

Quantifying and Reducing Nitrogen Footprints of Urban Areas: A Case
Study for Baltimore, Maryland

Elizabeth Milo

Thesis Research

Environmental Sciences Department

University of Virginia

Supervised by Professors James Galloway (UVA), Lawrence Band (UVA), and Peter Groffman
(CUNY)

Abstract

Reactive nitrogen (Nr; all N species except N₂) is created by the Haber-Bosch process for food production and is created as a by-product of fossil fuel combustion as well as a number of other natural processes. While it is vital for food production, too much Nr has a negative effect on the environment. Calculating its amount released to the environment as a result of an entities' resource use is useful for managing the amount of excess Nr in the environment. Footprints both provide a baseline for understanding N losses and are used to identify reduction strategies. The nitrogen (N) footprint tool for both individuals and institutions allows each of these entities to do that. Individuals use the personal N footprint calculator to calculate the N impacts of their daily activities. The institutional nitrogen footprint calculator is a tool designed for educational and operational purposes at institutions to quantify the impact of their activities on the institution's N footprint.

The objective of my project is to calculate the nitrogen footprint for Baltimore City, using the calculation to build an urban nitrogen footprint tool with census block groups as the organizational format. The baseline footprint calculation will then be used to test scenarios on what actions could be taken to decrease the N footprint of Baltimore City. The steps to create this tool are establishing system bounds, collecting relevant data, calculating the N footprint, and suggesting reduction strategies. Reduction strategies will include scenarios coinciding with the state of Maryland's Greenhouse Gas Action Plan as well as some food strategies intended to reduce the N footprint of the area. The intended result of this tool is to be able to communicate and implement N footprint reduction strategies in the Baltimore area by working with stakeholders. The intended users of this tool are scientists, city planners, and other city and county administrators. The model for the Baltimore N footprint calculation model can be applied to other cities in the US to provide an indicator of sustainability across cities.

For 2016, the total N footprint of Baltimore City was 17,128 MT N. The per capita N footprint of Baltimore City was 28 kg N. The N footprint of Baltimore is dominated by the food production sector (73%) and is comparable to the US average N footprint on a per capita basis. Energy sectors (electricity use, natural gas use, and transportation) made up 15% of the total Baltimore City N footprint. There is substantial variability among census block groups per capita N footprint within Baltimore City, governed primarily by economic factors. From the findings of this paper, there is a statistically significant relationship between per capita N-footprint and per capita annual budgeted expenditures. As an individual's annual expenditures increase, so does their N-footprint for census block group groups in Baltimore City. For these census block group groups the most effective reductions scenarios are those which decrease the N footprint in the food sector, however these will be the most difficult to implement on a broad scale. The effectiveness and feasibility of food, energy, and transportation scenarios were analyzed and recommendations made for suggested practices to reduce the Baltimore City N footprint over time.

Introduction

Nitrogen is abundant in the atmosphere as N_2 . It is also present throughout the biosphere in its reactive forms (e.g., NO_x (nitrogen oxides), N_2O , NO_3^- , NO_2^- , NH_4^+ , and NH_3) and as a component in multiple organic compounds. Unreactive N_2 is very stable in the atmosphere. Reactive forms of nitrogen (Nr) are found in the natural environment and are essential for all life. In the natural environment, the conversion of N_2 to Nr is done by biological N fixation (BNF) and by lightning. Humans create Nr in two ways. In 1913, the Haber-Bosch process was invented to synthetically convert N_2 to NH_3 to be used in munitions, and later as synthetic fertilizer and as an industrial feedstock. In addition, fossil fuel combustion and cultivation induced BNF (i.e., legumes) are also human sources of Nr to the natural environment. Humans use fossil fuels to produce energy in the forms of electricity, heat, and transport. Fossil fuel combustion releases NO_x and N_2O as a result of incomplete combustion. These are released to the atmosphere and can either be deposited to the land or oceans or will react with other elements in the atmosphere (*Products of Combustion* (2017)). Thus, humans add to the global Nr pool primarily through food and energy production. For the former, not all of the Nr created for food production is taken up by crops and converted in to the products for human consumption. The percent Nr crops take up

depends on factors such as species, climate, and soil conditions but on average, plants use less than half of Nr available and the rest is lost to the environment (Galloway et al., 2002). These losses can have detrimental effects to the environment which include smog and haze, forest die-back, acidification of waterways, eutrophication, climate change, and ozone depletion. These effects are called the nitrogen cascade. The nitrogen cascade refers to the multiple effects listed above that nitrogen can have on the environment. Over time, these effects are amplified as the Nr molecules move through and between earth's systems (Galloway et al., 2003).

A nitrogen footprint is the amount of reactive nitrogen released to the environment as a result of an entity's resource use (Leach et al., 2012). These resource uses include food consumption, energy production, transportation, fertilizer use, sewage treatment, and others depending on the entity. The entity could be a person, institution, or in this case a city.

To date, there are two variants of the nitrogen footprint tool (NFT)—one for individuals and one for institutions. The individual NFT evaluates the impacts of an individual's daily choices on their N footprint (Leach et al., 2012). There are tools specific to the United States and other countries and one version specific to individuals living in the Chesapeake Bay watershed (Chesapeake Bay Foundation, 2016). The personal NFT calculator bases a person's nitrogen footprint on personal decisions about diet, housing and energy use, transportation, goods and services, and sewage treatment. The output of this tool compares a person's N footprint with the average N footprint of either an individual in that country or watershed. The intended use of this tool is for individuals to govern the choices that they are making personally to reduce their N footprint.

The institution NFT is a tool for colleges, universities and research organizations (Leach et al., 2013). This variant of the NFT calculates an institution's nitrogen footprint by gathering data on its energy consumption, food purchases, sewage treatment, transportation, fertilizer and research facilities within the bounds of the institution. The use of the N footprint calculation within institutions is slightly different than in the individual calculator. The institution NFT has defined system bounds and is intended to be used as a sustainability metric to set top-down reduction goals by governing boards. For example, at the University of Virginia (UVA), after calculating

its N footprint for 2010, UVA's governing board set an N footprint reduction goal of 25% by the year 2025. These types of goals can be reached by implementing reduction plans for the university which include sustainability actions such as reducing meat purchases, reducing energy consumption, improving transportation strategies and many other sustainability efforts (Leach et al., 2013).

NFTs have been developed at personal and institution scales and are used for both tracking N footprints and setting reduction goals. On a larger scale, a city NFT could be used for the same objectives. The intended users of this tool would be city administrators (sustainability offices, administrative offices, or scientists), giving them the ability to track the N footprint of a city. Once this calculation is complete, city officials could use the N footprint as a tool to identify areas where N footprint reductions could be encouraged. Some challenges that could arise would be the lack of a centralized data source as well as ineffective implementation and enforcement protocols. In the personal N-footprint tool individuals are able to input personal resource use and institutions have a governing board as well as a centralized food provider and facilities management with data on resource consumption. A city is a collection of individuals and institutions with no centralized point of data collection on items like food, electricity, natural gas, or fertilizer. Obtaining data from multiple sources is a potential challenge for a city NFT. All cities may not have the same level of data collection so comparisons across cities' N footprints will need to be done with awareness to this issue. To create a prototype of a city NFT, a city will need to be chosen to collect relevant data and connect with city officials. Baltimore City is connected to a set of rich databases due to the establishment of a long-term ecological research station (LTER), the Baltimore Ecosystem Study (BES) to collect many different types of annual data. This makes Baltimore a perfect case study location for the city NFT.

My thesis addressed two research questions:

1. What is the total N footprint of Baltimore City and which sectors have the largest contribution to the total N footprint?
2. What is the impact of implementing specific N footprint reduction strategies on the N footprint at local (individual census block group group) and whole city scales?

These research questions were addressed as follows:

1. The total N footprint was calculated by building a tool to calculate the N footprint of a census block group (CBG) and collecting the data needed to apply this tool to each census block group in the Baltimore City. Then the CBG results were summed for the Baltimore City.
2. The impact of reduction strategies was assessed by altering specific sectors in the tool. Reduction strategies analyzed included:
 - a. Baltimore City Food Scenarios:
 - i. Replace 25% of beef purchased in the area with beans.
 - ii. Reduce protein consumption of areas consuming more than 80 grams per capita per day.
 - iii. Eliminate meat served at all fast-food restaurants
 - iv. Compost 100% of food waste in the area.
 - b. Energy Scenarios: Maryland Climate Action Plan
 - i. Increase renewables in fuel mix by 20% by 2022.
 - ii. Reduce overall energy consumption by 15% by 2022.
 - c. Transportation
 - i. Increase use of public transport by 10%.
 - d. Other
 - i. Reduce fertilizer use by 50%.
 - ii. Switch from dogs to cats as pets

Background

N Related Issues in Baltimore

One of the local effects of excess N_r in the Baltimore area is eutrophication. Baltimore City drains into the Chesapeake Bay, an important natural resource for ecosystem services related to water filtration, climate stability, recreation, and fisheries, producing an estimated \$22.5 billion in benefits each year (Phillips and McGee, 2016). The eutrophication issues caused by excess

nutrients (predominantly nitrogen and phosphorous) reduce capacity for the Chesapeake Bay to provide these ecosystem services. Reducing the detrimental effects of eutrophication improves the capacity of the bay to provide ecosystem services.

A second local effect of excess Nr in the Baltimore area is the presence of tropospheric ozone and smog in the area. In 2011 Baltimore ranked higher than 90% of cities in the US in NO_x concentrations over the year (*US Environmental Protection Agency: Ozone Pollution, 2015*). NO_x is emitted from fossil fuel burning and is captured in the N footprint model under the electricity, natural gas, and transportation sectors. Tropospheric ozone is formed by the reaction of NO_x with volatile organic compounds (VOCs) in the presence of solar radiation. The lifetime of NO_x in the atmosphere is relatively short because it is highly reactive with VOCs which create ozone. Although some ozone can be transported outside of the scope of Baltimore City, much of the NO_x emitted and transformed to ozone causes local environmental and human health effects. Tropospheric ozone can have negative health effects that include increased risk for respiratory disease, especially for people with existing health conditions such as asthma (*US Environmental Protection Agency: Ozone Pollution, 2015*). Reducing NO_x emissions in the Baltimore area would decrease the amount of ozone.

Issues such as eutrophication and tropospheric ozone are usually measured in terms of the amounts of pollutant. Birch et al., (2011) approached this topic in a unique way. Rather than stating an amount of pollutant and environmental effects caused by this pollutant, Birch et al. (2011) equated the costs associated with an amount in tonnes N and converted it to the dollar amount associated with the impacts to human health and the environment. Using these metrics, Birch et al. (2011) determined that the economic damage associated with ozone per tonne of N released to the environment is \$14,556 USD for the Chesapeake Bay region. NO_x and N additions to land (in the form of fertilizer and manure) are by far the two largest economic contributors to Nr pollution in the Chesapeake Bay region. Using economic metrics alongside N footprint metrics is a potential way to assess issues in the Chesapeake Bay area where Baltimore City is located.

Approaches used to Quantify Environmental Impacts of N in urban regions

Different approaches have been taken to quantify the environmental impacts of N in urban regions. These approaches included N budget approaches and Greenhouse Gas (GHG) Inventories.

A. N Budgets

An N budget approach estimates the major inputs and outputs of N across specific boundaries. In 2001, Baker et al. (2001) began to develop one of the first city N budgets for Phoenix, Arizona. Baker did this by quantifying the major inputs and outputs of N in the city. The paper states that humans are responsible for a little over 50% of the N_r present in the system. Baker et al. (2001) determined this by quantifying the amount of N_r fossil fuel combustion and planting of crops. This N budget also took into account the denitrification occurring in the system as a result of both human planted crops and natural systems. Measurements of N in streams and mass balance approaches were used to determine the amount of N_r stored in the system. Through this approach, Baker et al. were able to determine not only the inputs and outputs of the system but also distinguish the human induced N_r inputs and outputs from natural inputs and outputs. In urban watersheds in Minnesota, dominant inputs include runoff from personal fertilizer use and pet waste (Hobbie et al., 2017). Inputs were measured or modeled and include N deposition, estimation of fertilizer run off, estimation of number of pets and waste produced, and BNF estimations. Outputs were estimated by measuring the N content of storm water drainage and estimation of yard waste removal (Hobbie et al., 2017). The N retention in the watershed was measured as the difference between the N inputs and outputs.

Another type of N budget proposed in Singh et al. (2017) is a physical input-output table. This type of approach was used for crops grown in the state of Illinois. The approach quantifies the fertilizer used to grow each crop as the inputs and the N contained in the crops as outputs. It takes in to account crops grown and sold locally (within the state) as an input of fertilizer in to the system but not output outside of the system. The paper integrated the N budget with dollar amounts spent of N inputs (fertilizer cost) and N outputs (profits from crops sold). The majority of the N fertilizers were imports and the majority of the exports were from oil and soybean oils. The paper highlighted the imbalance of the N budget in agriculture-dominated states. This is caused by high N inputs due to fertilizer use while the majority of the products were exported.

The model concluded that the N outputs were higher than the N inputs which is contrary to most N budgets which show N retention within the system (Singh et al., 2017). However, this N budget took in to account exported goods as N losses and studied an agricultural area for a year while other N budget studies have been completed over a longer time period.

N budgets have been completed for some of the Baltimore area watersheds. The budgets for these watersheds quantify the amount of N being added to the system and determining how much of that N is removed before leaving the watershed via stream discharge (Groffman et al., 2004). This was done by measuring stream concentrations of N from six different urban and suburban watersheds in the Baltimore area with ranging gradients. The budget was calculated by comparing inputs from fertilizer and atmospheric deposition with stream runoff (output). This N budget also took in to account denitrification from different land cover sources in the area. This 2004 study of the Baltimore watershed determined that fertilization of suburban lawns was one of the largest inputs to the system which is consistent with the Hobbie et al. (2017) study in Minnesota where pet waste and fertilizer were the two largest N inputs to the budget.

In many N budgets, there is a certain amount of “unaccounted for N”. This refers to the N that is in the system but is not accounted for within the budget approach. This N can be stored in ground water, sequestered in the system, or taken up by plants. This N can also be released in the system as a result of agriculture occurring on site or sewer leakage or any type of source within a system. The unaccounted for N can be a large source in a system but is left out of many budget approaches.

B. Greenhouse Gas Inventory

The city level Greenhouse Gas (GHG) Inventory is another approach to quantify environmental impacts of GHG's including N₂O from a certain area. This type of an inventory takes a slightly different approach than a budget approach. A GHG inventory captures all of the GHGs emitted by all entities within the system bounds of the city regardless of where the environmental impacts ultimately occur. This type of inventory is separated into scopes one, two, and three based on the city's influence on each sector. A GHG inventory for Baltimore County and Baltimore city were completed in 2006 and 2011 (Brady and Fath, 2006; Aryal et al., 2011). The

approach was similar to the N footprint approach. A series of data was collected and then multiplied by emission factors to estimate the impact of each sector on the GHGs emitted in Baltimore County. The GHG inventory used by cities as a sustainability metric is especially important in Baltimore especially because it is a part of the International Council of Local Environmental Initiatives (ICLEI), a world-wide collection of cities committed to local governments for sustainability.

C. Difference between these methods and the N footprint

An N footprint approach is distinguished from an N budget by a few factors. One of the most important distinctions is the difference in what an N budget measures and what an N footprint measures. An N budget measures all relevant flows of N within a system, both anthropogenic and natural. An N footprint measures all flows that an entity (anthropogenic) flows that result from the entity's consumption and activities. . A footprint approach takes into account upstream losses of N which do not occur with the watershed. For example, food that is not fertilized and harvested in a specific watershed but purchased in that watershed would only be captured in the consumer waste portion of the N budget approach. The N footprint approach takes into account upstream losses that occur during the growing and harvesting stage as well as the consumer waste. The N budget approach also takes into account denitrification that occurs within the watershed before measuring the N output. The N footprint approach does not look at this but looks more at the total N lost.

An N footprint approach is different than a GHG inventory approach in the specificity of pollutant being measured. Although both a GHG Inventory and an N footprint measure N_2O , the N footprint measures flows of all other species of N as well, not only those considered a GHG. A GHG Inventory does not take into account species that are not considered greenhouse gases which are important in the N footprint, especially for food production and fertilizer use. The N footprint approach takes these aspects into account.

The best way to describe the N footprint approach is to use an example of an N footprint calculation completed for the University of Virginia (UVA). As a university, the institution is responsible for maintaining facilities such as labs, classrooms, and student housing facilities. The

buildings need to have electricity and be heated and cooled. This is included in the purchased electricity and on-site heating N footprint for UVA. Transportation to and from the university is provided by university buses and some students and employees use other forms of transportation to reach the university. This is included in UVA's transportation N footprint. The university is responsible for purchasing food to serve in on-campus dining locations as well as treating the sewage generated in facilities. This is included in the institution's food production and consumption N footprints. Other sectors included are fertilizer applied on campus and research animals used in labs. All up-stream losses for these sectors are accounted for when assessing UVA's N footprint. One example to illustrate this is with the food production sector. UVA's N footprint takes in to account all of the N losses that occur in the growing, harvesting, and transport of the food that it receives even though UVA is only purchasing the food. Figure 1 from the Leach et al. (2013) is a schematic of the system bounds of the UVA N footprint calculation.

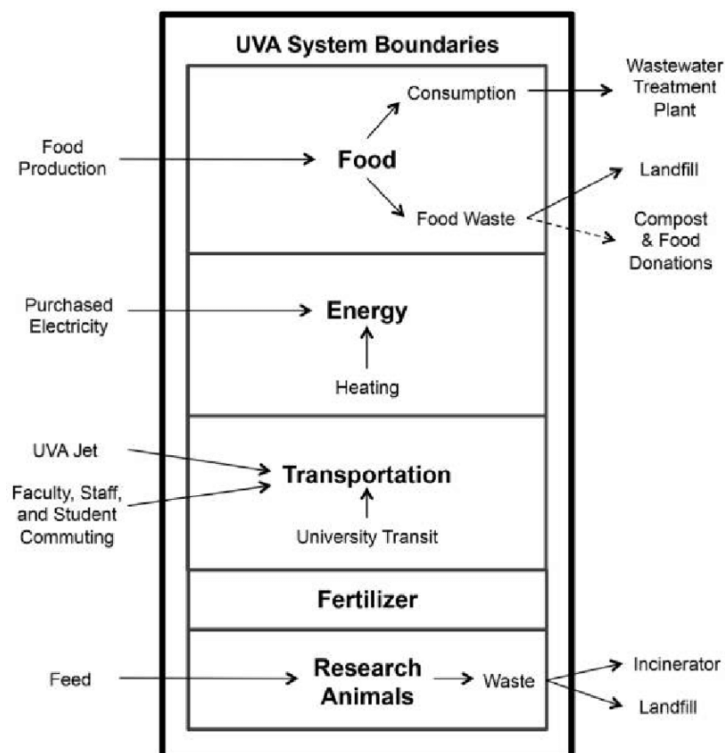


Figure 1: The system bounds of the University of Virginia Nitrogen Footprint (Leach et al., 2013). Items to the left of the box represent inputs to the university's footprint (food production, purchased electricity, UVA jet, faculty staff and student commuting, and feed); items within the boxes represent products consumer by the university (food, energy, transportation, fertilizer,

research animals); and items to the right of the box include waste products from the products consumed (wastewater treatment plant, landfill, compost and food donations), incinerator, landfill). N losses from inputs, products, and consumption losses are included in the university's N footprint.

The same idea would apply to the N footprint of an urban area; upstream losses (i.e., food production) are accounted for in the N footprint of the city. The difference in the institution N footprint calculation and the city N footprint calculation would be the different sectors that need to be accounted for. In a city N footprint, research animals would be excluded but pets would need to be included. Other inclusions to a city N footprint could include local gardens, airport emissions, or harbor emissions.

Using a Footprint Approach to Quantify and Reduce N_r

Using the N footprint as a metric for sustainability often expands the focus from energy initiatives and gives a quantitative method to assess the impacts of food choices on the environment (Castner et al., 2017). In cities, the N footprint tool can be used as a method alongside GHG assessments, N budget approaches, and Carbon Footprint assessments as comprehensive sustainability metrics.

One way to quantify the amount of excess N released to the environment is through the N footprint tool. There are many ways individuals can reduce their personal nitrogen footprints such as reducing meat consumption, reducing energy usage, taking public transportation, and reducing travel by flight. These solutions work well on an individual basis for those invested in reducing their personal environmental impacts. Reducing an N footprint can also come from top-down approaches which is the case in the institution NFT. Institutions change policies and set reduction goals to reduce their N footprints. Sustainability actions prompted by N footprint analysis often coincide with an institution's sustainability metrics already in place (Barnes et al., 2017).

Goal setting at institution from a top-down level are likely more feasible in an institution setting than in a city setting. A centralized governing board at an institution has the power to establish

reduction goals and also has the purchasing power to make systematic changes in the system. In a city, individuals and institutions are making decisions. Individual and institution decisions can be encouraged or regulated by city legislation but are often not under the direct control of the city itself. For example, a city can offer a tax break to individuals investing in solar panels on homes but enforcement by a city would be a less likely scenario. This will have an effect on the types of goals a city sets the N footprint reduction it can feasibly obtain

Approach

The objectives of this thesis are to calculate the N footprint of Baltimore City and develop strategies to reduce the N footprint of the city. The following lays out a series of four steps that need to be completed to accomplish these objectives.

Step One: System Bounds

The first step in addressing question one was to create a model for the N footprint for the Baltimore City. To do this, the system bounds and scale of the data has to be defined.

The system bound of the N footprint calculation is the city limits of Baltimore City. This system bound was chosen for two reasons: the intended use of the N footprint calculation and the scale of aggregated data available. The intended use of the N footprint calculation is for governance decisions to be made to reduce the N footprint of an area. An ideal centralized unit for governance over an N footprint is a city. Within Baltimore City, there is an Office of Sustainability (baltimoresustainability.org) which can be utilized to determine feasible strategies to reduce the N footprint of Baltimore and propose these strategies to legislators and city managers. The second reason the city was chosen as the intended scale is because of the aggregated data. Data such as the electricity, natural gas use, vehicle miles traveled, and wastewater are available at a city and county scale. Finer scales can be determined (such as by census block group) using methods such as taking a per capita average but the finest scale of the data sets above available are the city and county scale.

Data were collected by census block group groups. Using the data scale of a census block group as a data collection and as a unit of an N footprint was chosen because of the availability of food purchase data, population, and number of households as well as the existence of census block

group data across the US. Thus, the methodology could be used to calculate the N footprint for any census block group in the US and then scaled up to larger systems (e.g., census tracts, counties, watersheds, cities).

Figure 2 shows the Baltimore City broken in to census block group groups. Across the US, states, cities, counties, and watersheds are broken down into census block groups. Data from all census block group can be used as the data input to the urban nitrogen footprint tool.

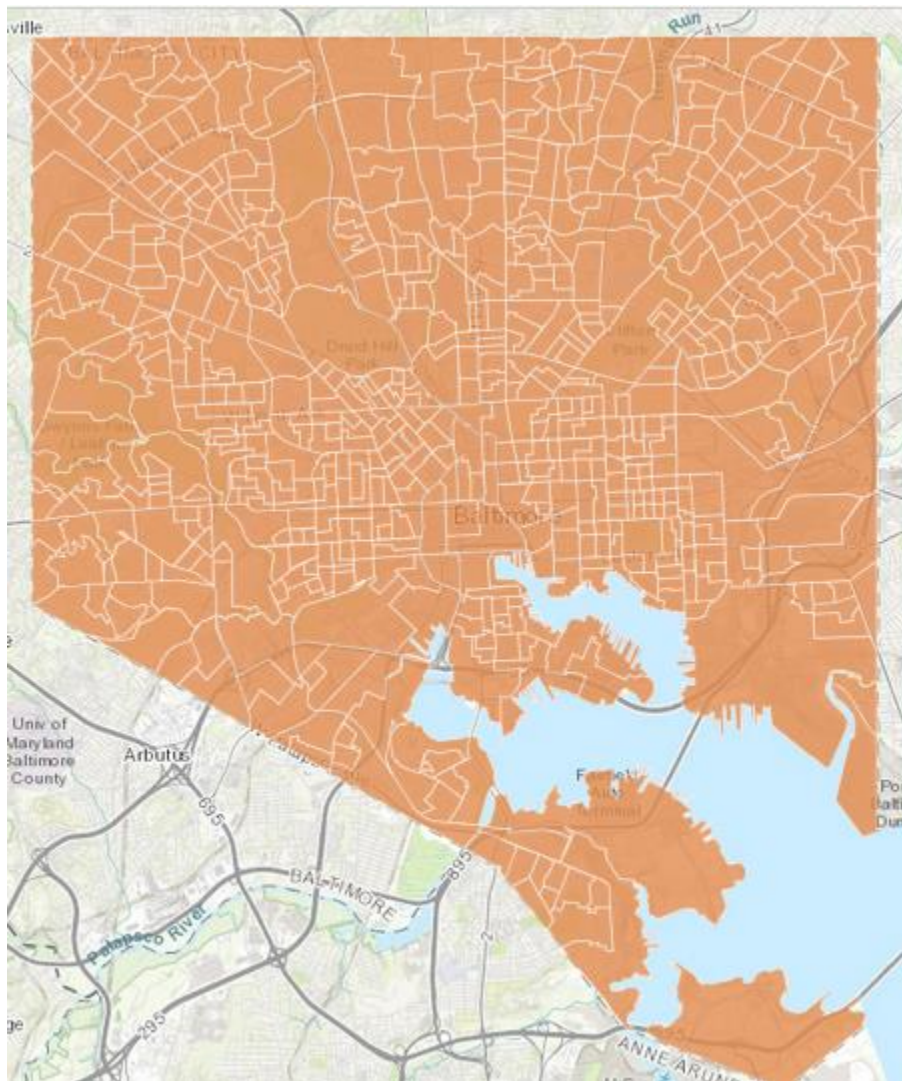


Figure 2: The outline of census block groups within the Baltimore City. There are 656 census block groups within Baltimore City.

Step Two: Data Collection

Data were collected by census block group on the electricity used and sources, food consumed, wastewater, fertilizer used, pet food and waste, and transportation types and distances for all activities occurring within the boundaries of the census block group. The data were collected from sources throughout the Maryland area. Data sources included: The US Bureau of Labor and Statistics, Baltimore Gas and Electric, Maryland Department of Transportation, Baltimore city Health Department, and The Baltimore Ecosystem Study Database. Table 1 shows the data needs of the NFT for an urban area as well as whether or not these data are available

Table 1: Data required to calculate the N footprint of a census block group, including source, format, scale and special considerations. See appendix for details on sources of data.

Data Input	Data Source (source details in appendix)	Data Format	Scale of data	Included in Data Source
Food Purchased	Esri Bureau of Labor and Statistics (BES; Dexter Locke) (5)	Dollars spent broken down by product type	Census block groups	Consumer data in dollars spent was converted from dollars to weight using the USDA Average Pricing Website (16) and the Bureau of Labor Statistic database
Wastewater	Cattaneo et al., (2017) paper on N removal in the US (9) Baltimore Public Works Department (15)	Gallons of wastewater treated	Baltimore City/County	This calculation did not include N ₂ O and losses may need to be accounted for due to leaky pipes (Groffman, 2004)

Transportation	MDOT (8) and HPMS (7)	Vehicle Miles Traveled (VMT) by vehicle type per year	Baltimore city/county	Miles traveled were divided by census block groups
Electricity Usage	Baltimore Gas and Electric (4)	Kilowatt hours	Baltimore city/county	Number of kilowatt hours was determined by determining the rate per kilowatt hour for businesses and residents
Pets and pet waste	Okin et al. (2017) (6)	Type, weight and number of pets	US Average based on population	Divided evenly as a per capita split of an average dog and cat value per capita
Gas Usage	Baltimore Gas and Electric (4)	BTU or therms of natural gas	Baltimore city/County	Number of therms was determined by determining the rate per therm for businesses and residents
Fertilizer Application	Frasier et al. 2014 (14) USGS dataset (16)	Area of green space and percent of land fertilized	Census block groups	Land cover data determined and area of greenspace used as data set

Step Three: Building an Urban NFT Tool

A tool was built to calculate the N footprint of the Baltimore City, using census block groups as the data framework. This tool was built in Excel and was modeled after the NFT for institutions (Leach et al., 2013). This Excel-based tool included formulas to calculate the N footprint of each of the different components necessary for an urban area's N footprint: food production, wastewater, fertilizer use, purchased electricity, natural gas use, pet food and waste, and transportation. There also were data collected on the emission factors produced from each of these components. An emissions factor was defined at the average emission rate of any form of nitrogen from a given source. The emission factors were then applied to each data input and converted to kg N. The food production and pet food factors included converting from amount of

food to protein, then nitrogen content, and used virtual nitrogen factors (VNFs) to convert to kg N. Emission factors from eGRID (Emissions and Generation Resource Integrated Database) were used to determine kg N lost from the transportation, electricity, and natural gas use. Wastewater and fertilizer calculations used removal and uptake factors to calculate the N lost to the environment from each source. Figures 2-7 show how each of these data sources were converted to kg N which are the units of the N footprint, along with data sources for each conversion. Figure 2 is N footprint calculation for one food product in the census block group. Summing all food products for the census block group will give the N footprint from food production. Figure 3 is the N footprint calculation for pet food and waste in the census block group. Summing all calculations for pets in the census block group gives the N footprint from pets in the census block group. Figure 4 shows the N footprint of the electricity used in the census block group. Figure 5 shows the N footprint for the natural gas in the census block group. Figure 6 shows the N footprint for transportation that occurred on all roads in the census block group during the years' time frame. Figure 7 displays the calculations to determine the N released from treated wastewater in the census block group. Figure 8 shows the N footprint of fertilizer use in the census block group. The sum of these components will give the total N footprint for the census block group in kg N.

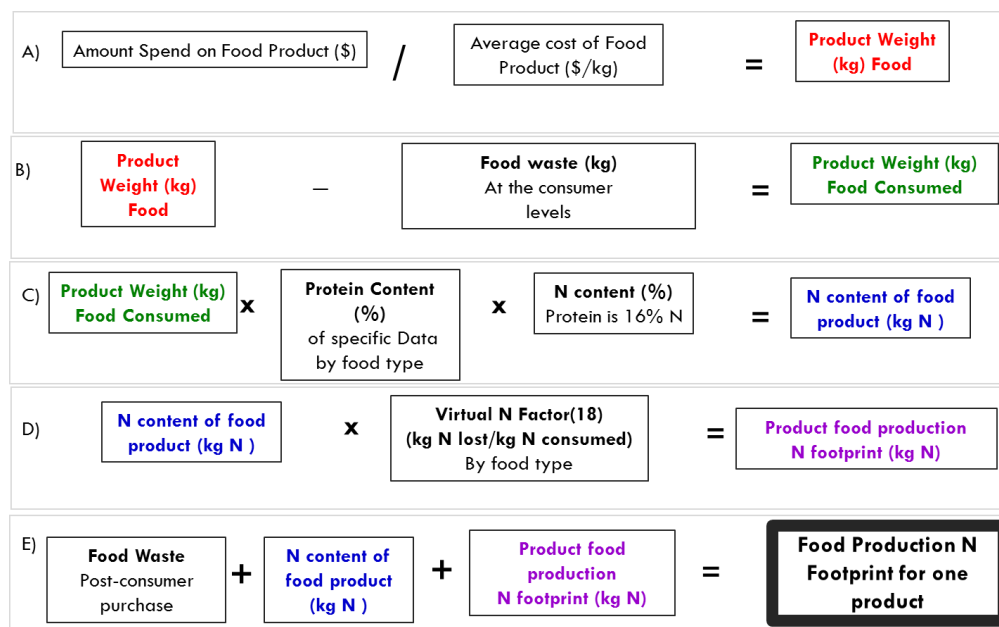


Figure 3a: For a specific food product, (A) the conversion from dollar amounts of food purchased to mass of food (kg), (B) the amount of food product consumed, corrected for amount

of food waste (kg), (C) the amount of N in the consumed food, (D) the amount of virtual N (kg N lost/kg N consumed) associated with the particular food product, (E) the sum of consumed N and virtual N associated with the food product. Summing each of the food products purchased in the census block group gives the food production N footprint for the census block group. Numbers in parenthesis represent data sources of calculation components (see Appendix for data sources). See Appendix Table 2 for conversions of dollars to weight by product. Colored boxes represent calculated values carried throughout the equation.

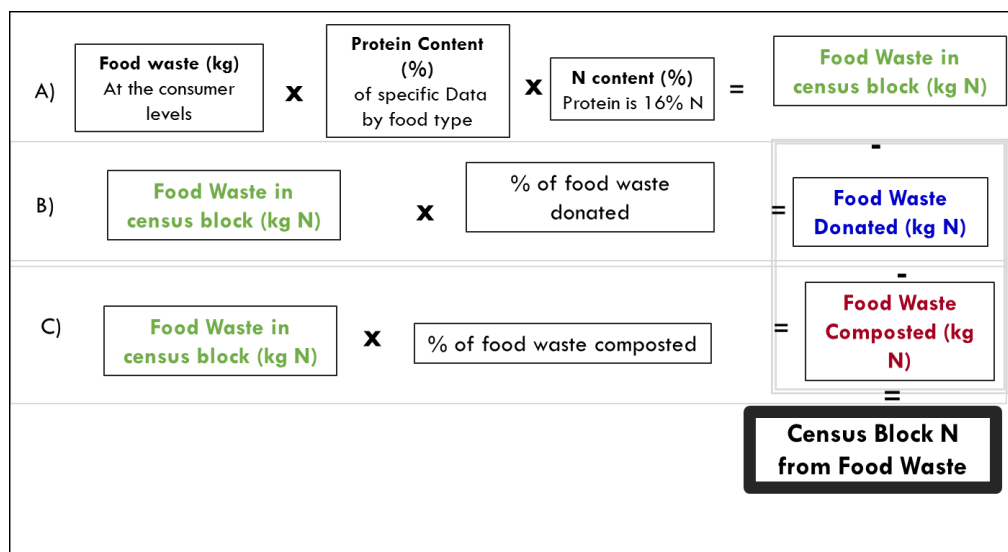


Figure 3b: The conversion of (A) food waste (kg) to food waste N (kg N) and (B) percent of food waste donated (kg N) and (C) food waste composted (kg N) to the total food waste N in the census block group. This value will be added to the N footprint of the census block group's food production calculation. Colored boxes represent calculated values carried throughout the equation.

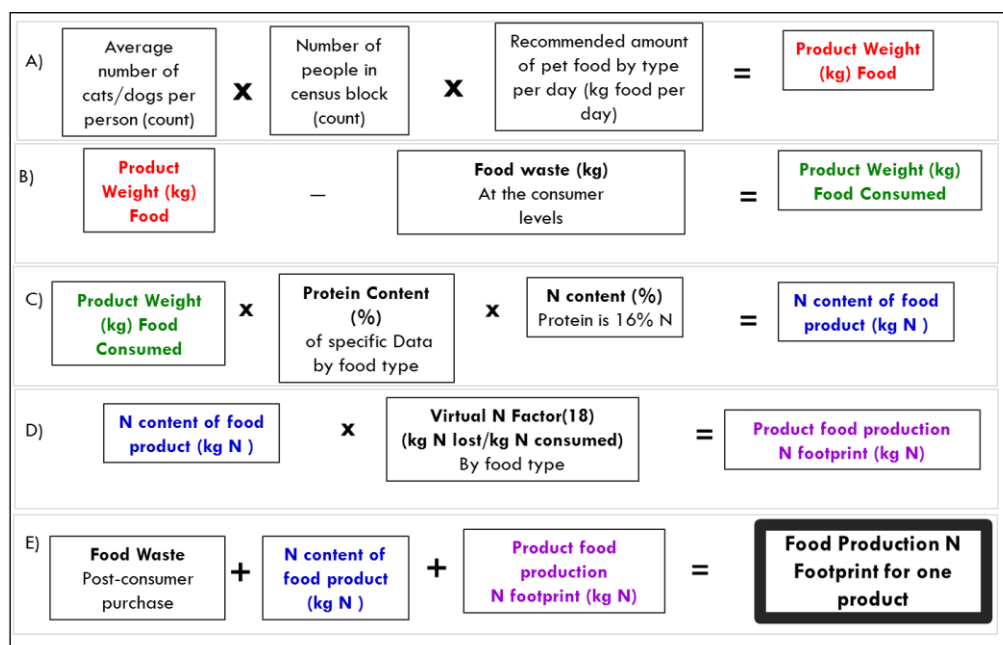


Figure 4a: For a specific pet type, (A) the conversion of number pets to amount of pet food consumed (kg), (B) the amount of pet food consumed, correct for amount of waste (kg), (C) the amount of N in the consumed pet food, (D) the amount of virtual N associated with the consumed pet food, (E) the sum of consumed N and virtual N associated with the pet food product. Summing the N footprint for each of the pets in the census block group gives the N footprint for the census block group. Numbers in parentheses represent data sources of calculation components (see Appendix for data sources). Colored boxes represent calculated values carried throughout the equation.

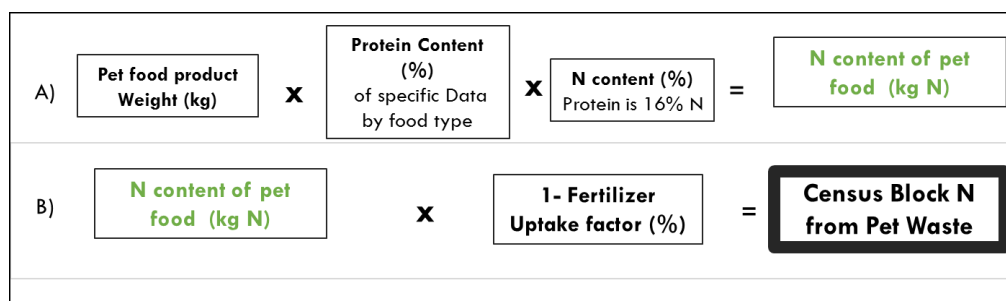


Figure 4b: The conversion of A) pet food (kg) to N content of pet food (kg N) and B) N content of pet food to pet waste (kg N). See Appendix Table 1 for data sources. Colored boxes represent calculated values carried throughout the equation.

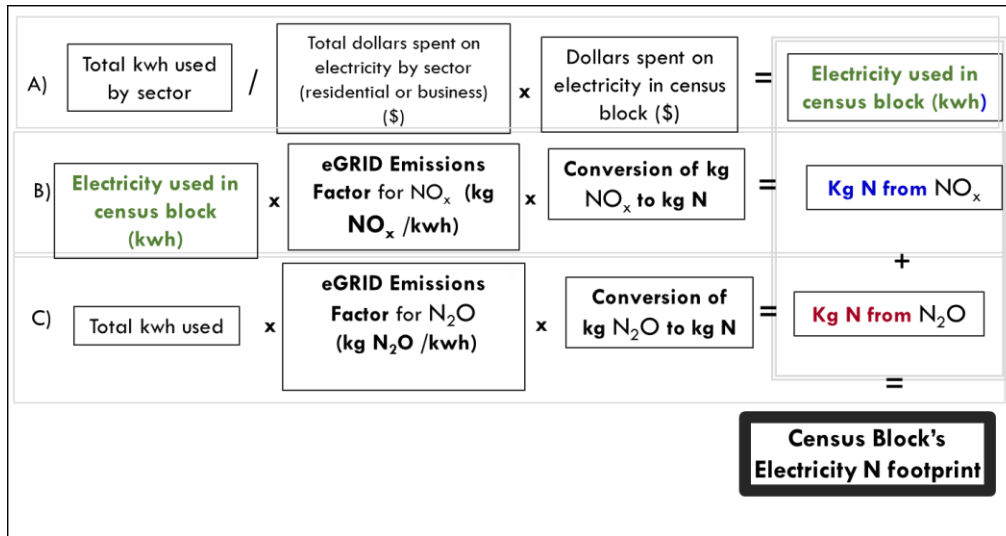


Figure 5: The conversion from (A) total kilowatt hours (kwh) to kilowatt hours per census block group (B) census block group kilowatt hours to kg N from NO_x and (C) total kwh to kg N from N₂O using eGRID emissions factors for the Baltimore eGRID region (SRVC). The sum of the kg N emitted as NO_x and N₂O is the census block group's N footprint from purchased electricity. Numbers in parenthesis represent data sources of calculation components. See Appendix Table 1 for data sources. Colored boxes represent calculated values carried throughout the equation.

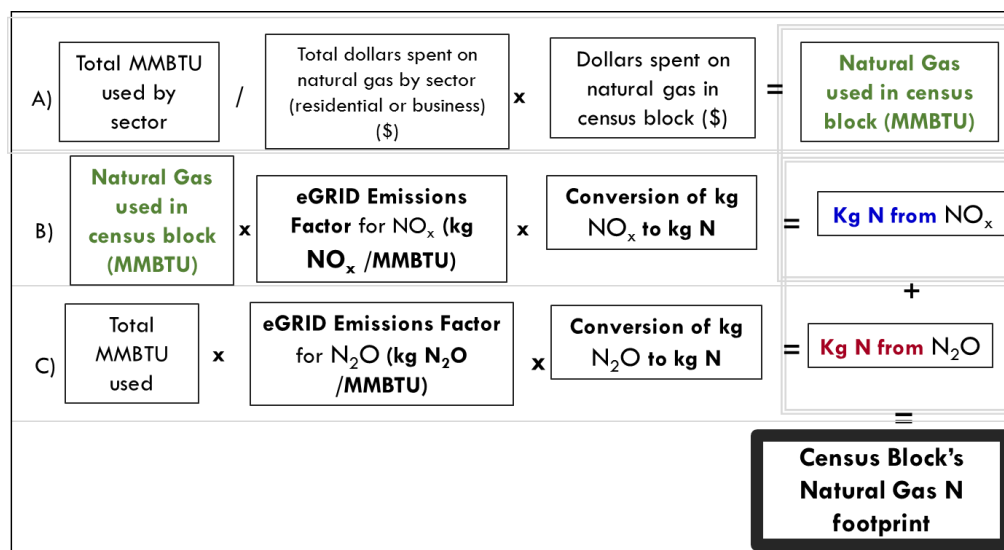


Figure 6: The conversion from (A) total therms (100,000 BTU) to therms per census block group and (B) therms per census block group to kg N from NO_x and, (C) total therms to kg N from N₂O using eGRID emissions factors for natural gas. The sum of the kg N emitted as NO_x and N₂O is the census block group's N footprint from natural gas. Numbers in parenthesis represent data sources of calculation components. See Appendix Table 1 for data sources. Colored boxes represent calculated values carried throughout the equation.

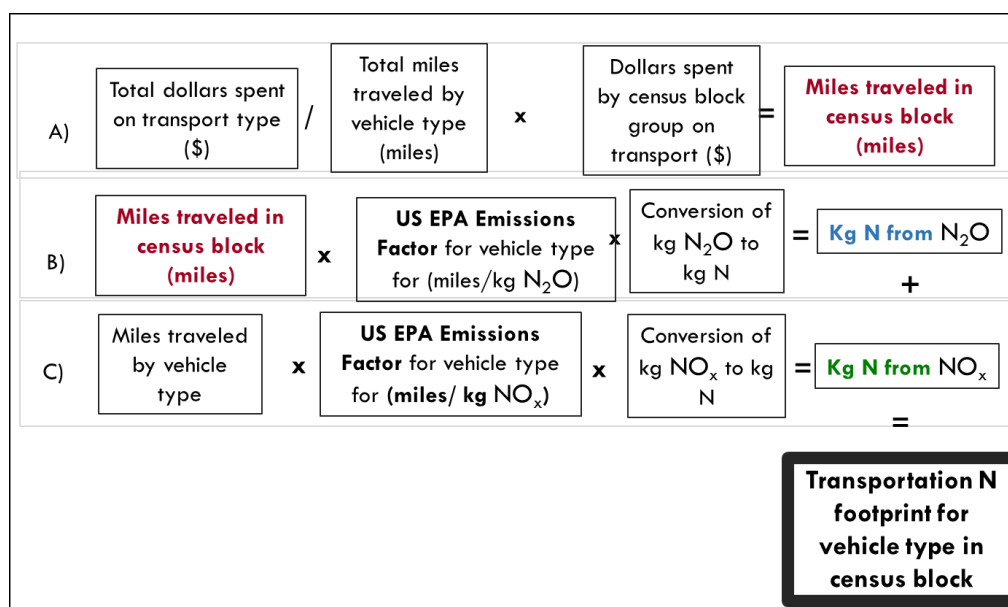


Figure 7: This figure displays (A) the conversion of miles traveled by vehicle type to miles traveled per census block group and (B) miles traveled per census block group to the emission of NO_x per mile using the eGRID emissions database (C) and the miles traveled per year used per year to the emissions of N₂O using the eGRID emissions database. The sum of these two gives the transportation N footprint for the census block group. If different vehicle types use different fuels (gasoline or diesel) this calculation was done for each using the appropriate eGRID emissions factor. The transportation N footprint would then be the sum of these two calculations. Numbers in parenthesis represent data sources of calculation components. See Appendix Table 1 for data sources. Colored boxes represent calculated values carried throughout the equation.

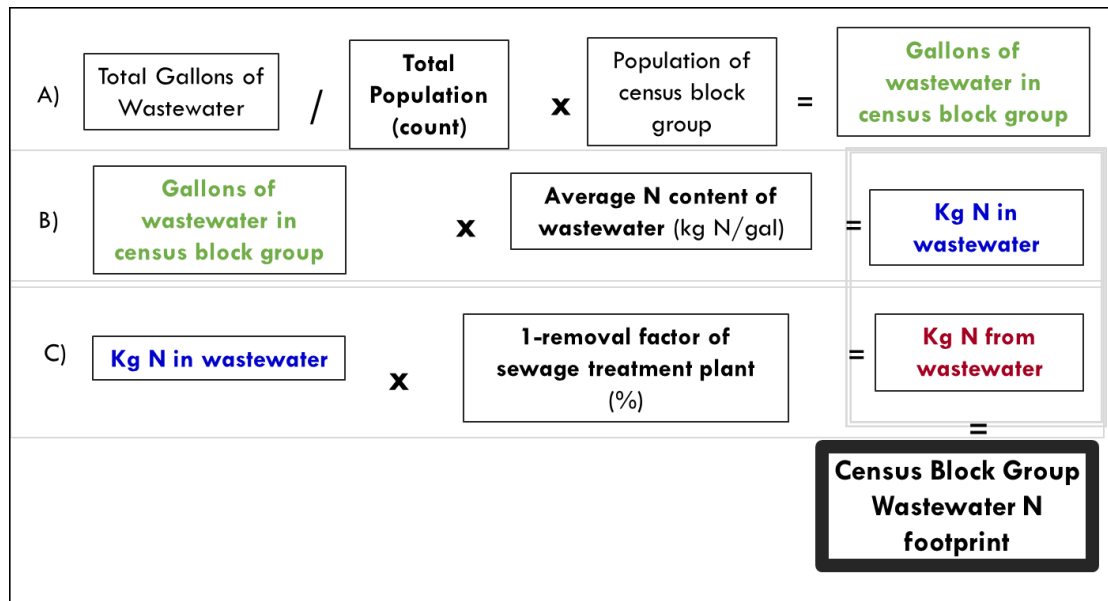


Figure 8: (A) the conversion of total gallons of wastewater to gallons of wastewater per census block group (B) gallons of wastewater per census block group to N content of wastewater (kg N/gallon), (C) multiplied by one minus the removal factor of the area's sewage treatment plant to equal the kg of N not removed from wastewater and released to the environment. Numbers in parentheses represent data sources of calculation components. See Appendix for data sources. Colored boxes represent calculated values carried throughout the equation.

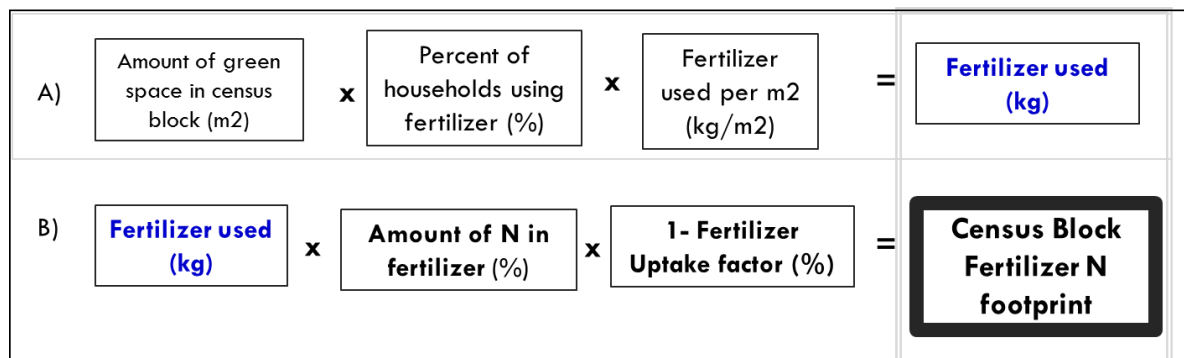


Figure 9: (A) The amount of greenspace in the census block group to total amount of fertilizer used in the census block group, (B) to the amount of N (kg) in fertilizer not taken up by plants on the lawn and subsequently lost to the environment which gives the census block group's N

footprint from fertilizer (kg N). Numbers in parenthesis represent data sources of calculation components. See Appendix for data sources. Colored boxes represent calculated values carried throughout the equation.

Step Four: Analyzing Results

The first step in analyzing results was to verify and validate results. This was done using estimations as well as other “reality checks” on the calculation. The results for the Baltimore City were compared to the average personal N footprint (Leach et al., 2012) and compared to the per capita footprint of Baltimore City. The scope of the two calculations was taken into account when completing these comparisons. Cities contain commercial, industrial and institutional entities which may contribute proportionally more than individuals. This was rectified by identifying large companies, small businesses, and personal residences and scaling by the number of each in the census block group. This was done because the purchased electricity data for Baltimore City is split into corporate and residential use. The next step was to determine the biggest contributors to the area’s N footprint. This was done by looking at the breakdown by percentage of each of the components to the N footprint. For the personal and institution N footprints, the food component is usually the largest component of an N footprint with energy use at a close second (Castner et al., 2017; Galloway et al., 2008).

Step Five: Developing Scenarios

After these large contributors were determined, the impact of scenarios on the N footprint for the area can be estimated. Suggested reduction scenarios were modeled along with projections to determine the potential scale of impact for individual and combined cases. The energy reduction scenarios were consistent with reduction strategies suggested in the 2012 Maryland Climate Action Plan. The food scenarios focused on reducing consumption of high N-footprint food products such as beef and other animal products. These scenarios were analyzed for their impact on the N footprint and given as recommendations for reduction for the area.

The following scenarios were analyzed:

- a. Baltimore City Food Scenarios:
 - i. Replace 25% of beef purchased in the area with beans.

- ii. Reduce protein consumption of areas consuming more than 80 grams per capita per day.
 - iii. Compost 100% of food waste in the area.
 - iv. All fast food restaurants go vegetarian
- b. Energy Scenarios: Maryland Climate Action Plan
 - i. Increase renewables to fuel mix by 20% by 2022.
 - ii. Reduce overall energy consumption by 15% by 2022.
- c. Transportation
 - i. Increase use of public transport by 10%.
- d. Other
 - i. Reduce fertilizer use by 50%.
 - ii. Switch from dogs to cats as pets (and vice versa).

The following table describes these scenarios run, the colocations completed to run these scenarios, and the stakeholders in each calculation. The feasibility and reductions are discussed more in depth below (Table 2). Below Table 2, each set of scenarios is discussed more in depth.

Table 2: The scenarios to be run, the sectors effected, the calculations completed, and the stakeholders in each event are listed below. These scenarios were run in the Excel-based tool by altering the outlined sectors and data inputs below.

Scenario	Effected Sectors	Calculation	Stakeholders
A1. Replace 25% beef purchased with beans	Food production of at-home food survey data	Subtract 25% of weight of beef from at-home beef purchases and add this weight to beans category	Personal Reductions, NGOs with environment and health goals
A2. Eliminate beef from census block groups consuming more than 80 grams of protein per capita per day	Food production for all census block groups consuming above 80 grams of protein per day	Calculate protein consumed in each census block group using equation one and the eliminate beef from census block groups consuming more than 80 grams of protein per day	Personal Reductions, NGOs with environment and health goals
A3. Compost 100% of food waste	Food waste of at home food waste	Rather than adding food waste at the end of the Figure 3a– calculation, this food waste will be subtracted as a compost credit represented in Figure 3b	Baltimore City Management, Personal

A4. 100% of fast-food restaurants vegetarian	Food production for fast food restaurants	Rather than using an average meat-meal to calculate the N footprint of fast-food meals, use an average vegetarian meal.	Companies, Personal Reductions
B1. Increase Renewables in fuel mix by 20%	Electricity sectors of business and residential locations	Alter the NO _x and N ₂ O emission factors by replacing 20% of coal with 20% renewables	City Government, Utility company (Baltimore Gas and Electric)
B2. Reduce Overall Energy Consumption by 10%	Electricity sectors of business and residential locations	Reduce the kilowatt hours by 10% overall	City government, personal choice, businesses
C1. Increase use of public transportation by 10%	Transportation	Reduce individual miles traveled by car by 10% and increase the number of miles traveled by bus by 10%	City government, personal choice
D1. Reduce Fertilizer use by 50%	Fertilizer	Divide the total kilograms of fertilizer by two for all land cover	City government, personal choice
D2. Switch from dogs to cats	Pets; both dogs and cats	Eliminate all dogs and add dogs number to the total number of cats	Personal choice
All scenarios	Pets, fertilizer, food production (at-home and fast-food), transportation, and business and residential electricity	All scenarios above combined with changes made to ensure no double counting which included switching 25% beef to beans was not completed on census block groups where beef was removed.	City government, personal choice, individual businesses

The food scenarios were run by altering the food data entered in to the urban footprint tool. This included altering the weights for each census block group for scenario one by subtracting 25% of the original weight of beef by 25% and adding an additional 25% of weight to beans. The footprint calculation for these two categories were then completed. Reducing the protein consumption of census block groups consuming more than 80 grams of protein was done by first determining the amount of protein each person is consuming per day in a census block group. The census block group groups where consumers were eating over 80 grams of protein per day were identified and all beef removed from the census block group. Composting all food waste was calculated by eliminating the food waste sector and assuming all food waste goes directly to compost. All nitrogen in food waste of composted food was subtracted from the final N food N footprint calculation.

The energy scenario calculations will be done by altering both the energy consumption patterns and the NO_x and N₂O emissions factors. For the energy consumption reduction scenario, 10% of the total kilowatt hours in each census block group will be eliminated. For the increasing renewables scenario, a fuel mix was calculated with 20% more renewables and replacing previously burned coal.

The transportation, fertilizer, and pet scenarios were run by reducing or replacing a percentage of car miles traveled with bus miles traveled, fertilizer used to no fertilizer, and 100% of cats to 100% dogs and vice versa.

Results

The calculations laid out in the Methods section were completed in an Excel-based tool created for the purpose of determining the nitrogen footprint of the Baltimore City. The results of this calculation are in Figure 10.

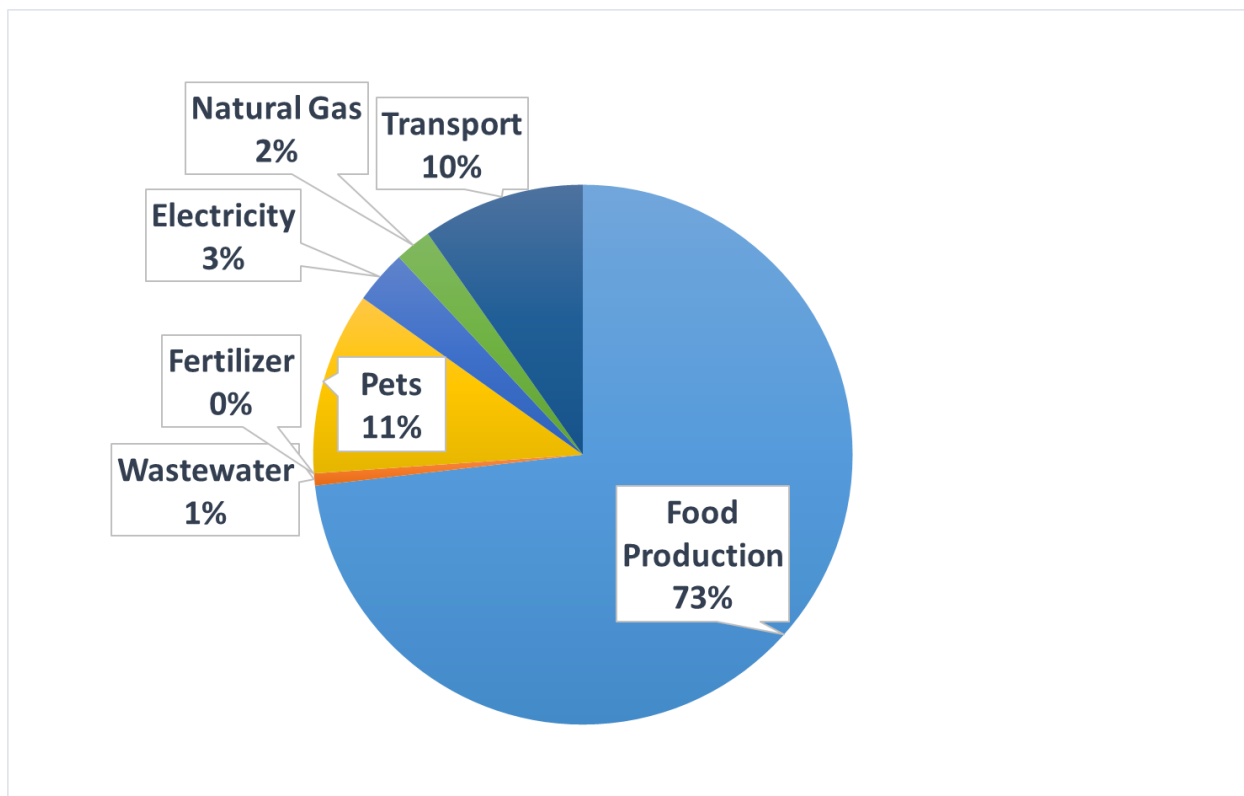


Figure 10: The percent contribution of the nitrogen footprint by sector for 2016. This includes residential and business data gathered from the United States Consumer Expenditure Report (2016), Baltimore Gas and Electric, Baltimore Public Works Department, and the Maryland Department of Transportation, and land cover data from US Geological Survey Data.

The largest contributor in this data set was food production (73%), which is consistent for both individual and institution N footprint across all published country and institution calculations. Pets are the second largest contributor at 11% of the total N footprint, which cannot be compared to individual or institution N footprint as this is the first calculations pets and pet food have been included. The estimate presented here is likely an overestimate for the actual footprint for pets. This is because the virtual nitrogen factors (kg N lost/kg N consumed) are the same as the normal food production factors which count by-products as waste which is usually not the case for pet foods. Transport (10%) is a close third followed by electricity (3%), natural gas (2%), wastewater (1%), and fertilizer (<1%).

While the total N footprint of Baltimore provides information about how much different sectors contribute overall, a more detailed understanding can be obtained by comparing the Baltimore Footprint to the US N footprint per capita population. Figure 11 shows the comparison of a direct average of the per capita Baltimore N footprint and the US average N footprint. The N footprint of electricity and natural gas make up about two times more than the individual N footprint in the US. However, the US N footprint calculation for electricity and natural gas are specific to individuals while this tool takes into account businesses in Baltimore City. The N footprint of transportation makes up about one third less than the US average. Again, this is due to the scope of the calculation including only travel within the city limits which will also not include flights because the Baltimore airport is outside the city limits of Baltimore. Fertilizer and wastewater make up small percentages of the N footprint. This can be explained due to the lack of greenspace requiring fertilizer in Baltimore and the upgraded sewage treatment plants in Baltimore making the N removal more efficient at wastewater treatment plants.

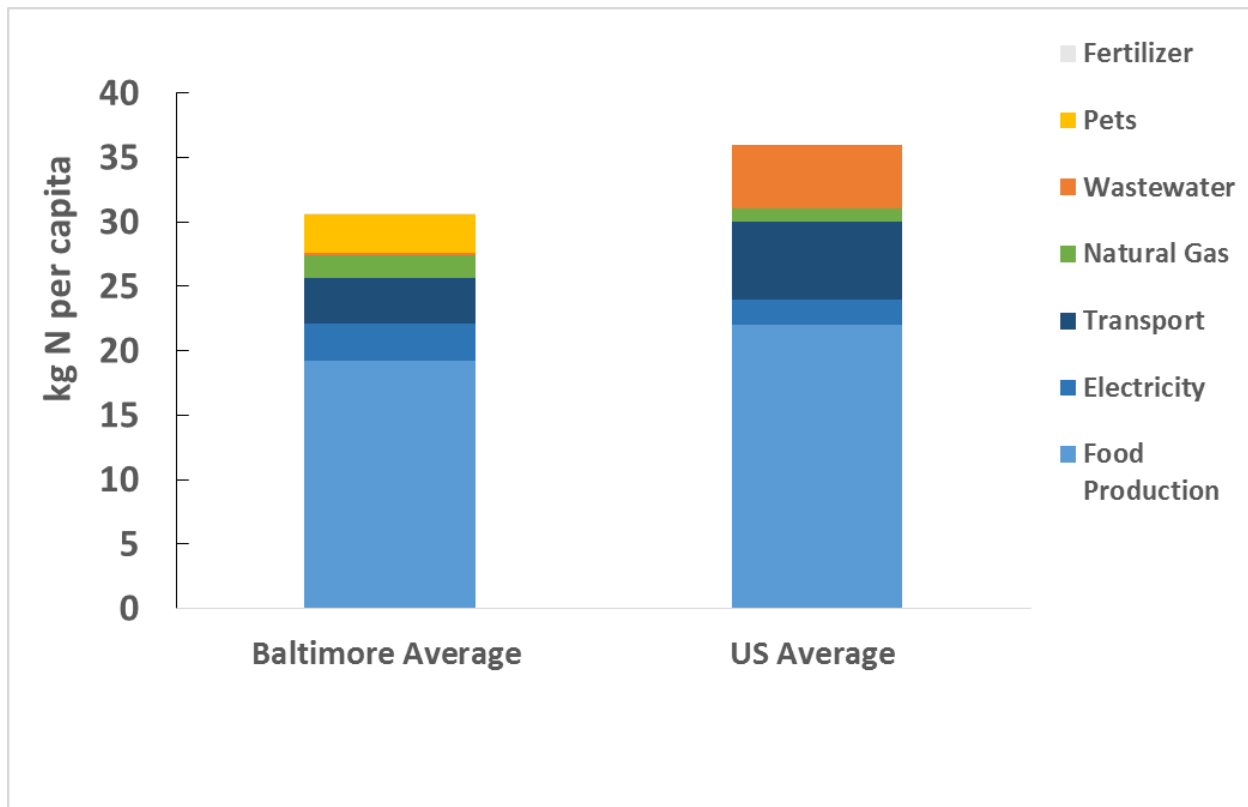


Figure 11: The average per capita N footprint for Baltimore City and for the US. The two selected census block groups and the Baltimore average footprints include fertilizer and pets while the US N footprint does not. The US N footprint is taken from Leach et al., (2013) while the other per capita footprint was calculated using 2016 census block group data from the Consumer Expenditure Report with the urban nitrogen footprint tool (NFT).

The second objective of this study was to evaluate the impact of certain reduction strategies on the N footprint of the Baltimore City. These strategies were evaluated relative to the current baseline year of 2016 and do not include growth projections or improvements in emissions factors for any future year. The scenarios are shown below in Figure 12.

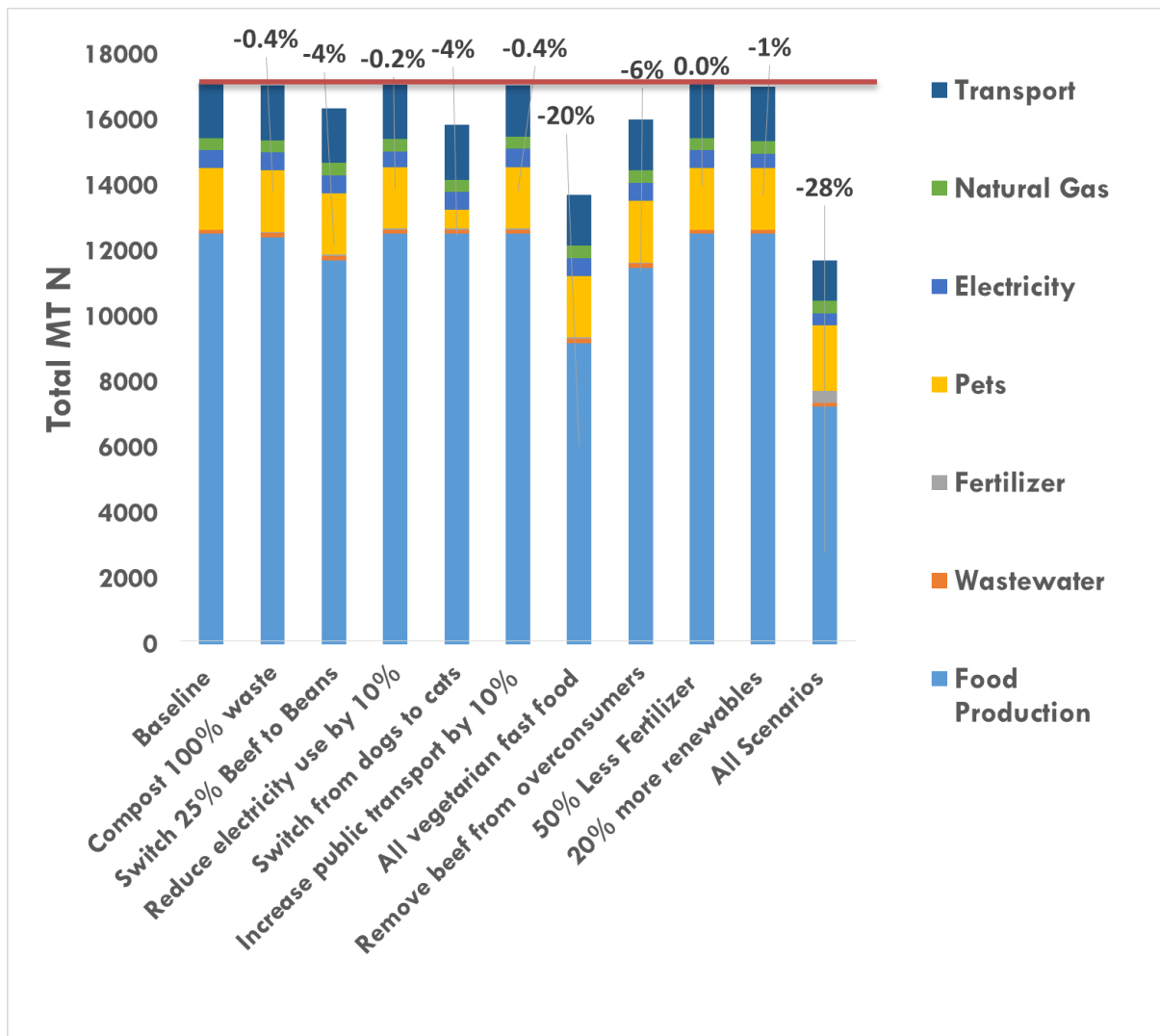


Figure 12: The total nitrogen footprint of the Baltimore City in metric tons, broken down in to sectors (colored bars). The first bar is the baseline N footprint of Baltimore and the red line represents the baseline N-footprint for Baltimore City. The following are scenarios run which include the following: composting 100% of food waste, switching 25% of beef purchased with beans (by weight), reducing energy consumption in residential and business locations by 10%, switching 100% of cats to dogs as pets, switching 100% of dogs to cats as pets, decreasing single passenger cars by 10% and increasing public transport by 10%, converting 100% of fast food locations to serve only vegetarian meals, elimination beef from census block groups consuming over 80 grams of protein per capita per day, reducing fertilizer application by 50%, increasing renewables by 20% and assuming a conversion from coal, and the implications of implementing

all of these scenarios. The percent decreases are shown above the bars as a decrease from the baseline.

The scenarios leading to the largest reduction are the scenarios pertaining to food. Referring back to Figure 10, this can be inferred as food production makes up 73% of Baltimore City's N footprint. The largest single scenario is eliminating meat from fast-food restaurants at 20% less than the baseline footprint. This is followed by switching from dogs to cats as pets. Pets are the second largest sector in the N footprint for Baltimore City. The third and fourth biggest reductions are also in the food production sector which are limiting beef from census block group consuming more than 80 grams of protein per day (6.5%) and switching 25% of beef purchased to bean purchases by weight (4%). Scenarios pertaining to energy do not make as big of an impact because of the already low percentage of the total N footprint these sectors make up. The total reduction from energy and transportation sectors in 4%.

Discussion

A. Sector Calculations of the Baltimore N Footprint per capita

When evaluating the accuracy of the urban NFT footprint calculation, the best place to draw from is other calculated N footprints. The system bounds of this urban N footprint are all activities occurring within Baltimore City by the residents. Other contributors such as flights taken outside of the city or food brought in to the city by commuters are not taken in to account. Since the calculation is taking in to account personal activities within Baltimore City, it is somewhat analogous to the personal N footprint calculation. However, electricity use, transportation, and natural gas use from not only residents but also businesses were taken in to account when calculating this N footprint which means we would expect these categories to be higher than the personal N footprint calculation per capita. In comparing the average per capita footprint of Baltimore City and the US average N footprint it is helpful to break each of the sectors down as seen in Table 3.

Table 3: The per capita N footprints in Baltimore City and the US based on the personal N footprint calculator by sector in kilograms of nitrogen lost per capita per year.

	US Per Capita (kg N)	Baltimore Per Capita (kg N)
Food	22	19
Electricity/Natural Gas	3	5
Transportation	6	4
Wastewater	5	0.2
Fertilizer	N/A	0.1
Pets	N/A	3
Goods and Services	3	N/A
Total	36	28

a. Food Production

The average per capita N footprint for food production is 3 kg N less than the US N footprint. The food data for the Baltimore City were determined based on personal spending on food items by category from the Consumer Expenditure Report (CEX) from the US census; the US N footprint per capita food is based on Food and Agriculture (FAO) recommended daily values. The CEX report only included dollar values spend on food by category and not weights. These values were then converted to weights using average pricing across the US (*United States Department of Agriculture (2012), Bureau of Labor and Statistics (2016)*). The conversion from dollars to weight contributed to some variation in the total weights of food purchased within census block group groups. These variations effected the food production N footprints of certain census block group groups. Adjusting these dollars to weight conversions as better data sets become available will improve the accuracy of the total N-footprint. The values for weights by category for both the US average and the Baltimore City average are shown in Figure 13.

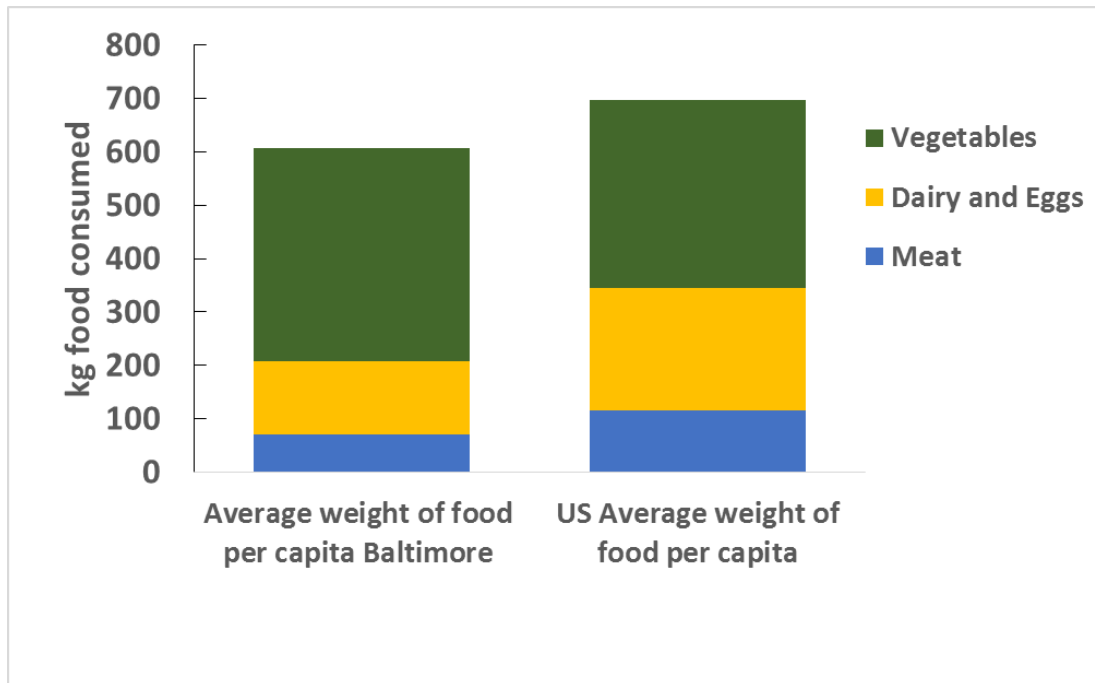


Figure 13: The weight of food by category consumed per capita per day in Baltimore City and on average in the US. .

There are some difference in the total weights by category in the Baltimore N and the US average weights. Overall, the weight of food purchased per capita was about 35% less than the US average. There are a few explanations for this. One is the way the CEX report collects data which is through two-week surveys of a sample population in each census block group. Cook et al. (2000) evaluated the accuracy of a dietary survey given to individuals in comparison to actually consumption and found that people are notoriously bad at reporting food consumption data and tend to under report by 29% to 46% of their daily intake. The datasets used to convert dollars to kilograms were both based on US averages which may not have held true for Baltimore City prices. The CEX report also did not include food purchases with food assistance programs. Since 24% of Baltimore City’s population is at or below the poverty level, this could make a substantial impact on the amounts of food report in certain census block groups where poverty levels are high (US Census). The final factor is the lack of inclusion of non-residential university students, hospital patients, and prisons in the consumer expenditure report data, which are included in population estimates but not in consumer reports. From this information, it is

clear that more comprehensive food data should be gathered to get a more accurate sense of the amount of food in Baltimore City.

b. Electricity and Natural Gas

From Table 2, it is evident that the per capita N footprint for electricity and natural gas are higher than the US average. This is due to the system bounds of each calculation. The US average N footprint takes in to account only personal, at-home energy use while the Baltimore City N footprint includes businesses, schools, and other institutions' electricity and natural gas use within the system bounds.

c. Transportation

The transportation N footprint of the Baltimore City residents are also lower per capita than the US average, even though non-residential transportation (such as cargo trucks and buses) are included in this Baltimore N footprint. However, there are a number of reasons which can explain why the Baltimore per capita N footprint is lower. In the personal N footprint calculator, all miles traveled by vehicle are included in the footprint regardless of the location. In the Baltimore N footprint, only miles traveled within city limits were included in the footprint which is an underestimate of the miles traveled for one person traveling outside of city limits. The Baltimore N footprint also did not include miles traveled by air because the Baltimore City airport is outside of city limits. N losses from air travel make up about one third of the average US N footprint (Leach et al., 2012).

d. Wastewater

The average wastewater N footprint of Baltimore is lower than the US average. This is due to the tertiary treatment at the wastewater treatment plants that service Baltimore City which removes 79% of the N in wastewater. The US average, which includes tertiary, secondary and septic systems N removal factors, is estimated at 50% N removal. . These values for Baltimore are also assuming all wastewater reaches the wastewater treatment plant. From the urban N footprint fluxes evaluated in Groffman et al. (2005), it is evident this is not the case as the Baltimore City is plagued with pipe leakages and overflows.

e. Pets, Fertilizer, and Goods and Services

For each of these categories (pets, fertilizer, and goods and services) there was no baseline from either the US average personal N footprint calculator (pets and fertilizer) or no data calculated from the Baltimore N footprint (goods and services) to compare to. This calculation of the N footprint of pets and fertilizer could be used in the US average N footprint calculation. Both the pets and fertilizer data sets use US average values to calculate the N footprints of each. The goods and services portion of the US N footprint could be used to determine the goods and services N footprint of Baltimore City.

B. Relationship Between the Nitrogen Footprint and Annual Budget in Baltimore City
Census block groups

The average N footprint per capita in Baltimore City was 3 kg N per year less than the US average. However to understand this average value it is important recognize the variation in N footprints within census block groups in the city. The highest N footprint per capita in a census block group was 101 kg N per capita and the lowest was 8 kg N per capita. The census block group with 8 kg N per capita splits were 53% food, 12% fossil fuels, and 35% pets and fertilizer. The census block group with 101 kg N per capita had 83% food, 15% fossil fuels, and 2% fertilizer and pets. The census block group with the higher N footprint included a larger percent per person food footprint than the lowest N footprint census block group. The per capita daily weight of food consumed per day varied as well; 7 kg per capita for the highest N footprint census block group and 0.4 kg per capita for the lowest N footprint census block group. This variability can be seen in Figure 15.

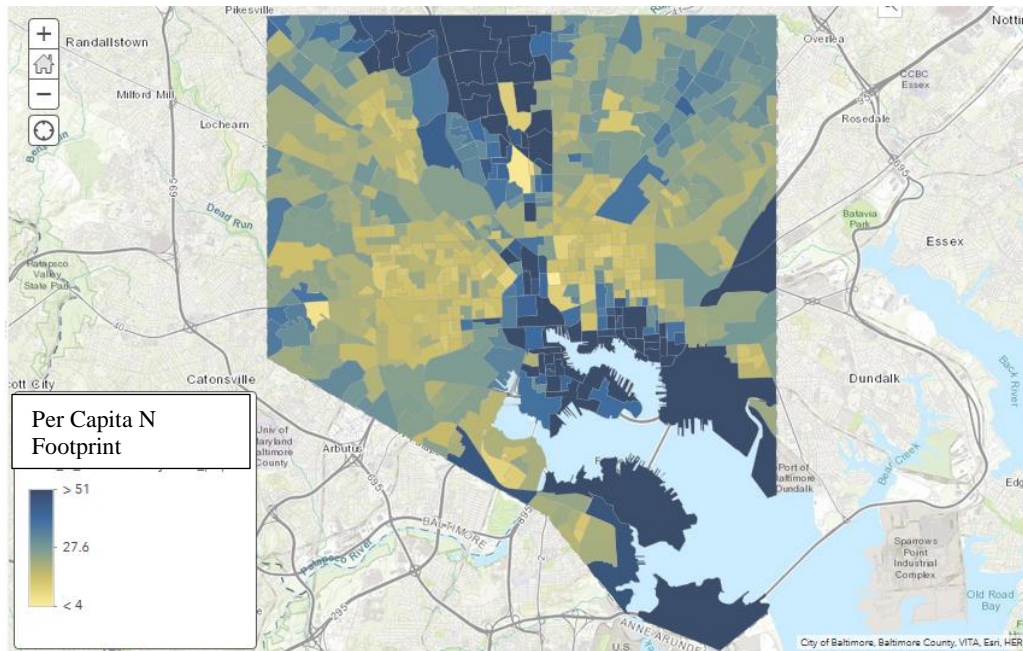


Figure 14: The N footprint of census block groups within Baltimore City. The median value is 28 kg N per capita. Values lower than the average are colored yellow and values higher are blue, with a gradient showing how much higher or lower than the mean these values are. This graph was created using ArcGIS online. *Note: this figure will be changed to reflect census block groups without complete datasets grayed out.*

The CEX report also included information on the annual budget of individuals within each census block group. The average annual budget per capita in the Baltimore City (\$19,707) is also less than the US average (\$22,221). The variation of this throughout Baltimore City can be seen in Figure 15.

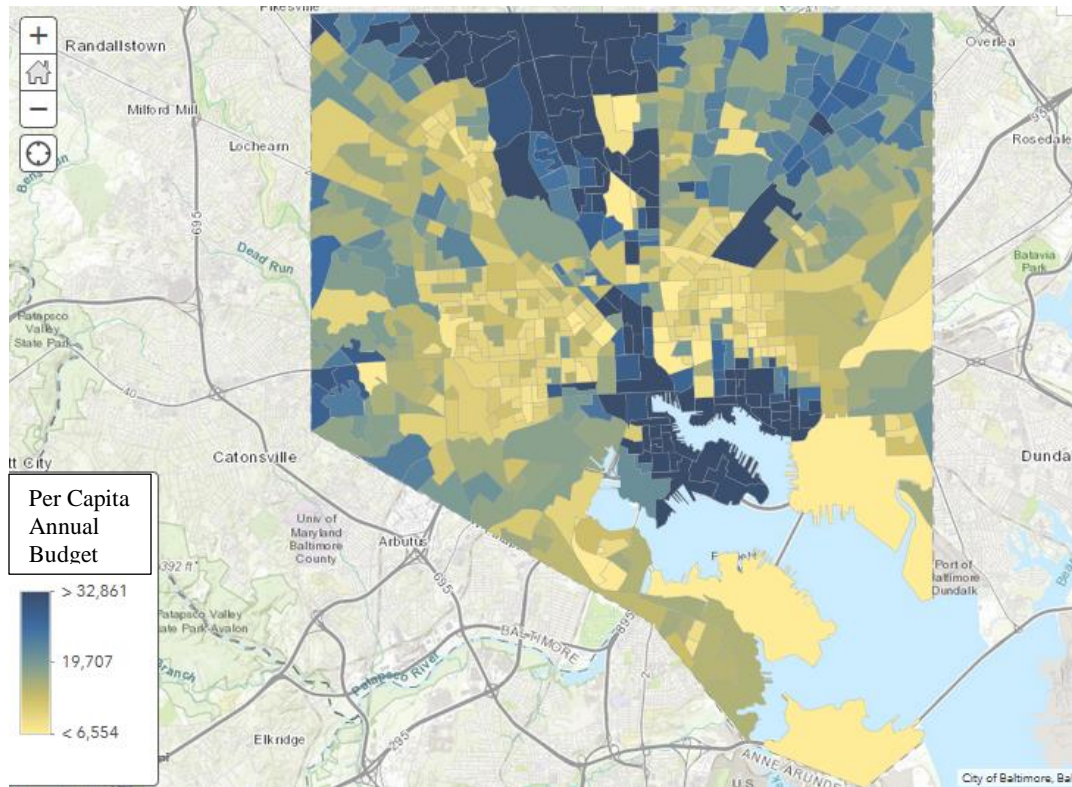


Figure 15: The annual budget of census block groups within Baltimore City from the CEX report. The median value is \$19,707 per capita per year. Values lower than the average are colored yellow and values higher are blue, with a gradient showing how much higher or lower than the mean these values are. This graph was created using ArcGIS online. *Note: this figure will be changed to reflect census block groups without complete datasets grayed out.*

Visibly, Figures 5 and 6 line up well. With a few exceptions, the colors of certain blocks in both maps. To determine the strength of the relationship a simple correlation was assessed using a linear regression to evaluate the strength of the correlation. The R^2 value for this linear model was 0.92 and the relationship can be seen in Figure 16. An R^2 value of 0.92 and a P value of 0.001 which indicates a very strong correlation of N footprint and annual budget. Census block groups without complete data sets were removed from this analysis.

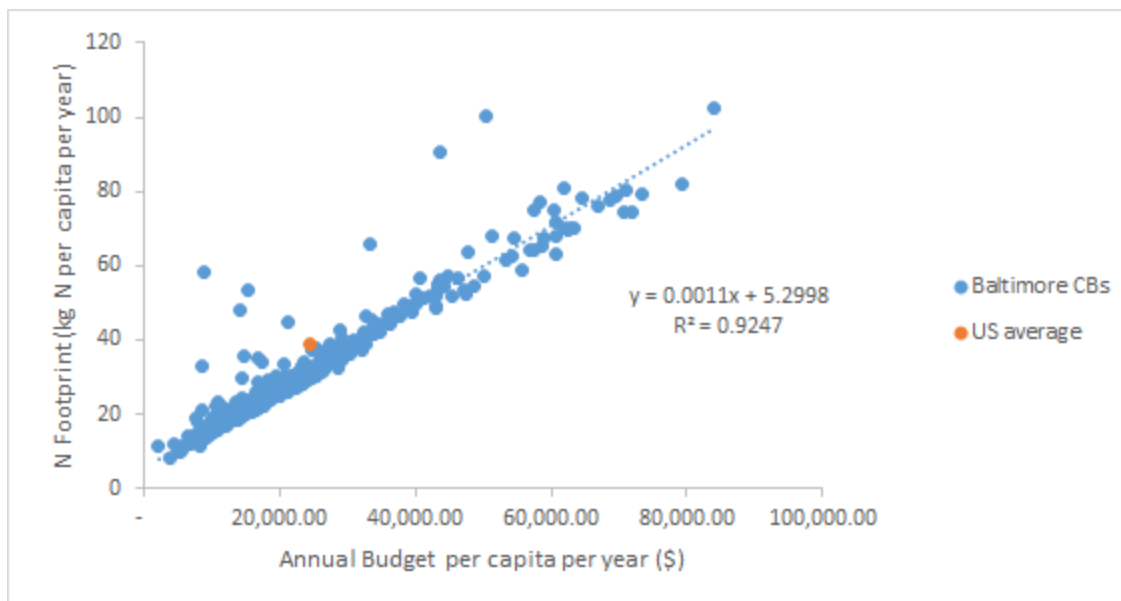


Figure 16: The relationship between the calculated N footprint value (kg N per capita) on the y-axis and the annual reported budget (dollars spent per capita) on the x-axis for all census block groups in the Baltimore City. The R^2 value shows the strength of the correlation of these two variables. With an R^2 value of 0.92, the correlation between the two variables is assumed to be very strong. The orange dot on the map shows the US average of both.

The relationship between the two values supports the notion that wealthier census block groups and individuals contribute more to global nitrogen pollution than poorer census block groups and individuals. This can help to determine focused actions to reduce a city's overall N footprint as well as target certain demographics for personal behavior-based reductions. .

C. Case Study: Comparing Two Census block groups Higher and Lower N Footprints

Other factors of higher N footprint census block groups and lower N footprint census block groups were compared. These included factors such as the amount of food by category consumed, average budget, and percentage of N footprint by sector for these census block groups. The two census block groups chosen were chosen from the upper and lower percentiles of N footprint. These census block groups were chosen because both have similar population (1169 and 1060 respectively) and businesses (12 and 13 respectively) counts and are located close to the inner harbor area. The high N footprint census block group (245100101001) has an average N footprint per capita of 42 kg N per year. The lower N census block group

(245101605001) has an average N footprint of 15kg N per year. However, these census block groups have different annual budgets, sector consumption patterns, and food category consumption patterns. The total annual budgets of \$49,330,745 and \$13,490,353 are for each census block group respectively. The sector consumption N footprint are shown alongside the US and Baltimore average N footprints in Figure 17.

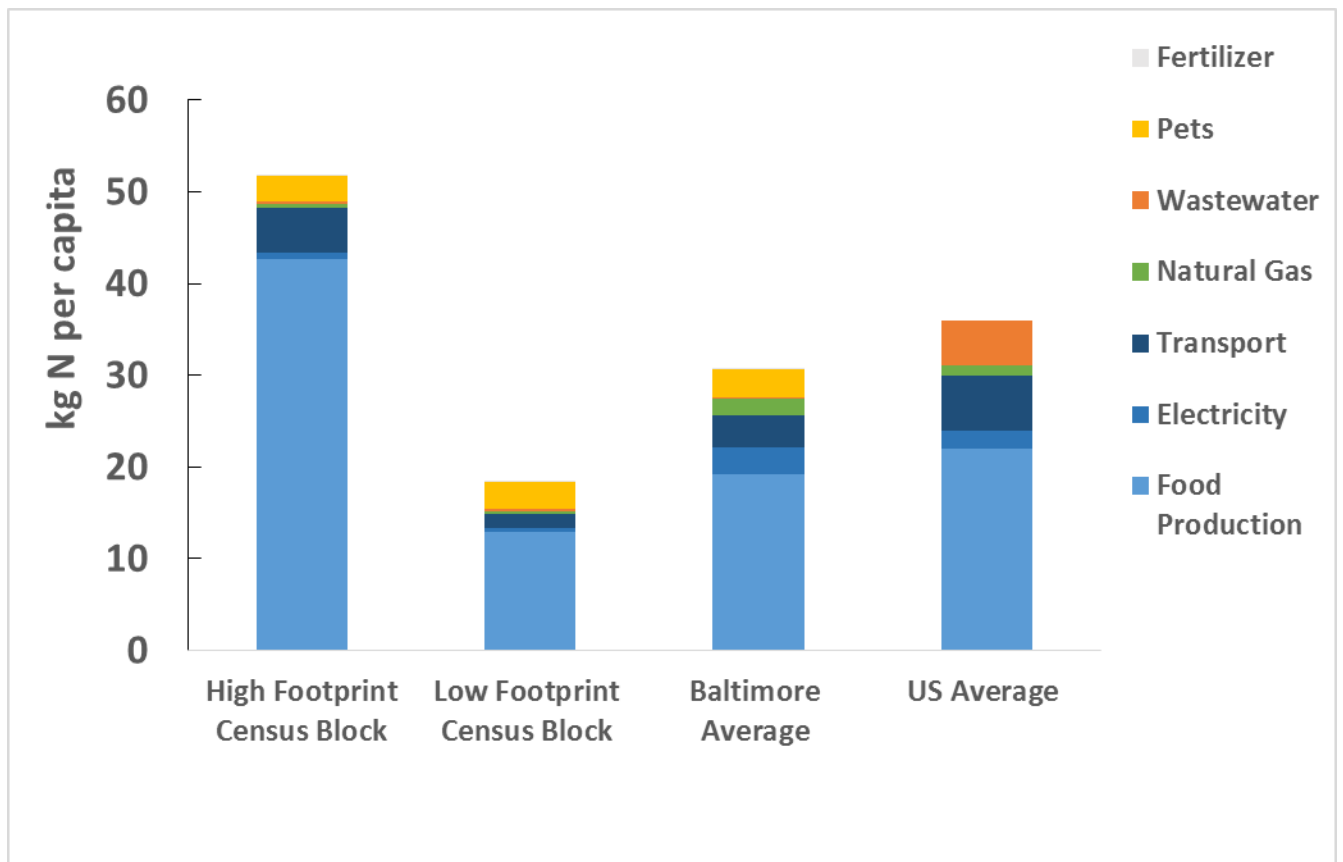


Figure 17: The N footprints of two census block groups with above and below average N footprints in the Baltimore City alongside the per capita N footprint average of Baltimore and the US. These two census block group's N footprint values were calculated using CEX data and the Urban NFT tool.

The N footprint in each census block group was lower in almost every sector. The electricity and natural gas use were different because the higher N census block group used 40% more kilowatt hours per capita more than the lower census block group and 66% more therms of natural gas than the lower census block group. Number of miles traveled was less in the lower N census block group due to the fewer number of people owning and driving vehicles. Food production was one of the categories with the largest difference. This can be attributed to both the calculated amounts of food consumed which was 70% more in the higher N footprint census block groups and the categories of food each are eating from shown in Figure 18.

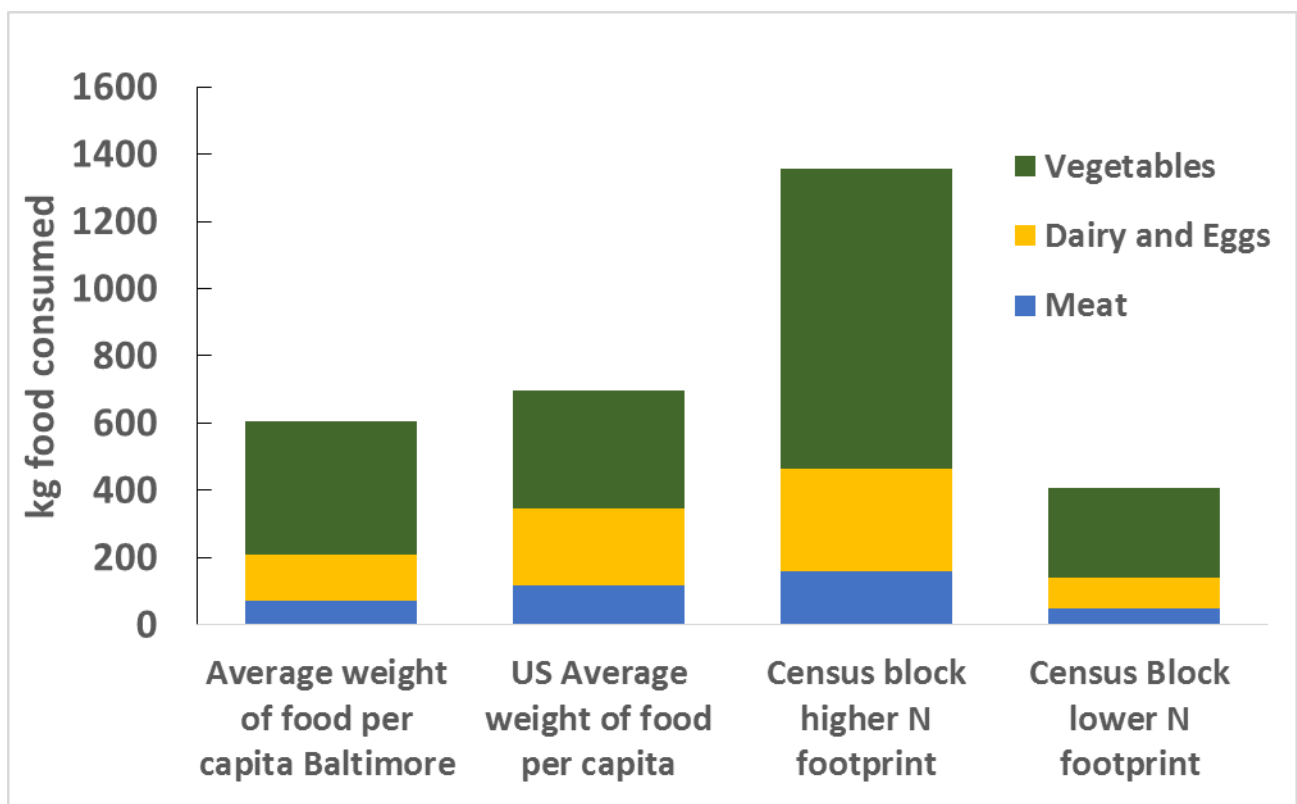


Figure 18: The comparison of the higher N footprints per capita in Baltimore and the lower N footprint per capita in Baltimore. These are shown alongside the breakdown of the average Baltimore City N footprint and the average US N footprint calculations.

In the data used to calculate the N-footprints per person, there was no inclusion of food assistance programs. It should be reiterated here that this likely contributes to the four times weight of food consumed increase from the low to the high census block group. However, the

census block group with the higher N footprint also consumed more high-N footprint food products than both the average and lower N footprint census block group which includes beef, chicken, pork, and fish. The census block groups have the same N footprint for the pets and wastewater categories because these sectors were broken down purely on a per capita basis due to the data availability.

The variability of census block groups within Baltimore City could be attributed to a number of factors. The factor evaluated here is annual budget per census block group. Other metrics that could be used are annual income, poverty levels, and demographics. In future studies where this data are available by census block group, it would be insightful to determine if these calculations line up with any other metrics.

D. Scenarios Overview and Feasibility Analysis

The second research question addressed is the impact of certain reduction strategies on the N footprint of Baltimore City. Figure 12 shows the reductions by sector of certain reduction strategies. Except for the switching from cats to dogs strategy, all scenarios resulted in a reduction of the overall N footprint. Some of the scenarios proposed are viable scenarios that could be implemented on a city-wide basis while others are unrealistic scenarios run to show the scale of strategies needed to make major reductions in the Baltimore City N footprint. An overview of the reductions by scenario and the feasibility are shown in table 4 with a more in depth discussion of each below.

Table 4: The proposed reduction scenarios with the sectors effected are listed below. The percent reduction of each scenario is also listed along with a brief analysis of the feasibility of the proposed scenario. Each also includes the stakeholders which would have ability and interest in implementing these scenarios.

Scenarios	Effect Sectors	Percent reduction	Feasibility	Stakeholders
Replace 25% beef purchased with beans	Food production of at-home food survey data	-4.5%	Low to moderate feasibility with significant consumer change or government incentives	Personal Reductions, NGOs with environment and health goals

Eliminate beef from census block groups consuming more than 80 grams of protein per capita per day	Food production for all census block groups consuming above 80 grams of protein per day	-6.5%	Low feasibility; not probable to assume all individuals will stop consuming red meat however some may.	Personal Reductions, NGOs with environment and health goals
Compost 100% of food waste	Food waste of at home food waste	-0.4%	Feasible at some capacity although maybe not at 100%	Baltimore City Management, Personal
100% of fast-food restaurants vegetarian	Food production for fast food restaurants	-20.0%	Low feasibility; at some capacity, fast food restaurants may begin to serve more vegetarian options	Companies, Personal Reductions
Increase Renewables in fuel mix by 20%	Electricity sectors of business and residential locations	-0.6%	Feasible and is a part of the Maryland Greenhouse Gas Action Plan	City Government, Utility company (Baltimore Gas and Electric)
Reduce Overall Energy Consumption by 10%	Electricity sectors of business and residential locations	-0.4%	Feasible and is a part of the Maryland Greenhouse Gas Action Plan	City government, personal choice, businesses
Increase use of public transportation by 10%	Transportation	-0.4%	Feasible and is a part of the Maryland Greenhouse Gas Action Plan	City government, personal choice
Reduce Fertilizer use by 50%	Fertilizer	-0.01%	Feasible in some respects with further restrictions	City government, personal choice
Switch from dogs to cats	Pets; both dogs and cats	-3.8%	Not feasible; scenario run for testing purposes	Personal choice
All scenarios	Pets, fertilizer, food production (at-home and fast-food), transportation, and business and residential electricity	-28.0%	Combination of feasible and non-feasible scenarios	City government, personal choice, individual businesses

a. Food Scenarios

Since food production is the largest sector in the Baltimore City N footprint calculation, food reduction scenarios have some of the largest impacts when completed on a large enough scale. The first food scenarios proposed deals more with food waste than food production and is composting 100% of food waste in Baltimore City which produces a 0.4% overall reduction.

This is because food waste has much less of a nitrogen footprint impact than the production process. Implementing more composting in Baltimore City is a feasible scenario in some capacity, even if reaching 100% of food waste is unlikely.

The less feasible scenarios are switching consumer purchasing patterns from 25% beef to beans and converting all fast food restaurants to vegetarian which have a 4.5% and 20% reductions, respectively. Although there is not much regulation or enforced action that can be taken to incentivize consumers and providers to reduce the amount of high N footprint foods served. One suggestion is to inform consumers on the environmental benefits of reducing beef consumption or providing sustainability labels for grocery stores and restaurants to highlight sustainable items on the menu. Often, eating less red meat can be linked to health benefits. The US Department of Health and Human services states that over-consuming red meat can lead to increased risk of diabetes, cardiovascular diseases, and certain types of cancers. By highlighting the benefits for both human health and the environment, this may reach a broader group of individuals who consider either when purchasing foods. One other idea is for individual restaurants to have monetary incentives for consumers who chose to purchase the vegetarian options like a lower price point or coupons for vegetarian protein sources.

b. Pets Scenario

The second largest sector in the urban N footprint is the pets sector. This sector takes into account both food production and waste removal of cats and dogs in the Baltimore City. The larger reduction comes from switching from dogs to cats. Although cats eat a higher N footprint diet, the average cat eats less and produces less waste than the average dog, giving cats the smaller N footprint in this scenarios. This scenario was run to further explore the N footprint of pets rather than to make feasible recommendations to reduce the N footprint of the city.

c. Energy and Transportation Scenarios

All of the energy and transportation scenarios were taken from the Maryland's Greenhouse Gas Reduction Plan. These scenarios were all deemed feasible by the Maryland Climate Change steering committee and approved by the Maryland State Governor. Since the carbon and nitrogen footprint overlap in the energy sector, all of the scenarios proposed to reduce the carbon footprint

of Baltimore City can also reduce the nitrogen footprint. These scenarios include reducing overall energy consumption by 10%, increasing public transportation by 10% (assumed converting 10% of by-car commuters to bus commuters), and increasing renewables in the fuel mix by 20%. These scenarios all produced an N footprint reduction but at a smaller scale than any of the food scenarios because of the relatively smaller percentage of the N footprint that these sectors make up. However, these reductions are still worthwhile to implement for complying with the set greenhouse gas reduction goals as well as reducing the nitrogen footprint. With all of these energy scenarios being implemented, there is a 4% reduction in the N footprint of the city. If some of these scenarios were implemented with more aggressive target reductions, higher N footprint reduction goals could be set.

E. Selectively Implementing Reduction Strategies in High N Census block groups

The scenarios above are all run on all census block groups within the Baltimore City. However, from Figure 5 above, it is evident that not all census block groups have an equally distributed impact on the N footprint. The final scenario impacts on the food production sector of only census block groups consuming excessive amounts of protein (higher than 80 grams per capita per day)

The recommended daily amount of protein is 45 to 60 grams per day (FAO). Most Americans consume about 90 grams per day or more (American Heart Association) and these high N footprint census block groups in Baltimore were no exception. Census block groups consuming more than 80 grams of protein per capita (183) were highlighted and all beef consumed in these census block groups was eliminated. Once this was done, the census block groups' protein consumption per capita was evaluated to determine if all were still above the recommended daily values. Each were at a sustainable value even with beef removed. The N footprint of Baltimore City was then re-calculated with high N census block groups beef consumption removed. This produced a 6.5% overall N footprint reduction.

Removing all beef purchased by consumers in certain census block groups is not a feasible scenario. However, this scenario shows the benefits of targeting certain high N footprint census block groups for reductions has substantial impacts. By eliminating beef from just 27% of

selected census block groups, the N footprint of the entire city decreased. Targeting these selected census block groups could mean implementing education and incentive campaigns in these areas.

F. Recommending impactful scenarios to reduce Baltimore City's N footprint

Recommendations for stakeholders to reduce N footprint of census block groups

The largest sector of the city's N footprint is the food sector. To reduce the N footprint from food in the city, I would recommend using an approach targeted at high N footprint census block groups. These areas are over-consuming protein and should reduce overall protein consumption for both environmental and health reasons. This can be conveyed through education campaigns as well as economic incentives to choose more sustainable protein options. Census block groups which are not eating enough protein per capita can also not be overlooked. These census block groups should be eating more protein per capita per day. Incentives to eat more sustainable protein sources, such as vegetarian based proteins should be implemented. These could include education campaigns and providing more vegetarian based protein options for food assistance programs.

Other scenarios that are largely controlled by centralized business and/or government regulated could make an impact on the energy side. These reductions are more easily implemented because of the centralized decision making bodies. This could include making the Maryland Greenhouse Gas Action Plan have more aggressive, higher reduction goals such as increasing the amount of public transportation and renewable energy fuel mixes. These scenarios may make less of an impact on the N footprint than other proposed scenarios but would be easier to implement. In this conclusion, it is important to note the areas needed for improvement in this preliminary calculation of Baltimore city's N footprint.

G. Data Sets and Next Steps of this calculation

Throughout the discussion section, the mention of lack of data was prevalent. The types of data collected for a city, especially food data, is primarily in the form of dollars spent. This would not be a problem for the N footprint calculation if there was a comprehensive dollars to weight

calculation. However, the number of ambiguous food items present made it difficult to be confident in the dollars to weight calculation completed. The food data section of this footprint could also be improved by switching from using personal consumer data to grocery store, school, prison, health system, and business purchasing data. The current model assumes that individuals purchase food within their census block group and not outside census block groups. Since some census block groups are small, this is not an accurate assumption. However, this is the best method to date because there is more extensive data publically available on consumer food purchasing.

Other data such as pets and wastewater was split up on a per capita basis rather than by census block group. For the wastewater data, a sum of the gallons of wastewater treated at both Patapsco and Back River sewage treatment plants. These values were then split up per capita for each treatment plant for each census block group. Leakage estimates were not included in this calculation. Leaky pipes and sewage overflows are prevalent in Baltimore (Groffman, 2004). Data by census block group on the number of occurrences and gallons of wastewater leaked during pipe overflows. For the pet data, the average number of dogs and cats per capita were split among census block groups. A better estimate would be to get the number of cats and dogs in the city from city pet registration tags in the Baltimore City to have data for the specific area rather than a US average.

The scope of this calculation was limited to activities occurring within Baltimore City. Activities that are not included in this calculation include miles from commuters traveling outside of Baltimore City to reach city limits, food (such as packed lunches) brought in from individuals living outside of Baltimore City limits, harbor emissions, food data for industrial census block groups (5), community gardens or larger scale food production activities inside the city, and food data from food assistance programs. Along with other improvements in the mentioned data sections above, these are next steps for the urban N footprint calculation from the Baltimore City. The highest priorities of these are to determine a better source for food data and include food purchased with food assistance programs in this calculation.

H. Uses of this model for other cities and localities and comparison

The model for this N footprint calculation can be used not only for Baltimore city but also other groupings of census block groups. Other possible studies include calculating another city, county, or watershed N footprint to compare to the results seen in Baltimore City. Comparing the two footprints can be a metric to assess sustainability in each area as well as understand reduction strategies to implement in either city.

Another next step after improving the data collection and accuracy of the N footprint calculation of the Baltimore City is to work with city managers, non-governmental organizations interested in the environment or human health, city offices for sustainability, and research groups such as the Baltimore Ecosystem Study (BES). These organizations can use the N footprint calculation to further assess the feasibility of suggested reduction strategies and suggest their own. Eventually, plans could be developed and implemented by city or local governing bodies to reduce the N footprint of the city. This is a route currently taken by institutions and could be implemented in cities for areas where governing bodies have a great influence. The area left unaddressed by solely focusing on centralized reduction goals is educating the public on the environmental and health issues of excess reactive N, especially for Baltimore City which is effected by nitrogen pollution issues. These areas could be addressed with NGOs and offices for sustainability within a city. Further research on the local effects of reducing the city N footprint could be undertaking in conjunction with local research groups such as the BES organization.

Conclusion

The nitrogen footprint tool has been an interface for individuals and institutions. The individual N footprint tool has helped connect personal choices with nitrogen pollution, and the institution N footprint tool has allowed for tracking the footprint and reducing it through mitigation strategies in a campus setting. The next logical step in nitrogen management is to address a broader population that is still linked to the locality of nitrogen issues: cities. The urban N footprint tool is able to assist stakeholders from governing bodies to NGO's to implement targeted reduction strategies within a city by determining. The case study location in this tool

was the Baltimore City. However, using census block group data, this tool can be used for any selected collection of census block groups.

With collaboration from multiple groups within a city, the urban NFT tool can be used to effectively assess the scope of nitrogen emissions associated with the functioning body and determine how sustainability actions could reduce those emissions. When used alongside other sustainability metrics such as the carbon footprint tool and greenhouse gas inventories, a nitrogen footprint calculation can provide a broader view of the overall sustainability of a city. If multiple stakeholders within a city are able to collaborate and come together on feasible reduction strategies, the nitrogen footprint tool can be a useful and effective tool to inform and reduce nitrogen pollution as a result of a city's resource use.

Acknowledgements

This thesis would not have been possible without the support and guidance of many others who have been essential in helping to complete this project. I would first like to thank my advisors, Dr. James Galloway, Dr. Lawrence Band, and Dr. Peter Groffman who have provided guidance and support throughout this project. I would also like to thank Allison Leach and Elizabeth Castner who developed the institution N footprint tools and have been mentors on developing the urban N footprint tool. I would also like to thank Julia Stanganelli who has assisted with data calculations and conversion. Finally, I would like to thank all those who have helped with data collection but especially Dexter Locke, Drew MacQueen, Jo-el Nelson, and Chris Gist who have been essential in assisting with collecting and displaying data in ArcGIS. This research was supported by USEPA Grant #83563201, Development/Application of Nitrogen Footprint.

References

- American Heart Association's Diet and Lifestyle Recommendations. 2015. <http://www.heart.org>
- Aryal, B., Cherewich, J., Field, A., Glinsky, A., Griffin, B., Hamm, M., Lemly, J., Valenti, J., Williams, K. 2011. Baltimore County Community Greenhouse Gas Inventory. *Townson University Environmental Science and Studies Senior Seminar*. 1-32.
- Baker, A, Hope, D., Xu, Y., Edmonds, J., Lauver, L. 2001. Nitrogen balance for the Central Arizona-Phoenix (CAP) Ecosystem. *Ecosystems*, 4, 582-602.
- Baltimore Ecosystem Study. NSF Long-term Ecological Research (LTER) Program. <https://beslter.org>.
- Baltimore Public Works Department. Kimberly Grove. 2018. www.publicworks.baltimorecity.gov
- Baltimore Office of Sustainability : People, Planet, Prosperity. 2017. <http://www.baltimoresustainability.org/>
- Barnes, R., Andrews, J., Orr, C. 2017. Leveraging the Nitrogen Footprint to Increase Campus Sustainability. *Sustainability: The Journal of Record* 10, 131-139.
- Birch, M., Gramig, B., Moomaw, W., Doering, O., Reeling, C. Why Metrics Matter: Evaluating Policy Choices for Reactive Nitrogen in the Chesapeake Bay Watershed. 2011. *Environmental Science and Technology* 45, 168-174.
- Brady, P.A., and Fath B.D., 2006. Greenhouse Gas Inventories of Baltimore County and County Government. Townson University. Baltimore Office for Sustainability.
- Bureau of Labor Statistics: Consumer Price Index. 2016. *US Department of Labor*. www.bls.gov
- Chesapeake Bay Phase 6 Land Use Viewer. 2017. *United States Geologic Survey*. <https://chesapeake.usgs.gov/phase6/map>

Cook, A., Pryer, J., Shetty, P., 2000. The problem of accuracy in dietary surveys. Analysis of the over 65 UK National Diet and Nutrition Survey. *Journal of Epidemiology and Community Health* 54 (8), 611-616.

Castner, E., Leach, A., Leary, N. Baron, J., Compton, J., Galloway, J., Hastings, M., Kimiecik, J., Lantz-Trissel, J., de la Reguera, E., Ryals, R. (2017). The Nitrogen Footprint Tool Network: A Multi-Institution Program to Reduce Nitrogen Pollution. *Sustainability: The Journal of Record* 10, 79-88.

Cattaneo, L., Bastian, R., Colosi, L., Leach, A., Galloway, J. Determining reactive nitrogen removal treatment in the United States, European Union, Japan, and Australia. *Journal of Cleaner Production (in preparation)*.

Chesapeake Bay Foundation: Saving a National Treasure. What's your bay footprint? 2016. https://secure.cbf.org/site/SPageNavigator/bay_footprint.html.

Dietary Guidelines for Americans. 2015. *US Department of Health* (8).

Fraser, J., Bazuin, J., Band, L., Grove, M. 2013. Covenants, cohesion, and community: The effects of neighborhood governance on lawn fertilization. *Landscape and Urban Planning* 115, 30-38.

Galloway, J.N., J. D. Aber, J. W. Erisman, S.P. Seitzinger, R. W. Howarth, E. B. Cowling, and B.J. Cosby. 2003. The nitrogen cascade. *Bioscience* 53, 341-354.

Galloway, JN, W Winiwarter, A Leip, AM Leach, A Bleeker, JW Erisman. 2014. Nitrogen footprints: Past, present, and future. *Environmental Research Letters* 9: 115003.

Galloway, J., Cowling, E. Reactive Nitrogen and The World: 200 Years of Change. *Ambio: A Journal of the Human Environment* 31, 64-71.

Groffman, P.M., Law, N.L., Belt, K.T., Band, L.E., Fisher, G.T. 2004. Nitrogen Fluxes and Retention in Urban Watershed Ecosystems. *Ecosystems* 7, 393-403.

Hogan, L., Ruthford, B., Grumbles, B., 2015. The 2015 Greenhouse Gas Emissions Reduction Act of 2009 (GGRA) Plan Update. Maryland Department of the Environment.
<http://climatechange.maryland.gov>.

Hobbie, S., Finlay, J., Janke, B., Nidzgorski, D., Millet, D., Baker, L. 2017. Contrasting nitrogen and phosphorous budgets in urban watersheds and implications for managing urban water pollution. *Proceedings of the National Academy of Science of the United States of America* 114, 4177-4182.

Kaushal, S., Groffman, P., Band, L., Shields, C., Morgan, R., Palmer, M., Belt, K., Swan, C., Findlay, S., Fisher, G. 2008. Interaction Between Urbanization and Climate Variability Amplifies Watershed Nitrate Export in Maryland. *Environmental Science and Technology* 42, 5872-5878.

Leach, AM, JN 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.

Okin, G. Environmental impacts of food consumption by dogs and cats. 2017. *PLOS*.
<https://doi.org/10.1371/journal.pone.0181301>

Phillips, S., McGee, B. 2016. Ecosystem Services Benefits of a Cleaner Chesapeake Bay, *Costal Management* 44, 241-258.

Products of Combustion. 2017. *Energy Conservation and Environmental Protection*. Penn State College of Earth and Mineral Sciences.

Singh, S., Compton, J., Hawkins, T., Sobata, D., Cooter, E. 2017. A Nitrogen Physical Input-Output Table (PIOT) model for Illinois. *Ecological Modeling* 360: 194-203.

The Gwynns Falls Watershed Ecological Resource Atlas. 1999. United States Forest Service through the *Revitalizing Baltimore* project 4-5.

US Environmental Protection Agency: Ozone Pollution. 2015. <https://www.epa.gov/ozone-pollution>.

Appendix: Table 1: Data sources used for calculations done in Figures 2-8.

1. USDA Agricultural Marketing Service: Custom Average Tool: <https://cat.ams.usda.gov/>
2. AAHA Nutritional Assessment Guidelines for Dogs and Cats: <https://www.aaha.org>
3. Local Governments for Sustainability (ICLEI): <http://www.iclei.org/>
4. Baltimore Gas and Electric: <https://www.bge.com>
5. Ersi Consumer Spending Methodology 2016: Demographic and Business Data List
6. Baltimore City Health Department: How to Apply for a pet licenses: <https://health.baltimorecity.gov>
7. Office of Highway Policy Information (HPMS): www.fhwa.dot.gov
8. Maryland Department of Transportation: State Highway Administration: <http://roads.maryland.gov>
9. Cattaneo, L., Bastian, R., Colosi, L., Leach, A., Galloway, J. Determining reactive nitrogen removal treatment in the United States, European Union, Japan, and Australia. *Journal of Cleaner Production* (in review).
10. US Department of Transportation, Research and Innovative Technology Administration, and Bureau of Transportation Statistics: www.bts.gov/publications/national_transportation_statistics
11. Food and Agriculture Organization of the United Nations (FAO): www.fao.org/es/faodef/faodefe.htm
12. Emissions & Generation Resource Integrated Database (eGRID): <https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid>
13. A.B. Baker, D. Hope, Y. Xu, J. Edmonds, L. Lauver. 2001. Nitrogen balance for the Central Arizona-Phoenix (CAP) Ecosystem. *Ecosystems*, 4, 582-602.
14. Fraser, J., Bazuin, J., Band, L., Grove, M. 2012. Covenants, cohesion, and community: The effects of neighborhood governance on lawn fertilization. *Landscape and Urban Planning* 115, 30-38.
15. Wuest S, Cassman K. 1992. Fertilizer-nitrogen use efficiency of irrigated wheat: I. Uptake efficiency of pre-plant versus late-season application. *Agronomy Journal* 84: 682-688.
16. Food and Agriculture Organization of the United Nations: Food and Energy: www.fao.org/docrep/006/y5022e/y5022e00.HTM
17. Food and Agriculture Organization: Average Food Waste Factors in the US. <http://www.fao.org/docrep/014/mb060e/mb060e00.pdf>
18. Leach, AM, JN 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.
19. Calculated from Atomic Weights (NO_x)
20. Calculated from Atomic Weights (N₂O)
21. Baltimore City Department of Public Works: <https://publicworks.baltimorecity.gov/pw-bureaus/water-wastewater/wastewater/patapsco>

Appendix: Table 2: Dollars to Weight Conversions Sources By Category

CEX Item	Price Used (per lb)	Source	CEX Item	Price Used (per lb)	Source
Flour	0.53	BLS	Oranges	1.25	BLS
Prepared Flour Mixes	0.53	BLS	Citrus Fruit excluding Oranges	1.16	BLS
Ready-to-eat & Cooked Cereal	2.18	USDA	Other Fresh Fruit	2.04	BLS
Rice	0.72	BLS	Potatoes	0.68	BLS
Pasta/Cornmeal/Other Cereal	1.30	BLS	Lettuce	1.06	BLS
White Bread	1.37	BLS	Tomatoes	1.93	BLS
Bread excluding White	1.80	BLS	Other Fresh Vegetables	1.93	BLS
Cookies	3.35	BLS	Prepared Salads	1.93	BLS
Crackers	2.18	USDA	Frozen Orange Juice	2.71	BLS
Frozen & Refrigerated Bakery Goods	4.15	USDA	Frozen Fruit Juice	2.71	BLS
Fresh Biscuits/Rolls/Muffins	2.18	USDA	Frozen Fruit	2.18	USDA
Fresh Cakes & Cupcakes	2.79	USDA	Canned Fruit	1.48	USDA
Bread & Cracker Products	2.18	USDA	Dried Fruit	1.26	USDA
Sweet Rolls/Coffee Cakes/Donuts	2.79	USDA	Fresh Fruit Juice	0.87	USDA
Fresh Pies/Tarts/Turnovers	2.79	USDA	Canned/Bottled Fruit Juice	0.87	USDA
Ground Beef	4.57	BLS	Frozen Vegetables	1.78	USDA
Chuck Roast	4.66	BLS	Canned Beans	1.30	USDA
Round Roast	5.21	BLS	Canned Corn	0.89	USDA
Other Roast	5.46	BLS	Misc Canned Vegetables	1.30	USDA
Round Steak	5.82	BLS	Dried Beans & Peas	1.41	BLS
Sirloin Steak	8.39	BLS	Misc Dried Vegetables	1.41	BLS
Other Steak	7.52	BLS	Vegetable Juice	0.87	USDA
Other Beef	4.50	BLS	Candy & Chewing Gum	4.46	USDA
Bacon	5.42	BLS	Sugar	0.63	BLS
Pork Chops	3.88	BLS	Artificial Sweeteners	0.63	BLS
Ham	3.07	BLS	Jam/Jelly/Pres & Other Sweets	1.22	USDA
Pork Sausage	2.68	BLS	Fats & Oils	2.65	USDA
Other Pork	2.68	BLS	Salad Dressings	1.22	USDA
Other Meat	2.68	BLS	Nondairy Cream & Milk	0.39	BLS
Lamb & Other Meat	2.68	BLS	Peanut Butter	2.58	BLS
Frankfurters	3.24	BLS	Potato Chips & Other Snacks	4.46	BLS
Bologna/Liverwurst/Salami	2.65	BLS	Nuts	3.41	USDA
Other Lunchmeat	2.65	BLS	Salt/Spices/Other Seasonings	0.63	BLS
Whole Chickens	1.46	BLS	Olives/Pickles/Relishes	1.30	
Chicken Parts	1.53	BLS	Sauces & Gravies	1.22	USDA
Other Poultry	3.25	BLS	Other Condiments	1.22	USDA
Canned Fish & Shellfish	3.13	BLS	Soup	1.22	USDA
Fresh Fish & Shellfish	5.70	USDA	Prepared Desserts	2.79	USDA
Eggs	1.68	BLS	Baby Food	1.22	USDA
Fresh Milk (All Types)	0.39	BLS	Cola Drinks	0.46	USDA
Cream	0.39	BLS	Other Carbonated Drinks	0.46	USDA
Butter	1.82	BLS	Roasted Coffee	4.39	BLS
Margarine	1.82	BLS	Instant/Freeze-dried Coffee	4.39	BLS
Cheese	5.23	BLS	Tea	0.30	USDA
Ice Cream & Rel Prod	1.15	BLS	Noncarbonated Fruit Drinks	0.52	USDA
Other Dairy Products	2.15	BLS	Sports Drinks	0.52	USDA
Apples	1.44	BLS	Other Noncarb Beverages(excl water)& Ice	0.52	USDA
Bananas	0.57	BLS	Beer & Ale	1.35	BLS
Oranges	1.25	BLS	Wine	2.32	BLS
Citrus Fruit excluding Oranges	1.16	BLS	Whiskey	14.54	gizmod.com