As the least complex of the five options, this option may be a good first step for an institution interested in calculating its nitrogen footprint.
- **Calculation 2** uses the weighted number of people served at the institution in a given year to scale the average meal and population data from UVA.
- **Calculation 3** uses three or more average meals served at an institution and scales those meals to represent the total number of meals served in one year.
- **Calculation 4** uses individual purchase records for all food items purchased at the institution. This detailed method has the highest level of accuracy because it calculates the N footprint for each food item entering an institution.
- **Calculation 5** scales the N footprint of one dining facility so that it represents all dining facilities of similar type at the institution. This method is best for large institutions with many dining facilities. It builds on data from Calculation 4 (also required for this method) and adds scaling factors.

In the first food tab of the template, ***Food Summary***, select which food calculation method will be used by entering the corresponding number. The ***Food Summary*** tab also summarizes the results of the food calculations, showing for each food category the total food production N released.

The food calculations will ultimately include the following components of your institution's food N footprint, which are described in more detail in subsequent sections:

- *Production (Section 2.7.1)*: Nitrogen losses resulting from food production, including the raising of the crop or animal and food processing.
- *Transportation (Section 2.7.1)*: Nitrogen emitted through the transportation of the food products to the institution.
- *Diversion (Section 2.7.2)*: Food diversion (e.g., composting) initiatives are a credit that can be subtracted from the N footprint because they describe N being reused or repurposed outside of the institution.
- *Consumption (Section 2.7.3)*: Nitrogen contained in a food item's embedded protein that is consumed at the institution and ultimately released as human waste.

#### 2.7.1. Five methods for food data

Institutions can select one of five methods for calculating their food N footprint, which considers food consumption, production, transport, and diversion. These methods range in accuracy and ease of data collection. The required data varies based on the method selected. Below are detailed explanations of the five calculation options. Detailed data requirements for each calculation method can be found in **Appendix A**.

***Calculation 1:*** Calculate food N footprint based on the total number of meals served at the institution.

The least complex of the five options, this method calculates the food N footprint based only on the total number of meals served at the institution. Data on the average nitrogen released per meal at UVA will be scaled to the number of meals served at the institution of interest. This option is a good first step for an institution interested in calculating its nitrogen footprint with

limited data availability; however, it requires many assumptions. The calculations for this method can be found in the tab *Food – Calculation 1* in the data template. **See Table 4 in Appendix A for detailed data requirements.**

***Calculation 2:*** Calculate food N footprint based on the population of the institution.

This method calculates the food N footprint based only on the population at the institution. Similar to Calculation 1, the food N footprint of your institution will be estimated using the population of your institution and the average per-person food N footprint at UVA. Your institution's population will be determined using a weighted calculation from the Association for the Advancement of Sustainability in Higher Education (AASHE)<sup>1</sup>. The Weighted Campus User measures an institution's population adjusted for the intensity of use by certain community members (AASHE 2013). The equation adjusts the number of students and employees based on full-time equivalent (FTE) units. FTEs reflect the number of hours worked, courses taught, or courses taken for employees, faculty, and students, respectively (AASHE 2013). The calculation uses the following formula:

$$\text{Weighted Campus Users} = (A + B + C) + 0.75 [(D - A) + (E - B) - F]$$

A = Number of residential students (annualized headcount)

B = Number of residential employees (annualized headcount)

C = Number of in-patient hospital beds

D = Full-time equivalent enrollment (annualized FTE)

E = Full-time equivalent of employees (annualized FTE)

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<sup>1</sup> AASHE is a 501(c)(3) nonprofit that supports and promotes sustainable practices at colleges and universities. They run the Sustainability Tracking, Assessment and Rating System (STARS), a self-reporting and benchmarking system for colleges and universities to measure sustainability performance. Learn more at <http://www.aashe.org>.

F = Full-time equivalent of distance education students (annualized FTE)

If your institution does not have access to all of these values, include those that you do have and use “0” for the unknown variables.

This calculation option is a good first step for an institution interested in calculating its nitrogen footprint with limited data availability, but it has a high level of uncertainty. The calculations for this method can be found in the tab ***Food – Calculation 2*** in the template. **See Table 5 in Appendix A for detailed data requirements.**

***Calculation 3:*** *Calculate food N footprint based on a few average meals served and the total number of meals served in one year at the institution*

This method determines the food N footprint based on a few average meals and the total number of meals served in one year at the institution. This could be completed with only three meal types, but accuracy increases when more meals are considered. Unlike calculations 1 and 2, this method does not rely on average meal data from UVA. This may be useful for institutions with many dining facilities, or it may be preferable to calculations 4 and 5 because it is less data-intensive. This method can be used when specific food purchase data is not available at an institution. The calculations for this method can be found under the tab ***Food – Calculation 3*** in the template. **See Table 6 in Appendix A for detailed data requirements.**

***Multi-ingredient foods:*** If food enters the institution in a pre-prepared, multi-ingredient form, it will need to be split into major food categories. This calculation assumes that all of the ingredients contribute equal mass to the food (i.e., total mass divided by number of ingredients) and the template will calculate this mass breakdown. In order to split up the food items, enter the item as many times as necessary for the number of ingredients; enter the total mass of the item in each entry; identify the food type associated with each ingredient; select Y for multi-ingredient;

and indicate the number of ingredients. See Figure 6 for example with peach yogurt and French toast.

	A	B	C	D	E	F	G	H	I
1	<b>Food Orders - Calculation #3</b>							Key for cell colors:	Enter data here
2	On this worksheet: Method 3 for food calculations involves the scaling of the nitrogen footprint by meals offered by the institution.								
3	This method is recommended for medium to large universities that do not have access to food purchase records								
4	Section		Food Model Calculations						
5	Worksheet		Food - Calculation 3						
6	Food Product Information								
7	Meal Served	Number of Meals Served in Year	Meal Components	Total mass	Food type	Multi-ingredient?	If multi-ingredient, what are the food categories?	If multi-ingredient, how many?	
8	Units	#		kg	Type	Y/N	food items	number	
9	(In this row, insert source number as listed in Reference Tab)								
10	Meal 1	100,000	Scrambled Eggs	0.12	Eggs	N			
11			Whole wheat toast	0.08	Cereals	N			
12			Bacon	0.03	Pigmeat	N			
13			Turkey sausage	0.03	Poultry	N			
14			Cream Cheese	0.03	Cheese	N			
15			Peach Yogurt	0.03	Fruits	Y	Fruits, Milk	2	
16			Peach Yogurt	0.03	Milk	Y	Fruits, Milk	2	
17			French Toast	0.03	Cereals	Y	Cereals, Eggs	2	
18			French Toast	0.03	Eggs	Y	Cereals, Eggs	2	
19									4
20									4
21									4
22									4

**Figure 6.** Calculation 3, showing examples of multi-ingredient food items (i.e., Peach Yogurt, French Toast).

The template currently includes space for three meals. If you would like to add additional meals, or your meals include more ingredients than space allows, insert new rows following the procedure outlined in Section 2.1. After entering data for your institution, delete any UVA-specific information (e.g., meal data) that will not be part of your calculations.

**Calculation 4:** Calculate food N footprint of every food item entering the system

This option requires the most detailed data; it requires calculating the nitrogen footprint of every food item coming into the institution. This method may be possible for smaller

institutions with only a few dining facilities, though if the institution has a good accounting system size should not matter. See Calculation 5 to scale representative dining facilities. The calculations for method 4 can be found under the tab **Food – Calculation 4** in the template.

*Multi-ingredient foods:* If food enters the institution in a pre-prepared, multi-ingredient form, it will need to be split into major food categories. This calculation assumes that all of the ingredients contribute equal mass to the food (i.e., total mass divided by number of ingredients) and the template will calculate this mass breakdown. In order to split up the food items, enter the item as many times as necessary for the number of ingredients; enter the total mass of the item in each entry; identify the food type associated with each ingredient; select Y for multi-ingredient; and indicate the number of ingredients. Figure 7 shows an example of this with several food products (i.e., Beef brisket, meat lasagna).

Food Orders - Calculation #4							
On this worksheet: Calculation method 4 for nitrogen released in food production based on individual food orders. This method is recommended for small to medium universities where detailed food purchasing information is available							
Section	Food Model Calculations						
Worksheet	Food - Calculation 4						
Provider	Food Product	Total mass	Food type	Multi-ingredient?	If multi-ingredient, what are the food categories?	If multi-ingredient, how many?	Mass by
		kg	Type	Y/N		number	kg
(In this row, insert source number as listed in Reference Tab)							
(Vendor Name)	Beef brisket flat ch angus	50	Bovine	N			50
	Entree lasagna meat	50	Bovine	Y	Bovine, cheese, cereals, vegetables	4	12.5
	Entree lasagna meat	50	Cheese	Y	Bovine, cheese, cereals, vegetables	4	12.5
	Entree lasagna meat	50	Cereals	Y	Bovine, cheese, cereals, vegetables	4	12.5
	Entree lasagna meat	50	Vegetables	Y	Bovine, cheese, cereals, vegetables	4	12.5
							0
							0

**Figure 7.** Calculation 4, showing an example of a multi-ingredient food item (i.e. Entree lasagna meat).

The template currently includes space for several food purchases. If you would like to add additional purchases, insert new rows following the procedure outlined in Section 2.1. **See Table 7 in Appendix A for detailed data requirements.**

***Calculation 5:** Calculate food N footprint of representative facilities (i.e., Calculation 4) and scale similar facilities.*

This option calculates the food N footprint of representative facilities and scales similar facilities. Representative facilities can be scaled by the weight of food at each facility, a percent basis by cost (\$) of purchases at different facilities, the number of cases purchased, or a different scaling factor. When this method is used, data for the representative facility is entered into the template for Calculation 4. Then, the appropriate scaling factor is entered on the tab ***Food - Calculation 5***, which references the food data from Calculation 4. Large institutions with several similar facilities may choose this option, which, while less data intensive than Calculation 4, has improved accuracy over Calculations 1 and 2. The calculations for this method can be found under the tab ***Food – Calculation 5*** in the template. **See Table 8 in Appendix A for detailed data requirements.**

#### 2.7.2. Food diversion

Food diversion is the reuse of food not consumed within the institution. These initiatives include all efforts of reuse; upcycling (i.e., converting materials into products of better quality or value); and downcycling (i.e., converting materials into products of lesser quality or value). Downcycling includes recycling. These are more likely to be associated with data from Calculation methods 3-5.

The two most common types of food diversion are 1) food composting and 2) food donation. This diverted food is repurposed and reused outside of the system bounds, allowing it to be a credit to an institution's N footprint. Alternatively, food that is thrown away and ends up in a landfill or incinerator remains part of an institution's N footprint because that food N is lost to the environment.

For diverted food to be a credit to the nitrogen footprint, data collection must include an inventory of the amount and destination of food diverted. Unless more detailed data are available, the model assumes that the food is diverted in the same proportions in which it is purchased. **See Table 9 in Appendix A for detailed data requirements.**

### **Composting**

Many institutions have developed composting initiatives, either on-site or in partnership with an off-site composting group. All composted food effectively leaves the system bounds (and is therefore subtracted from the footprint) because it is being reused and repurposed as fertilizer elsewhere. Only the N actually embedded in the food—and not the N lost during the food production—is considered a credit to the N footprint because the composted food is not repurposed in its original form.

### **Food donation**

Extra food at institutions is often donated directly to community shelters. A common donation organization that facilitates this donation is Campus Kitchen, a student-initiated, national organization that is found at many universities (<http://www.campuskitchens.org/>). Nitrogen losses due to both the production and consumption of donated food are considered

donated (and a credit to an institution's N footprint) because donated food is used in its original form—therefore transferring its full nitrogen footprint.

### 2.7.3. Food Consumption

All food ordered by the institution leaves in one of the following pathways: human consumption (i.e., sewage), food waste (i.e., landfill or incineration), or diverted food waste (i.e., recycling or composting). Human consumption is estimated by subtracting average food waste proportions (Gustavsson et al. 2011) from the amount of food entering an institution; it is assumed that the remainder is consumed and ultimately enters the institution's sewage stream (Leach et al. 2013). Nitrogen losses from all food waste are considered to be part of the food production nitrogen footprint.

The food diversion calculation will subtract the food mass of the diversions from the food N footprint, and (when appropriate) the associated production and transport N footprints are subtracted from the food production portion of the N footprint. More details can be found in Section 2.7.3.

The amount of food entering the system is calculated in each of the five food calculation methods. The only additional data requirement for the food consumption N footprint is the local sewage treatment N reduction factor. Data inputs for this section can be found in the tab ***Food Consumption***.

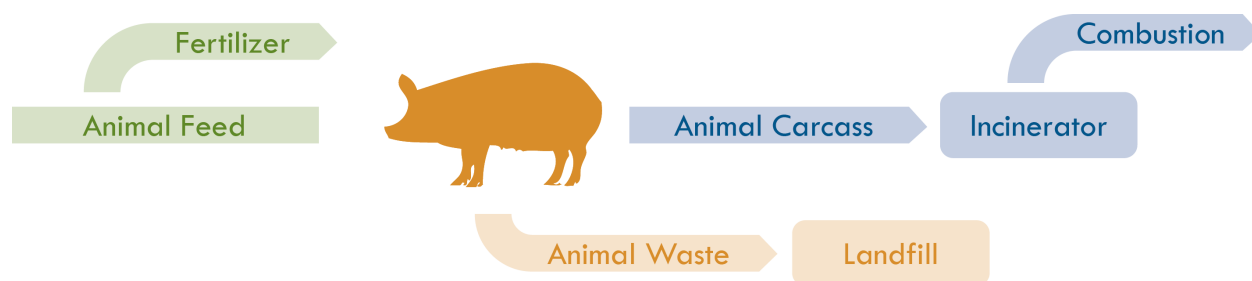
### 2.7.4. Food Factors

The model uses Virtual Nitrogen Factors (VNFs) to determine the N losses (kg N lost/kg N consumed) associated with food items. The VNFs listed under “Model Values” represent the

average values for the U.S. (Leach et al. 2012). These can be changed if your institution is located in another country, or purchases all organic food.

## 2.8. Calculations: Research animals

Animals used for research contribute to an institution's nitrogen footprint. The specific components of the research animal N footprint include the production of feed, feed consumed over an animal's lifetime (i.e., animal waste), and carcass disposal (Figure 8). Research livestock (e.g., cattle) at an institution such as a land grant university are very important to consider when calculating that institution's nitrogen footprint. If your institution has a significant research animal component (such as at a land grant university), please talk with the developers directly to be sure the data template can accommodate your institution's needs.



**Figure 8.** Schematic of nitrogen losses due to research animal use.

If your institution has the same types of research animals as UVA (see Data Template for list), then the only required data are the standing stock population and the number of animals euthanized per year (see template tab **Research Animals**). The calculations will then be performed using average N consumption and excretion data by research animal type. If your institution has research animals not included in the UVA footprint (i.e., land-grant institutions

with agricultural research), you will also need to enter data about the rate and types of feed consumption for these animals. These should be according to the procedure outlined in Section 2.1.

The virtual nitrogen lost during the production of animal feed must be considered. Average diets and protein intakes are reported by animal type (Feldman January 2012; Feldman August 2012; Tacon 1990), and the virtual N factors (Leach et al 2012) are applied to estimate the feed production nitrogen losses. Unlike human waste, animal waste rarely undergoes sewage treatment; thus, all nitrogen consumed is considered ultimately released back into the environment. Feed transportation is also included in the calculation of the animal feed production N footprint. The model will assume that feed has the same average food miles as the food consumed by humans. If data are available to improve the accuracy of these calculations, the model can be updated.

The method of animal carcass disposal should be reported, as it impacts the amount and type of nitrogen emissions. If animal carcasses are incinerated, then the associated N footprint is derived from two sources – (1) the nitrogen endogenous to the animal and (2) NO<sub>x</sub> emissions resulting from the fixation of N<sub>2</sub> during the incineration. If animal carcasses are disposed without incineration, then only the former N loss is included. In order to calculate the nitrogen content of animal carcasses, average masses for the research animals should be reported (Feldman January 2012; Feldman August 2012; Fisher 2012; BC Ministry of the Environment 2001) (see template tab ***Research Animals***; column I – Average Body Mass). A 15% protein content in animal body mass and 16% nitrogen content in protein is then applied to each animal carcass mass and totaled to determine the biological nitrogen released through disposal (National Research Council 2003). If carcasses are incinerated, then a NO<sub>x</sub> emission factor for waste incineration is applied to the

total mass of animal carcasses to determine the amount of NO<sub>x</sub> released during combustion (US EPA 1995a). **See Table 10 in Appendix A for detailed data requirements for research animals.**

### **3. Projections**

After the model has been created and an institution's N footprint calculated, the model may be used to run scenarios to see how the footprint could change in the future. Future changes depend on two components: projected growth (this section) and scenarios to see how the footprint might be changed (Section 4). The first step in this process is to determine projected changes at your institution. Entering these data into the data template will show how your institution's N footprint will change in the coming years based on current and planned activities. These projections are based on:

Part 1. Population changes

Part 2. Food consumption and food production changes

Parts 3 and 4. Commuting and institutional transportation changes

Parts 5 and 6. Utilities N<sub>2</sub>O and NO<sub>x</sub> emissions

**See Table 11 in Appendix A for detailed data requirements.**

### **4. Scenarios**

#### **4.1. Scenarios description**

Scenarios will use the footprint calculated for the base year and the projections for future changes to see how alterations to consumption patterns or institution activities may change the N footprint. The results of these scenarios will be useful in creating N footprint reduction goals. The following are only some example scenarios, and others could be run as well in coordination

with the model developers. First, scenarios testing an individual action (such as food waste composting) may be considered. Second, the scenarios may be grouped into different projections describing possible paths forward for the institution. These scenarios may be used to inform a nitrogen footprint reduction target.

Scenarios that can be tested in the current data template are the following, with possible choices in parentheses. The scenario decisions on the ***Projection Summary*** tab, and the calculations and some data entry are completed on the ***Scenarios*** tab.

*Business as usual* (Yes/No). Assumes that no nitrogen-reduction strategies are in place. If this scenario is selected, no others can be chosen.

1. *Transportation demand management strategies* (Yes/No). Determines the impact of a percent reduction goal for commuting by with faculty, staff, and student commuting. This scenario considers the impact of expected population growth.
2. *Planned carbon and utilities reductions* (Yes/No). Determines the impact of a percent reduction goal for institution utilities usage. Specific fuel types are not considered directly here. This scenario considers the impact of expected population growth.
3. *Implementation of tertiary sewage treatment* (Yes/No). Determines the impact of an increased rate of nitrogen removal at the local sewage treatment facility.
4. *Composting of all food waste* (Yes/No and Percent). Determines the impact of increased food composting. Users can identify the percent of food waste that will be composted.
5. *Participation in food donation programs* (Yes/No and Percent). Determines the impact of donating some food waste. Users can identify the percent of food that will be donated.

6. *Participation in Meat Free Mondays* (Yes/No). Determines the impact of replacing a meat-based meal with a vegetable-based meal on Mondays. The number of meals per year and weeks of service can be identified.
7. *Substitution of chicken for beef* (Yes/No and Percent). Determines the impact of replacing beef purchases with chicken purchases. Users can identify the percent of beef purchases that will be replaced.
8. *Purchases made from farms with more sustainable practices* (Yes/No). Determines the impact of replacing all food purchases with food produced sustainably in terms of nitrogen.
9. *Locally purchased food* (Yes/No). Determines the impact of exclusively purchasing local food. This scenario changes the food transport miles to a local radius, which can be entered by the user.

**Consult the model developers to add additional scenarios.** For example, if protein is over-consumed at your institution, you could consider a scenario that encourages consumers to reduce protein consumption to the recommended level. **See Tables 12 and 13 in Appendix A for detailed data requirements.**

The specific scenarios described above may be grouped into projections that describe different paths forward for your institution (see Figure 10 for more information). The projection pathways considered for the UVA nitrogen footprint included the following

- A. No actions taken to reduce the institution's carbon or nitrogen footprints, including current efforts.
- B. The institution achieves its stated goal to reduce carbon emissions.

C. In addition to projection B, the institution also implements scenarios that are deemed feasible and realistic.

D. All modeled scenarios implemented, including scenarios that would be difficult to fully achieve.

It is important to note that scenarios and projections have inherent uncertainty. However with careful consideration of the data, they can be used to identify nitrogen footprint reduction goals and inform institutional decision-making.

#### 4.2. Projection Summary

Projections and scenario results are summarized in the Projection Summary tab. The Projection Summary tab has 4 steps for analysis:

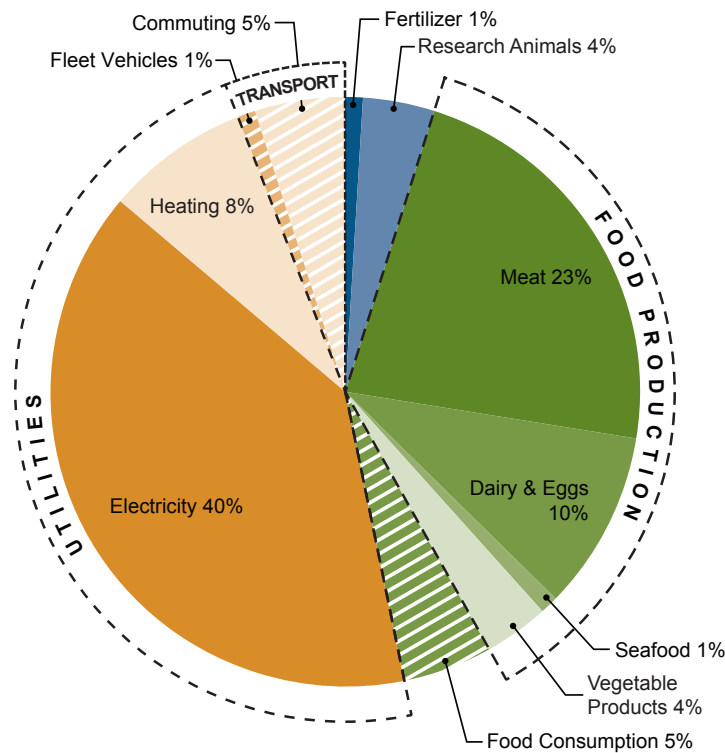
1. *Enter baseline footprint.* It is important to copy-paste the baseline footprint from the Summary tab into the Projection Summary tab. This is because some of the scenarios require the entire model to run, and it is important to have the baseline footprint available for comparison.
2. *Select whether to run scenarios.* Here the options are “No scenarios (business as usual)” and “Scenarios.”
3. *Select scenarios to run.* In this table, you can select which of the 9 available scenarios you would like to run. You can also run a combination of these scenarios.
4. *Analysis output, baseline year and projection year.* These two tables show the results for both the baseline year and the projection year at the same time. Note that you cannot view business as usual results and scenario results at the same time, but you can copy-paste results to a table at the end of the Projection Summary tab for comparison.

Once you have run the projections and scenarios, you can compare the results. To do this, copy-paste the results from step 4 into the “Comparison of Projection and Scenario Results” table at the end of the Projection Summary tab. Be sure to name each result, identify the year (baseline or projection), and identify the type of analysis (business as usual or scenarios). We encourage you to run multiple scenario analyses with different combinations of scenarios. At a minimum, we suggest running the following analyses and enter them into the comparison table: baseline year, business as usual; baseline year, with some scenarios; baseline year, with all scenarios; projection year, business as usual; projection year, with some scenarios; projection year, with all scenarios. A graph then presents all of these separate model runs.

#### 4.3. A case study: The University of Virginia

This section presents the results of the nitrogen footprint of the University of Virginia for the 2010 calendar year. The original institution-level N footprint model was developed for UVA (Leach et al. 2013) and has since been adapted for use by other institutions.

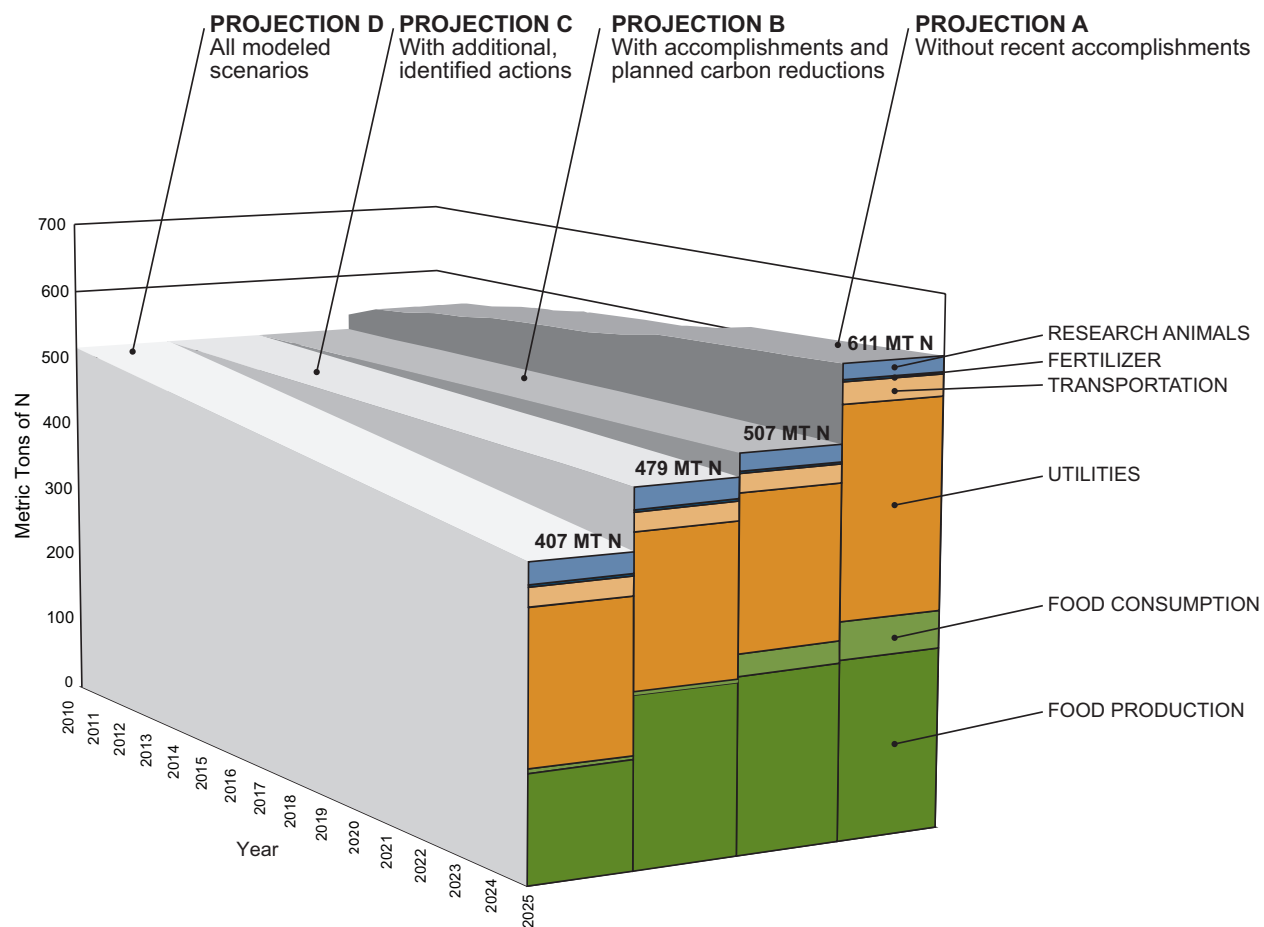
The total nitrogen footprint of UVA in 2010 was found to be 492 metric tons (MT) N (Figure 9). Utilities usage (including electricity and heating) contributed the most to UVA’s N footprint (48%), and food production was the second biggest contributor (37%). The other sectors (food consumption, fertilizer usage, and research animals) made up the remaining 25%. Of the food categories, meat production made up the largest portion of the footprint (22%).



**Figure 9.** Nitrogen footprint of the University of Virginia in 2010, by sector.

Expected future growth, planned construction, and individual scenarios were considered to identify potential paths forward for the UVA nitrogen footprint. Four specific projections were identified to see how UVA's N footprint could change between the years 2010 and 2025 (Figure 10). The first of those projections (A) assumes that no actions are taken to reduce UVA's carbon or nitrogen footprints and, furthermore, that some N-saving actions (e.g., composting) that contributed to a decrease in the 2010 N footprint had not occurred. Growth in UVA's footprint is driven by increases in population and energy use. Projection B assumes that 2010 actions remain in place (e.g., food composting) and that UVA also achieves its stated goal (adopted in 2011) to reduce carbon emissions by 25% by the year 2025, relative to 2009 levels (UVA 2011). This projection assumes that carbon emissions will be reduced by strategies that also generally favor nitrogen reduction, such as reduced fuel consumption and fossil fuel combustion. Projection C

builds on projection B by factoring in new tertiary sewage treatment (installed in 2011) and modeling additional actions that were identified as realistic in discussions with UVA stakeholders. Projection D includes all modeled scenarios, including scenarios that would be difficult or impossible to fully achieve (e.g., 100% food purchases from low nitrogen farms).



**Figure 10.** A comparison of four projections for the UVA nitrogen footprint from 2010 to 2025.

Of the food scenarios, the incorporation of a tertiary sewage treatment and the purchase of sustainably produced food most significantly reduced the total N footprint. Purchasing only local food led to the smallest footprint reduction. Of the energy scenarios, the most effective was control of  $\text{NO}_x$  emissions from point sources. The footprint reduction calculated for UVA in

2025 due to the implementation of all modeled scenarios was 20%, relative to the 2010 N footprint. Additional scenarios can be identified to achieve a greater N footprint reduction.

## **5. What to do with the results**

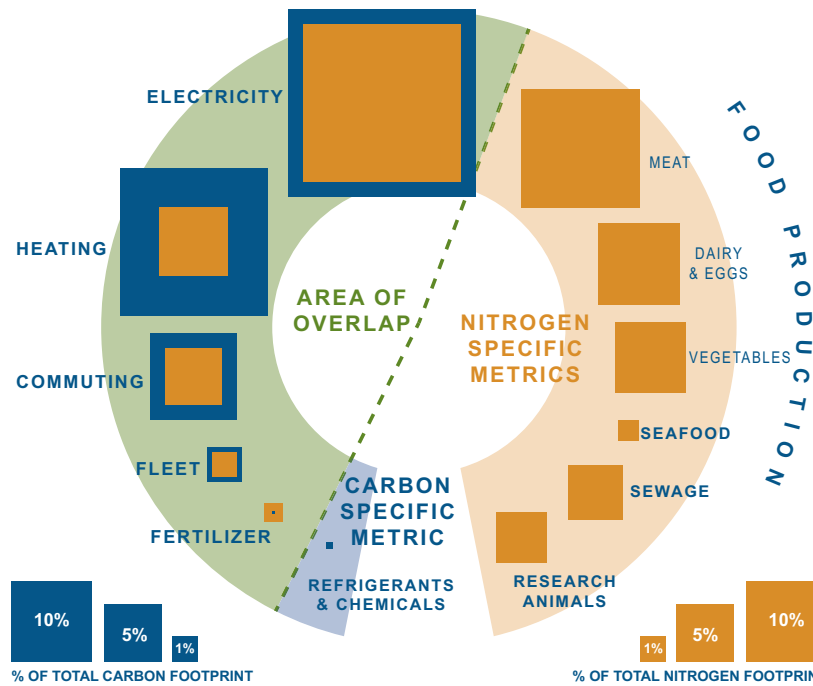
### **5.1. Suggested goals for nitrogen footprint reduction**

The main function of this institution-level N footprint model is to provide institutions with the tools necessary to determine and reduce their nitrogen impact. The results of your institution's N footprint calculation and the associated scenarios analysis will provide a wealth of information that your institution can use to improve its sustainability. We suggest the following actions be taken:

1. Compare your institution's N footprint to other institutions
2. Identify achievable N footprint reduction strategies
3. With the above, identify an N footprint reduction target
4. Encourage your institution to officially commit to achieve a N footprint reduction target
5. Use the model to track progress towards N footprint reduction goals

### **5.2. Carbon and nitrogen footprints**

If a carbon reduction goal is already in place or in progress at your institution, it may be synergistic to combine the carbon and nitrogen footprints. A combined carbon and nitrogen footprint reduction goal would have a broader reaching sustainability impact than either individual goal. Figure 11 shows the overlap between the carbon and nitrogen footprints at the University of Virginia.



**Figure 11.** A comparison between the sectors contributing to the carbon and nitrogen footprints of the University of Virginia. Blue boxes show the relative contribution to the total carbon footprint from each category (e.g., electricity, refrigerants & chemicals). Orange boxes show the relative contribution to the total nitrogen footprint from each category (e.g., electricity, meat production). Categories may contribute to an institution's nitrogen footprint, carbon footprint, or both. The blue area indicates the categories that are only accounted for in the carbon footprint, the orange area indicates the categories that are only accounted for in the nitrogen footprint, and the green area indicates the categories that are accounted for in both footprints.

## **6. Glossary**

**American College & University Presidents' Climate Commitment (ACUPCC):** A collaboration between higher educational institutions aiming to reduce net greenhouse gas emissions from campus operations and educate on climate solutions through leadership

**Biological nitrogen fixation (BNF):** The process by which some plants, with the help of soil microorganisms, fix  $N_2$  and convert it to ammonia ( $NH_3$ ).

**Carbon footprint:** The total sets of greenhouse gas emissions caused by an entity's activities.

**Haber-Bosch process:** An industrial process that transforms unreactive nitrogen and hydrogen into ammonia.

**Nitrogen budget:** Accounts for the flow of Nr through a system, taking into account natural processes and anthropogenic processes.

**Nitrogen cascade:** The concept that a single molecule of Nr may contribute to multiple environmental effects in sequence before it returns to the unreactive form.

**Nitrogen footprint:** Quantifies the Nr released to the environment as a result of an entity's activities.

**Reactive nitrogen (Nr):** All forms of nitrogen besides  $N_2$ . Nr is measured by a nitrogen footprint.

**Scopes (of an environmental footprint):** Identifies where footprint losses occur relative to the entity of interest.

**System boundaries:** Parameters (geographic, operational, etc.) that define the extent of the system being evaluated.

**Virtual nitrogen factor (VNF):** A factor that represents the nitrogen lost to the environment during the production of a food item, expressed as kg N released to the environment per kg N contained in the food product.

**Weighted campus user:** A formula derived from the AASHE STARS assessment to accurately capture annual campus population by accounting for fluctuations over time.

## **6. References**

- [AASHE] Association for the Advancement of Sustainability in Higher Education. 2013. STARS Technical Manual, Version 2.0, Administrative Update One.
- [ACUPCC] American College and University Presidents' Climate Commitment.  
<http://www.presidentsclimatecommitment.org/>. Last accessed on 1 January 2013.
- BC Ministry of Environment. 2001. "Animal Weights and Their Food and Water Requirements."  
<http://www.env.gov.bc.ca/wat/wq/reference/foodandwater.html>. (Last accessed on 21 April 2013).
- Eastern Research Group, Inc. 2007. "Emission Factors for Priority Biofuels in Minnesota."  
<http://www.pca.state.mn.us/index.php/view-document.html?gid=3402>. Last accessed on 21 April 2013.
- Feldman, Sanford. University of Virginia, Center for Comparative Medicine, personal communication, January 2012.
- Feldman, Sanford. University of Virginia, Center for Comparative Medicine, personal communication, 6 August 2012.
- Galloway, JN, J Aber, J Erisman, S Seitzinger, R Howarth, E Cowling, B Cosby. 2003. The nitrogen cascade. *BioScience*. 53:341-356.
- Galloway, JN, AR Townsend, JW Erisman, M Bekunda, Z Cai, JR Freney, LA Martinelli, SP Seitzinger, MA Sutton. 2008. Transformation of the nitrogen cycle: Recent trends, questions and potential solutions. *Science*. 320:889-892.
- Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., and Meybeck, A. 2011. Food and Agriculture Organization of the United Nations. Global Food Losses and Food Waste.  
<http://www.fao.org/docrep/014/mb060e/mb060e00.pdf>. Last accessed on 1 January 2013.
- Kazas, Tom, ed. "Fuel Sources for 2010." *Dominion Customer Connection* (Mar. 2011): 2.
- Leach, AM. 2009. The Impact of Changes in Meat Consumption on the University of Virginia's Nitrogen Footprint (Undergraduate thesis). University of Virginia, Charlottesville VA
- Leach, AM, J Galloway, A Bleeker, JW Erisman, R Kohn, J Kitzes. 2012. A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. *Environmental Development*. 1: 40-66.
- Leach, AM, AN Majidi, JN Galloway, AJ Greene. 2013. Toward institutional sustainability: A nitrogen footprint model for a university. *Sustainability: The Journal of Record*. 6: 211-219.
- [GHG Protocol] World Resources Institute/World Business Council for Sustainable

Development. A Corporate Accounting and Reporting Standard. Revised Edition.  
<http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf>. Last accessed on 13 December 2013.

National Research Council (U.S.). 2003. Air emissions from animal feeding operations: Current knowledge, future needs. National Academies Press, Washington, D.C.

Rockström, J, W Steffen, K Noone, A Parsson, F Chapin, E Lambin, T Lenton, M Scheffer, C Folke, J Schellnhuber, B Nykvist, C de Wit, T Hughes, S van der Leeuw, H Rodhe, S Sorlin, P Snyder, R Costanza, U Svedin, M Falkenmark, LR Karlberg, W Corell, V Fabry, J Hansen, B Walker, D Liverman, K Richardson, P Crutzen, A Foley. 2009. A safe operating space for humanity. *Nature*. 461:472-475.

Savanick, S, L Baker, J Perry. 2007. Case study for evaluating campus sustainability: nitrogen balance for the University of Minnesota. *Urban Ecosystems*. 10:119-137.

Tacon, A.G.J. 1990. Food and Agriculture Organization of the United Nations. Fish Feed Formulation and Production.  
<http://www.fao.org/docrep/field/003/U4173E/U4173E00.htm#TopOfPage>. Last accessed on 21 April 2013.

[USDOT] US Department of Transportation. Federal Highway Administration. 2000. Comprehensive Truck Size & Weight Study. <http://www.fhwa.dot.gov/reports/tswstudy/>. Last accessed on 21 April 2013.

[US EPA] US Environmental Protection Agency. 1995a. 2.3 Medical Waste Incineration.  
<http://www.epa.gov/ttnchie1/ap42/ch02/final/c02s03.pdf>. Last accessed on 21 April 2013.

[US EPA] US Environmental Protection Agency. 1995b. AP 42, Fifth Edition: Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources.  
[www.epa.gov/ttnchie1/ap42](http://www.epa.gov/ttnchie1/ap42). Last accessed on 21 April 2013.

[UVA] University of Virginia. Resolutions Adopted by the Board of Visitors, June 9-10, 2011.  
<http://www.virginia.edu/bov/meetings/11june/'11%20JUNE%20BOARD%20MINUTES.pdf> (last accessed 1/01/2013).

Vitousek, PM, DNL Menge, SC Reed, CC Cleveland. 2013. Biological nitrogen fixation: Rates, patterns, and ecological controls in terrestrial ecosystems. *Phil Trans*: in press.

Wuest, S, K Cassman. 1992. Fertilizer-nitrogen use efficiency of irrigated wheat: I. Uptake efficiency of preplant versus late-season application. *Agronomy Journal*. 84:682-688.

## 7. Appendix A: Data Requirements Tables

**Table 1. Utilities**

Data category	Data requirements
Utilities	<ul style="list-style-type: none"><li>• Fuel type</li><li>• Amount of fuel</li><li>• Fuel type breakdown</li><li>• Emission factors (NO<sub>x</sub> and N<sub>2</sub>O)*</li></ul>

\* *Optional data inputs for improved accuracy*

**Table 2. Transportation**

Data category	Data requirements
Institutional transportation	<ul style="list-style-type: none"><li>• Vehicle type</li><li>• Fuel Type</li><li>• Amount of fuel</li><li>• NO<sub>x</sub> and N<sub>2</sub>O emission factors for any additional transportation types</li></ul>
Commuting transportation	<ul style="list-style-type: none"><li>• Vehicle type</li><li>• Fuel Type</li><li>• Number of individuals</li><li>• Percent commuting by vehicle type (the proportion of individuals who take each mode of transportation to commute to the institution)</li><li>• Percent driving alone</li><li>• Number of trips per day</li><li>• Number of days per year commuting</li><li>• Number of miles per trip (a trip is the distance from home to school)</li><li>• NO<sub>x</sub> and N<sub>2</sub>O emission factors for any additional transportation types</li><li>• Commercial flight data: total miles or hours travelled, or number of trips taken</li></ul>

**Table 3. Fertilizer**

Data category	Data requirements
Fertilizer use	<ul style="list-style-type: none"><li>• Amount of fertilizer</li><li>• N uptake factor by vegetation type*</li></ul>

\* *Optional data inputs for improved accuracy*

**Table 4. Food Calculation 1**

Data category	Data requirements
Meal information	<ul style="list-style-type: none"><li>• Number of meals served</li></ul>

**Table 5. Food Calculation 2**

Data category	Data requirements
Population	<ul style="list-style-type: none"> <li>• Number of residential students (annualized by headcount)</li> <li>• Number of residential employees (annualized by headcount)</li> <li>• Full-time equivalent enrollment (annualized FTE)</li> <li>• Full-time equivalent of employees (annualized FTE)</li> <li>• Full-time equivalent of distance education students (annualized FTE)</li> <li>• Number of in-patient hospital beds</li> </ul>

*Source: AASHE STARS Technical Manual*

**Table 6. Food Calculation 3**

Data category	Data requirements
Meal information	<ul style="list-style-type: none"> <li>• Food types, split into major food categories**</li> <li>• Weight of each type of food</li> <li>• Truck fuel efficiency*</li> <li>• Emission factors*</li> </ul>
Amount of food served	<ul style="list-style-type: none"> <li>• Number of meals served</li> </ul>

\* *Optional data inputs for improved accuracy*

\*\* *Pre-prepared multi-ingredient food items (e.g., lasagna) will need to be split up into the major food categories (e.g., meat lasagna = beef, grains, vegetables, and cheese).*

**Table 7. Food Calculation 4**

Data category	Data requirements
Meal information	<ul style="list-style-type: none"> <li>• Food types, split into major food categories**</li> <li>• Weight of each type of food</li> <li>• Truck fuel efficiency*</li> <li>• Emission factors*</li> </ul>

\* *Optional data inputs for improved accuracy*

\*\* *Pre-prepared multi-ingredient food items (e.g., lasagna) will need to be split up into the major food categories (e.g., meat lasagna = beef, grains, vegetables, and cheese).*

**Table 8. Food Calculation 5**

Data category	Data requirement
Meal information	<ul style="list-style-type: none"> <li>• All data required for Calculation 4</li> </ul>
Scaling	<ul style="list-style-type: none"> <li>• Scaling factor for representative facility, such as by weight or by actual cost</li> </ul>

**Table 9. Food diversion**

Data Type	Data Requirement
Food diversion	<ul style="list-style-type: none"> <li>Amount of food diverted (by % of purchases or weight)</li> <li>Destination of diverted food (e.g., composted, donated)*</li> </ul>

\* *Optional data inputs for improved accuracy*

**Table 10. Research animals**

Data Category	Data Requirement
Incineration	<ul style="list-style-type: none"> <li>Are carcasses incinerated? (Y or N)</li> <li>Nitrogen in carcass*</li> <li>NOx emission factor for carcass incineration*</li> </ul>
Live Animals	<ul style="list-style-type: none"> <li>Type of animal</li> <li>Number of animals (standing stock and number euthanized per year)</li> <li>Protein requirement per day*</li> <li>Average body mass*</li> </ul>
Feed	<ul style="list-style-type: none"> <li>Percent of food per food type*</li> <li>Total food mass*</li> <li>Virtual N factors*</li> <li>Food miles*</li> <li>Truck fuel efficiency*</li> <li>N<sub>2</sub>O emission factor*</li> <li>NOx emission factor*</li> <li>Total N due to food transport*</li> </ul>

\* *Optional data inputs for improved accuracy*

**Table 11. Projections**

Data Category	Data Requirement*
Population	<ul style="list-style-type: none"> <li>Projected increase in population (% or numbers)</li> </ul>
Transportation	<ul style="list-style-type: none"> <li>Commuting data (e.g. number of individuals, average fuel efficiency)</li> <li>Institutional travel data (e.g. average fuel efficiency, emission factors)</li> </ul>
Utilities	<ul style="list-style-type: none"> <li>N<sub>2</sub>O emissions data</li> <li>NOx emissions data</li> </ul>

\* *Optional data inputs for improved accuracy*

**Table 12. Energy scenarios**

Question Number	Scenario	Data Requirement
1	Transportation management	<ul style="list-style-type: none"> <li>Projected % increase with respect to calculation year (no reduction strategies)</li> <li>% commuting reduction goal with respect to calculation year</li> </ul>
2	Carbon and utilities reductions	<ul style="list-style-type: none"> <li>Projected % increase with respect to calculation year (no reduction strategies)</li> <li>% utilities reduction goal with respect to calculation year</li> </ul>

**Table 13. Food scenarios**

Question Number	Data Category	Data Requirement
3	No efforts made to reduce the nitrogen footprint (no sewage treatment or food recycling)	<ul style="list-style-type: none"> <li>Food waste factors*</li> </ul>
4	Implementation of tertiary sewage treatment	<ul style="list-style-type: none"> <li>Food waste factors*</li> <li>Sewage treatment N reduction factor</li> </ul>
5	Composting all food waste	<ul style="list-style-type: none"> <li>Food waste factors*</li> <li>Percent composting</li> </ul>
6	Full participation in food donation programs	<ul style="list-style-type: none"> <li>Percent of food donated</li> </ul>
7	Participation in Meat Free Mondays	<ul style="list-style-type: none"> <li>Food types, split into major food categories**</li> <li>Weight of each type of food</li> <li>Protein contents*</li> <li>Virtual N factors*</li> <li>Food miles*</li> <li>Truck fuel efficiency*</li> <li>Emission factors*</li> <li>Number of meals per year</li> <li>Number of weeks of service per year</li> </ul>
8	Substitution of chicken for beef	<ul style="list-style-type: none"> <li>Percent replacement</li> </ul>
9	Purchases made from farms with more sustainable practices	<ul style="list-style-type: none"> <li>Virtual N factors for sustainable food*</li> </ul>
10	All locally purchased food	<ul style="list-style-type: none"> <li>Local food miles*</li> </ul>

\* *Optional data inputs for improved accuracy*

\*\* *Pre-prepared multi-ingredient food items (e.g., lasagna) will need to be split up into the major food categories (e.g., meat lasagna = beef, grains, vegetables, and cheese).*

## 8. Appendix B: Emissions Factors Guidelines

Most fuel emissions factors (EFs) come from the EPA Clearinghouse for Inventories and Emissions Factors. (<http://cfpub.epa.gov/webfire/index.cfm?action=fire.detailedSearch>)

The N footprint includes both NO<sub>x</sub> and N<sub>2</sub>O emission factors. In general, the NO<sub>x</sub> and N<sub>2</sub>O EFs used in the UVA data template can be used for other institutions. However we recommend calculating an EF specific to your institution for purchased electricity, as the fuel mix varies by region and has a big impact on the EF.

### Purchased Electricity Emission Factors

In the data template, the *standard units* for a purchased mix EF are kg N<sub>2</sub>O/kWh and lb NO<sub>x</sub>/kWh (the conversion to kg is done later). All the individual emissions factors need to be converted to kWh to calculate the mix.

Energy conversion factors can be found here: <http://www.epa.gov/appdstar/pdf/brochure.pdf>

As an example, here are a few converted emissions factors for NO<sub>x</sub>:

Fuel type	EF from database	Database units	Conversion factor	Converted EF (lb NO <sub>x</sub> /kWh)
Natural Gas	2.80E+02	lb NO <sub>x</sub> /10 <sup>6</sup> ft <sup>3</sup>	(1/10 <sup>6</sup> /970 ft <sup>3</sup> /Btu)*10107 Btu/kWh	0.002917
Coal	1.80E+01	lb NO <sub>x</sub> /ton	(1/21,000,000 lb/ton)*10107 Btu/kWh	0.008663
Biomass	0.109	lb NO <sub>x</sub> /Mmbtu	(1/10 <sup>6</sup> btu/Mmbtu)*10107 Btu/kWh	0.001102

Utility providers use a mix of different fuels and energy sources. The fuel type breakdown (by %) is used to calculate a total emissions factor for purchased electricity.

Fuel mix EF = SUM(Fuel type EF x % contribution of fuel type)

In the current data template (version 1.5), this calculation is shown in the table for NO<sub>x</sub> and not in the table for N<sub>2</sub>O. The region-specific purchased mix EF for N<sub>2</sub>O can be found in the Campus Carbon Calculator, which is the tool commonly used to calculate university carbon footprints. If you do not use this resource, you can calculate the N<sub>2</sub>O EF for purchased electricity with the above formula.

### Adding Emissions Factors

The data template currently includes only fuels used at UVA. If there are additional fuel or energy sources used at your institution, you can add an EF to the Data Inputs tab under 'Utilities'. Make sure to reference the correct cells so that fuel types and EFs match the data you entered on the Data Inputs tab.

## **9. Appendix C: Data template practice exercise**

The purpose of this exercise is to help the user gain familiarity with the data template and excel with a standard dataset. Results are provided to check against your output. First, review common excel tools, including those listed in Section 1. Second, enter data into the correct tabs on the data template as described in section 2.

### **Section 1: Excel Hacks**

- Paste special: right-click or Edit-Paste Special, this allows you to paste only values without changing any of the spreadsheet formatting
- Trace precedents/trace dependents: In the Formulas toolbar, these tools will show which cells contain information that relates to a selected cell
- Hidden sheets: Right-click in the sheet tab section on the bottom to hide or un-hide sheets
- Insert copied/cut cells: When you need to copy cells to make room for more data, select the section you are extending and copy it, then right-click to insert copied cells (rather than pasting them)
- Drag down formulas: select the cell with the formula you need to copy, and drag down from the bottom-right corner of the selected cell

### **Section 2: Data Template Exercise – Calculating the N Footprint of an imaginary school**

This exercise focuses on participants' use of transportation and the food production values associated with our meals consumed at UVa.

#### **1. Data Inputs Tab**

Copy the column “Value - used in the UVa model” to the “Value - for your institution” column, making sure to use “Paste special” to preserve the formatting.

#### **2. Transportation Tab**

Assuming that the imaginary school does not provide institutional transport (those cells should be empty) and that commuters make 2 trips per day, enter the following transportation data for commuting:

Commuter group	Vehicle type	Fuel type	# of Individuals	% by vehicle type	% driving alone	% carpooling	Days/year	Miles
Faculty	Personal	Gasoline	250	84%	67%	17%	170	15
	Bus	Diesel	250	7%	NA	NA	170	5
Staff	Personal	Gasoline	835	84%	67%	17%	220	15
	Bus	Diesel	835	7%	NA	NA	220	5
Students	Personal	Gasoline	1785	17%	15%	2%	180	7
	Bus	Diesel	1785	12%	NA	NA	180	5

### 3. Food Calculation Tabs

#### *Food Factors Tab*

Enter 'N' for the first three questions about using your own data. You will use UVA data for this exercise.

#### *For Calculation 1*

This scaling factor uses data from UVA's O'Hill Dining Hall and scales it by number of meals served. Enter 963,900 for number of meals served.

#### *For Calculation 2*

The student population is 1,785 – enter this number for student population.

#### *For Calculation 3*

Enter these sample meals. The number of meals served in a year is 323,100.

Meal Served	Food Item	Total Mass (kg)	Components
Breakfast – Coffee, fruit, and pastries, and eggs	Coffee	0.007	Coffee
	Fruit	0.25	Fruit
	Pastries	0.18	Wheat flour
			Sugar
	Omelet	0.20	Eggs
			Vegetables
Cheese			
Lunch – Soup, turkey sandwich, and cookies	Soup	0.25	Vegetables
	Turkey Sandwich	0.25	Turkey
			Wheat flour
			Cheese
			Apple
			Bacon
	Cookies	0.08	Wheat flour
			Sugar
Eggs			
Dinner - Beef lasagna, salad, and roasted root vegetables	Salad	0.13	Vegetables
			Nuts
	Beef lasagna	0.30	Wheat
			Beef
			Cheese
			Vegetables
Roasted root vegetables	0.20	Vegetables	
Beverages	Milk	0.02	Milk
	Juice	0.02	Beverages
	Soda	0.02	Beverages

You will need to come up with the entries for the Food Type and Multi-Ingredient categories. Food Types in the Data Template are: Poultry, Bovine, Pigeat, Milk, Cheese, Eggs, Fish,

Cereals, Fruits, Pulses, Starchy roots, Vegetables, Stimulants, Oilcrops, Sugarcrops, Nuts, Spices, and Beverages. Each of the food items above is split into its component ingredients.

*For Calculation 4*

<b>Food Product</b>	<b>Total Mass (kg)</b>	<b>Multi-Ingredient? Which categories?</b>
Coffee	2,262	N - Stimulants
Fruit	80,775	N - Fruits
Pastries	29,079	Y – Cereals, Sugarcrops
Eggs	21,540	N - Eggs
Tomatoes	10,770	N - Vegetables
Peppers	10,770	N - Vegetables
Potatoes	64,620	N – Starchy roots
Sliced turkey	16,155	N - Poultry
Sandwich rolls	16,155	N - Cereals
Vegetable soup	80,775	N – Vegetables
Cookies	8,616	Y – Sugarcrops, Cereals, Eggs
Apples	16,155	N - Fruits
Bacon	16,155	N - Pigmeat
Lettuce	21,002	N - Vegetables
Pecans	21,002	N - Nuts
Beef lasagna	96,930	Y – Cereals, Bovine, Cheese, Vegetables
Milk	6,462	N - Milk
Juice	6,462	N - Beverages
Soda	6,462	N - Beverages

*For Calculation 5*

There is only one dining hall at this imaginary school, so enter a scaling factor of 1.

4. Utilities Tab

For the N<sub>2</sub>O Emissions Table (top), enter the following:

Utility Type	Location	Utility Source	Fuel Type	Amount	Unit	EF Unit
Electricity	Provider	Purchased	Mix	65,400,920	kWh	Kg N <sub>2</sub> O/kWh
Heating	On-site	On-site	Natural gas	95,740	MMBtu	Kg N <sub>2</sub> O/MMBtu
Heating	School	On-site	Propane	25,200	Gallons	Kg N <sub>2</sub> O/gal

For the NO<sub>x</sub> Emissions Table (below), enter the following:

Utility type	Location	Utility source	Fuel type	Total fuel type	% contribution of fuel type
Electricity	Provider	Purchased mix	Natural gas	65,400,920	14%
Electricity	Provider	Purchased mix	Coal	65,400,920	45%
Electricity	Provider	Purchased mix	Nuclear	65,400,920	41%
Heating	On-site	On-site	Natural gas	95,740	100%
Heating	On-site	On-site	Propane	25,200	100%

#### 5. Fertilizer Tab

3450 lbs. of N were applied as synthetic fertilizer.

#### 6. Food Recycling Tab

Enter “%” for the type of calculation used. 45% of food waste is composted and 15% is donated. Keep 25% for the Pulper water removal factor.