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Building a Carbon Footprint of Clemson University's Main Campus

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BUILDING A CARBON FOOTPRINT OF CLEMSON UNIVERSITY'S MAIN CAMPUS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirement for the Degree
Master of Science
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by
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Accepted by:
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ABSTRACT

Greenhouse gas (GHG) inventories have become a popular means for colleges and universities to better understand their environmental impact and quantify sustainability efforts. Clemson University is one of the many institutions that signed the American College & University Presidents Climate Commitment, which explicitly calls for a comprehensive inventory of GHG emissions to be created. In the past, Clemson University has contracted an external consulting firm to quantify Clemson's GHG emissions, however, a transparent method of calculating emissions is needed. Carbon footprinting is an effective method to measure GHG emissions, and carbon footprinting of higher education institutions is currently an underdeveloped research area.

As a contribution to efforts on the subject, this research presents the carbon footprint for Clemson University's main campus. This footprint was built using a consumption-based, hybrid life cycle assessment approach and included scope 1 (direct), 2 (indirect from electricity), and 3 (other indirect) GHG emissions. The scope 1 emissions include steam generation, refrigerant usage, univeristy owned vehicles, univeristy owned aircraft, fertilizer application, and wastewater treatment. Scope 2 is electricity generation. Then, scope 3 includes electricity life cycle, transmission and distibution losses, commuting, univeristy related travel, paper usage, waste and recycling transportation, wastewater treatment chemicals, and water treatment.

The total carbon footprint of Clemson University's main campus in 2014 was calculated to be 95,000 metric tons CO_2-e, sources of uncertainty include data quality and the streamlined life cycle assessment approach. This research found that 49% of GHG emissions were from electricity related activities, while fossil fuel dependent activities such as automotive commuting (18%), steam generation (16%), and university related travel (13%) added significantly to the footprint. Overall, creating a reproducible baseline carbon footprint can be used to compare Clemson against other higher education institutions, while helping develop goals, strategies, and policies to reduce emissions. The high emissions related to electricity could be decreased through increased renewable energy sourcing. Therefore, as a further component of this research, LiDAR data was utilized in GIS to demonstrate campus rooftop photovoltaic potential.

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LIST OF ABBREVIATIONS

ACUPCC	American College & University Presidents Climate Commitment
C_2H_6	Ethane
C_3H_8	Propane
C_6H_{14}	Hexane
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalents
EPA	Environmental Protection Agency
HFCs	Hydrofluorocarbons
IO	Input–output analysis
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life cycle assessment
LiDAR	Light detection and ranging
N_2O	Nitrous oxide
PA	Process analysis
PFCs	Perfluorocarbons
SF_6	Sulphur hexafluoride
CO2-e	Carbon dioxide equivalents
eGRID	Emissions & Generation Resource Integrated Database
g	Gram
EIA	Energy Information Administration
GHG	Greenhouse gas
GIS	Geographic information system
GTP	Global Temperature change Potential
GWP	Global warming potential
HCFC	Hydro-chlorofluorocarbon
HEI	Higher education institution
HLCA	Hybrid-LCA

HRSG	Heat recovery steam generator
kg	Kilogram
kWh	KiloWatt hour
m	Meter
MTCOe	Metric tons carbon dioxide equivalent
PV	Photovoltaic
UNFCCC	United Nations Framework Convention on Climate Change
WBSCD	World Business Council for Sustainable Development
WRI	World Resources Institute

1 INTRODUCTION

1.1 Problem Statement

Rising greenhouse gas (GHG) emissions from human activities have created international concern due to their global warming implications. This has sparked a movement to reduce emissions that has been joined by nations, cities, corporations, and higher education institutions. Clemson University is one such intuition that has pledged to reduce its emissions, and to do this they need to build a comprehensive GHG inventory.

1.2 Motivation

In 2007 Clemson University President James Barker signed on to the American College & University Presidents Climate Commitment (ACUPCC), the most widespread movement higher education institutions have adopted to address GHG emissions. This commitment challenges institutions to measure and report their GHG emissions, take immediate actions to reduce them, and to develop and implement a plan to become climate neutral [1]. To accept this challenge, institutions must commit to: (1) creating institutional structures to guide the implementation of a plan; (2) complete a comprehensive inventory of all GHG emissions; and (3) develop a plan to become climate neutral, including benchmark targets and dates [2]. This research was motivated to focus on (2) creating a transparent inventory of GHG emissions from Clemson University, which can serve as the foundation so that the other objectives can be met.

Clemson has also set long term goals to increase their renewable energy sourcing to 10% by 2025, and to become carbon neutral by 2030. In the past, Clemson University has contracted Sightlines, a consulting firm which quantified Clemson’s GHG emissions and compared them to other research institutions. However, their method of calculating emissions is proprietary, and cannot be reproduced to incorporate new data or compare strategies to reduce emissions. Therefore, this research is motivated to create a foundation to assess the current state of Clemson’s GHG emissions. Then, this research may be used as a baseline to compare alternatives to the system, and to compare Clemson against other universities.

1.3 Goals and Objectives

Clemson University has set goals with a firm timeline, therefore a baseline for GHG emissions must be created to develop improvement strategies and monitor progress. The primary goal of this research is to calculate a transparent carbon footprint of Clemson University’s main campus. Carbon footprints measure the amount of GHG emissions associated with human activities. Carbon footprinting of higher education institutions is currently an underdeveloped research area despite a growing movement to reduce GHGs from these systems. As a contribution to efforts on the subject, and to address Clemson’s GHG reduction efforts, this research evaluates Clemson’s operational activities that emit GHGs. The cumulative contribution of these activities creates Clemson’s carbon footprint. From this, a secondary goal of this research is to identify which products and processes are the greatest contributors to the carbon footprint, and then provide recommendations are offered to decrease emissions. One such recommendation is the implementation of a renewable electricity source. Accordingly, a third goal of this study is creating a map to depict campus rooftops suitable for solar photovoltaic arrays.

Objectives

- Identify GHG emission sources associated with Clemson University's campus operations
- Quantify GHG emissions from each source
- Recommend strategies to decrease emissions from each source
- Sum emissions from all sources to calculate carbon footprint
- Create map to demonstrate solar photovoltaic potential for campus rooftops

1.4 Organization of Thesis

This thesis will be organized to give the reader background to the concerns with GHG emissions, and then describe the methodology used to quantify emissions from Clemson University's campus. Chapter 2 will introduce Clemson University, and disclose the background regarding rising GHG emissions and the action this is inspiring. Chapter 2 also discusses what a carbon footprint is, describes the various types of life cycle assessment, and reviews previous life cycle assessments conducted to carbon footprint higher education institutions. The life cycle assessment design for the study is then described in Chapter 3. The methods and results of the study are broken down in Chapter 4, with each activity contributing to the campus carbon footprint having its own section. The final conclusions and recommendations are presented in Chapter 5. Supplemental figures are shown in the Appendix.

2 BACKGROUND

2.1 Overview

This chapter introduces the information necessary to understand the significance of GHG emissions. First Clemson University is described, then the GHG effect and global warming are explained. Further subsections then outline the actions resulting from the rise in GHG emissions, including movements by higher education institutions. Then, this chapter will describe what a carbon footprint is, and the decisions that are involved in defining the footprint. Next, life cycle assessment will be described, along with its methodological approaches. This chapter will then review previous carbon footprints of higher education institutions that were conducted using a life cycle assessment approach.

2.2 Clemson University

Clemson University resides in the northwest corner of South Carolina, in the foothills of the Blue Ridge Mountains. Clemson was founded in 1889 after Thomas Green Clemson bequeathed his home and fortune to the state of South Carolina. From this action, the Clemson Agricultural College was established, with its trustees made custodians of the Morrill Act and Hatch Act funds [3]. Thus, Clemson University remains a public land-grant university [3]. Clemson’s campus sits on 1,400 acres bordering Hartwell Lake, and owns an additional 17,500-acre experimental forest that is dedicated to education, research and demonstration [4]. The forest also has many trails and recreational opportunities that are available to the public. According to Clemson Facilities, the main campus has 6,607,060 square feet of building area. Over the years, the university also has expanded to include remote facilities throughout the state in Greenville, Greenwood, Columbia, and Charleston [5]. Clemson is the second largest university in South Carolina, and recently, Clemson University has been classified as a "highest research activity" university. In 2014, the year of this study's scope, there were 21,857 total students with 17,260 undergraduates and 4,597 graduate students [6]. In this year, Clemson employed 1,388 faculty, 208 administrators, and 3,304 staff. [7]. Clemson has a 17:1 student-to-faculty ratio, and offers students over 80 majors, and more than 75 minors [5].

2.3 Greenhouse Gas Effect

The Earth's temperature is maintained by a balance of incoming and outgoing energy. Solar radiation from the Sun is absorbed by the Earth, then reemitted into the atmosphere where it is partly reflected to Earth. Greenhouse gases (GHGs) in the atmosphere absorb and emit radiation in random directions, so when this radiation is reflected downward it intensifies warming of the Earth's atmosphere. This is called the greenhouse effect, as the atmosphere acts in the similar manner of the glass of a greenhouse trapping in heat. This temperature balance is disrupted when high concentrations of GHGs are added to the atmosphere.

GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), water vapor (H_2O), and fluorinated gases. The atmospheric concentrations of CO_2, CH_4, and N_2O have increased to levels that haven't been measured in the last 800,000 years [8]. Specifically, CO_2 concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel combustion [8]. Combustion occurs when fossil fuels react with oxygen (O_2) to give off heat. Fossil fuels are made up of carbon and hydrogen and are consequently considered hydrocarbons. When burned, hydrocarbons produce CO_2 and H_2O as their products. The reactions for CH_4, ethane (C_2H_6), propane (C_3H_8), and hexane (C_6H_{14}) are shown below and will be used in later analysis.

$$\mathrm{CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O\,(g)} \tag{1}$$

$$\mathrm{2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)} \tag{2}$$

$$\mathrm{C_3H_8\,(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)} \tag{3}$$

$$\mathrm{2C_6H_{14}\,(g) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(g)} \tag{4}$$

Since the beginning of the Industrial Revolution, atmospheric concentrations of CO_2 have risen rapidly from about 280 parts per million (ppm) to over 408 ppm [9] [10]. Anthropogenic GHG emissions have steadily increased, spurred by growing economies, technology, and population growth. Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere grew to about 2,040 gigatonnes [11]. Of this, about half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years [11]. Since, emissions from fossil fuels and cement alone have grown from 9.6 gigatonnes CO_2 in 2012, to nearly 9.8 gigatonnes CO_2 in 2014 [12]. About 40% of these emissions stayed in the atmosphere, while the rest has been removed from the atmosphere and stored on the ocean, or land based plants and soil [11]. Thus, these GHGs that wouldn’t otherwise be in the atmosphere trap heat, causing a change in the Earth’s climate. This swift rise in GHGs from human activity and the associated rise in global temperature is known as the “enhanced greenhouse effect” [13]. The Intergovernmental Panel on Climate Change (IPCC) stated that these increased GHGs emissions coupled with other anthropogenic drivers are extremely likely to have been the dominant cause of the observed global warming since the mid-20th century [8].

2.4 Global Warming Effect

Further GHG emissions will cause continued global warming and changes in the climate system. This increases the likelihood of severe and irreversible impacts for people and ecosystems [8]. The IPCC Fifth Assessment Report found with very high confidence that observational evidence from all continents and most oceans show that many natural systems are being affected by regional climate changes, particularly temperature increases [8]. The change in climate has caused loss of sea ice, accelerated sea level rise, and more extreme climate related events such as heat waves, droughts, floods, cyclones, and wildfires. These events will have severe impacts on ecosystems, the environment, and human health. Left unchecked, some consequences of climate change, such as sea level rise, can be irreversible [9]. These events may alter the habitats of many animal and plant species.

Humans will be affected in a variety of ways. An increase of 2 ºC of warming will increase drought in the mid-latitudes and semiarid low latitudes, displacing 1 to 2 billion additional people, decrease low-latitude crop productivity, and bleach and eventually kill most ocean corals [14]. If the ocean continues to warm, it will induce the melting of Antarctica and Greenland’s ice shelves, and eventually it will be impossible to avoid large scale ice sheet disintegration and several meters of sea level rise [15]. These rising sea levels, extreme weather, and flooding threaten infrastructure. Agriculture may also be threatened by changing weather patterns, rising temperature, and inconsistent water supplies. Areas dependent on hydropower for energy may also have to find alternative power sources if they don’t have a consistent water supply.

Socially, middle and low income countries are at immediate and disproportionately high risk of being adversely affected by global warming [13]. This may endanger the United Nations “Sustainable Development Goals” that include ending poverty and hunger [16]. Economically, the global impacts from climate change are difficult to estimate as the climate system is complex to model. The latest United Nations Environment Program (UNEP) Adaptation Finance Gap Report declared that the costs of global adaptation could range from $280 billion and $500 billion by 2050 [17]. Another analysis by the Natural Resources Defense Council examined the cost of damage from hurricanes, real estate losses, increased demand for energy, and water stress in the U.S. If present trends continue, the projected cost from climate change impacts on the U.S. alone is almost $1.9 trillion annually, or 1.8 percent of the country's GDP per year by 2100 [18].

2.5 Global Change

In 2008, one of America's foremost climatologists, NASA scientist James Hansen stated, "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, CO_2 will need to be reduced to at most 350 ppm" [19]. According to the National Oceanic & Atmospheric Administration (NOAA) measurements at Mauna Loa, levels of CO_2 have already surpassed 408 ppm [10]. To limit the increase of future global warming to 2 °C above pre-industrial levels, it is necessary to stabilize the atmospheric concentration of CO_2 equivalent to about 450 ppm [20]. For this to be achieved, global emissions would need to peak around 2015 and decrease 40 to 45 percent by 2050 compared to 1990 levels [9]. If this reduction target is met, there is more than an 85% likelihood that global average temperature will remain under 2 ^{o}C [9].

A global effort is needed to address and limit global warming. If GHG emissions are decreased and monitored in the next few decades, this could reduce future climate risks and the associated costs and challenges of mitigation [8]. The importance of GHG emissions reduction was first internationally recognized in 1992 by the United Nations Framework Convention on Climate Change (UNFCCC). In 1997, the Kyoto Protocol was established to set national and regional reduction targets. Industrialized countries were expected to have higher reductions than countries that had economies in transition, however all parties committed to reducing their emissions by an average of 5 percent against 1990 levels over the five-year period from 2008 to 2012 [21]. This protocol did not obtain equal support from all the nations and some countries such as the United States and Australia did not accede it, claiming that their economies may suffer [13]. Furthermore, there were issues such as major emitters China and India having no emission limits under the protocol [20].

More recently, the UNFCCC drafted the Paris Agreement which seeks to bring nations together to combat climate change and adapt to its effects. This agreement builds upon the convention that GHG concentrations must be stabilized "at a level that would prevent dangerous anthropogenic interference with the climate system" [22]. For this agreement, each country made an intended nationally determined contribution. As of July

2017, 153 of the 197 parties that signed the agreement have ratified the Convention [23]. Many major GHG emitters signed the agreement, including the U.S., China, Russia, India, Japan, the European Union, Brazil, Canada, and South Korea. While the U.S. originally adopted the agreement through an executive order by President Obama, President Trump has since decided that the U.S. would withdraw from the agreement.

2.6 U.S. Emissions

The United States have the highest cumulative GHG emissions. In 2000, total emissions reached 6,928 million metric tons of carbon dioxide equivalent, which accounted for 20.6% of the world's cumulative emissions [9]. In the U.S., electric power production, transportation and several manufacturing industries including petroleum refining, iron and steel manufacturing, and cement production are estimated to generate around 80% of GHG emissions [24]. The failure of the U.S. to ratify the Kyoto Protocol and continued reluctance to regulate GHG emissions has caused concern both internationally and domestically [25].

One step forward nationally has been the Consolidated Appropriations Act in 2008, which instructed the U.S. Environmental Protection Agency (EPA) to require mandatory reporting of GHG emissions from appropriate sources in all sectors of the U.S. economy [26]. Then, in 2014, the EPA proposed the Clean Power Plan under the Obama administration, which was a policy that required individual states to meet specific standards to reduce CO_2 emissions from existing power generation [27]. This plan aimed to have carbon emissions from the power sector reduced 32% from 2005 levels by 2030, and allowed states to submit their own plan for reductions. There was a varied response to this plan; a coalition of 27 states filed lawsuits against the EPA to block the plan, while other states stayed on track to meet targets. In 2015, the Obama administration continued its policy to combat anthropogenic climate change when President Obama signed the Paris Agreement. With this agreement, the U.S. submitted to the UNFCCC that they intend to make their best efforts to reduce their GHG emissions by 28% below its 2005 level by 2025 [28].

Then, on January 20th, 2017, Donald Trump became the 45th president of the United States. On March 28, 2017, President Trump issued an Executive Order that established a national policy to favor energy independence, economic growth, and the rule of law [27]. With this he signed an executive order directing the EPA to review the Clean Power Plan [27]. Then, on June 1st, 2017 President Trump announced that the U.S. would withdraw from the Paris Climate Agreement. President Trump's declaration to abandon the agreement has inspired mayors, governors, university presidents, and businesses across the country to declare their support to meet the standards set in the Paris Accord.

Governors of Washington, New York, and California have formed the United States Climate Alliance, which is a coalition for states committed to taking climate change action. Furthermore, many local and regional governments have already created their own policies for GHG emissions. For example, the California Global Warming Solution Act in 2006 planned to lower the state's GHG emissions to the level of 1990 by 2020 [13]. Additionally, more than 150 U.S. cities participate in the Cities for Climate Change Protection and almost 700 mayors have enrolled in the U.S. Mayors Climate Protection Agreement [25]. Now, hopefully even more regional and local organizations will take their own initiative to combat GHG emissions and changing climate.

Another method GHG emissions may lower is through corporate initiative. Corporate ecological response is mostly driven by legislation, stakeholder pressures, economic opportunities, and ethical motives [29]. However, there has also been an increased motivation for businesses, organizations, and governmental institutions to track their environmental performance and manage it over time [30]. Executives are concerned they will soon face a 'carbon-constrained' economy in which greenhouse-gas emissions are taxed, capped or under some other form of regulation [31]. There is also added incentive to improve revenues through green marketing [29]. Globally, many corporations have already begun calculating their carbon footprint to cut down their emissions and gain a competitive economic advantage in the future [31]. In January 2007, a group of U.S. corporations including Lehman Brothers, Alcoa, and Pacific Gas and Electric, appealed for mandatory, economy-wide regulatory programs that support a 10% to 30% reduction of GHGs over 15 years [32]. More than 40 Fortune 500 companies have also announced their support for mandatory federal regulation of GHGs [32]. Walmart met and surpassed its commitment to reduce 22 million metric tons of GHG emissions from its global supply chain in 2015, meanwhile companies like Coca-Cola and Unilever have set ambitious goals to cut their emissions by 25% and 50% respectively [33]. However, until legislation or stakeholder pressure exists many companies may not decide to curb GHG emissions.

2.7 Higher Education Institutions

2.7.1 Motivation

The movement to lower GHG emissions has also trickled down to higher education institutions (HEIs). There are more than 4,000 post-secondary schools in the U.S. that enroll approximately 25 million students [34]. Universities can influence students' personal and professional decisions and future environmental impacts though their education and also by using the university as a role model [35]. Large univerities have emissions profiles similar to those of small cities [25] and if society is moving towards an emissions reduction, universities should play an active role [36].

2.7.2 Greening Programs

Through the 1990's, campus greening efforts focused mainly on topics such as increased recycling, more efficient lighting, water conservation, and waste reduction [37]. More recently, campus greening initiatives have shifted their focus to energy and climate [37]. Currently, programs for the HEI sector have focused mainly on two issues: (i) reducing energy consumption and waste on university and college campuses (so-called 'campus greening') and (ii) on 'greening the curriculum' [38]. In recent years, campus greening projects are growing at an exponential rate [39]. Many colleges and universities have already responded to global warming concerns through curriculum changes that target sustainability awareness and design [2]. This is important, as universities can influence the direction of society by teaching environmental education, modeling environmental operations, and researching environmental solutions in their curricula [35]. The greening of curricula has also been addressed at the American Society for Engineering Education National Symposium, where the development of new undergraduate majors, graduate programs, course sequences, and experiential learning activities related to sustainability and energy were discussed [2].

2.7.3 Climate Commitments

Universities exert a form of bureaucratic control over their emissions, therefore they can respond to concerns about climate change with their own climate commitments. Internationally, HEIs have participated in several declarations such as the Talloires, Halifax, and Kyoto Declarations which address sustainable development and GHG emissions reduction [40]. Nationally, over 650 schools have joined the American College & University Presidents Climate Commitment (ACUPCC), which is now also known as the Carbon Commitment [1]. In this commitment, signatories pledge to measure and report their GHG emissions and incorporate resilence into their carbon neutrality efforts. Other colleges and universities have joined organizations such as the Association for the Advancement of Sustainability in Higher Education, and Second Nature, which create programs that challenge HEIs to become more sustainable [39]. Overall, more than 1,000 campuses have utilized the “Clean Air-Cool Planet Campus Carbon Calculator” to produce a GHG inventory to the unique scale and character of their university [41]. Beyond that, over 20 universities have partnered with Clean Air Cool Planet to initiate climate change mitigation, while regionally six universities have signed on with the Chicago Climate Exchange, and 11 have signed on to the California Climate Action Registry [25].

2.7.4 Future Efforts

Once a climate commitment or another plan is made, an institution must develop and implement a plan to follow through on their goals. James & Card (2012) found six key factors for institutions achieving environmental sustainability; (1) green campus operation measures, (2) campus administration, organization and leadership, (3) teaching, research, and service; (4) campus wide actions and activities, (5) institutional assessment of campus sustainability measures, and (6) established methods for overcoming barriers [42]. Greening campus operations needs administration and leadership to implement. Most universities address environmental imperatives by establishing an environment committee or employing an individual to decide on and implement programs [43]. When greening a univeristy, it’s important that the faculties, staff members, students, and stakeholders must be considered together [36]**.** There have been a variety of approaches used by HEIs to implement sustainability programs. Ball State University used a whole systems approach that tracked the ‘greening of the campus’ history, evaluated the progress, and modified the approach where needed to and constantly refocus efforts [44]. The University of Southampton distributed a staff and student questionnaire, and its results suggested increasing awareness on impacts of energy usage will promote a cultural shift towards becoming more energy efficient [45]. Yale University created a program that aimed to meet their GHG reduction target, while also increasing student participation and awareness of the target by challenging students to reduce their collective energy use, and for every 5% reduction in energy, the university matched a third of the university's electrical use with the purchase of renewable energy credits [46]. This program is a good example of a measure to green the campus while including students in a campus wide action. Making plans and tracking progress on climate commitments is an important consideration for HEIs moving forward.

2.8 Background Significance to Research

Overall, there are many reasons why organizations are monitoring and reducing their GHG emissions. This chapter has thus far outlined the implications of rising GHG emissions, and described a range of political initiatives that have arose to address these emissions. The U.S. is a world leader, and a leading GHG emitter, therefore they have the potential to set an example of how emissions can be reduced. Implementing policies to reduce emissions on the federal level have been challenging, and decreasing emissions will require commitment from all entities that emit GHGs. Already, many regional governments, corporations, and HEIs have adopted their own commitments to curb their emissions. However, to decrease emissions, they must first be quantified before plans can be made to strategically reduce and monitor emissions. Now that the movement to address rising GHGs has been discussed, the next section will outline how GHG emissions can be quantified with a carbon footprint.

2.9 Carbon Footprint

2.9.1 What is a Carbon Footprint?

Carbon footprinting has proven to be an effective measure of direct and indirect GHG emissions in a wide range of studies, ranging from global, regional, national to the sub-national level [30]. A carbon footprint is an indicator of the contribution made to climate change by a product, activity or population, and it can be treated as a decision-assisting tool [47]. The concept of carbon footprinting stems from "ecological footprinting," or a measure of the biologically productive land and sea area required to sustain a given human activity [13]. The common definition for a carbon footprint is "a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities" [48]. In literature, this term is also used interchangeably with other phrases such as 'carbon accounting' or 'carbon inventory' [47]. Other terms used associated or sometimes as a synonym of carbon footprint are embodied carbon, carbon content, embedded carbon, carbon flows, virtual carbon, GHG footprint, and climate footprint [13].

There is currently no consensus on how to measure or quantify a carbon footprint, or the spectrum of GHGs that should be included in the analysis [48]. The carbon footprint is simply the sum of GHGs emitted that can be attributed to an activity, process, organization, or entity [49]. Despite its limited scope, a GHG inventory can be used to establish a baseline for policy and as a planning tool for goal setting [39]. Considerations on how to measure and quantify the carbon footprint are discussed in the following sections.

2.9.2 Scopes

The World Resources Institute (WRI) and World Business Council for Sustainable Development (WBSCD) Greenhouse Gas Protocol Corporate Standard is a commonly used standard for GHG emissions. This standard presents guidelines to help compile carbon footprints by classifying emission sources falling under three scopes [50]. Scope 1 emissions are direct GHG emissions that occur from sources that are owned or controlled by the organization [50]. Some examples of these emissions on a university campus might be steam generation, refrigerant usage, campus vehicles, and fertilizer application. Scope 2 consists of the upstream emissions from the generation of purchased electricity [50]. Scope 3 emissions are the indirect emissions that come from sources owned or controlled by another entity [50]. For example, this would include emissions from commuter transportation, paper manufacture, and off-site waste and recycling operations. Only recently have carbon footprints been widely accepted to apply to various applications, so very few papers have focused on emissions from higher education institutions and their management approach. Most studies focus on scope 1 and 2 emissions with fewer studies including scope 3. However, it has been suggested that in some cases Scope 3 might account for 80% of an organization’s carbon footprint [45]. Thus, this reseach will contribute to the growing subject of carbon footprinting higher education institutions with scope 3 emissions included.

2.9.3 Greenhouse Gas Selection

There are a wide range of opinions on what GHGs should be included in a carbon footprint. Wiedmann and Minx (2008) suggest that a carbon footprint is a measure of the exclusive total amount of only CO_2 emissions directly and indirectly caused by an activity or accumulated over the life cycle stages of a product [48]. They support only using CO_2 in this measurement since the other GHGs are not carbon-based and are more difficult to quantify due to data availability [48]. Furthermore, they argue that the term carbon footprint refers specifically to a carbon (only) metric. This concept is shared by the European Emissions Trading Scheme, which only requires reporting of CO_2 emissions [47]. However, the boundaries continue to be argued. Wright, Kemp, & Williams (2011) suggest that a carbon footprint is most easily calculated through the inclusion of CO_2 and CH_4, and propose that the inclusion of all GHGs should adopt the term ‘climate footprint’ [47]. Wiedmann and Minx (2008) also share a similar view, stating that if other GHGs are included in a carbon footprint the indicator should be termed 'climate footprint’ [48].

While the name for a carbon footprint is a topic of debate, the major GHGs that should be included is also disputed. The IPCC lists a total of 18 GHGs with different global warming potentials, but under the UNFCCC and its Kyoto Protocol, only six gases; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) are considered in the carbon accounting [51]. Chlorofluorocarbons (CFCs) are not included in the Kyoto Protocol because they were phased out under the terms of the Montreal Protocol, and their emissions have reduced substantially. There are other gases such as water vapor, carbon monoxide, ozone, and aerosols like black carbon that also have radiative forcing impacts. However, these are more complicated to quantify since they are short lived in the atmosphere and vary spatially. Biogenic carbon dioxide and carbon monoxide emissions (e.g. from burning bio-fuels) are also not included in most GHG accounting. The ACUPCC signatories are expected to track and report emissions of the six GHGs consistent with GHG standards from the Kyoto Protocol [52]. The ACUPCC implementation guide further states that the focus should be on CO_2 since, “emissions of PFCs or SF_6 are unlikely to originate on campus, and emissions of CH_4, N_2O, and HFCs are likely to represent only a small percentage of an institution's total emissions” [52]. Accordingly, the case study of Clemson University will include these six GHGs and with the addition of hydro-chlorofluorocarbon (HCFC), since it is a widely-used refrigerant on campus and has a high global warming potential.

2.9.4 Impact Metrics

GHGs trap heat at different rates and have different lifetimes in the atmosphere. For instance, the lifetime for CO_2 depends on the processes that remove it from the atmosphere, while atmospheric CH_4 is usually oxidized to produce carbon dioxide and water vapor. Despite the differing characteristics of the emitted gases, there is often a requirement to place their impacts on a common scale to directly compare the substances emitted [53]. Calculation of GWP integrates the radiative forcing of an emitted substance over a chosen time horizon, relative to that of CO_2 [8]. The First Assessment Report of the IPCC in 1990 tentatively embraced the concept of GWP, but has since retained the GWP as its metric of choice [54].

However, there has been continuous debate for the use of GWP as the metric for global warming [54]. GWP is based on the time integrated radiative forcing due to a *pulse* emission of a unit mass, but one criticism relates to the fact that GWP does not indicate the impact of gas emissions on temperature [55]. Two gases that are identical in mass could cause a different temperature change at a given future time, but have the same GWP because one is a strong GHG with a short lifetime and the other is a weaker GHG with a longer lifetime [55].

Shine, Fuglestvedt, Hailemariam, & Stuber (2005) propose alternatives to the GWP with metrics that represent the global-mean surface temperature change. The Global Temperature change Potential (GTP) is the ratio of change in global mean surface temperature at a chosen point due to an emitted substance relative to that from CO_2. The proposed GTP metric has two variants: GTP_P which compares the temperature effect from pulse emissions, and GTP_S which compares the effect of sustained emission changes [55]. While GWP measures the heat GHGs trap in the atmosphere, GTP are not integrated over time, so they indicate a temperature change at a specific time in the future. There are significant uncertainties related to both GWP and GTP, however the relative uncertainties are larger for GTP [8]. Therefore, the IPCC continues to use GWP as its metric of choice. GWP also seems to have retained its attractiveness and widespread use due to the simplicity of its definition, the small number of required input parameters and the relative ease of calculation, compared to some of the alternatives.

Additionally, its transparency and ease of application appear to be important aspects of acceptability amongst policymakers [55]. Therefore, in the Clemson University study, GWP will be applied.

2.9.5 Time Horizon

The GWP for GHGs are given for yearly time horizons of 20, 100, and 500 years. The application of different time horizons is influenced by how far in the future impacts are being considered. The Kyoto Protocol uses a 100-year time horizon. To public knowledge, this is not based on any published conclusive discussion or IPCC assessments about the three time horizons [53], and it is widely believed that the Kyoto Protocol chose this horizon since it was the middle one of the three choices [54]. In the IPCC Fifth Assessment Report, only the 20 and 100-year GWP were given [8]. However, when assessing a HEI, the ACUPCC implementation guide states that GWPs should be calculated over a 100-year time horizon [52]. Therefore, the 100-year time horizon was chosen for the Clemson University study.

Table 2-1. Global Warming Potentials for major Greenhouse Gases

Greenhouse gas	**Chemical formula**	**GWP_{20} (kg CO_2-eq/kg)**	**GWP_{100} (kg CO_2-eq/kg)**
Carbon dioxide	CO_2	1	1
Methane	CH_4	84	28
Nitrous oxide	N_2O	264	265

[8]

To calculate carbon footprints, the GHGs emitted over the life cycle of the product or activity of interest must be quantified. This can be achieved by examining the entire life cycle of the product or activity from its conception to its disposal. This process is known as life cycle assessment (LCA). LCA can create a collective picture of inputs and outputs for a product activity with respect to pollution generated, energy consumed, water used, wastewater produced, and other similar environmental parameters of interest. The LCA methodology is outlined in the following section.

2.10 Life Cycle Assessment

Life cycle assessment (LCA) is a technique to evaluate the environmental aspects and potential impacts associated with a product, process, or service [56]. The LCA method assesses systems from “cradle-to-grave” and has been described by the

International Organization for Standardization (ISO) in their 14040 standards. By collecting the energy and material inputs and environmental releases for a product, process, or service the environmental impacts associated with these inputs and outputs can be evaluated. There are four stages to conduct an LCA, which are executed iteratively. These stages are (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation as depicted in Figure 1.

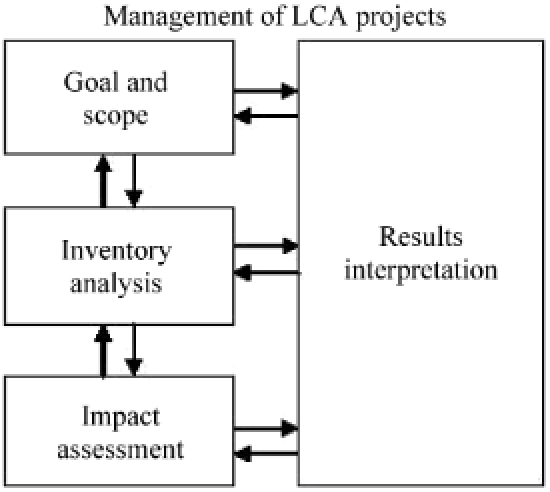

Figure 1. Model of Life Cycle Assessment

Goal and scope definition describe the product, process or activity being evaluated, and defines its functional unit. This stage also defines which life cycle phases will be included in the study. The life cycle phases are the activities performed to manufacture and use a product, process, or service. The life cycle starts with materials acquisition, and may include transportation, materials processing, manufacturing, distribution, operation, and disposal. A generalized life cycle is shown in Figure 2.

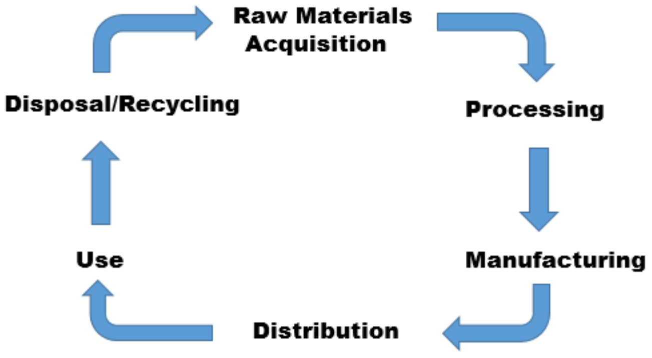

Figure 2. Life Cycle Assessment Phases

For each phase in the life cycle, the energy, water, raw materials, and emissions (to air, soil, and water) are identified and quantified in the inventory analysis. There are two approaches to perform an LCA for GHG estimation. The first approach is known as "bottom up" or "process analysis" (PA), and the alternative method is known as "top down" or "input–output analysis" (IO) [13]. Both methods aim to quantify the direct and indirect impacts of activities or products and are discussed in the following sections.

2.10.1 Process Analysis LCA

Process analysis (PA) uses detailed unit process data for goods and services to build a model of the physical production system. This method is usually used in traditional LCAs since it provides more detail and a deeper understanding of the nature of activities at the product level [57]. For this reason, this type of LCA is more accurate for small entities, and it is a useful tool to identify areas of process improvement [13]. Universities have commonly used this method of LCA to compare specific items (e.g. packaging material options) [58].

However, data and time requirements limit process-based LCAs in their ability to accurately assess the environmental impacts of purchased services [59]. Thus, applying this method is limited as it becomes too complex for large firms [13]. One significant drawback is that the approach is very laborious, so it isn’t as feasible to perform for cost-conscious organizations [59]. Another complication is that process LCA is determined in the terms of energy and mass units (i.e. kWh, kg, etc.), however most of the companies’ material and energy inputs and outputs are primarily collected and expressed in monetary terms rather than energy and mass units [59]. Since these studies require more detailed information, this approach can also be impractical if an organization is trying to assess many items simultaneously [58]. Also, since all economic activities are fundamentally related, an accurate description of a supply chain would require that the entire economy be inventoried. As such, the analyst must decide where to draw the boundary of which upstream processes to include, an issue known as the truncation problem. In this regard, process-based LCAs fail to account for all of the activities associated with a final demand, which systematically underestimates environmental impacts [57].

2.10.2 Input-Output LCA

Input–output (IO), or “top-down” LCA applies economic tables of industry sector monetary flows by adding a vector of exchanges between the industries and the environment [57]. This approach can calculate a carbon footprint by using these economic input–output (EIO) models extended to accept and perform operations on specific environmental variables (e.g. GHG emissions) [13]. There are also Environmental Extended Input–Output models which also includes environmental information and considers non-physical flows [30]. The IO approach is often faster and easier for companies to use because material, energy, and services need to be defined only in terms of monetary value, and all the supply chain information is already included in the IO tables [59]. This method is practical for companies since it can assess goods and services produced within the economy consistently [59]. IO based carbon footprint modeling has been applied in studies to focus on universities overall design, operation, and supply chain strategies [49].

However, with this technique there are some inherent drawbacks. First, applying an aggregated model of industry sectors, there is no way to differentiate between products within a single sector other than using differences in price [58]. Therefore, all goods and services within a sector are considered identical in terms of GHG emissions per dollar, regardless of their physical makeup, functionality, or the location where they were produced [58]. This could be problematic when the carbon footprint of university purchases is calculated. For example, if a university chooses to purchase more environmentally-friendly paper at a higher price, the EIO model will determine this purchase has a higher carbon footprint. As such, the level of aggregation of most input-output models is too high for company purposes as its not adequate for detailed LCA studies [59]. Most IO tables are a few years old since they are time-consuming and complex to construct [60]. Therefore, changes in production technology from year to year are not sufficiently captured [30], and furthermore the detailed input-output tables utilized in these models are only issued on average every five years [61]. This method is also limited since it depends only on monetary flows, which are inexact proxies for physical flows, so that if a company is able to negotiate a lower price for an item, then the impacts of that purchase will be calculated as lower even though its carbon footprint has not changed [58]. Additionally, since the EIO-LCA method is country-specific, imported goods are assumed to have the same production characteristics as if it were made in the company's native country [58].

2.10.3 Hybrid LCA

Production and consumption systems are best represented by a combination of bottom-up and top-down perspectives [57]. Several authors now apply combinations of EIO-LCAs and process-based LCAs to compensate for the weaknesses of both LCA methods [30]. This merge of the two LCA methods is known as a hybrid-LCA (HLCA). In some HLCA studies, PA is used to quanitfy the main inputs to the environmental inventory while additional upstream inputs are assessed using IO analysis [62]. In other hybrid methods, smaller emissions are quantified with PA-LCA, while rest is taken up by EIO-LCA [13]. Hybrid LCA methods are appropriate to calculate organizational footprints because they produce complete results whilst being application-specific [62]. This combination of methods increases completeness, flexibility, and reliability of estimates [13]. For these reasons, this methodology will be used in the Clemson University case study.

2.10.4 Productions vs Consumption Accounting

When assigning responsibility for GHG emissions either a production or consumption approach can be taken. Production accounting assigns responsibility to the producer of emissions, in this method emissions are located to the actual site of the emitting process [47]. For example, if a computer is manufactured in China and shipped for use in the U.S., China is responsible for the emissions associated with the manufacture. This method estimates GHG emissions occurring within a geographically defined area [60]. This method can apply top-down modeling where national GHG emissions are allocated to specific areas or bottom-up modeling that utilizes local emissions data [30].

On the other hand, a consumption based inventory is defined by Larsen & Hertwich (2009) to be “the life-cycle GHG emissions caused by the production of goods and services consumed by a geographically defined population or activity, independent of whether the GHG emissions occur inside or outside the geographical borders of the population or activity of interest” [60]. Therefore, if the computer manufactured in China is shipped for use in the U.S., then the U.S. is responsible for the emissions associated with the manufacture. With this method, the final consumption of goods and services is assigned responsibility for the emissions associated with the manufacture and transportation [47]. The carbon footprint using a consumption based inventory can be calculated using IO or PA LCA [60]. Larsen & Hertwich (2009) found that a consumption-based perspective gives a more insightful indicator after they studied a GHG emissions inventory related to the provision of municipal services, and found that that approximately 93% of the total carbon footprint is indirect emissions [60].

2.10.5 Streamlined LCA

Performing a LCA covering all stages of the life cycle requires comprehensive data and may require a prolonged period of time. For these reasons, they are not often used as a routine assessment tool. One method to expedite this process is to streamline the LCA. This can be done by limiting the life cycle phases included in the study. Companies streamline LCA to reduce costs, and to analyze the phases they have control over in their products. A common streamlined LCA is "cradle to gate" which examines a product from the raw materials acquisition phase through its manufacturing until it reaches the "factory gate." Other options to streamline an LCA include omitting life cycle stages (e.g. interpretation), including only select environmental impacts (e.g. GWP), using surrogate data, or using specific inventory parameters. By reducing the complexity of the LCA, the efficiency of the process can be improved while still evaluating many of the impacts of a full LCA. Most carbon footprints using LCAs apply a streamlined methodology to capture the phases with the most impact. In the Clemson University case study, a streamlined LCA approach will be used to quantify the impacts from specific phases of activities in the carbon footprint, this is further outlined in Table 3-1 of section 3.5.

2.11 Previous Carbon Footprints of Higher Education Institutions

Carbon footprints have been performed for several institutions of higher education applying methods and activities for each scope. Table 2-2 lists higher education institutions that have performed carbon footprints using either process analysis (PA), hybrid life cycle assessment (HLCA), or input-output analysis (IO). Some studies have self-identified their method of LCA, such as Institute of Engineering at Universidad Nacional Autónoma de México, De Montford University, University of Sydney, The Norwegian University of Technology & Science, Yale University, and University of Leeds. Other studies used a life cycle approach, but did not explicitly state their type of LCA, so this was gathered from their methodology description. All these studies included Scope 1, 2, and 3 emissions in their carbon footprint. However, while PA and HLCA were selective in choosing their emissions sources, the IO studies could use procurement records to include a wider breadth of activities, products, and services.

Table 2-2. Published Case Studies of Carbon Footprints for Higher Education Institutions

Case Study	Method
Institute of Engineering at Universidad Nacional Autónoma de México, Mexico	PA
University of Illinois at Chicago (UIC), USA	PA
The University of Cape Town (UCT), Africa	PA
Tongji University, China	PA
University of Sydney (USyd), Australia	HLCA
University of Maribor (Engineering Campus only), Slovenia	HLCA
De Montfort University (DMU), England	HLCA
Rowan University, USA	HLCA
The Norwegian University of Technology & Science (NTNU), Norway	IO
Yale University (YU), USA	IO
University of Leeds (UoL), England	IO

2.11.1 Process Analysis Studies

The emission sources of the PA studies varied depending on the HEI. The Institute of Engineering at Universidad Nacional Autónoma de México used a consumption based methodology integrating LCA approach for the GHG inventory. Their inventory included electricity, the vehicle fleet, purchased electricity, commuting, air travels, courier shipments, paper consumption and solid waste. In this study 42% of the GHG emissions were from electricity use, and 50% from transportation including the campus fleet and commuting vehicles [20]. University of Illinois at Chicago (UIC) created a GHG inventory for 2004–2008 and included a similar range of emission sources. They included production of electricity, hot water or steam, solid waste, and commuting of faculty, students, and staff [39]. This study found that UIC's carbon footprint in 2008 was was not significantly higher than in 2004, and also found that buildings accounted for 83% of emissions, followed by commuting, which contributed 16% of emissions [39]. Meanwhile, the University of Cape Town in South Africa included more processes and products in their analysis. Their carbon footprint included electricity consumption for the main campus and satellite residences, direct combustion from liquefied petroleum gas and acetylene, and transportation emissions from commuting and University owned vehicles [51]. This study also included emissions from goods and services, photocopying paper, toilet paper, paper towels, waste removal and recycling, and wastewater [51]. Tongji University took a different approach to their PA to determine their carbon footprint. They estimated carbon footprints via student's personal carbon footprints. They conducted an extensive online survey of consumption and behaviors and combined it with utility data to determine student's average carbon footprint [49]. However, this study only included personal GHG emissions, so upstream and downstream emissions were not considered [49]. All these studies included varying scopes of emissions sources in their carbon fooprints. The studies did not state which phases were included in the lifecycle for each emissions source. This may also have had a significant effect on the final carbon footprint.

2.11.2 Hybrid Life Cycle Assessment Studies

The HLCA studies included many of the same emission sources as the PA studies, however their methodology adopted top-down approaches to create the carbon footprint. The University of Sydney used a hybrid approach called Path Exchange method to allocate expenses and revenues using IO tables. This study quantified life-cycle environmental impacts from cradle to gate for on-site consumption of water, natural gas and electricity, materials such as paper plastic, glass and chemical products, transportation, and many other procured items [62]. The University of Maribor used a different method. They found their carbon footprint using the LCA software package GaBi and Ecoinvent databases. These databases contain lifecycle assessments for thousands of products, energy systems, and materials that can be adopted. Since these databases are usually based on an average product, and not the specific product being examined, studies applying this method are considered a HLCA. This study performed a HLCA for its engineering departments, and included the construction and demolition of buildings, operations such as heating, lighting, electricity, and water consumption, and maintenance such as cleaning and painting [63]. The consumption of PET water bottles and printing paper was also included. Another HLCA method is to use primary data from emission sources (bottom up), while emissions factors data orginated from top down data (i.g. national average) for the analysis. This method was used by De Montfort University.

Their consumption based carbon footprint evaluated the lifycle and supply chain emissions for on-site natural gas and biomass combustion, grid electricity, student commuting, business travel, university owned fleet diesel consumption, and procuremnt of goods and services [64]. Rowan University used a methodology similar to used De Montfort University, as they applied top-down emission coefficients from the Energy Information Administration (EIA) and other sources to their process based data. Their carbon footprint considered electricity from the electric grid, on campus generation of steam, direct combustion of natural gas for heat and cogeneration plants, and HVAC [2].

2.11.3 Input-Output Analysis Studies

IO is the top down method that is used to calculate carbon footprints based on monetary flows. The Norwegian University of Technology & Science (NTNU) used more than 200 financial account entities in their environmental extended input-output (EEIO) study. In their study, they corresponded the combustion of fuel and heating oil, the purchase electricity and district heating, and other purchases of goods and services to 58 domestic EEIO sectors [30]. Similarly, Yale University created a GHG inventory using procurement of goods and services over a one-year period with the goal to pinpoint the financial expenditures with the greatest indirect GHG emissions [46]. This study utilized the economic input-output (EIO) LCA tool developed by the Green Design

Institute at Carnegie Mellon University. The calculations using this tool included Yale's power plants, electricity, the university vehicle fleet, employee commuting, business air travel, and non-power plant fuel purchases such as diesel fuel and natural gas [46]. Yale also quanitified impacts from construction, food and beverages, air travel, lab/software supplies and other procurements [46]. The University of Leeds also used IO Analysis to find its carbon footprint. Applying financial data, they quantified impacts from gas, steam and hot water, electricity, food and drink, paper and publishing, machinery and computers, utilities and construction, transportation, communication, and public services [61].

3 Life Cycle Assessment Design

3.1 Overview

In 2007 Clemson University signed the ACUPCC. Part of this commitment is creating a transparent inventory of GHG emissions from Clemson University, which can serve as the baseline to set goals and develop strategies to decrease emissions. This chapter will discuss the LCA approach used to assess the entire system, and will also describe uncertainty associated with data quality.

3.2 LCA Approach

In this research, an LCA was conducted for each major GHG emission source on Clemson University's campus to build a GHG inventory for the carbon footprint. For this analysis, a carbon footprint may be defined as "the quantity of GHGs expressed in terms of CO_2 equivalents (CO_2-e), emitted into the atmosphere by an individual, organization, process, product, or event from within a specified boundary" [13]. A carbon footprint is an indicator of the contribution made to climate change by a product, activity or population, but is not a full LCA [47]. Keeping with the ACUPCC guidelines, this report's focus will be CO_2, but it will also include the six Kyoto gases and hydro-chlorofluorocarbon (HCFC) which is still being used on campus. These gases will be examined using IPCC defined GWPs with a 100-year time horizon. To build the carbon footprint, a series of LCAs for each activity was streamlined based on data availability and what activities pose the greatest potential impact. Weighing the pros and cons of the various LCA approaches, this study applied a hybrid LCA methodology to conduct LCAs and create the carbon footprint. The main justification for this decision is the way data are collected for Clemson University's campus. In order to use the EIO LCA method, the university's financial expenditure data would need to be expressed in monetary flows and organized into categories that match the sectors used by the Bureau of Economic Analysis (since these are used in the EIO-LCA tool). Most of the data available from campus facilities were recorded in the terms of energy and mass units, except for university-related travel which is reported in monetary terms. For this reason, it was more practical to apply a PA LCA method to most of the campus activities.

However, this study adopted an HLCA approach similar to Ozawa-Meida, Brockway, & Letten (2013), who used a consumption based LCA approach to study emissions from De Montfort University [64]. In a similar manner, this study combined a top-down approach for the estimation of emission factors, while using a bottom-up approach for the accounting of activity intensities. Due to data availability, the LCAs were streamlined to include the phases of the life cycle for which data was attainable, and for the phases that have the highest potential GHG contribution. Each activity in Scope 1 and Scope 2 will consider the operation phase, while Scope 3 emissions will include operation and any other upstream phases with high contributions to the GHG inventory. This will be described in more detail for each section. There is uncertainty in LCA stemming from parameters, the model, choices, temporal variability, spatial variability, and variability between objects or sources. Much of this uncertainty can be related to the inventory phase of LCA, but also applies to the characterization and weighting of the analysis [65]. Since this analysis will use IPCC values to characterize life times of GHGs, and results will not be weighted, only uncertainty in the inventory phase will be discussed.

There are several reasons why a HLCA approach was preferred over the use of a tool such as the Clean Air-Cool Planet Campus Carbon Calculator. This tool considers Scope 1, 2, and 3 emissions, and inputs are put into a spreadsheet that has formulas, conversion factors, and emission factors are already built-in and adapted from IPCC values to find the GHG emissions [66]. For electricity, it uses the EPA Emissions & Generation Resource Integrated Database **(**eGRID**)** sub-region rather than the specific utility, so the electricity generation mix is not as accurate. The quantities inputted still need to be calculated by the user, such as fuel for vehicles, refrigeration, fertilizer, and wastewater. Thus, many assumptions would still have to be made before inputs could be found, such as how much fuel was used by commuters. However, some estimations would have used emissions factors rather than the site specific information. For example, natural gas used in steam generation accounted for the specific gas composition and plant efficiency factors. There were also several things that were not an option to be inputted into the calculator such as bathroom tissue and paper towels. Campus owned aircraft is also not available in the calculator. While it can calculate emissions from air miles flown, the approach outlined in this assessment uses more specific fuel economy and distance traveled for the aircrafts. Another issue is that university related travel data for Clemson is recorded in monetary terms rather than distances, so there would not be a method to input these data unless distances were calculated.

3.3 Goal

The goal of this study was to build a carbon footprint for the operations of Clemson University that focuses on CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and HCFCs. This analysis included both direct emissions from campus-owned operations (Scope 1), such as steam generation and indirect emissions from upstream processes or processes not owned by Clemson (Scope 2 & 3). Overall, this resulted in a more complete understanding of the impact of Clemson's operations, as well as identify significant emission sources. This information can help educate and inform stakeholders within Clemson University about the global warming impact of their activities. The analysis will also establish a baseline for future improvements and comparative assessments.

Increasing renewable energy sourcing to 10% by 2025 is one of Clemson University's long term goals, and this action will also help the University reach its goal of the campus reaching carbon neutrality. This research recommends possible strategies to decrease GHG emissions and increase renewable energy sourcing. One strategy is to implement solar photovoltaic (PV) panels within the current campus. Therefore, as part of this research, a map was created using geographic information system (GIS) and light detection and ranging (LiDAR) data to determine possible locations to integrate solar panels on campus rooftops. Rooftop solar PV panels are a safe and renewable method for campuses to increase renewable energy sourcing by using space not being utilized on roofs. This map demonstrates the potential for future solar development and provide timely access to areas where solar PV is suitable. This is also a further component to distinguish this research from prior carbon footprint studies conducted for HEIs.

3.4 Scope

Function of the System

In this study the system analyzed was Clemson University's main campus, whose function is to provide educational and research services and extension activities. Some of the activities included in this function are supplying the campus with electricity, water, and heat. Other activities include transporting students around campus, policing the campus, and disposal of campus waste. The activities selected for the study are based on their relative significance to campus operation and potential for global warming impacts. This was based on services that prior studies have chosen in their carbon footprints.

Functional Unit

The functional unit allows for comparative performance between other HEIs. In this study, the functional unit is a year’s worth of educational and research services for Clemson University’s main campus.

Activities Included

This LCA will include a novel combination of major emission sources that have not been published. These sources are listed in Figure 3. Previous HLCA studies have looked at heating from natural gas, [63] [64] [2] and emissions from University owned vehicles in their Scope 1 emissions [62] [64]. However, none have included emissions from fertilizer application and only one considered refrigeration in their analysis [2]. For Scope 2, this study included the emissions associated with electricity from the grid in a manner similar to other studies. In Scope 3, this study included life cycle emissions from electricity, electricity transmission and distribution losses, commuting, paper usage, transporting waste and recycling, water used, and wastewater treated. Emissions associated with water used and wastewater treatment have not been included in prior HLCA studies.

Initial Flow Diagram

The following diagram displays how the main services relate to Clemson University's operations.

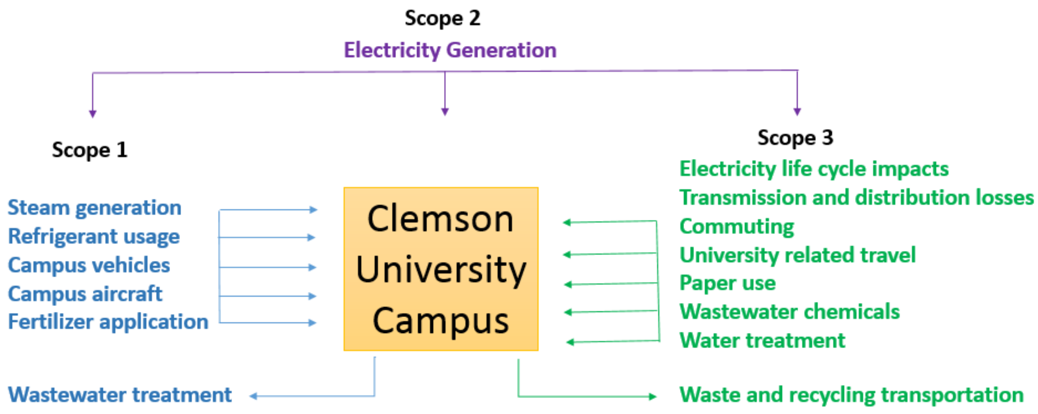

Figure 3. Overview of Campus Activities

System Boundaries

The Clemson University LCA investigated all life cycle stages. However, as a streamlined LCA, only emissions from specific life cycle phases (e.g. manufacturing, distribution, operation) were quantified. When specific data were not available for a life cycle phase, estimates gathered from the literature or generic data were used.

Geographic boundaries

The systems investigated were limited to activities and buildings on or related to Clemson's main campus. Therefore, the Madren Center and Clemson Wastewater Treatment Plant will be included in the analysis. However, buildings outside Clemson's main campus, such as the research park in Anderson were not included. Any surrogate data used in the LCA were representative of the U.S. market, however if no data for the U.S. were available (e.g. for wastewater chemicals), data from the European or global market were used.

Figure 4. Boundary of Clemson University's Main Campus

Technological boundaries

As stated previously, the reference year is 2014. The principal data provided by Facilities pertains to systems operating in 2014. In cases where data were not available for 2014, it was assumed that newer data within the past three years could be used to characterize the system.

Time boundaries

The LCA investigated represented the services provided by Clemson University in 2014. The principal data provided by Facilities all pertains to systems operating in 2014.

Allocation

Allocation is needed when a service is provided to multiple entities outside the functional unit. This can be performed by dividing the total environmental impact of the process between the system outputs. The ISO standard states that allocation should only be used when the product system cannot be divided and the system boundary cannot be expanded [67]. In this study, this allocation approach was used to determine the emissions associated with electricity generation since Clemson receives electricity from a larger system that cannot be divided or expanded. One method of allocation is partitioning, which distributes impacts from the system among flows of interest.

Partitioning can be based on economic, mass, or energy values. For electricity, impacts will be allocated based on energy flows from a larger system (e.g. GHGs attributed to 1 kWh electricity). The ISO states that this allocation method based on underlying physical relationships between the inputs and outputs of a system is preferable to allocation based on other relationships, such as economic value [67].

3.5 Inventory Analysis

The inventory analysis creates an inventory of flows to and from the system being analyzed. Inventory flows include inputs of water, energy, raw materials, and outputs to air, land, and water. Each activity that contributes to Clemson University operations has inputs and outputs to and from the environment as seen in Figure 5. This demonstrates how the life cycle for each service was considered.

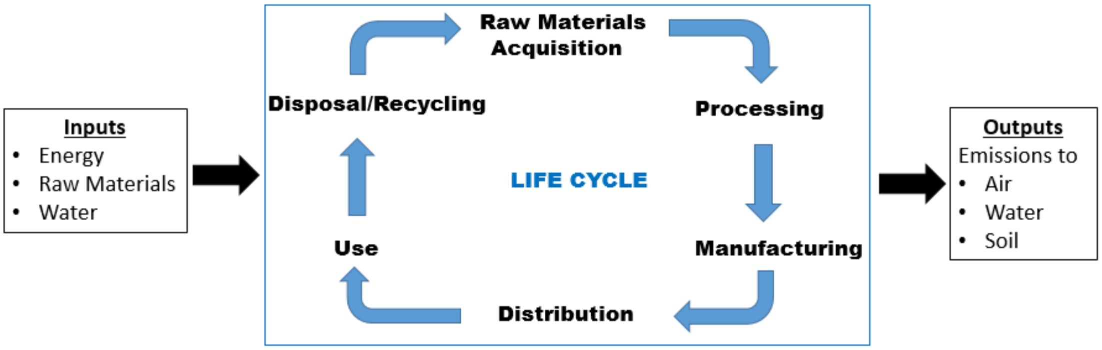

Figure 5. Elementary Flows in Life Cycle Assessment

This study focused on emissions to air; specifically, GHGs. The GHGs examined were CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and HCFCs. Thus, the flows of interest and the phases examined are listed below for each service that contribute significant GHGs. The main focus was on CO_2, and overall on campus there were no sources of PFCs or SF_6. The following page contains a table describing the services and phases considered for emissions generation.

Table 3-1. Services and Phases Considered in LCA

Service	Flow of Interest	Phase
	Scope 1	
Steam Generation	Natural gas combustion	Use
Refrigerants	HFCs and HCFC releases	Use
University Owned Vehicles	Gasoline & diesel combustion	Use
University Owned Aircraft	Jet fuel combustion	Use
Fertilizer application	Fertilizer nitrification and denitrification	Use
Wastewater Treatment	Aerobic digestion of sludge	Use
	Scope 2	
Electricity Generation	Coal, Gas, & Oil combustion in power plant	Manufacturing
	Scope 3	
Electricity	Plant, construction, operation, materials, and decommissioning	All phases
Transmission and Distribution Losses	Coal, Gas, & Oil combustion in power plant	Distribution
Automotive Commuting	Gasoline combustion	Use
Clemson Area Transit	Electricity use & diesel combustion	Use
University Related Travel	Gasoline and jet fuel combustion	Use
Paper Usage	Office paper, paper towels, & bathroom tissue	Manufacturing
Waste and Recycling	Gasoline combustion	Use
Water Treatment	Chemicals & operation	Manufacturing and Use
Wastewater Treatment	Chemicals	Manufacturing

Data coverage

The primary data collected from this study were from a variety of departments and facilities within Clemson University. Secondary data were gathered from literature and public databases. The data were evaluated based on its reliability, temporal boundary, technological correlation, and completeness. By assessing the appropriateness and completeness of the data a qualitative assessment of the data was created.

Cutoff Criteria

Preferably, phases should be cut off based on their relevant environmental impact. However, data must be first collected to fully understand the impact of a specific phase. In this study, cutoff criteria were based on accessible data and the phase deemed to have the most significant impact based on inclusion in previous studies.

3.5.1 Uncertainty in Data Quality

Data quality pertains to data uncertainty, reliability, completeness, age, geographical area, and technological level for which the data are representative [68]. The overall uncertainty in inventory data refers to the spread and pattern of distribution of these data quality indicators [68]. There are improving initiatives to understand, incorporate, and reduce uncertainty in LCA [69]. Several approaches to quantifying uncertainty in LCA have been proposed and implemented. A limited number of LCA studies apply uncertainty, though some methods used include intervals, scenario modeling, fuzzy data sets, analytical uncertainty propagation, probabilistic simulation, and Bayesian statistics [69]. Stochastic modelling has become a popular technique for making data inaccuracy in life cycle inventories operational, and can be performed using a Monte Carlo simulation [70]. Thus, some LCA software platforms are now offering the ability to calculate uncertainty using Monte Carlo [69]. In Monte Carlo simulations, each uncertain input parameter must be specified as an uncertainty distribution [68]. Characterizing the uncertainty ranges for these enormous number of parameters involved can be a very difficult and time-consuming exercise [70]. However, in this study, the specific and limited nature of the data points (e.g. monthly averages) provided meant that an uncertainty distribution could not be created with Monte Carlo methods.

The life cycle inventory data for this research consists of the processes of interest includes data representing the flows of raw materials and energy, and data related to system performance and environmental impacts. Data gaps regarding flows between economic processes and the environment are usually set to zero, resulting in a systematic bias towards lower emissions [70]. Most uncertainty studies in LCA quantify only input data uncertainty [68]. However, uncertainties can also arise from uncertainty in the functional unit, characterization factors, scenario uncertainty, and model uncertainty [68]. Due to available information and time considerations, this study will focus on characterizing input data uncertainty in the inventory.

The existing data quality should be understood and considered before conducting an LCA. Weidema and Wesnaes (1996) considered five independent data quality indicators to describe the aspects of data quality which influence the reliability of the result; reliability, completeness, and correlations temporally, geographically, and technologically. Reliability depends on the methods used for measurements, calculations, assumptions, and quality control of data, while completeness is judged based on the number of data collection points and periods and their representativeness of the total population [68]. Temporally, the year of the original measurement is important, the geographical area for of the data must correlate with the defined area, and the technological indicator is concerned with all other aspects of correlation than the temporal and geographical considerations [68]. These data quality indicators can be used to create a pedigree matrix as seen in Table 3-2.

The scores given in the pedigree matrix are semi-quantitative identification numbers, so they should not be aggregated or taken to represent a certain ‘amount’ of data quality [68]. Their purpose is to serve as a data quality management tool, which can expedite the survey of data quality and highlight area for improvements in uncertainty [68]. While a quantitative assessment of the uncertainty related to the use of unrepresentative data within an LCI is preferable, it is also extremely difficult due to a lack of knowledge about actual uncertainty of data on inputs to and outputs from industrial processes [70]. For each activity analyzed in this study, this pedigree matrix will be applied to rate data quality.

Table 3-2. Pedigree Matrix of Data Quality Indicators from Weidema and Wesnaes (1996)

Indicator Score	**1**	**2**	**3**	**4**	**5**
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal correlation	Less than three years of difference to year of study	Less than six years difference	Less than 10 years difference	Less than 15 years difference	Age of data unknown or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes, and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

3.6 Impact Assessment

The impact central to this study is global warming, for which GHG emissions were inventoried. Thus, the output of each activity in the scope of the study was assessed for its GHG contribution and global warming impact. Global warming causes climate change, which has significant effects on ecosystems, human health, agriculture, and infrastructure. The global warming impact of each activity in Clemson was assessed using global warming potential (GWP) characterization factors as recommended in the latest version of the IPCC Fifth Assessment Report (as detailed in Section 2.9.4). The 100-year time horizon was applied and expressed in kilograms of carbon dioxide equivalents (CO_2-e) per kilogram of emission, as discussed in Section 2.9.5. However, this method offers a broad screening approach to predict potential global warming impacts from emissions [71]. The impact for each activity in the scope are described in the Methods and Results Section.

3.7 Interpretation

The interpretation stage of LCA is where the findings from the inventory analysis and the impact assessment are combined. The results of individual studies of Clemson University activities were interpreted separately. Therefore, conclusions and potential improvements were presented on an individual basis. However, a synthesis of overall observations and potential improvements for the whole system are presented and discussed in Section 5. This included an examination of all activities and their cumulative carbon footprint. The ISO 14040 recommends that the LCA report should allow the results and interpretation be used in a way consistent with the goals of the study. Therefore, this final report will be made public through the Clemson Library.

4 METHODS AND RESULTS

4.1 Overview

This section describes the Scope 1, 2, and 3 emissions for Clemson University's main campus. For each scope, activities are explained individually, and a LCA approach is used to determine their contribution to the carbon footprint. Then, each section explains background information, data, calculation methods, and the conclusions and recommendations. After results from the three scopes are presented, there is also a section illustrating where best to install solar PV panels on campus to increase renewable energy sourcing. The following figure displays locations of interest that will be discussed in the upcoming sections.

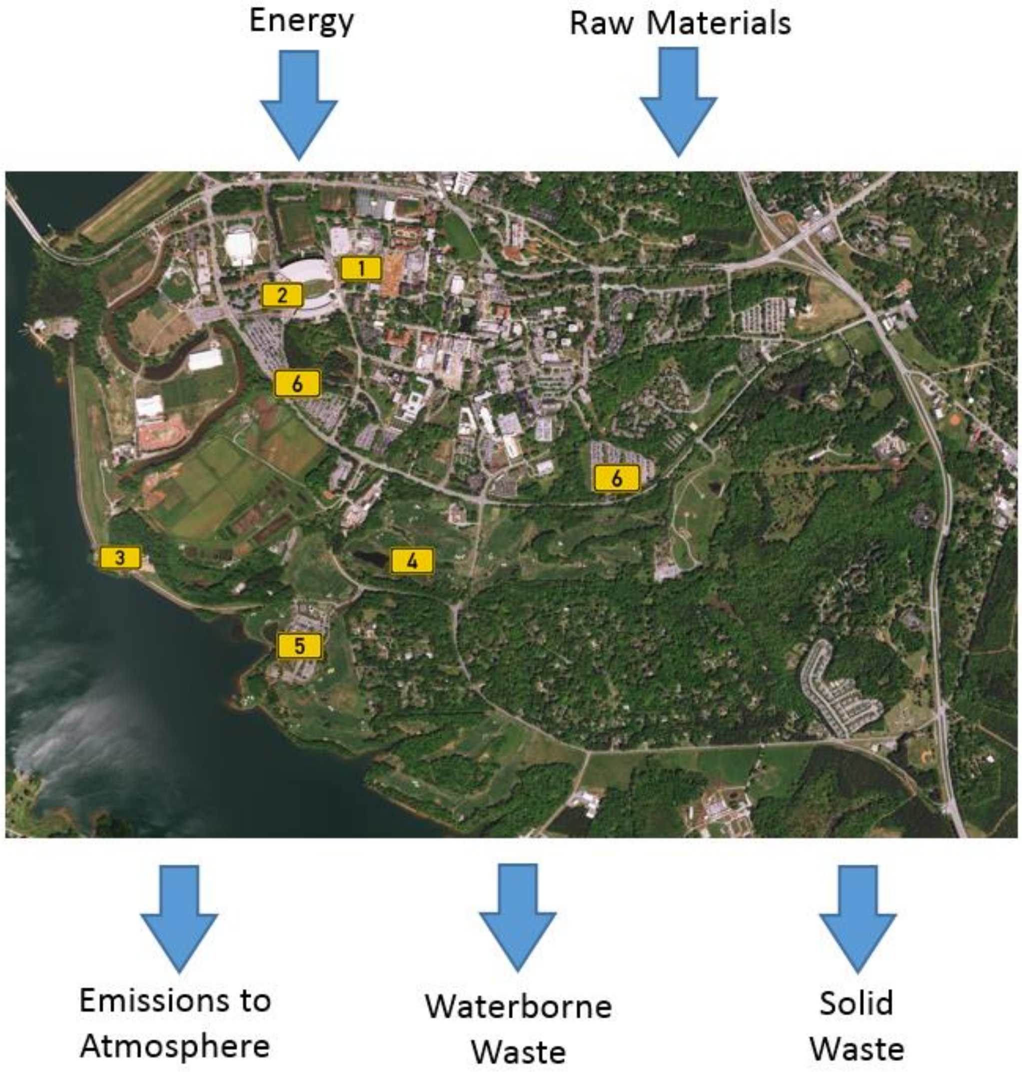

Figure 6. Clemson University Locations of Interest

The Scope 1 emissions considered will be the operational phase of steam generation, refrigerant usage, university owned vehicles and aircraft, fertilizer use, and wastewater treatment. In Figure 6, the steam generation plant is labeled (1), the TigerTransit and Clemson University Police headquarters (university owned vehicles) are labeled (2) and operate throughout campus, the wastewater treatment plant is labeled (3), and the Walker golf course (which receives the majority of fertilizer) is labeled (4). Electricity generation is considered a Scope 2 emission, and used throughout campus. The wastewater treatment plant and Madren Center (labeled 5) have their own electricity meters so their specific emissions will be discussed. Then, upstream emissions related to electricity generation and losses from transmissions and distribution are discussed in Scope 3 emissions. Scope 3 also includes commuting via personal vehicles and Clemson area transit, university related travel, paper usage, waste and recycling transportation, chemicals used in wastewater treatment, and emissions from water treatment. Two of the campus's larger commuter and employee parking lots are labeled (6).

4.2 Scope 1

Scope 1 emissions are direct GHG emissions that occur from sources that are owned or controlled by the organization [50]. For this assessment, emissions will be analyzed from the operational phase for steam generation, refrigerant use, university owned vehicles and aircraft, fertilizer, and wastewater treatment.

4.2.1 Steam Generation

4.2.1.1 Background

The system analyzed in this section is the Clemson steam generation plant. Since this system is producing emissions directly from Clemson's campus it is considered a Scope 1 emission source. Clemson's steam generation plant was constructed in 1948 with additions to the plant occurring in 1953. The purpose of the plant is to create steam for space heating, domestic hot water, dehumidification, and other miscellaneous processes. Historically, the plant used coal fired boilers to generate steam, however they have now been replaced with more efficient natural gas technology and heat recovery systems. While the current boilers have the capacity to use an oil and gas mixture, Clemson Facilities are choosing to use natural gas since it is currently cheaper. The heat from the combustion of natural gas in the boilers converts water to steam. The steam generated is then conveyed across Clemson's campus through an underground tunnel system, meanwhile a heat recovery steam generator (HRSG) is used to generate steam using water collected from the condenser loop.

4.2.1.2 Data

Clemson Facilities provided data regarding boilers use, amount of steam generated, natural gas consumption, water use, and electricity use. The outside temperature was also collected on hourly intervals every day for the year of 2014.

Boilers

Since 2014, four new Miura boilers have been phased in. The Miura boilers now make up 25% of the capacity of the steam generation while the Cleaver-Brooks boiler sustains the remaining 75%. Clemson Facilities reported that the Cleaver-Brooks boiler has an 83% efficiency, while the Miura operate at an 85% efficiency. Since the Miura boilers have a higher efficiency they are used initially for the steam generation needs, then supplemented by the Cleaver-Brooks as needed. Since these data are from 2014 it only relates information for the Cleaver-Brooks boiler and the heat retention steam generator. Since this time, the annual natural gas use and associated emissions may have decreased slightly due to the increased efficiency of the boilers.

Natural Gas

Daily, the Cleaver-Brooks boiler consumes a natural gas flow averaging 1,071 cubic meters per hour. This natural gas comes from the Transco transmission pipeline system operated by Williams Companies. They regularly have the quality of their natural gas feed analyzed to determine its exact mixture. An average composition was calculated using daily chromatography data over 3 months (Table 4-1). Methane, ethane, and propane together make up around 98.23%. The remaining 1.77% of the natural gas feed consists of trace amounts of various butanes, pentanes, and hexanes. Since this composition varies, it was assumed that this remaining proportion was entirely made up of hexane as a 'worst case' scenario since it has the highest carbon content.

Table 4-1. Main Composition of Natural Gas feed for Steam Generation

Elements	Formula	Molecular Weight (g/mol)	Composition (%)
Methane	CH_4	16.04	94.60
Ethane	C_2H_6	30.07	3.43
Propane	C_3H_8	44.10	0.20
Hexane	C_6H_{14}	86.18	1.77

Water

The Cleaver Brooks boiler uses water sourced from the Anderson water authority for steam generation with an unspecified amount of water from nearby Lake Hartwell for condenser loop cooling. Each day, the condenser loops returns approximately 12,300 gallons of water to the steam generation plant.

Electricity

Electricity is used to power the monitors and computers related to the boilers and for lighting and other general functions within the plant. The electricity use for this system is included in the total electricity calculations in the Electricity Section (4.3.1).

Data Quality

Table 4-2. Data Quality for Steam Generation Data

Indicator Score	Score	Explanation
Reliability	1	Data was collected hourly by Facilities or natural gas provider
Completeness	1	Data was collected over an adequate period to balance fluctuations
Temporal correlation	1	Boiler data are from 2014 and natural gas composition is from 2017, which is less than three years difference to year of study
Geographical correlation	1	Data are from area under study
Further technological correlation	1	Data are specific to the processes under study

4.2.1.3 Methods

Resource Usage

The total usage of natural gas and steam production was calculated by summing up the daily recorded hourly flow rates. The total quantities found are shown in Table 4-3.

Table 4-3. Annual Inputs and Outputs of Steam Generation Plant

Boiler	Natural Gas Consumption (m^3/yr)	Stream Generation (kg/yr)
Cleaver-Brooks	9,378,547	155,839,978
HRSG	167,980	10,247,103
Total	9,546,527	166,087,081

The total quantity of natural gas consumed for steam generation was converted to grams so that the CO_2 from combustion can be calculated. To convert natural gas from the recorded unit of cubic feet, the density had to be applied to this quantity. The density (ρ) of natural gas according to the Transco transmission data was 0.59 kg/m^3. When burned, hydrocarbons produce CO_2 and H_2O as their products. Therefore, for these calculations CO_2 is the only GHG to examine. In properly tuned boilers nearly all the carbon fuel in the natural gas (99.9%) is converted to CO_2 during combustion [72]. Any incomplete combustion will cause trace amounts of fuel carbon to be converted to CH_4, carbon monoxide (CO), or volatile organic compound emissions [72]. For these calculations, it will be assumed that the natural gas is completely combusted.

The balanced stoichiometric equations can be used to determine the CO_2 produced from combustion. In the stoichiometric equation for methane (see equation 1 in Section 2.3) each molecule of methane reacts with two molecules of O_2 to produce one molecule of CO_2 and two molecules of H_2O. Similarly, in two molecules of ethane react with seven molecules of O_2 to create four molecules of CO_2, in propane one CO_2 molecule combusts to create three molecules of CO_2, and two molecules hexane combust to create 12 molecules CO_2. Using these stoichiometric relations and the total amount of natural gas used, the total CO_2 emissions from combustion was calculated.

Emissions

First, the total amount of natural gas used over the year 2014 was determined using the data provided by Clemson facilities. Then, this data was converted from its initial flow rate of cubic feet to grams of natural gas. Applying the percent composition of each hydrocarbon that makes up the mixture (Table 4-1) can determine the grams of each hydrocarbon combusted. Then the molecular weight of each hydrocarbon can be used to find the equivalent number of moles. Once the moles of each hydrocarbon are known, the stoichiometric relations to CO_2 can be put into use to determine the moles of CO_2 from combustion. To do this the following equation was used.

$$G_P NG_c MW_G MF_G MW_{CO2} \tag{5}$$

In this equation, G_P is the percent composition of a specific gas in the natural gas feed (e.g. 94.6% methane), NG_C is the total natural gas consumption by the University, MW_G is the molecular weight of the specific gas, MF_G is the stoichiometric mole fraction of the specific gas to CO_2, and MW_{CO2} is the molecular weight of CO_2. The results of these calculations can be seen in Table 4-4. Annually, it was determined that combustion at the steam plant produces 15,522 metric tons of CO_2.

Table 4-4. Combustion Reaction Results

Element	**Emissions (g/yr)**	**Moles of Element**	**Moles CO_2**	**g CO_2**	**Metric tons CO_2**
Methane	5,328,289,929	332,136,713	332,136,713	14,617,170,660	14,617
Ethane	193,192,753	6,424,972	12,849,945	565,519,649	566
Propane	11,264,884	255,465	766,395	33,728,649	34
Hexane	99,694,220	1,156,814	6,940,883	305,464,801	305
Total	**-**	**-**	**-**	**-**	**15,522**

Efficiency of system

The efficiency of the underground tunnel delivery system at Clemson has not been measured, so the amount of steam lost during delivery is unknown. To address this limitation a steam distribution loss factor of 15% was adopted from Cornell University who have quantified the losses in their system [73]. Cornell's system over 60,000 feet of underground steam, condensate, and hot water lines to provide heat to its campus to serve nearly 22,000 students [73]. Clemson's system is 41,560 feet, and serves a comparable population. Facilities have calculated the efficiency of the boilers to be 83%. With these losses in mind, the figure below displays the amount of steam lost to the inefficiencies of the system.

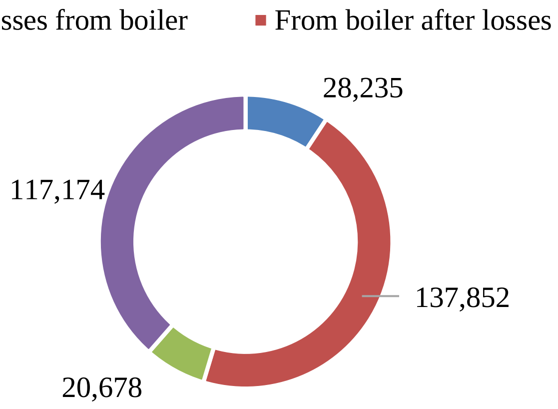

Figure 7. Steam Generation Losses (metric tons steam/year)

Trends in Steam Generation

As previously stated, steam is used for heating water, dehumidification, and space heating. Hot water and dehumidification demand is consistent year-round, with dehumidification being especially essential in the summer. However, space heating primarily occurs in the colder months. The figure below displays the inverted relationship between the average outside temperature, and the demand for steam. During colder months, Facilities aims to keep the room temperature maintained at 69°F in occupied rooms, and when possible temperatures are dropped to 55°F during unoccupied periods [74]. During the air-conditioning season, room temperatures are maintained at 76°F when occupied and allowed to warm to 85°F when unoccupied [74]. The demand for steam is at its highest in the winter months, therefore carbon emissions from steam generation are also highest during these months. As seen in Figure 8, the highest emissions in 2014 were during the month of January, with 1,694 metrics tons of CO_2 produced from steam generation. Meanwhile, emissions were lowest in June and July producing about 940 metric tons of CO_2 per month. These lower emissions may be due to the absence of students and lower heating and dehumidification needs. The total monthly emissions can be seen in Table 4-5.

Table 4-5. Monthly Average CO_2 Emissions from Steam Generation in 2014

Month	Total Natural Gas (m^3)	Steam Generated (kg)	CO_2 (metric tons)
January	1,041,667	16,497,340	1,694
February	954,607	16,066,858	1,552
March	973,951	16,452,023	1,584
April	754,874	12,842,596	1,227
May	637,477	10,790,587	1,037
June	578,168	9,632,978	940
July	578,579	9,546,041	941
August	584,877	9,269,513	951
September	652,672	10,176,410	1,061
October	772,178	12,207,506	1,256
November	994,913	15,922,257	1,618
December	1,022,563	16,449,727	1,663

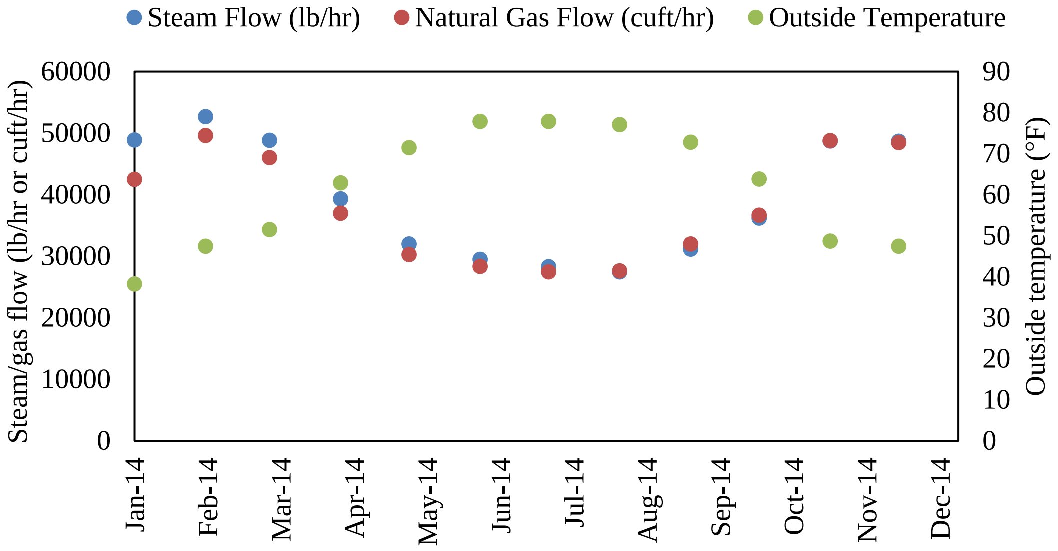

Figure 8. Monthly Average Steam and Natural Gas Flow compared to Outside Temperature

This figure shows that the steam and natural gas flow rates are closely correlated to outside temperature. The flow rates are shown in imperial units so that they could be shown to scale together on a graph. These flow rates are averages for the month, so it should be noted that the total monthly natural gas used and steam production varied, thus in January natural gas and steam produced was higher than in February, even though its average flow rates were lower. This may have been due to varying temperatures in these months.

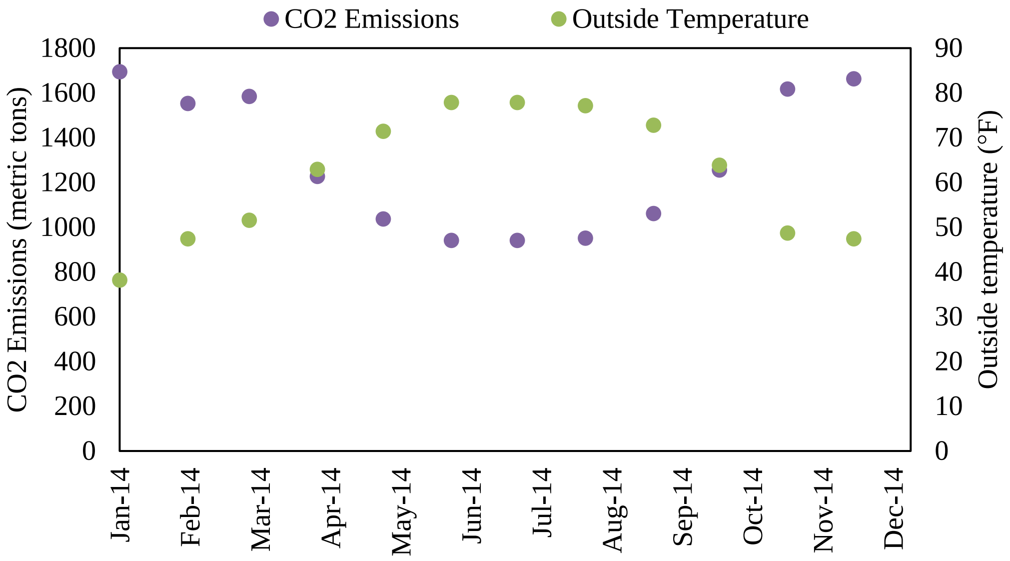

Figure 9. Monthly CO_2 Emissions compared to Outside Temperature

4.2.1.4 Conclusions and Recommendations

Steam is essential for the comfort of students at Clemson University to provide hot water, heating, and dehumidification services. Steam generation in 2014 produced 15,522 metric tons of CO_2 from natural gas combustion. Steam generation needs could be reduced by reducing hot water use, dehumidification, and space heating. Hot water use could be reduced with low-flow showerheads, faucet aerators, shortening showering times (e.g. by installing metering shower valves), or reducing temperatures on clothes washers. Adjusting set temperatures in buildings can also reduce dehumidification and heating needs. Applying passive heating strategies to new building design could further help to reduce future heating loads. To meet the university's increasing heating needs, a natural gas combined heat and power plant is under consideration. Future studies could also analyze the potential impact to reduce carbon emissions of supplement natural gas used for steam generation biogas or solar thermal panels. Analysis could also be done on replacing the steam lines with hot water lines. There was some uncertainty with the estimation of losses in the underground delivery tunnel, since Clemson has not performed an evaluation on their tunnel system. Therefore, a better estimation for losses in the underground delivery tunnel is recommended for future studies.

4.2.2 Refrigerant Usage

4.2.2.1 Background

Refrigerants are used in air conditioning systems for buildings at Clemson University. Refrigeration is responsible for GHGs both through its electricity use and from refrigerant fluid leaking into the atmosphere. Refrigeration units are built to minimize fluid leakage, however it is nearly impossible to produce a completely sealed system. Over time a leak may result from a weld fracture, a speck of dirt on a gasket, or even from a small groove between fittings. Significant leaks are reported and fixed, however often leaks aren't extensive enough to repair so the refrigerants are "topped off" periodically. The refrigerant most commonly used by Clemson University is R-22 which is a hydro-chlorofluorocarbon (HCFC), also known as HCFC-22. UNFCCC and its Kyoto Protocol include hydro-fluorocarbons (HFCs) in their carbon accounting, and in this analysis HCFCs will also be included. As of 2010, HCFC-22 was discontinued for use in new air conditioning systems in accordance with terms and agreement reached in the Montreal Protocol. In new systems, this refrigerant has been replaced by HFCs which do not contribute to ozone depletion, but still have high GWP. Thus, the Kigali Amendment of the Montreal Protocol has set controls to phase down their production and consumption due to their global warming effect. Clemson University uses smaller quantities of HFC-404A (R-404A), and HFC-410A (R-410A), however most of the systems still use HCFC-22. Since refrigerant use and its leakage is a direct emission produced from a source controlled by Clemson University, it is considered a Scope 1 emission.

4.2.2.2 Data

Refrigerants

Clemson University Facilities provided refrigerant ‘top-off’ data for 2014. Refrigerant logs for the East and West areas of campus were given along with refrigerant logs for HVAC and Clemson Utilities. These logs listed the weight of the drums before refrigerant was added to top it off, the volume of fluid needed, and the final weight of the drum to determine the mass of refrigerant added. For each log entry, the time, location, unit, and type of refrigerant were recorded. Refrigerant location data was broken to East, West, and HVAC refrigerants, so the exact unit location was not always clear.

Data Quality

Table 4-6. Data Quality for Refrigerants

Indicator Score	Score	Explanation
Reliability	1	Data based on measurements
Completeness	1	Data are from all refrigerant sites included in study
Temporal correlation	1	Data are from 2014
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data are specific to enterprises under study

4.2.2.3 Methods

Emissions

If there are no leaks in the system, refrigerants will last indefinitely. Therefore, it was assumed that any refrigerant added during 2014 represented the amount of refrigerant leaked out of the unit and into the atmosphere during the same period. Most leakage was refrigerant type R-22. There were also small leakages of HFC-404A and HFC-410A. By summing the recorded refrigerant added to all the campus units over 2014, the total amount of leaked refrigerant was determined. Then, the GWP for each substance was applied using the following equation.

$$\mathrm{CO_2\ emissions} = (\mathrm{l})(\mathrm{GWP}) \tag{6}$$

Here, *l* is the quantity of refrigerants leaked, and *GWP* is the global warming potential of the refrigerant.

Table 4-7. Carbon Emissions from Refrigerant Leakage

Refrigerant Type	**Greenhouse Gas**	**Quantity leaked (kg)**	**GWP (kg CO_2-e)**	**CO2-e emitted (metric tons)**
R-22	HCFC-22	76.80	1,760	135
R-404A	HFC-404A	0.77	3,922	3
R-410A	HFC-410A	2.21	2,088	5

4.2.2.4 Conclusions and Recommendations

In 2014 about 143 metric tons of CO_2-e were emitted into the atmosphere due to refrigerant leakage from Clemson's campus. Some buildings received several pounds of refrigerant 'top off' with no repair recorded. Therefore, further investigation is needed as to how leaks are found, and what constitutes a large leak. For this, a cost benefit analysis may also be helpful to compare the financial cost of repair to the cost of fluid leaked. Of the total leakage, 135 metric tons CO_2-e were from R-22, the most commonly used refrigerant for campus systems. Only one unit leaked R-404A, and it was repaired. This small leak only required 0.77 kg (1.7 lbs.) of refrigerant to be added, however due its high GWP this leak was responsible for 3 metric tons of CO_2-e to be emitted into the atmosphere. Similarly, the few leakages of R-410A that totaled in 2.21 kg (4.9 lbs.) had a GWP equivalent to 5 metric tons of carbon. When the Montreal Protocol discontinued HCFC-22 use in new air conditioning systems in new systems, this refrigerant was replaced by HFCs. However, the HFC-404A and HFC-410A used by Clemson have a higher GWP than HCFC-22. While it is difficult to ensure that systems do not leak, it is important to recognize the global warming significance of even small leakages for the campus carbon footprint. If possible, finding refrigerants with lower GWP such as HFC-32 and HFC-152a would be better to reduce the impact of leaked gas as they have GWPs of 677 and 138, respectively [75].

4.2.3 University Owned Vehicles

4.2.3.1 Background

Clemson University owns a variety of vehicles to aid in campus operations. One service offered is a shuttle service called Tiger Transit. Clemson's Tiger Transit operates 7 days a week, from 6 p.m. to 6 a.m. to serve Clemson University students, faculty, staff and visitors. During the day, the Tiger Transit buses provide a park and ride service for students parking on the outskirts of campus. At night, these buses can be requested to provide a safe ride around campus or back to a parked vehicle. Clemson University also has its own Police Department (CUPD) which ensures that the campus is safe for students, teachers, employees and visitors. Since both services utilize multiple vehicles for long periods of time, they are considered a significant source of Scope 1 emissions. Clemson also operates a bus route to the Greenville, but this was considered outside the boundaries of this study. CUPD uses gasoline in its vehicles while Tiger Transit buses use both diesel and gasoline fuel which produce CO_2 after combustion. The university also owns several golf carts, however, it was assumed that the emissions from these vehicles would be negligible since they are used intermittently compared to the constantly running Tiger Transit and CUPD services. Clemson also produces its own biodiesel to fuel University Facilities trucks on campus. These emissions are assumed to be carbon neutral.

4.2.3.2 Data

Tiger Transit

This service is controlled by Parking and Transportation Services, who record the number and type of buses running, miles traveled, and gallons used per month. This system has 18 vehicles total with 3 different sized vehicles ranging in fuel efficiency from 5 to 8 miles per gallon (mpg). Most nights, the buses switch between the multiple routes. Parking and Transportation services provided information on the number of miles traveled each month by each type of vehicle. The number of gallons used per vehicle per month fluctuates, however the fleet uses a total of 53,310 gallons of gasoline and 110,579 gallons of diesel fuel per year. This data was gathered in the Fall of 2016, however it was assumed that the fuel consumption was comparable in 2014.

Data Quality

Table 4-8. Data Quality for Tiger Transit

Indicator Score	Score	Explanation
Reliability	1	Data from Parking and Transportation records
Completeness	1	Data are representative over a year
Temporal correlation	1	Data are from 2016, which is less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from enterprises under study

Clemson University's Police Department

As of November 2016, CUPD has a fleet of 20 vehicles. According to the fleet coordinator, at any given time 10 vehicles are on duty, and overall each vehicle patrols about 20 miles per day. The two types of vehicles used by CUPD are the Ford Crown Victoria and the Ford Explorer, 17 and 19 miles per gallon, respectively. This data was also collected in the Fall of 2016, and it was assumed that this fuel consumption trend was comparable in 2014.

Data Quality

Table 4-9. Data Quality for Clemson University Police Department

Indicator Score	Score	Explanation
Reliability	4	Non-verified data partly based on assumptions
Completeness	2	Representative data from a smaller number of vehicles, but for adequate periods
Temporal correlation	1	Data obtained in 2016, which is less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	2	Data are from enterprises under study, but vehicle usage and fuel economy is estimated

Emission Factors

The U.S. Energy Information Administration has determined that 19.60 lbs CO_2/gallon gasoline and 22.40 lbs CO_2/gallon diesel are produced from combustion [76]. This factor is an average published in 2016 which is based on home heating and diesel fuel practices.

Data Quality

Table 4-10. Data Quality for Gasoline and Diesel Emission Factors

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements by EIA
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	3	Data pertains to similar combustion conditions
Further technological correlation	3	Data from processes and materials under study but from different enterprises and technology

4.2.3.3 Methods

Total Fuel Used

The total amount of fuel used had to be determined for the CUPD fleet. Considering the number of vehicles in the fleet, their average driving distance, and the average fuel economy, the total fuel usage could be determined with the following equation.

$$\text{Fuel used} = \frac{\text{Vdt}}{\text{m}} \tag{7}$$

Where *V* is the number of vehicles used, *d* is the average distance driven daily, *t* is the amount of time driven per year, and *m* is the average fuel economy for the fleet. Aligning with information from the police chief, it was assumed that CUPD patrolled year-round, and that the fuel economy was 18 mpg, which is the average mpg of the Ford Crown Victoria and the Ford Explorer. Using this equation, the total amount of fuel used is recorded in Table 4-11 below along with the given annual fuel usage for Tiger Transit.

Table 4-11. Fuel Usage by University Owned Vehicles

	Gasoline (gallons)	**Diesel (gallons)**
Tiger Transit	53,310	110,579
CUPD	8,111	N/A

Emissions

Once the total fuel usage was determined, the associated CO_2 emissions from combustion can be determined using average emissions factors of 19.60 lbs CO_2/gallon gasoline and 22.40 lbs CO_2/gallon diesel from the EIA [76]. The results of these calculations are shown in Table 4-12.

Table 4-12. Total Emissions from University Owned Vehicles

	Gasoline Emissions (metric tons CO_2)	Diesel Emissions (metric tons CO_2)	Total Emissions (metric tons CO_2)
Tiger Transit	474	1,124	1,597
CUPD	72	N/A	72

4.2.3.4 Conclusions and Recommendations

Tiger Transit contributed 1,597 metrics tons of CO_2 while CUPD emitted 72 metrics tons of CO_2. Overall, 1,669 metrics tons of CO_2 were generated from University-owned vehicles. A change in driving practices could decrease this. The data for CUPD was based on estimates by the police chief, so more detailed data could be gathered for future studies. While it may not be feasible to decrease CUPD patrolling or Tiger Transit services, policies to reduce idling could help reduce emissions. Also, future purchases of university-owned vehicles could aim for vehicles with higher fuel economy. A transition to electric vehicles may also be a possible alternative, the impact of this transition could be examined in future studies.

4.2.4 University Owned Aircraft

4.2.4.1 Background

Clemson University has two private aircraft that are based at the Clemson University hangar at Oconee County Airport. The Clemson University aircraft are only used for official University business with the purpose of expediting travel for designated officials and employees. The aircraft are used by the administrators and by the Athletic Department when justified. The policy states university aircraft can be used in instances where the destination is not served by commercial carriers, the commercial travel time interferes with other important official obligations, departure and arrival times interfere with a required travel itinerary, the number of travelers makes it cost effective, there is a need for confidentiality, or on-demand athletic transportation for athletic events or recruiting [77]. Since the aircraft are owned by Clemson University, they are considered Scope 1 emissions. Other university-related air travel is a Scope 3 emission, and is discussed in Section 4.4.5. Aircraft jet engines produce CO_2, H_2O, nitrogen oxides, carbon monoxide, oxides of sulfur, volatile organic compounds, particulates, and other trace compounds [78]. For this analysis, the CO_2 created from the jet fuel combustion will be examined.

4.2.4.2 Data

University Aircraft

The Chief Pilot for Clemson University provided information about the type of aircraft Clemson uses and their average annual mileage. The University has two private aircraft, the first is a 2008 Citation CJ3 jet that seats two crew and eight passengers. The jet can fly 480 mph (420 nautical miles, or knots) while burning about 140 gallons of Jet A fuel per hour. The second plane is a 1998 Beechcraft King Air C90B Turboprop airplane that seats two crew and six passengers. The turboprop plane can fly 265 miles (230 knots) per hour while consuming about 79 gallons per hour of Jet A fuel. The jet averages about 300 hours per year of use while the turboprop airplane averages about 150 hours per year. This data are recorded in Table 4-13.

Table 4-13. University Aircraft Annual Travel

Aircraft	Fuel consumption (gallons/hour)	Average Use (hours/year)
2008 Citation CJ3 Jet	140	300
1998 Beechcraft King Air C90B Turboprop Airplane	79	150

Data Quality

Table 4-14. Data Quality for Clemson University Aircraft Travel

Indicator Score	Score	Explanation
Reliability	4	Annual mileage is a qualified estimate by aircraft pilot
Completeness	3	Data provided does not have an adequate sample size to account for fluctuations
Temporal correlation	1	Data are current and less than three years of differences to year of study
Geographical correlation	1	Data are from area under study
Further technological correlation	1	Data regarding emissions is for aircraft under study

Emissions Factor

According to the EIA, jet fuel produces 9.57 kg CO_2 per gallon upon combustion [76].

Data Quality

Table 4-15. Data Quality for Jet Fuel Emission Factor

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements by EIA
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	3	Data pertains to similar combustion conditions
Further technological correlation	3	Data from processes and materials under study but from different enterprises and technology

4.2.4.3 Methods

Since the University jet averages about 300 hours annually and uses 140 gallons of Jet A fuel per hour the total emissions from annual flights can be determined using the following equation.

$$\mathrm{CO_2\ emissions} = \mathrm{EFft} \tag{8}$$

Here, *f* is the fuel consumption of the aircraft represented in gallons per hour, *t* is the total hours the aircraft is used per year, and *EF* is the emissions factor for the combustion of jet fuel.

Table 4-16. Emissions from University Aircraft Travel

Aircraft	CO_2 emissions (metric tons)
2008 Citation CJ3 Jet	402
1998 Beechcraft King Air C90B Turboprop Airplane	113

4.2.4.4 Conclusions and Recommendations

The use of the university aircraft contributed 515 metric tons CO_2-e. This data was based on estimates from the university pilot, and more detailed data may be obtained for future studies. There are many factors that influence the fuel efficiency of jet fuel such as take off and landing, wind speed and direction, weight carried, and altitude. Therefore, the total annual fuel used would be the most beneficial data to gather for future analysis, along with more specific combustion statistics for the aircrafts. To reduce these emissions, it is recommended that commercial flights or alternative transportation are considered as the emissions per passenger mile would be smaller. Video conferencing rather than traveling would also greatly reduce emissions.

4.2.5 Fertilizer Application

4.2.5.1 Background

Clemson University uses fertilizer to enhance the growth of landscaping around campus and on its golf course at the Madren Center. The areas that are treated are mostly hybrid or common Bermuda grass. The application of fertilizers adds nitrogen to the soil, which in turn increases the emissions of N_2O into the atmosphere. This process occurs through both nitrification and denitrification. Nitrification occurs when ammonium experiences aerobic microbial oxidation to nitrate, while denitrification occurs anaerobically through the microbial reduction of nitrate to gaseous nitrogen (N_2) [79]. Nitrous oxide (N_2O) is a GHG that is produced as an intermediate in denitrification and as a by-product of nitrification. Emissions from fertilizer application vary due to differences in soil type, moisture, temperature, season, plant type, fertilization, and management practices [80]. However, any increase in available nitrogen will enhance nitrification and denitrification rates, which increases the production of N_2O [79]. Emissions from fertilizer application are considered a Scope 1 emission because it occurs from sources that are owned and controlled by Clemson University.

For this analysis, only direct atmospheric emissions associated with denitrification and nitrification after fertilizer application on university-owned land are included.

Indirect emissions from potential leeching and runoff will not be considered. There are also GHG emissions associated with the production process, transportation of the fertilizer from the production facility, and possibly from the energy use in machinery required for fertilizer application. However, these emissions will not be included.

4.2.5.2 Data

Fertilizer Usage

Clemson University Facilities provided a summary of the fertilizer applied in 2014. The golf course had 12,766 lbs of inorganic nitrogen fertilizer applied, while landscape services used 2,820 lbs of inorganic nitrogen fertilizer with an additional 50 lbs of organic nitrogen fertilizer. This combined is a total 15,636 lbs of nitrogen fertilizer.

Data Quality

Table 4-17. Data Quality for Clemson University Fertilizer Application

Indicator Score	Score	Explanation
Reliability	2	Data was given by Clemson University Facilities based on non-verified measurements
Completeness	2	Representative data for sites, but does not give annual comparison for fluctuations
Temporal correlation	1	Data are from year of study
Geographical correlation	1	Data are from area under study
Further technological correlation	2	Data are for materials under study, but does not give exact type of fertilizer

Emissions

Emissions from fertilizer application varies due to variations in soil type, moisture, temperature, season, plant type, fertilization, and management practices [80]. However, facilities did not record this information when applying fertilizer. Therefore, an average emissions factor was applied. Per the IPCC (2006) Tier 1 protocol, the direct emissions factor of N_2O for various synthetic and organic N applications to soils has is 1% of the N applied to soils [79]. The uncertainty range for this value is 0.003 – 0.03 kg N2O-N/ kg N [79]. In this study the emissions factor will be 0.01 kg N_2O–N per kg N applied.

Data Quality

Table 4-18. Data Quality for Fertilizer Emission Factor

Indicator Score	Score	Explanation
Reliability	1	Data was verified by the IPCC
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	3	Less than 10 years difference
Geographical correlation	4	Data from a variety of areas with similar production conditions
Further technological correlation	2	Data from processes and materials under study but from different enterprises

4.2.5.3 Methods

Emissions

According to the EPA, the following equation must be used to calculate N_2O emissions from fertilizer application [80].

$$N_2O \text{ Emissions} = (FC)(EF)(\frac{44}{28}) \tag{9}$$

Here, *FC* represents fertilizer consumption, *EF* is the emission factor for application, and 44/28 is the molecular weight ratio of N_2O to N_2. Since the GWP of N_2O is 265 times that of CO_2 by mass for a 100-year timescale, the overall global warming potential can be calculated with the following equation.

$$\mathrm{CO_2\ equivalent\ emissions} = (\mathrm{E})(\mathrm{GWP}) \tag{10}$$

In this equation, *E* is the emissions of N_2O, while *GWP* is the global warming potential of 265 kg CO_2-e/kg N_2O [8]. Using this formula, it was found that the application of 15,636 lbs of nitrogen fertilizer produced the equivalent of about 19 metric tons of CO_2-e.

4.2.5.4 Conclusions and Recommendations

Fertilizer is used to enhance plant growth, and on Clemson's campus its use is purely aesthetic. Therefore, it is recommended that fertilizer use could be reduced or eliminated completely as a simple method to reduce the carbon footprint. While most fertilizer emission factors are related to agricultural application and landscapes, future studies may also want to seek a more precise emissions factor for the fertilizer used in nonagricultural settings.

4.2.6 Wastewater Treatment

4.2.6.1 Background

Clemson University owns and operates its own wastewater treatment plant (WWTP) which is located on the shore of Lake Hartwell. The WWTP plant is responsible for treating used water that contains human waste, food scraps, oil, soap, and chemicals. The main unit operation at the plant is a sequencing batch reactor, where large volumes of air are delivered to the wastewater to facilitate degradation. Aerobic digestion of sludge is also performed. GHGs from the wastewater are emitted during both of these processes. The system is similar enough to a conventional activated sludge process that it will be considered as such for this study

4.2.6.2 Data

Data was received from Clemson Faculties regarding the waste water treated. This data was given in millions of gallons (MG) per month for 2014 as seen in the table on the following page.

Table 4-19. Clemson University Wastewater Treated

Date	Wastewater (MG)
14-Jul	15.09
14-Aug	20.87
14-Sep	27.49
14-Oct	25.20
14-Nov	17.13
14-Dec	12.55
15-Jan	17.50
15-Feb	17.40
15-Mar	16.80
15-Apr	19.61
15-May	9.93
15-Jun	11.45
Total	**211.01**

Data Quality

Table 4-20. Data Quality for Wastewater Treatment

Indicator Score	Score	Explanation
Reliability	1	Data based on measurements
Completeness	1	Data are for all wastewater processed by WWTP
Temporal correlation	1	Data are from 2014
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data are specific to enterprises under study

Emissions Factor

Monteith et al. (2005) developed a procedure to estimate GHG emissions for many different wastewater treatment plants when facility-specific data are unknown [81]. They used data from Canadian wastewater treatment plants, site specific data was compared to generalized calculations to create province and national estimates. They evaluated emissions from various wastewater treatment processes, and didn't account for solid waste disposal or electricity for operation. From this study, they estimated that conventional activated sludge treatment processes have CO_2 emissions of 0.153 - 0.280 kg/m^3 [81]. This process was the most similar to the wastewater treatment system Clemson possesses. For this analysis, the middle of this range, 0.217 kg/m^3, will be assumed.

Data Quality

Table 4-21. Data Quality for Wastewater Treatment Emissions Factor

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	3	Less than 10 years of difference to year of study
Geographical correlation	3	Data pertains to similar wastewater treatment process
Further technological correlation	3	Data from processes and materials under study but from different enterprises and technology

4.2.6.3 Methods

Carbon Emissions

Aerobic wastewater treatment systems emit a mixture of CH_4 and CO_2. The amount of GHGs produced from treating wastewater depending on the characteristics of incoming wastewater, the required treated water criteria, and the on-site processes used [81].The U.S. EPA provides a guide to estimate these emissions based on the assumption that all organic carbon removed from the wastewater is converted to either CO_2, CH_4, or new biomass [82]. Emissions can be calculated using wastewater influent flow rate, oxygen demand of the influent wastewater to the biological treatment unit, and the oxygen demand removal efficiency of the biological treatment unit [82]. However, these values could not be obtained for the Clemson WWTP. Therefore, surrogate data from Monteith et al. (2005) was used in the following equation.

$$(EF)(CF)(WW_{Clemson}) \tag{11}$$

Here, EF is the emissions factor, CF is the conversion factor from m^3 to MG, and $WW_{Clemson}$ is the amount of wastewater treated by Clemson in a year. This calculation produced the results shown in Table 4-22 .

Table 4-22. Clemson University Wastewater Treatment Emissions

Date	Emissions (metric tons CO_2)
14-Jul	12
14-Aug	17
14-Sep	23
14-Oct	21
14-Nov	14
14-Dec	10
15-Jan	14
15-Feb	14
15-Mar	14
15-Apr	16
15-May	8
15-Jun	9
Total	**173**

4.2.6.4 Conclusion and Recommendations

Overall, the emissions related to the operation of Clemson's WWTP were 173 metric tons CO_2. This estimate was based on surrogate data for a conventional activated sludge system. Future studies may want to seek out more detailed information specific to the Clemson system, which can be considered a conventional activated sludge system, but also has an aerobic digestion set-up. Regardless, one method to reduce emissions is to reduce the wastewater volume treated. This could be achieved by installing greywater recycling systems that use water from sink and showers for toilet flushing and other non-potable uses. Also, domestic wastewater can be reduced by using more water efficient appliances (e.g. washers, dishwashers, toilets), and installing low flow shower heads and faucets. Behaviorally, taking shorter showers and general water use awareness could help lower the amount of wastewater produced.

Another option is to change the system itself. For example, transitioning to an anaerobic system and trapping biogas can reduce emissions and the biogas can be used in cogeneration units to produce electricity. Another option with an anaerobic system is to flare methane so that it has a lesser global warming impact. GHGs can also be decreased through the change of operational conditions. Activated sludge systems operating at high solid retention times promote endogenous respiration of biomass, this increases the amount of COD oxidized to CO_2 and decreases overall sludge production [83]. Thus, CO_2 emissions can be minimized with shorter solid retention times as long as it does not negatively affect the effluent quality [83].

4.3 Scope 2

Scope 2 emissions are associated with purchased electricity generation and other sources of energy (e.g. steam, chilled water) that are generated upstream from the organization. The only scope 2 emission source for Clemson University is purchased electricity consumption.

4.3.1 Electricity Generation

4.3.1.1 Background

Electricity is vital part to the successful functioning of Clemson University. Electricity is needed to power lighting, equipment, electronics, and is integrated in various other systems such as water distribution, steam generation, and refrigeration. Clemson University electricity is provided by Duke Energy, who supply to customers in several regions throughout the United States, including North South Carolina. Specifically, Clemson receives its electricity from Duke Energy Carolinas, LLC, whose service territory covers the western part of North and South Carolina. Therefore, emissions from purchased electricity generation were allocated based on energy and emissions flows to Clemson from the greater electricity generation system.

4.3.1.2 Data

Electricity Usage

Data was obtained from Clemson Utility Services for electricity consumption for the 2013-2014 school year. The total energy consumption obtained from Utility Services included all buildings owned by Clemson University. The Clemson University International Center for Automotive Research (CU-ICAR) campus in Greenville was excluded since it is not a part of Clemson's main campus, hence outside the bounds of this study. Included are the main campus meter, facilities meters, the wastewater treatment plant, and all departmental buildings. The total electricity consumed by Clemson University's main campus in 2014 was 119,703,787 kWh. Annually, the main meter used 117,331,603 kWh, the Madren facilities used 1,406,280 kWh, and Clemson WWTP related activities used 965,904 kWh for plant controls and sewage pumping.

Data Quality

Table 4-23. Data Quality for Electricity Usage

Indicator Score	Score	Explanation
Reliability	1	Data was collected by Facilities and recorded on Duke Energy bills
Completeness	1	Data was collected over an entire year, an adequate period to balance fluctuations
Temporal correlation	1	Data are from 2014, which is less than three years difference to year of study
Geographical correlation	1	Data are from area under study
Further technological correlation	1	Data are specific to the processes under study

Generation and Emissions

The U.S. Environmental Protection Agency (EPA) has created an Emissions & Generation Resource Integrated Database (eGRID). Environmental characteristics included in eGRID are emissions of NO_x, SO_2, CO_2, CH_4, N_2O, mercury, net generation, and the resource mix [84]. This database is based on plant data for all the individual electricity generating plants that supply power to the electric grid and report data to the U.S. government. In January of 2017, the EPA released eGRID2014 which lists comprehensive data for electricity generation in 2014.

Data Quality

Table 4-24. Data Quality for eGRID Database

Indicator Score	Score	Explanation
Reliability	1	eGRID data are based on plant specific data reported to U.S. government
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	eGRID data are specific to 2014
Geographical correlation	2	Average data from larger area in which the area under study is included
Further technological correlation	2	Data from processes and materials under study but exact providers and electricity mix for Clemson University cannot be determined

4.3.1.3 Methods

Electricity Generation

Using EPA's eGRID2014 database, the data was filtered to only include plants where the plant operator was Duke Energy Carolinas, LLC. Summing net generation from power plants with the same primary fuel (e.g. coal, gas, hydro), the generation mix was found as seen in Table 4-25 and displayed in Figure 10. In this section, GHG emissions will be allocated based on Clemson's use of electricity compared to the total generation and emissions from Duke Energy Carolinas, LLC. An alternative method would be to calculate emissions would be to use a national or state wide average.

Table 4-25. Duke Energy Carolinas, LLC Electricity Generation

	Biomass	Coal	Gas	Hydro	Nuclear	Oil	Solar	Total
Net Generation (MWh)	7.50 E+05	3.17 E+07	1.65 E+07	2.48 E+06	5.75 E+07	7.04 E+04	2.60 E+05	1.09 E+08
Percent	0.69%	28.99%	15.14%	2.27%	52.61%	0.06%	0.24%	

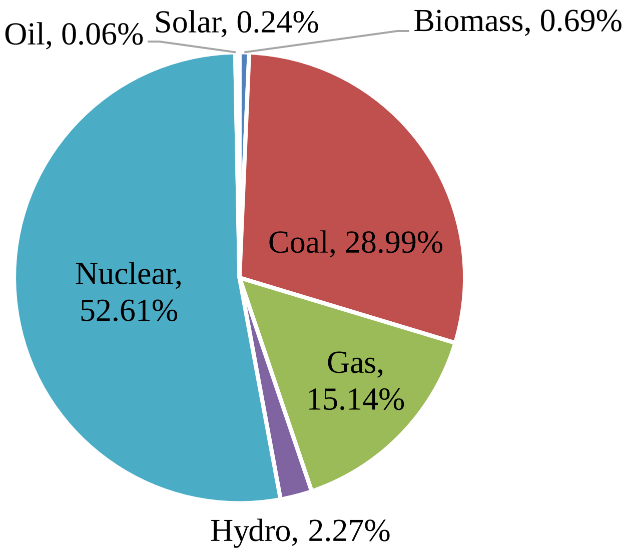

Figure 10. Duke Energy Carolinas, LLC Electricity Generation Mix

Plant Emissions

The EPA's eGRID2014 database lists individual plant emissions for CO_2, CH_4, and N_2O. The emissions for the plants operated by Duke Energy Carolinas, LLC were quantified for each GHG. The CO_2-e in the database recorded emissions in short tons, and used the IPCC Second Assessment Report GWP in their calculations. This data had to be recalculated to find the more accurate global warming potential using the updated IPCC AR5 values as stated in Table 2-1. Then, the calculated emissions are shown in Table 4-26. There are no direct emissions associated with electricity generation from biomass, hydro, nuclear, or solar sources. Furthermore, eGRID plant data only reports emissions associated with the generation of electricity, and does not account for transmission and distribution losses or life cycle emissions such as emissions from the extraction, processing, and transportation of fuels. This will be addressed in Section 4.4.1.

Table 4-26. Summed Plant Emissions for Duke Carolinas, LLC (metric tons)

	Coal	**Gas**	**Oil**	**Total**
CO_2	27,755,783	7,301,041	63,220	35,120,044
CH_4	3,230	133	2	3,364
N_20	470	14	0	484
CO_2-e	27,970,756	7,308,348	63,378	35,342,482

Emissions

The total GHG emissions from Duke Energy Carolinas LLC was 35,342,483 metric tons CO_2-e. The total GHG emissions associated to Clemson University's electricity use was calculated by finding the fraction of Clemson's energy use compared to overall generation for the Duke Energy Carolinas LLC. The total annual generation in 2014 for the plants operating under this entity was 109,269,164 MWh. Clemson University consumed 119,703,787 kWh in 2014, or 119,704 MWh. This equates to about 0.11 percent of Duke Energy Carolinas net generation. Using these values, the following equation can be used to find the allocated emissions that are attributed to Clemson University.

$$\text{GHG emissions} = \frac{\text{E}_{\text{Clemson}}}{\text{E}_{\text{Duke}}}(\text{P}_{\text{CO2e}}) \qquad (12)$$

Here, $E_{CLEMSON}$ is the annual electricity use by Clemson, E_{DUKE} is the net annual electricity generation by Duke Energy Carolinas LLC, and P_{CO2e} is the total GHG emissions produced by Duke Energy Carolinas LLC annually. Overall, it was calculated that 38,718 metric tons CO_2-e are emitted to produce the electricity to meet Clemson's electricity needs. Of this, the main campus, the Madren Center, and the WWTP activities are attributed about 37,950, 455, and 312 metric tons CO_2-e, respectively.

Trends in Electricity Use

Clemson University electricity use varies as seen in Figure 11. Electricity use is the lower in winter months, with January being the month with the lowest consumption. One possible reason for this may be the outside temperature. Section 4.2.1 discusses how in the winter, the cooler temperatures cause a higher demand for steam generation for heating and hot water. According to Clemson Facilities, the largest use of electricity are our four chiller plants, which aren’t in use during the winter.

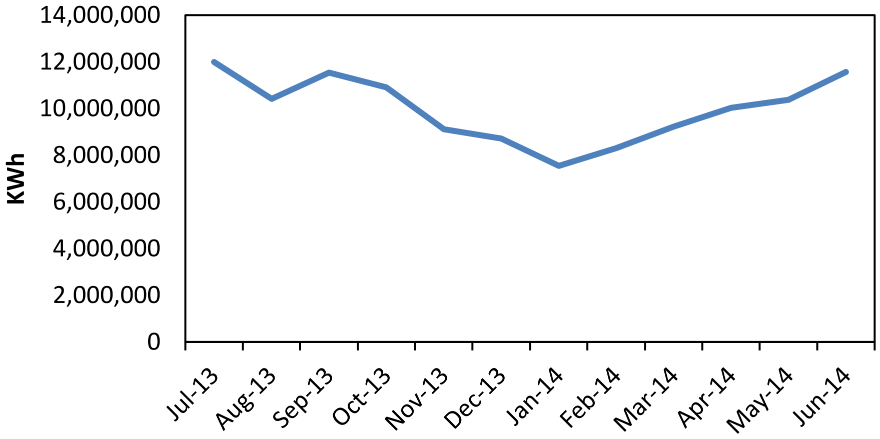

Figure 11. Clemson University Monthly Electricity Use

4.3.1.4 Conclusion and Recommendations

Duke Energy Carolinas covers a wide service territory in North and South Carolina that receives energy from a mixture of over 200 facilities. This assessment only included emissions from the plant, and did not account for other emissions associated with plant operation such as electricity used for lighting. There is also uncertainty of how representative the electricity use from 2014 is for other years. The five prior years to this study used more electricity annually, so more information would be needed to assess the cause for the decrease in consumption in 2014.

Emissions from electricity can be reduced by addressing how energy is generated and utilized. Improving the electricity mix with more renewable energy would lower emissions. Duke Energy plans to reduce the carbon emissions of their electricity generation by 40% from 2005 levels [85]. Clemson University also has the ability to influence future electricity sources by joining forces with Duke Energy in their plans for future electricity generation. In the past, Duke Energy has proposed a large solar installation on university land, and more recently, Duke Energy Carolinas has proposed the construction of a 16-megawatt combined heat and power plant on Clemson’s campus [86]. By collaborating with Duke Energy, Clemson could seek to improve its electricity mix, or investigate the possibility of supplying its own electricity with wind turbines or solar panels.

A change in utilization would also lower emissions. Further investigation into what can be done to lower electricity demands. Demands could be reduced through increased conservations and efficiency. Measures such as promoting the shutdown of electrical devices when not in use, installing motions sensors for lights, and purchasing energy efficient appliances are all methods to reduce electricity demands.

According to campus facilities, the largest users of electricity are the four chiller plants. Their energy demand could be reduced if thermostats were set lower or passive cooling strategies were applied to buildings, however this is difficult to retrofit on old buildings. Overall, many of these improvements to reduce electricity demand can be changed with human behavior or automation (i.e. adjusting thermostats, turning off appliances).

4.4 Scope 3

Scope 3 emissions include the indirect emissions that come from sources owned or controlled by another entity [50]. Most studies focus on scope 1 and 2 emissions, but it has been suggested that in some cases Scope 3 might account for 80% of an organization’s carbon footprint [45]. For this study emissions will be analyzed related to the lifecycle of electricity generation, transmission and distribution, various forms of commuting, university related travel, paper usage, waste and recycling transportation, wastewater treatment chemicals, and water treatment.

4.4.1 Electricity Life Cycle

4.4.1.1 Background

As described in 4.3.1, electricity is essential part to the successful functioning of Clemson University. While electricity has emissions from generation, it also has upstream indirect emissions associated with raw materials extraction, materials manufacturing, component manufacturing, materials transportation, and infrastructure construction. Since Scope 2 of this analysis were restricted to the electricity generation phase, this section will assess the additional upstream impacts.

4.4.1.2 Data

Since many plants are included in Duke Energy Carolinas electricity generation, average life cycle emissions were found from surrogate data for each generation energy source. They are discussed below and shown in Figure 12.

Biomass

The IPCC AR5 conducted a review to determine lifecycle emissions from biomass. Analysis included global climate impacts of CO_2 emissions from combustion of regenerative biomass such as biogenic CO_2, along with associated changes in surface albedo following ecosystem disturbances [87]. They found the minimum, median, and maximum gCO_2-e/ kWh life cycle emissions to be 130, 230, and 420 respectively [88].

Coal

NREL screened 270 references that reported life cycle environmental impacts of several coal electricity generation technologies and a meta-analytical process called “harmonization” was applied to their results [89]. This process disaggregated emissions estimates according to the life cycle stages they included, and then altered all the studies to have consistent boundaries so they could be compared [89]. CO2, CH4, and N2O were used, and other GHG contributions were negligible. Upstream life cycle processes included in the analysis were raw materials extraction, materials manufacturing, component manufacturing, materials transportation to the construction site, and construction [89]. Operational life cycle processes included were mining, preparation, transport, combustion of coal, power plant operation, and maintenance [89]. The, downstream life cycle processes within the boundaries were waste disposal, power plant decommissioning, and coal mine rehabilitation [89]. After technology specific harmonization, the emission factors ranged from 930 to 1,050 g CO2-e/kWh with a median of 980 g CO2-e/kWh [89]. This median was the value used in emissions calculations.

Hydropower

The IPCC Fifth Assessment Report conducted a review to determine lifecycle emissions from hydropower. Hydropower life cycle emissions are mostly associated with construction, materials manufacturing, and transportation of materials. In this assessment, biogenic CO_2 emissions from reservoirs were not included [87]. They found the minimum, median, and maximum g CO_2-e/ kWh life cycle emissions to be 1, 24, and 2,200 respectively [88].

Natural Gas

NREL gathered published LCAs of GHG emissions from the production and use of shale gas. They examined a mixture of different unconventional gas resources that all either focused on or included shale gas [90]. The life cycle stages were adjusted to be consistent throughout the studies so that each included accounted for power plant construction, the drilling and casing of the wells, water supply and treatment, liquids unloading, and frequency of well recompletions [90]. In this analysis CH_4 leakage was not a parameter used in the estimates of life cycle GHG emissions since it had a very wide range of estimations [90]. Coproduct allocation was also not included in this analysis as it was not reported for many studies. The published results for shale gas range from 437 to 758 g CO_2-e/kWh with the median being 488 g CO_2-e/kWh [90].

Nuclear

NREL screened published estimates of lifecycle GHG emissions from light water reactors, this included boiling water reactors (BWRs) and pressurized water reactors [91]. This process reviewed of all data sources, adjusted parameter estimates, realigned system boundaries within each life cycle phase, or added missing life cycle phases when necessary to produce a detailed meta-model [91]. Operational processes included uranium mining, milling, conversion, enrichment, fuel rod fabrication, transportation, facility operation and maintenance, reprocessing, and mine rehabilitation [91]. The downstream life cycle phases included were facility decommissioning, nonradioactive waste disposal/recycling, and waste storage after facility's operational processes cease [91]. After all boundaries were adjusted, the harmonized results had a published median of 12 g CO_2-eq/kWh, an interquartile range of 17 g CO_2-e/kWh, and a range of 110 g CO_2-e/kWh [91].

Oil

Oil-fired generation produce a negligible amount of energy for Clemson's electricity mix and only at times of extreme peaks. This represents less than 1% of annual energy contribution. Neither the IPCC nor NREL provided a harmonized estimation for oil. However, an estimate used by Sovacool (2012) cited that heavy oil used by various generator and turbine types emit 778 g CO_2-e/kWh [92].

Solar

NREL reviewed 109 studies, of which 91 passed the screening for quality of reporting, validity of analysis methods, relevance of the system, and data source used [93]. Harmonization of the studies adjusted life cycle stages, lifetime, performance ratio, solar irradiation, and efficiency degradation, and the life cycle stages included upstream are raw material acquisition, materials production, film deposition, module production, and installation [93]. The operational processes included are electricity generation and maintenance, while downstream processes such as decommissioning and disposal were considered. The recycling stage of the thin-film PV life cycle was not included in the system boundary of this study since thin-film installations are relatively new. The resulting estimates of GHG emissions after harmonization were 21, 14, and 27 g CO_2-e/kWh for amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS), respectively [93]. Assuming Duke's solar generation is composed equally of these three technologies, the average GHG emissions associated with solar PV in this analysis was 20.67 CO_2-e/kWh.

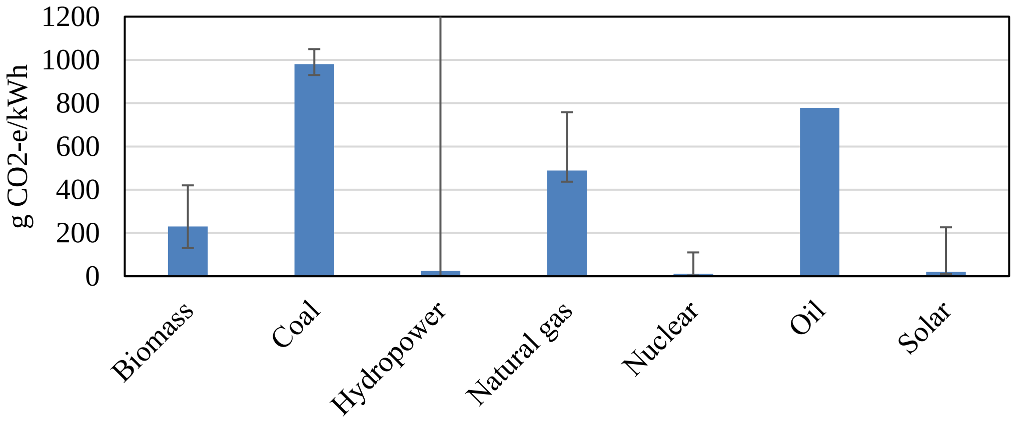

Figure 12. Life Cycle Emissions Factors for Electricity Generation

Data Quality

Table 4-27. Data Quality for Electricity Emissions Factors

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a several paper manufacturers to even out normal fluctuations
Temporal correlation	5	The studies publishing harmonized values re recent publications, however some of the references they included in their assessment were 10-15 years of difference
Geographical correlation	3	Data from area with similar production conditions
Further technological correlation	2	Data from processes and materials under study, but from different enterprises

4.4.1.3 Methods

For each source, the emissions factor was applied to the total generation and electricity mix percentages found in Section 4.3.1. The following equation was used for to do this.

$$Lifecycle\ Emissions = (EF)(\ E_{Clemson})(E_{Percent}) \tag{13}$$

Here, EF is the respective emissions factor, $E_{CLEMSON}$ is the annual electricity use by Clemson, and $E_{CLEMSON}$ is the percentage that the source is of the electricity generation

Clemson receives. After this was performed for each source, the results were summed to find the total lifecycle emissions.

Table 4-28. Life Cycle Emissions of Electricity Generation

	Generation (%)	Median emission factor (g CO_2-e/kWh)	CO_2-e (metric tons)
Biomass	0.69	230	190
Coal	28.99	980	34,008
Gas	15.14	488	8,844
Hydro	2.27	24	65
Nuclear	52.61	12	756
Oil	0.06	778	56
Solar	0.24	20.67	6
TOTAL			43,925

The total life cycle emissions from all electricity generation sources used by Clemson was 43,925 metric tons CO_2-e. The surrogate data used for this analysis did not break down the estimated life cycle emissions by phase, so the emissions from operation found in Scope 2 (section 4.3.1) had to be subtracted from this total so that they would not be double counted. These emissions calculated in Section 4.3.1 from the combustion of coal, gas, and oil, for electricity generation were 38,718 metric tons CO_2-e. The difference between this and the total life cycle emissions is 5,207 metric tons CO_2-e.

4.4.1.4 Recommendations and Conclusions

The lifecycle emissions from electricity generation included the many processes such as upstream raw material acquisition, materials production, component manufacturing, materials transportation, construction, facility operation and maintenance, and decommissioning [89] [93] [91]. For each source, its specific processes were analyzed, its lifetime was considered, and the CO_2-e emissions per kWh were determined for the overall generation. These emissions factors used calculated by evaluating LCA studies from varying locations, and the ranges for some emissions factors were broad. For this analysis the median value was chosen to be most representative, however there is uncertainty because they are not specific representations of the plants in Clemson's electricity generation mix. Further assessment on the plants used in the Duke Energy Carolinas electricity mix could produce more accurate lifecycle emissions.

There is uncertainty surrounding NREL's harmonized value for gas life cycle emissions for electric power generation. This study does not account for methane leakage since there was a very wide range of leakage in the studies chosen [90]. Brandt et al. (2014) has estimated that natural gas systems can have an excess percentage leakage of 1.8% to 5.4% of end use gas [94]. Not including this leakage is significant because natural gas's components have a higher GWP and would contribute to Clemson's carbon footprint.

There is also uncertainty linked to the harmonized value used for coal generation. This LCA study used outdated GWP values for CH_4, and N_2O to determine their emissions factor as it was published before the Fifth Assessment Report was released. Similarly, nuclear generation used GWP from the IPCC Fourth Assessment Report, but since it only included GHGs from CO_2 this value was unaffected [91]. Meanwhile, NREL's original study for natural gas was recently updated to include new GWP from the Fifth Assessment Report [90].

The lifecycle emissions associated with electricity generation may be able to decrease if their impact was considered for future power plants. Nuclear, solar PV, and hydropower had the lowest median emissions factors of the sources analyzed, being 12, 20.67, and 24 g CO_2-e/kWh, respectively. Therefore, future planning for power plants may want to consider these sources preferentially to reduce future GHG emissions.

4.4.2 Transmission and distribution

4.4.2.1 Background

Transmission and distribution losses represent the difference between the electricity generated at power plants and the power that is purchased by the customers. When energy is transmitted over long distances there are power losses in the transformers and power lines. The energy may be lost as heat in the conductors, and it can also dissipate in generating an electro-magnetic field. There are also losses from resistance, which depend on the conductors, voltage, and the length of the transmission lines. By transmitting electricity at high voltage, the energy lost to resistance is reduced. However, there are still losses. This disparity between electricity produced and consumed is considered a Scope 3 emission as it is an indirect energy related emissions source.

4.4.2.2 Data

As described in Section 4.3.1, data was obtained from Clemson Utility Services for electricity consumption for the 2013-2014 school year. Emissions and grid loss factors were obtained from the U.S. EPA’s eGRID database. The grid loss factors are determined using data from 2009 data, and are based on the consumption, generation, foreign net imports, and interchanges within and between the U.S. balancing authorities in the sub-regions of the grid [95]. According to eGRID, since Clemson is located in the Southeastern U.S. Virginia/Carolina area, its gross grid loss factor is 5.82% [95].

Data Quality

Table 4-29. Data Quality for eGRID Grid Loss Factor

Indicator Score	Score	Explanation
Reliability	1	Electricity usage based off of Clemson meters, eGRID data are based on plant specific data, and grid loss data are verified based on measurements
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	2	Data are from 2009, so there is less than six years difference
Geographical correlation	2	Average data from larger area in which the area under study is included
Further technological correlation	2	Data from processes and materials under study but different enterprises are included in grid loss factor

4.4.2.3 Methods

To find the GHG emissions associated with Clemson, the electricity purchased by the University and the transmission and distribution losses from the electricity purchases must be accounted for. Transmission and distribution losses are a Scope 3 emission, however to properly allocate emissions the total electricity use must be known. The electricity use by Clemson in 2014 was 119,704 MWh as described in Section 4.3.1. To determine electricity lost in transmission and distribution the following equation was adapted from eGRID methodology [95].

$$E_{TD} = E_{Clemson}(\frac{1}{1 - GGL} - 1) \tag{14}$$

Here, E_{TD} is the electricity lost in transmission and distribution, $E_{CLEMSON}$ is the amount of electricity used by Clemson annually, and GGL is the eGRID grid gross loss factor. According to eGRID, the gross grid loss factor in the area Clemson is located in is 5.82% [95]. Using equation 14 it was found that the electricity from combined generation and line losses is approximately 7,397 MWh. Therefore, in total 127,101 MWh of electricity is attributed to Clemson annually. Using the methodology described in Section 4.3.1, these electricity losses account for 2,393 metric tons of CO_2-e.

4.4.2.4 Conclusions and Recommendations

Transmission and distribution losses from power plants to Clemson University can be minimized, but not eliminated entirely. These losses are dependent on the design of the lines and equipment used, which is out of the University's control. Therefore, reducing GHG emissions associated with these losses would parallel the electricity reduction strategies discussed in Section 4.3.1. Transmitting electricity shorter distances would decrease power losses in the transformers and power lines, so another method to decrease these emissions is to increase on-site electricity generation. If a fossil fuel source was used, this may come at the expense of greater Scope 1 emissions since on-site generation would be under the ownership and control of the university. However, an on-site renewable electricity generation source would have emissions from use, and it could decrease both electricity demand and associated transmission and distribution losses.

4.4.3 Automotive Commuting

4.4.3.1 Background

Students, faculty, and staff travel to and from campus to participate and ensure its functioning. While some students live on campus, the rest of the student body and faculty commute to school by means of walking, biking, driving a personal vehicle, or taking public transit. In this study, commuting is defined as daily travel to and from campus by students, faculty, and staff. This does not include student travel at the beginning and end of the semester or during vacation periods. The scope of this analysis will include tailpipe emissions from the mode of transportation for driving a personal vehicle or taking public transit. The GHG considered from tailpipe emissions from diesel and gasoline combustion is CO_2. This analysis will not include emissions associated with infrastructure construction, such as roads, necessary to operate the vehicles nor those associated with non-operation life cycle phases of the vehicles themselves. Since these indirect commuting emissions are a consequence of the activities of the University, but not from a university-owned source, these emissions are classified as Scope 3.

In this section, parking permits data was obtained to represent the commuter population. Data was also obtained describing the type of vehicle registered vehicle with each permit. This was combined with vehicle specific data from the DOE to find an average fuel economy for the commuting fleet. Then, a survey from Clemson's Parking and Transportation Services was used to determine the average distance commuted. These values were used to determine overall fuel use, which was applied with EIA emissions factors to determine emissions from fuel combustion.

4.4.3.2 Data

Parking Permits

Data was obtained from Clemson University Parking and Transportation Services for the number of parking permits bought for students and employees in 2014. The type of permit purchased was either broken down by the type of commuter or the type of vehicle used (e.g. student commuter, moped, motorcycle, etc). The number of each type of permit purchased is shown in Table 4-30. There are also a variety of passes available for parking with different restrictions. Weekend and weekday visitor passes were not included in analysis, nor were passes for department guests. Fike Recreation Center annual passes were also not included, as it was assumed these were most likely pertinent to community members outside the university. Parking passes for after 4:30 only were included within commuter total and there were only 66 permits purchased. Resident passes included the East and West resident parking lots, apartments, and the Clemson House. However, resident parking was not included in the analysis as it was assumed this population would walk to campus. Parking permits for the Bridge program (404 permits) were included in the total student commuting permits.

Table 4-30. Parking Permits Sold in 2014

Resident	Student Commuter	Employee	LEV	EV	Motorcycle	Scooter/Moped
4,261	11,026	4,627	222	12	319	325

Type of Vehicle

The type of vehicles registered for each permit was also obtained in 2016 from Clemson University Parking and Transportation Services. For each vehicle, the make, model, and year were listed. This data records moped permits separately from other vehicles. A small number of vehicles had incomplete information (e.g. missing vehicle model) and these were excluded from the analysis. For student commuters, there were 9,333 complete records, and 1,128 incomplete. While for employees there were 5,433 complete records and 1,159 incomplete records.

Data Quality

Table 4-31. Data Quality for Vehicle Permits

Indicator Score	Score	Explanation
Reliability	1	Permits and vehicles registered emissions are verified measurements by Parking and Transportation Services
Completeness	2	Representative data from a sufficient sample of sites over an adequate period, but some data are incomplete
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data are from enterprises under study

Vehicle Emissions

Vehicle emissions were obtained from the U.S. Department of Energy (DOE) who have compiled a list of all the average fuel economies for vehicles produced after 1984. The city mileage was assumed to be more similar to the Clemson geography rather than highway mileage.

Data Quality

Table 4-32. Data Quality for Vehicle Emissions

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	Data are up to data and specific to the vehicles in study
Geographical correlation	3	Emissions data from area with similar production conditions
Further technological correlation	1	Data are from enterprises under study

Commuting Habits

A survey performed by Clemson University Parking and Transportation services was also obtained. This survey gathered commuting information from 1,081 student commuters, 422 faculty members, and 756 staff through an online survey. Comparing the 2,259 surveyed to of 16,521 permits sold produces a confidence interval of 1.92 with a 95% confidence level. This survey data described the days of the week that the surveyor commuting on average, the distance traveled, and the mode of transportation (e.g. walk, bike, CATBUS, personal vehicle). From the commuter survey, weekly frequency for commuting was gathered for students who drove to campus. By providing their average distance traveled, an average commute could be calculated from this data and an average amount of days per week traveled.

Data Quality

Table 4-33. Data Quality for Commuting Habits Survey

Indicator Score	Score	Explanation
Reliability	2	Commuting survey data are verified partly based on assumptions or non-verified data based on measurements
Completeness	2	Representative data from a smaller sample size, but for adequate periods
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from commuting is specific to processes and enterprise under study

Emission Factors

The U.S. EIA has determined that 19.60 lbs CO_2/gallon gasoline are produced upon combustion [76]. The data quality for this emissions factor can be seen in Table 4-10 of Section 4.2.3.

4.4.3.3 Methods

Commuter Fleet Fuel Efficiency

Data listing the make, model, and year for all vehicles registered was coupled with fuel efficiency information from the U.S. Department of Energy to determine the miles per gallon (mpg) for each individual vehicle. The city mpg was applied rather than highway mpg. Since the data gathered is limited to the make and type of vehicles, there were estimations in the mpg for certain vehicles. For example, several vehicles were registered as a BMW 3 Series, however without knowing the exact model of the vehicle, the average of the range of this series (19 mpg) was used for all. This was performed for both student and faculty registered vehicles to find the average mpg of the fleet. Since detailed information was not provided for mopeds/scooters, an average value was also found for mopeds using the average mpg of the top selling scooters. The average for motorcycles was based upon the average of the U.S. Department of Energy data. Low emissions vehicles (LEV) and electric vehicles (EV) were also recorded separately so that their mpg could be determined, however EV will not have emissions associated with combustion. The results of this investigation are below.

Table 4-34. Average Fuel Economy for Commuters (mpg)

Student Commuters	Employee	LEV	EV	Motorcycle	Scooter/Moped
19.68	19.44	29.53	61.57	43.54	76.29

Annual Commuter Distance

Using the survey conducted from Clemson University Parking and Transportation Services an average weekly frequency for commuting and the median distance commuted could be calculated for students, faculty, and staff. From the survey carpooling was counted in the total driving days as there was not enough information to appraise if students within the survey were carpooling with each other.

Table 4-35. Average Commuting Trends from Survey

	Responses	Average commute (days)	Distance commuted (miles one way)		
			25th percentile	50th percentile	75th percentile
Students	1,081	4.83	2	4	5
Faculty	422	4.45	4	7	18
Staff	756	5.04	6	12	20

These results can be seen in Figure 13. The boxes represent the first quartile to the third quartile, with the inner line displaying the median. The mean is represented by an "x" marker. The lines shown or "whiskers" indicate variability outside the upper and lower quartiles, and the points outside this range are considered outliers. Each demographic had several outliers. For students, the maximum value reported to commute one way was 290 miles, for faculty the highest reported was 107 miles, and for staff it was 80 miles. These could not be shown due to the scale of the plot.

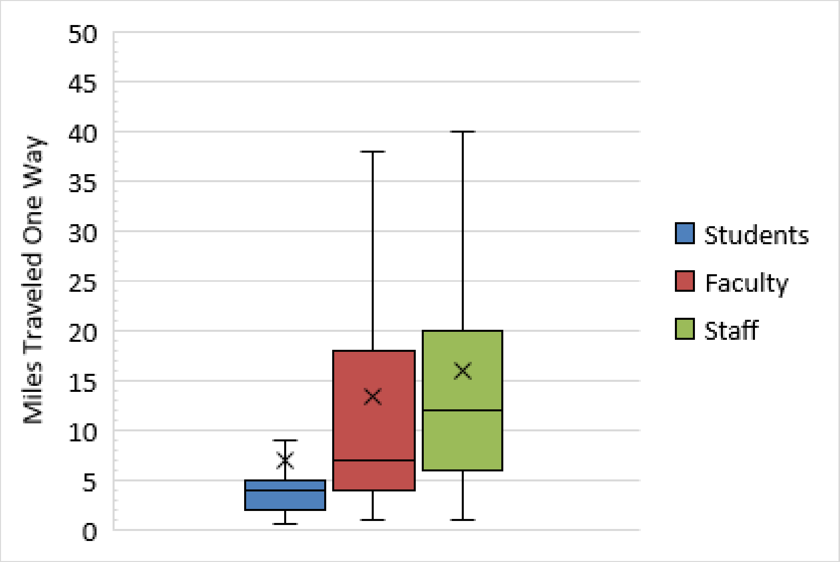

Figure 13. Box and Whisker Plot of Miles Commuted One-Way

The 25th, median, and 75th percentile distances were then applied to the commuting frequency and then scaled up to the total number of permits bought by students and employees. However, since parking permits do not differentiate between faculty and staff, their data was conglomerated and averaged to be applied to the employee permits.

In 2014, the University employed 1,388 faculty [7]. Therefore, it was assumed that all faculty bought a parking permit and the remaining 3,239 employee permits belonged to staff and administrators. Furthermore, it was assumed that LEV, EV, motorcycles, and scooters/mopeds were all students.

Total Emissions

The total CO_2 emissions were calculated separately for student commuters, faculty, staff, LEV, motorcycles, and mopeds/scooters since they each had varying fuel economies and commuting distances. The distance traveled in a roundtrip commute was calculated for each commuter demographic. This was then used with the average mpg for each pertinent vehicle group to determine the gallons of gas used per day per person. Next, the frequency of travel had to be determined. To do this, the total number of days per week commuted was converted to a daily decimal (e.g. if a student drove to campus 4 days of the week this would be 0.57 commutes per day). Thus, weekends are accounted for in the daily average. This value was then applied to the length of time over the year commuting occurs to determine the annual distance commuted. Using the academic calendar, it was assumed that students commute 206 days out of the year, which neglects summer and holidays. For faculty and staff the national holidays and two weeks of vacation was assumed, which left 347 days out of the year for commuting. From this, the gallons of gas used per person annually was found for student commuters, faculty, staff, LEV, motorcycles, and mopeds/scooters. This value was then scaled up by the number of permits purchased to find the total gallons of gas combusted for each demographic. An average combustion emissions value was then applied to the total quantity of gasoline used to calculate the GHG emissions associated with driving. Per the EIA, 19.60 pounds CO_2 are produced from burning a gallon of gasoline [76]. The unit conversions for this process can be seen in the following equation and the converted results are listed in Table 4-36.

$$(\mathrm{D})(\mathrm{g})(\mathrm{Com_d})\left(\mathrm{Com_y}\right)(\mathrm{P})(\mathrm{EF}) \tag{15}$$

Here, D is the distance traveled in miles per day, g is the gallons of gasoline used per mile drive, Com_d is the daily commuting frequency per person, Com_y is the average frequency (in days) commuted per year, P is the number of permits sold, and EF is the emissions factor of lbs of CO_2 emitted per gallon of gasoline combusted. The overall emissions were calculated using the first, second, and third quartiles of distance commuted as shown as follows.

Table 4-36. Metric tons of CO_2 Produced from Commuting

	25th percentile	50th percentile	75th percentile
Student Commuters	2,836	5,673	7,091
Faculty	1,122	1,964	5,051
Staff	4,454	8,908	14,846
LEV	38	76	95
EV	NA	NA	NA
Motorcycle	37	74	93
Scooter/Moped	22	43	54
Total	8,509	16,738	27,230

Trends in Commuting

The survey provided by Parking and Transportation Services also asked participants “If you do not primarily use alternative transportation (bike, walk, mass transit, etc.) to commute to campus, what is the main reason?” and gave them options for what their reason was for not using alternative transportation. The results of this study are shown in Figure 14.

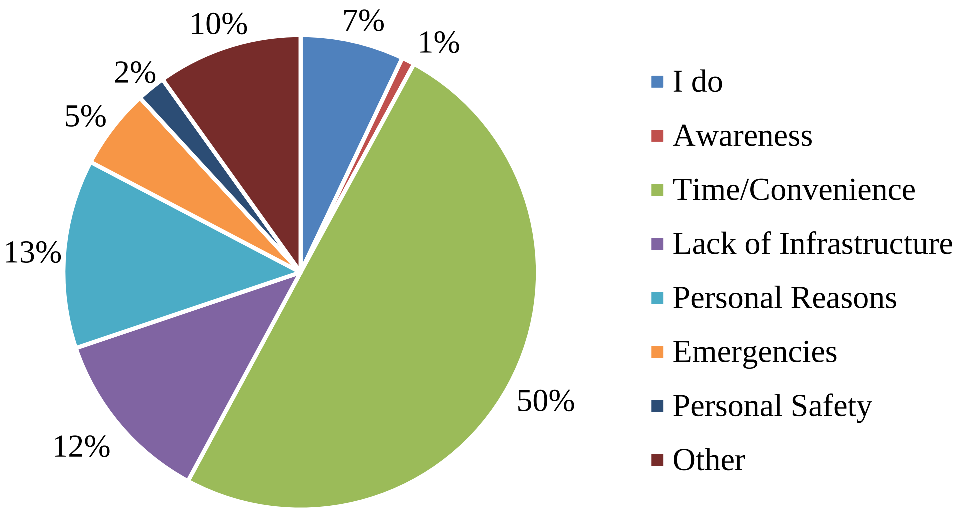

Figure 14. Overall Survey Response to "if you do not primarily use alternative transportation (bike, walk, mass transit, etc.) to commute to campus, what is the main reason?"

The overall trends for not using alternative transportation were similar among the student, staff, and faculty. In all demographics, respondents cited that time/convenience was their main reason for driving their personal vehicle on the commute. This explanation was significant for student commuters being true for 66% responders, while for faculty and staff time/convenience was cited for 36% and 37% of the population respectively. For faculty, the other major contributors for using personal vehicles was lack of infrastructure (23%) and personal reasons (18%). Staff cited that personal reasons was their cause for not using alternative transportation for 24% respondents, while only 10% placed responsibility on lack of infrastructure.

The survey also asked survey respondents “how much impact, if any, do you think your commuting habits have on Clemson University's "carbon footprint" on the environment?” This question was then followed by another question asking respondents “how important is it that Clemson University reduces its carbon footprint or impact on the environment?” The overall results are displayed in Figure 15 and Figure 16. There was some discrepancy between the rated impact of commuting and the importance of reducing one’s carbon footprint. Overall, 33% of respondents believed that commuting impacts were very significant or significant. However, 64% stated that reducing their footprint is very important or important.

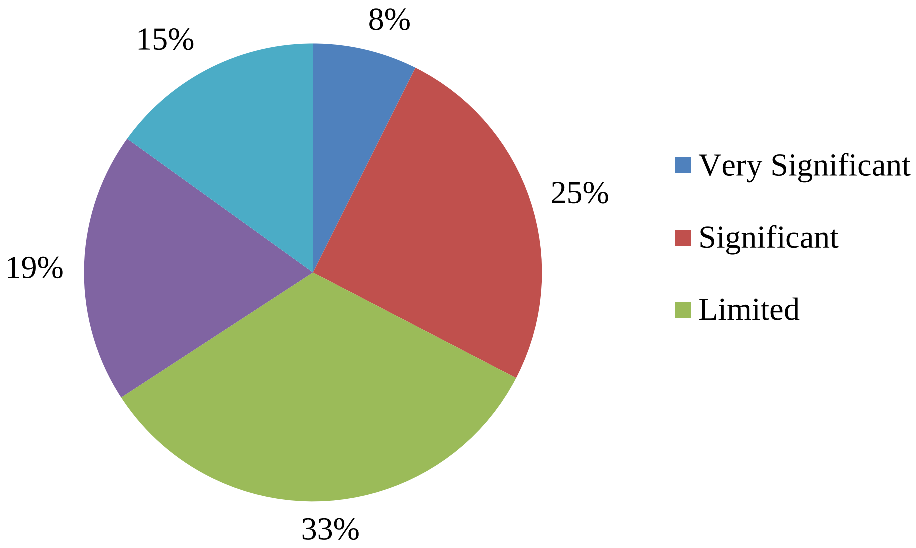

Figure 15. Survey Responses to "how much impact, if any, do you think your commuting habits have on Clemson University's "carbon footprint" on the environment?"

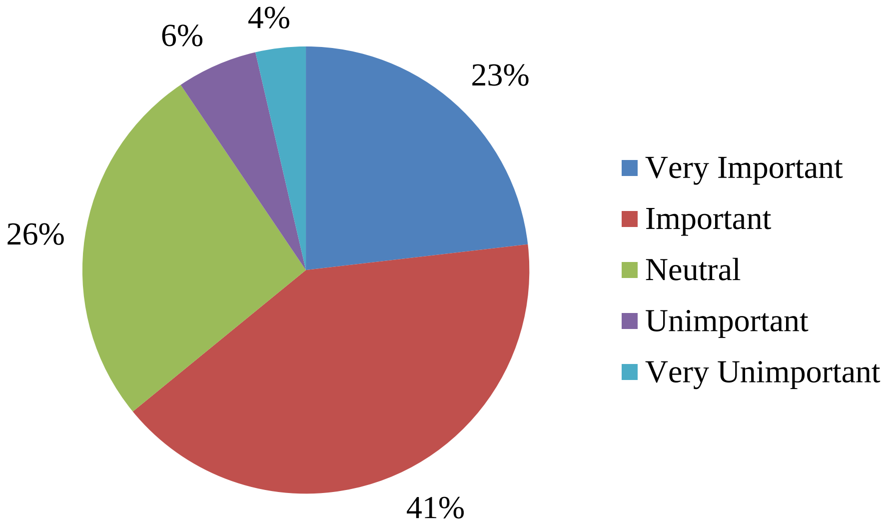

Figure 16. Survey Responses to "how important is it that Clemson University reduces its carbon footprint or impact on the environment?"

4.4.3.4 Conclusions and Recommendations

Overall, using the median commuting distance with the other calculations found that that 16,738 metric tons of CO_2 were produced from commuting. Of this 5,673 metric tons CO_2 were attributed to student commuters, 1,964 to faculty, 8,908 to staff, 76 to LEV, 74 to motorcycles, and 43 to scooters/mopeds. Staff were found to have the highest associated emissions because they had the highest distance commuted (12 miles compared to 7 for faculty and 4 for students). They also had the highest average for days per week commuted, and it must also be considered that faculty and staff commute year-round.

There were several sources of uncertainty in the data that may lead to error in the final calculations. The average mpg found from the DOE applied average fuel economics for city driving, which may not be fully accurate since some commuter’s habits may be more representative of highway driving. This consideration would lead one to think that the mpg calculated may be a higher estimation. Also, both student and employee vehicles records contained some incomplete records for which the mpg could not be factored in to the total. Furthermore, employee vehicle registration was conglomerated between faculty and staff so there was a shared average mpg for this demographic that was applied to their separate commuting distance (from survey).

There is also uncertainty as the survey regarding distance traveled, weekly frequency, and mode of transportation used. These statistics were applied to all the registered vehicles, however individual driving patterns vary and influence emissions based on the vehicle driven. There is also a possibility that respondents were not fully honest in their survey about their driving habits. Also, driving patterns may have changed from the time respondents took the survey since changing schedules each semester influences driving habits. Some students could be making multiple trips to campus per day, and this was not indicated on the survey.

There are additional sources of commuting emissions that may not have been accounted for. This analysis did not account for students that might commute without a permit and park downtown, or commuters that might be dropped off on campus by someone with an unregistered vehicle. Another further consideration is that during peak hours some students drive around campus for extended periods of time searching for a place to park.

Future studies could focus on obtaining more detailed data for commuting to more accurately estimate these emissions, which are significant to the entire campus's footprint. Overall, emissions could be reduced if commuters were encouraged to carpool, use more fuel-efficient vehicles, or use alternative sources of transportation such as biking, walking, or CATBUS. Based on the calculations, if (standard) personal vehicle commuting was reduced by 2,000 student permits, the associated CO_2 emissions would decrease by nearly 1,030 metric tons of CO_2 per year. Since many apartment complexes are located within walking or biking distance to campus, it is feasible that the number of parking permits could be reduced if alternative transportation was convenient for students. However, there seems to be some disconnect between the perceived impact of commuting habits and the concern for Clemson reducing its carbon footprint as seen in the survey results. If a large amount of the population feels that reducing Clemson’s carbon footprint is important, then additional education about the cumulative impact of commuting may promote a change in behavior.

4.4.4 Clemson Area Transit

4.4.4.1 Background

Clemson Area Transit Bus System (CATBUS) is a public transit system that is fare free, provided through federal, state, and local assistance. This alternative mode of commuter transportation has routes running to Seneca, Pendleton, Central, and around Clemson. CATBUS also operates three campus routes that run loops on the east and west sides of campus to transport students from academic buildings to parking lots. While CATBUS is currently transitioning to have an all-electric bus fleet to reduce tailpipe emissions, the majority of its buses are currently fueled by diesel. Most of ridership around the community is for student commuting, therefore the buses in this transit system are considered to produce Scope 3 emissions since they are an indirect consequence of the activities of the University.

4.4.4.2 Data

Data was obtained from Clemson Area Transit regarding the CATBUS system. Data included all local bus routes for 2015 and 2016. This analysis examined the emissions associated with the operation of the buses, but not the operation of its facilities. The Seneca bus route is an entirely electric-powered bus fleet, so for this route the total electricity consumption was recorded. The rest of the routes use diesel fuel, so the total monthly fuel usage and mileage for the fleet was obtained.

Electric Bus Fleet

The total electricity consumption for the Seneca electric bus fleet was recorded monthly. The transit supervisor for CATBUS provided data for the month of December 2016. In this month, the electric fleet recorded 12,440 miles driven, 280 charge cycles, 25,274 kWh consumption, and an average charge cycle lasting 7 minutes and 39 seconds (which includes 1 minute for docking).

Data Quality

Table 4-37. Data Quality for CATBUS Electric Bus Fleet

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements by CATBUS
Completeness	3	Representative data from an adequate number of buses, but for a short period (one month)
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from enterprises, processes, and materials under study

Diesel Bus Fleet

Clemson also has a diesel bus fleet that services intercampus routes, and commuting routes around Pendleton, Central, and Clemson. CATBUS provided annual reports of the fuel consumption and mileage for 2015. The annual fuel consumption for these routes totaled 413,055 miles and used 109,258 gallons of diesel fuel.

Data Quality

Table 4-38. Data Quality for CATBUS Diesel Bus Fleet

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements by CATBUS
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from enterprises, processes, and materials under study

Diesel Emissions

The U.S. Energy Information Administration has determined that 22.40 lbs CO_2 are produced from the combustion of a gallon diesel fuel [76]. This factor is an average published in 2016 which is based on home heating and diesel fuel practices.

Data Quality

Table 4-39. Data Quality for Diesel Combustion Emission Factor

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements by EIA
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	3	Data pertains to similar combustion conditions, but not specific process
Further technological correlation	3	Data from processes and materials under study, but from emissions factor gathered from different enterprises and technology

4.4.4.3 Methods

Electricity

According to the transit supervisor for CATBUS, the CATBUS facility in Clemson is outfitted with 210 solar panels on its roof. Most these panels are solar PV, which cover 4,000 square feet of the roof and generate 66,100 kWh of electricity annually. There are also 320 square feet of solar thermal panels that heat water for the bus washing station, and in doing so offset the equivalent of 18,250 kWh of electricity that would have been used annually. For this analysis, the electricity consumption used by the CATBUS facilities was not obtained, although if it had been, the electricity offset from the solar PV panels would been applied to the entire operation. Electric buses charge at the CATBUS facility in Seneca, however to acknowledge CATBUS's sustainability efforts, it was assumed that the electricity generation from the solar PV panels would be applied to offset the electric fleet. This offset about 22% of the annual electricity consumed for charging, then it was then assumed that the remaining electricity was provided by Duke Energy Carolinas, LLC. For this, it was estimated that the month of December was representative of the year, and so the annual electricity consumption for charging would be 303,288 kWh. By subtracting the electricity offset by the solar PV panels, this leaves 237,188 kWh annual requirement from Duke Energy for charging. Since CATBUS is in the same region as Clemson University, the electricity mix and emission calculation methods are the same as described in section 4.3.1 for electricity, and the methods described in Section 4.4 for transmission and distribution losses are incorporated. Accounting for grid losses, the electricity needed annually from Duke Energy to charge the electric buses is approximately 252 MWh, which has an associated 82 metric tons CO_2-e in emissions.

Diesel Bus Fleet

The annual fuel consumption for 2015 totaled 413,055 miles and required 109,258 gallons of diesel fuel. The emissions can be calculated assuming 22.40 lbs CO_2 are produced from a gallon diesel fuel [76] and equation 16 below.

$$(f)(EF) \tag{16}$$

Here, f is the total fuel used over a year, and EF is the emission factor for the fuel. From this, it is determined that 1,110 metric tons of CO_2 are produced from the diesel combustion in the CATBUS fleet.

Ridership

According to CATBUS, there is no system to track which riders are students since there is not a need for a 'card swipe' to ride the buses. However, the on-campus routes such as the orange, purple and blue routes are known to have 99% student ridership. This was the only ridership statistic that could be provided, as studies to estimate ridership on the Red, Pendleton and Seneca routes are too costly. For this study, it will be assumed that ridership on the Red, Pendleton and Seneca will also be 99% student ridership. This is most likely an overestimation, as these routes are more likely to have non-student riders since operate outside of Clemson's campus. Since the CATBUS routes are geared towards student commuting, we will use the 99% student ridership to allocate 99% of the emissions from this public transit to Clemson. Therefore, applying this percentage it is determined that Clemson is attributed about 81 metric tons CO_2 in emissions from the electric fleet, and 1,099 metric tons of CO_2 are produced from the combustion in the diesel fleet.

4.4.4.4 Conclusions and Recommendations

There was some uncertainty in the data received from CATBUS. The estimation for annual energy use for the electric buses may not be representative as it is only based on data for one month. Also, the average emissions from diesel combustion were calculated using EIA's combustion factor, which in reality may vary since it is based on an average of diesel combustion manners.

When CATBUS transitions fully to an electric bus fleet, then their GHG emissions will reduce dramatically. With the given data for the electric bus fleet, the average bus achieved 2.03 miles/kWh of charge. Applying this statistic to the total mileage of the diesel fleet in 2015 (and accounting for grid losses) it was found that charging this fleet electrically would require about 839 MWh annually. This rough estimation would result in 271 metric tons CO_2-e annually from the electricity provided by Duke Energy, compared to the 1,110 metric tons of CO_2 found from the diesel combustion. While this entity outside the control of Clemson, efforts to install solar PV panels could further reduce their emissions once their fleet is entirely electric.

In general, if students were to commute via CATBUS rather than their personal vehicles, Clemson's associated emissions would decrease. Therefore, efforts to make CATBUS more convenient for students may be desirable. Currently, reports from CATBUS operators disclosed that bus pickups may become more frequent, with buses picking up students from stops on a 15 minute intervals rather than 30 minute intervals. While this may increase the distance traveled by buses, future studies could compare the tradeoff between more frequent bus schedules and decreased driving by students.

4.4.5 University Related Travel

4.4.5.1 Background

Clemson University administrators, faculty, and staff frequently travel for administrative purposes, to attend conferences and meetings, conduct field work, visit collaborators, and to present their research. This travel enables campus functioning, along with high-level research and collaboration, integral to being an R1 Research University. Students also travel for similar purposes. Traveling involves transportation, accommodations, and food. In this analysis, emissions from food and accommodations associated with travel will be deemed negligible such that transportation will be the most significant source of GHG emissions associate with travel. The most common forms of travel are commercial flights or driving to the desired destination. Aircraft jet engines, like many other vehicle engines, produce CO_2, H_2O, NOx, CO, SOx, VOCs, particulates, and other trace compounds [78]. Since this travel results in indirect greenhouse emissions which are the outcome from activities that sustain university operations, these emissions are considered Scope 3 emissions.

4.4.5.2 Data

Data was obtained from Clemson Facilities recording the travel expense for students and faculty. Faculty expenses were categorized by costs from driving, commercial air fare, university aircraft, charter flights, and private aircraft. This data for faculty was further broken down in to in-state, out-of-state, and foreign travel costs. However, student travel costs were not classified by how they were incurred. Due to its monetary nature, the specifics of this data will not be disclosed.

Data Quality

Table 4-40. Data Quality for University Travel Expenses

Indicator Score	Score	Explanation
Reliability	1	Verified data based on receipts of travel
Completeness	2	Representative data for travel paid for by University over the course of a year. University travel paid by other sources are not included
Temporal correlation	1	Data are for 2014
Geographical correlation	1	Data pertains to travel from University employees and students
Further technological correlation	3	Data pertains to processes under study, but from exact mode and distance traveled is not given

4.4.5.3 Methods

Where possible, a bottom-up process has been used to conduct the LCAs. However, the charter flights, commercial flights, and driving recorded only has data in monetary terms. From the driving data, the mileage reimbursement charge was used with university commuter fleet fuel economy to determine distances driven. Then, for flight data a top-down approach was applied. Expenses incurred by university employees was recorded in more detail than for students, so student travel required many assumptions as to how money was spent.

Employee Driving

Clemson has a known mileage reimbursement charge, so the mileage driven for University related activities could be determined by the total charges. Examination of the data and the expenses described indicated that the data was purely for mileage reimbursement and not rental car use or other costs. The total costs reimbursed for in state, out of state, and foreign travel were summed. In-state and out-of-state travel included direct travel to locations of interest, and travel to airports for travel. Costs incurred related to foreign travel was exclusively driving to and from airports. For this analysis, it was assumed that the vehicles driven were personal vehicles and operating with gasoline. With the equation below, the carbon emissions from fuel usage were determined.

$$\text{Total emissions from driving} = \frac{(\mathrm{C})}{(\mathrm{r})(\mathrm{m})}(\mathrm{EF}) \tag{17}$$

Here, *C* is the total cost reimbursed for driving mileage, *m* is the average fuel economy of the vehicles, *r* is the reimbursement price per mile, and *EF* is the emissions factor for the combustion of gasoline. The average reimbursement Clemson paid for driving mileage in 2014 was $0.54 per mile. This was used in conjunction with the average fuel economy for vehicles registered by faculty and staff (19.44 mpg as described in Section 4.4 and shown in Table 4-34). The emissions factor from the EIA is 19.60 pounds CO_2 per a gallon of gasoline [76]. From this, it was determined that 174,023 gallons of gasoline were consumed over 2014 for University travel by personal vehicles, using the methods in equation 17 from Section 4.4.4 this resulted in 1,550 metric tons of CO_2 to be emitted.

Employee Commercial and Charter Flights

Since the cost of commercial and charter flights was recorded, a top-down method was needed to estimate the GHG emissions associated with this economic value. The Carnegie Mellon Economic Input-Output Life Cycle Assessment (EIO-LCA) tool was used to estimate the emissions resulting from spending in the air transportation sector of the U.S. economy. This model uses aggregated sector-level data to quantify the environmental impacts that can directly attributed to a specific economic sector. For this assessment, the 2002 U.S. purchaser price model was used. This models the U.S economy in 428 sectors based on the 2002 commodity by industry model of the U.S. Bureau of Economic Analysis [96]. The model also links the inputs and output transactions for sectors that support the production of each other. In this case, the sector evaluated was air transportation and faculty spent $2,681,383 on commercial, charter, and private flights in state, out of state and internationally. Since an internationally based input-output model was not offered, the foreign travel was assumed to impacts consistent with domestic air transportation. Overall, the associated GHGs were 5,320 metric tons CO_2-e. Of this, 4,120 metric tons CO_2-e are directly attributed to the air transportation sector, the additional emissions stem from sectors such as oil and gas extraction, petroleum refineries, and power generation and supply.

Student Travel

Overall, $4,951,073 were expensed for student travel with descriptions ranging from hotels, driving, and flights. Mileage, flights, accommodations, and per diem had to be estimated based on the cost of an average trip. Based on typical conference travel, it was assumed that the average trip would be three days, consisting of driving to the airport, a flight, accommodations, and per diem. Three days was assumed as the average length of a conference. The per diem was assumed to be $32 per day, as this is Clemson's out of state per diem rate. The average cost of a hotel room domestically is $131 [97] and this was accounted for over 3 days. This cost was assumed to be comparable to international hotel rooms, though average prices for hotels ranges by country. Furthermore, there is the possibility that rooms are shared between students, reducing the cost per trip, though there is no information given to support this. The emissions associated with the food and accommodations won't be included in this analysis, rather it will focus on the transportation. The average driving expenses for faculty foreign travel was \$77.35. Presumably, this cost was travel to airports, so it was assumed that student travel to airports would be comparable in cost. The Bureau of Transportation provides yearly statistics on the average flight fares based on the total ticket value [98]. The statistics for 2014 were analyzed for three common nearby airports; Atlanta, GA, Charlotte, NC, and Greenville/Spartanburg, SC. The average fare between these three airports in 2014 was \$423.57. Per the National Travel and Tourism Office of the U.S. Department of Commerce the average international airfare for a U.S. traveler was \$1,347 [99]. Finding the percentage that each of these costs would be to the total expenses, the amounts for each category could be calculated. Using the domestic airfare cost, the emissions associated with flying were 3,910 metric tons CO_2-e, while driving produced 328 metric tons CO_2-e. For international airfare, the emissions associated were 6,440 metric tons CO_2-e from flying, and 170 metric tons CO_2-e from driving. These ranges area shown in Figure 17, and the averages for the range are 249 metric tons CO_2-e for driving and 5,175 metric tons CO_2-e for air travel.

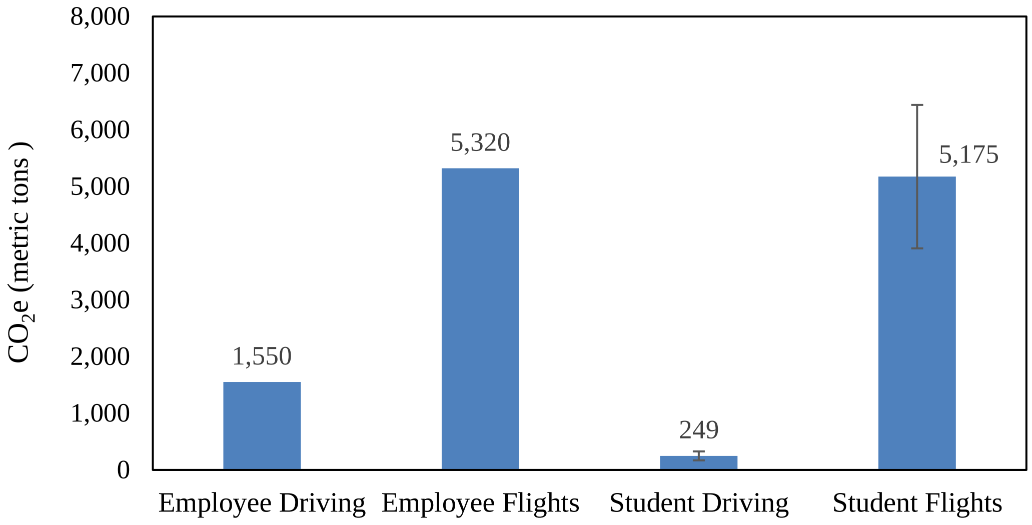

Figure 17. University Related Travel Emissions

4.4.5.4 Conclusions and Recommendations

Emissions from university related travel were 5,320 metric tons CO_2-e for employee air travel, and 1,150 metric tons CO_2-e for employee driving. For students, the average of the ranges found were 249 metric tons CO_2-e for driving and 5,175 metric tons CO_2-e for air travel. Therefore, overall 12,294 metric tons CO_2-e were attributed to university related travel.

Since this data was given in the term of monetary flows, finding the emissions associated with these activities used methods that included varying life cycle phases. The driving was estimated using mileage rates and the EIA combustion emissions factor. Therefore, this only included the use phase in the emissions accounting. However, the EIO-LCA tool used for flights considers use and upstream materials and energy resources throughout the supply chain in its emissions accounting. This tool also considers the air transportation sector as a whole for its calculations, while in this analysis the travel expenses were primarily charter and commercial flights, whose emissions may differ from the entire sector. Another source of uncertainty was within the student travel records, which were aggregated and not appropriately described. Assumptions regarding the travel expenses in this category led to uncertainty in the final calculations. The main assumption was that the costs incurred were related to travel for a conference. In these calculations, average costs were used for typical expenses, however the average value may not be representative and other expenses may have been incurred that were not accounted for. While conference travel was assumed, it is also likely that some of the student travel costs were not attending conferences, or if they were it may have been for a different period of time than the assumed 3 days. Overall, using cost of travel for air transportation leaves room for uncertainty as cost may not be accurately indicative of distance travels, and associated GHG emissions. For example, a flight from Atlanta, GA to Miami, FL may have the same ticket price as a flight from Atlanta, GA to San Francisco, CA. However, the flight to San Francisco would have higher emissions associated with farther distance traveled. In the future, the university may want to obtain more detailed travel information from the employees and students they fund to travel so that their associated emissions can be estimated more accurately.

Some inherent limitations to the method applied are that ticket prices of flying fluctuate, and air transportation emissions may have changed over time. The data used in this IO model is from 2002, and is representative of this year. This model was deemed to be appropriate to use with 2014 data since the average age of the worldwide air transport jet fleet has been between 10 and 12 years old, and the growing population of airplanes many have aged more than 20 years [100]. Another consideration with this data are that the EIO-LCA model is based on U.S. economic sectors, while some university related flights were international.

Overall, university related travel is a significant source of emissions as it involves transportation by vehicles and airplanes; both dependent on fossil fuels. Travel could be reduced by setting up carpools for travel, use of videoconferencing, and traveling by train rather than plane, especially back and forth to Washington DC, which has lower associated emissions.

4.4.6 Paper Usage

4.4.6.1 Background

Paper products serve many purposes for Clemson University. Copy paper is used throughout campus to print out materials for classes, research, and administrative documents. Clemson also uses a great quantity of paper towels and bathroom tissue for hygienic purposes. The printing on office paper will use electricity which was accounted for in Scope 2 emissions. The production of paper products is an upstream activity that has GHG emissions associated with Clemson's need for these products. Since these emissions are from an entity not controlled by Clemson, they are a Scope 3 emission source.

4.4.6.2 Data

Paper Usage

Data for copy paper used was obtained from Clemson University Facilities. The majority of Clemson's copy paper usage is standard 8.5 by 11-inch white card stock. This makes up 78% of the overall paper use, with 20% being recycled multipurpose paper, and the remaining 2% consisting of laser paper, inkjet paper, and fine business paper. Annually, the University uses about 336 reams of paper for its printing needs.

Data regarding paper towels and bath tissue bought came from the University's current contractor. Clemson has varying paper towel dispenser, and accordingly must use paper towels that match the containers. The brown and white multi-fold towels and paper towel rolls varieties are seen in Table 4-41.

Table 4-41. Clemson University Paper Usage

Product Description	Product Details	Annual Usage	Units
Printing Paper	Colored Copy Paper	263	reams
	Multipurpose Paper	66	reams
	Laser Paper	5	reams
	Inkjet Paper	2	reams
	Fine Business Paper	1	reams
Paper Towels	Brown Multi-fold Towels	5,232	packs
	Enmotion Brown Towels	7,554	rolls
	White Roll Towels, 2-Ply	1,290	rolls
	Envision Brown Roll Paper Towel	216	rolls
	Single Fold Towels, White	192	packs
	Enmotion White Roll Towel	138	rolls
Bathroom Tissue	2-Ply Coreless Bath Tissue, White	35,604	rolls
	Angel Soft Toilet Tissue	8,960	rolls

Data Quality

Table 4-42. Data Quality for Paper Usage

Indicator Score	Score	Explanation
Reliability	1	Verified data based on purchases by University
Completeness	1	Representative data from a sufficient sample of sites over an adequate period of one year
Temporal correlation	1	Office paper data are for 2014, while paper towels and bathroom tissue are less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from enterprises, processes, and materials under study

Various methods were considered for this analysis. Data from the Ecoinvent database related to pulp and paper making processes was specific to Europe rather than North America, and not did not have information to model the manufacturing of the individual product production. Therefore, more complete surrogate data from other LCAs was adopted for this assessment.

Office Paper

The American Forest & Paper Association and the Forest Products Association of Canada conducted a LCA of varying grades of printing and writing paper in North

America. One of the LCAs analyzed a ream of office paper made of uncoated freesheet. This study used data from 72 mills in the U.S. and Canada, making it the most comprehensive study conducted for North American paper [101]. In this study, one ream of paper was responsible for approximately 2.91 kg CO_2-e from cradle-to-gate [101]. This value fell within the range of other literature values. One cradle-to-costumer study following ISO 14040/14044 standards found that one A4 sheet of office paper produced 4.64 g CO_2-e per sheet, translating to 2.32 kg CO_2-e per ream of paper [102]. Another European study approximated climate change gas emissions from a typical cut-size paper to find areas where emissions could be reduced. This study estimated that 1.5 metric tons CO_2-e were produced per ton of paper from forestry, pulping, paper-making, and printing, which is equivalent to 3.75 kg CO_2-e per ream of paper [103]. Since this study was on a per ton basis, its significant figures for each activity was only one decimal place (e.g. 0.3 tons CO_2-e/ton paper from pulping) which may have overestimated the emissions on a per ream basis. Therefore, the middle lifecycle emissions value from the American Forest & Paper Association study was used and was preferred as it was specific to paper produced in North America.

Washroom Towels

In 2007, Kimberly-Clark Corporation contracted Environmental Resource Management to conduct LCAs on its various tissue products distributed in North America and Europe. These LCAs were performed for three scenarios; (A) products with a larger share of virgin fibers; (B) products containing 100% recycled fibers or a significant percentage of recycled fibers, and (BB) products containing recycled fibers where the waste paper used to produce recycled fibers doesn't have a significant environmental burden [104]. The paper towels used by Clemson meet the Green Seal Standard and EPA Comprehensive Procurement Guidelines, so they contain at least 50% post-consumer recycled fibers. Therefore, scenario B (for North America) was chosen as it was assumed the products contain a significant percentage of recycled fibers. The functional units for the chosen products are displayed in Table 4-43. The assessment performed for Kimberly-Clark included all phases of the tissue product life cycles. This study was chosen over others as impacts were comprehensively broken down by life cycle phase. Further, this study was conducted following the ISO 14040 guidelines and underwent a critical review by an external review panel [104]. Extracting the cradle-to-gate impacts, the lifecycle included energy use, sorting of recycled paper, and processes up until manufacturing produced 550 kg CO_2-e for a 72,000 linear feet of 8-inch wide hard roll towel. These limited life cycle phases also keep boundaries consistent with other Scope 3 emissions as disposal is not included.

Emissions values from other studies were compared to this factor for consistency. One comparative LCA study found that 9.4 g CO_2-e was produced per two sheets of white paper washroom towels with 100% recycled content roll, and 873 sheets per a 800 foot roll [105]. Assuming the width of the roll is 8-inches, this would translate to about 369 kg CO_2-e for the household functional unit that the Kimberly-Clark study used. Another cradle-to-grave study from the Massachusetts Institute of Technology found that 14.8 g CO_2-e were produced for 100% recycled paper towels had a reference flow of 2 towels, plus its packaging and dispenser, waste bin, and bin liner [106]. This report didn't specific the dimensions of the sheets, but assuming the same sheet quantity and dimensions as the prior study, then this would equate to 580 kg CO_2-e for the equivalent functional unit in the Kimberly-Clark study. However, since this study did not provide the data for separate phases, or just the paper towel alone, so it was not considered for use in this study. Overall, the Kimberly-Clark study was preferred as it was more comprehensive.

Bathroom Tissue

For consistency, another LCA performed by Kimberly-Clark was used for bathroom tissue. This LCA used similar scenarios in its assessment. Further investigation in the product description uncovered that the coreless toilet paper meets EPA Comprehensive Procurement Guidelines of containing at least 25% post-consumer recycled fibers. The product also meets the Green Seal Standard, which is dependent on chlorine free processing, energy and water efficiency, and content of 100% recovered material, with a minimum of 25% post-consumer material. The Angel Soft bath tissue also contains at least 20% post-consumer recycled fiber and meets or exceeds EPA Comprehensive Procurement Guidelines. Since the bathroom tissue used by Clemson uses a significant percentage of recycled fibers, scenario B was chosen. For this scenario, the life cycle processes examined were the cradle-to-gate impacts, which included energy use, sorting of recycled paper, and processes up until manufacturing. This produced 55.1 kg CO_2-e for a household’s use of bathroom tissue.

Table 4-43. Paper Product LCA Functional Units

	Functional Unit	Reference Flow
North American Office Paper	The production in the U.S. and Canada, delivery to an average U.S. customer, use and final disposal or recovery of one standard ream of office paper	One ream of office paper (500 sheets)
North American Washroom Towel	One year of hand drying for 50 workers in a typical U.S. washroom	72,000 linear feet of 8-inch wide hard roll towel
North American Bathroom Tissue	One year of bathroom use for a large U.S. household	40,000 sheets regular/economy bathroom tissue

Data Quality

Table 4-44. Data Quality for Paper Products LCAs

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a several paper manufacturers to even out normal fluctuations
Temporal correlation	3	Less than 10 years difference
Geographical correlation	5	Studies are pertinent to paper products produced in North America, exact areas and production conditions are unknown
Further technological correlation	2	Data from processes and materials under study but from different enterprises

4.4.6.3 Methods

Office Paper

The American Forest & Paper Association study was a cradle-to-grave LCA, so it looked at all phases in the life cycle of office paper. However, to be consistent with the boundaries for other Scope 3 emissions this LCA had to be limited to include fiber procurement, production, and transport, and eliminate the end of life phase. In this study, one ream of office paper was responsible for approximately 2.91 kg CO_2-e [101]. Here it is assumed that all paper used in Clemson is comparable to a ream of office paper made of uncoated freesheet as used in the study.

$$Emissions = (S_{FU})(U) \tag{18}$$

Here, SFU is the functional unit of the study for a specific paper product (e.g. 2.91 kg CO2-e/ream office paper), and U is Clemson's annual usage of the specific paper product. From this, it was found that about 1 metric ton of CO2-e was produced from office paper used by Clemson University.

Washroom Towels

The functional unit for the Kimberly-Clark studies were scaled to serve a household over a year [104]. For the varying packs of paper towels, the length and widths of the rolls or folding towels were given in the product descriptions. The widths of the paper towels were assumed to be the same as this was not given in the product description. From this, a total square area of paper towels was calculated, assuming the impacts from creating a square foot of paper towels was comparable for the various types of towels. Overall, it was found that Clemson University uses 6,117,567 square feet of paper towels. The Kimberly-Clark LCA for washroom towels determined that 72,000 linear feet of 8-inch wide hard roll towel produced 550 kg CO_2 equivalent in emissions. Using equation 18, it was found that washroom towels produce 70 metric tons of CO_2 equivalent.

Bathroom Tissue

For the bathroom tissue, the amount of cases purchased was known, as was the number of rolls per case. From this is was assumed that the individual sheets on each roll were the same standard dimensions as in the Kimberly-Clark study, since they were not known. Then, it was calculated that Clemson uses 57,438,000 sheets of bathroom tissue annually. The Kimberly-Clark LCA found that 40,000 sheets regular/economy bathroom tissue produced 55.1 kg CO_2-e [104]. Applying Using equation 18, it was found that bathroom tissue account for 79 metric tons of CO_2-e.

4.4.6.4 Conclusion and Recommendations

Overall, the total emissions associated with Clemson's purchased paper usage was 150 metric tons. There was uncertainty in using surrogate data from LCA studies, as the data used in these studies may not be fully representative of the products used by Clemson. There was also uncertainty in comparing the products used by Clemson to the functional unit described in the LCA studies since the sizes of the products were of different dimensions. In all cases length and width were given, so it was assumed that area of paper towels used corresponded with GHG emissions. However, the thickness of the paper products were not given, therefore there is uncertainty related to overall mass of functional units compared.

To reduce these emissions the university could promote use less office paper use by promoting printing on both sides of paper, and electronic distribution of course materials, homework, and announcements. Another recommendation is that bathrooms have bulletins to encourage users to limit the amount of paper towels used each time they wash their hands and having paper towel dispenser that have an automatic stop. Future studies may also analyze if it would lower the impact to install electric hand dryers to replace paper towels.

4.4.7 Waste and Recycling Transportation

4.4.7.1 Background

Clemson runs a Recycling Services site on campus at Kite Hill, located on the eastern corner of Clemson’s campus (labeled (1) in Figure 18). Kite Hill Recycling Center has a drop off area that will separate cardboard, scrap metal, plastic, paper glass, toner, electronics, batteries, oil, and yard waste. This recycling center is considered a multi re-use facility since it separates and prepares the recyclable materials for end-user manufacturers. Recycling from the center is loaded onto a truck and then taken to American Recycling Center outside of Asheville, NC. According to Facilities, in 2014-2015 Clemson University produced 1,348 tons of solid waste. Of this, the 276 tons were cardboard, 355 tons were paper, 263 tons were compost, 119 tons were scrap metal, and 127 tons of waste were from the home football games alone. This waste had to be transported to waste and recycling facilities to be processed. This is organized by Clemson’s recycling services, and is considered a Scope 3 emission.

Figure 18. Location of Kite Hill Recycling Center on Clemson University Campus

4.4.7.2 Data

According to the Clemson Recycling Services operator, recycling is brought to the American Recycling Center to Asheville, NC about once per week on a refuse truck. Meanwhile, trash goes to a transfer station in Pendleton, SC five days per week during the Fall and Spring, and 3 days per week during the Summer on the same type of truck. The waste station in Anderson is 16.7 miles away while the fastest route to the American Recycling Center in Asheville, NC is 83.3 miles away.

Data Quality

Table 4-45. Data Quality for Waste and Recycling Transportation

Indicator Score	Score	Explanation
Reliability	2	Verified data partly based on weekly pickup assumptions
Completeness	2	Data are an assumed waste and recycling schedule
Temporal correlation	1	Data are from 2016-2017 school year, which is less than three years of difference to year of study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data are from enterprises under study

Fuel Economy

Refuse trucks have low fuel economy since they are heavy and stop repeatedly when driven. According to the Department of Energy, the average fuel economy of a refuse truck is 2.53 miles per gallon [107].

Data Quality

Table 4-46. Data Quality for Fuel Economy of Refuse Trucks

Indicator Score	Score	Explanation
Reliability	1	Data based on national measurements
Completeness	1	Data are collected by the Federal Highway Administration and is representative of national trends for refuse vehicles
Temporal correlation	1	Data are from 2015, which is less than three years of difference to year of study
Geographical correlation	3	Data represents a national average
Further technological correlation	2	Data are from process under study, but is not specific to the model of the refuse truck

Emission Factors

According to the EIA, 19.60 lbs CO_2/gallon gasoline are produced from combustion [76]. The data quality for this emission figure can be seen in Table 4-10 of Section 4.2.3.

4.4.7.3 Methods

Emissions

Assuming the time frame from the Fall and Spring academic sessions, which is about 39 weeks, a refuse truck picks up trash from Clemson’s campus 5 times per week.

During the 13 weeks of summer the refuse truck only comes 3 times a week. This means that the refuse truck takes 170 trips to Anderson during the school year, and 39 trips during the Summer. Meanwhile recycling is taken to Ashville 52 times over the year. With the total trips and distance driven to the facilitates, the total distance traveled can be found, which was 7,822 miles per year. Using the following equation, the GHG emissions associated with combustion were determined.

$$(\mathrm{d})(\mathrm{f})(\mathrm{EF}) \tag{19}$$

Here, *d* is the total annual distance traveled by the refuse trucks, *f* is the average fuel economy, and *EF* is the emissions factor for gasoline combustion. Using the previously used average emissions factors of 19.60 lbs CO_2/gallon gasoline from the EIA [76], it was found that about 27 metric tons of CO_2 were produced from the refuse truck.

4.4.7.4 Conclusion and Recommendations

Overall, 27 metric tons of CO_2 are associated with waste and recycling transportation. There was uncertainty in these calculations as they were based on estimations for an average refuse truck. Future studies should seek more precise data regarding pickup schedules and the type of refuse trucks used.

One method to continue decreasing waste is to change student behavior. For example, in 2012 a printing limit was put into place for students with their student ID cards. From this and the increased use of online materials, paper use has decreased significantly across campus. Programs could be enacted to encourage students to produce less waste. This could even spread to the campus food venues by encouraging them to decrease use of bags and wrappers where possible, and choosing to sell food in recyclable or reusable containers. Another recommendation to increase recycling and decrease landfill waste is educational signage and proper recycling bins dispersed around campus, including outside. Regular plastic, such as packaging or other food containers can be recycled in along with plastic bottles, however this is not specified on the signs. On the same note, items like paper cups cannot be recycled because they have a waxy coating on the inside. Better educational signs may be able to improve recycling practices. An option to compost food waste outside of dining halls may also reduce waste sent to landfills. Then, using a closer waste and recycling facility could reduce the emissions associated with transportation.

4.4.8 Wastewater Treatment Chemicals

4.4.8.1 Background

Section 4.2.6 described the emissions from the Clemson WWTP operations in regards to GHGs emitted from operation. However, there are also several significant quantities of chemicals used to treat the wastewater which can be considered upstream emissions of the plant. Alum, also known as aluminum sulfate ($Al_2(SO_4)_3$) is the coagulant used during this process. Lime is also used in treatment to adjust the pH and alkalinity during coagulation. After water has been separated from sludge, and remaining sediments and organic matter are removed, the water is then treated with chlorine. Then, before the water is released, it is treated with sulfur dioxide to reduce chlorine.

4.4.8.2 Data

Chemical Use

Data for wastewater treatment was received from the Clemson Wastewater Treatment Plant. Operators at the plant measure the amount of liquid lime and alum in their tanks daily. From this and knowing the tank dimensions, the annual usage could be gathered by tracking the amount added when the tanks were refilled. The plant also receives regular shipments of gaseous chlorine and sulfur dioxide. These are delivered in

150 lb. tanks. Using the records for the shipments received, the annual usage of these chemicals could be found. The results of this investigation are shown in Table 4-47.

Table 4-47. Annual Chemical Use by Clemson WWTP

Chemical	Amount
Lime	14,755 ft^3
Alum	29,178 ft^3
Chlorine	7,050 lbs
Sulfur dioxide	3,600 lbs

Chemical Properties

Data was received on where the chemicals were supplied from, however their production origins were not known. Chlorine and sulfur are fed as a gas, and are not diluted. However, lime and alum are diluted with water. Per the manufacturing specifications provided by the WWTP, the lime had a concentration of 30.0 % by weight and a density of 1.17 – 1.19 g/mL, so the specific gravity was assumed to be the average of the range; 1.18. Meanwhile, the alum mixture had a concentration of 48.5% by weight and a density of 1.335 g/mL.

Data Quality

Table 4-48. Data Quality of Wastewater Treatment Plant

Indicator Score	Score	Explanation
Reliability	1	Verified data based on manufacturing information or regular measurements performed by WWTP operators
Completeness	1	Data are representative over an adequate period to even out normal fluctuations
Temporal correlation	1	Data pertains to 2016-2017, which is less than three years of difference to study
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from enterprises, processes, and materials under study

EcoInvent Database

The ecoinvent database is the largest transparent unit-process LCI database worldwide [108]. This database provides well documented process data for thousands of products in the form of generic background LCI data. Data are regularly updated, and this study used from ecoinvent version 3.1 which was released in July of 2014. This study utilized consistently available, global datasets which represent background supply chains that can be relied on, no matter for which region a dataset is created [108]. This is helpful for areas where data for processes aren’t readily available.

Data Quality

Table 4-49. Data Quality for Ecoinvent Database

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	1	Less than three years of difference to year of study
Geographical correlation	3	Data from area with similar production conditions
Further technological correlation	3	Data from processes and materials under study but from various enterprises and technology

4.4.8.3 Methods

Chemical Quantity

For lime and alum, the amount of chemical within the diluted mixture had to be determined. The WWTP tracks these chemicals in daily volume (already diluted) in their tanks. Since the concentration and specific gravity of the chemical were known, the following equation could be used to determine the mass of the chemical used annually.

$$(CF)(c)(\rho) \qquad (20)$$

CF is the conversion factor for volume in cubic feet to milliliters (mL), *c* is the percent concentration of the chemical in the diluted mixture, and ρ is the density of the chemical. From this, the total mass of chemicals in the mixture were found. Thus, 326,082 lbs. of lime and 1,179,390 lbs. of alum were used.

Ecoinvent

The ecoinvent database was used with openLCA software. Ecoinvent documents the life cycles of processes and products using global datasets to represent average production. The data for chemicals is from cradle to gate, so it includes the manufacturing process with consumption of raw materials, energy, infrastructure, and ends with production. From these processes, it also includes the emissions to air and water. Therefore, for each chemical, the amount manufactured, and transportation from the supplier was added since the production facility was not known. For each chemical, it was assumed transportation by a lorry equipped to carry 3.5-7.5 metric tons. Then, the CML baseline method was used to calculate the impacts, which were given in GWP-100.

The lime product used in wastewater treatment is Cal-flo, sold by Burnett Lime out of Campobello, SC. Further investigation found that this liquid calcium hydroxide solution is an alternative to using dry lime, and wasn't in the ecoinvent database. Therefore, it was excluded from this analysis. Chemtrade in Catawba, SC supplies the

WWTP's alum, which is 138 miles from the WWTP. For this, in ecoinvent aluminum sulfate, without water, in 4.33% aluminum solution state was chosen. For gaseous chlorine production, it was assumed it was manufactured using the membrane cell process, which is the most widely used manufacturing method. Therefore, the manufacturing process chosen was chlor-alkali electrolysis with a membrane cell, and it was assumed the transportation was from the supplier Airgas, which is in Anderson, SC and 20.3 miles away. Sulfur dioxide gas is also supplied by Airgas. Only liquid sulfur dioxide manufacturing was available in the database, so this was used assuming the same mass. The results of the openLCA analysis are displayed in Table 4-50.

Table 4-50. Global Warming Potential of WWTP chemicals

	CO_2-e (metric tons)
Alum	0.00036
Sulfur Dioxide	0.61
Chlorine	0.95
Total	1.57

4.4.8.4 Conclusions and Recommendations

Overall, the total upstream GHG emissions from the chemicals used in wastewater treatment were less than 2 metric tons of CO_2-e. This is a small contribution compared to the other Scope 3 activities. Furthermore, since these chemicals are necessary to treat wastewater before discharge, reducing their use may not be a feasible option. However, one method to reduce their use is to reduce the wastewater volume treated. Wastewater can be reduced using some of the behavioral methods outlined in Section 4.4.8.

4.4.9 Water Treatment

4.4.9.1 Background

Clemson University uses potable water for drinking, washing, and in steam generation. The university receives its water from Anderson Regional Joint Water System. This water treatment plant (WTP) operates in Anderson, SC and utilizes water from Lake Hartwell. The plant has a capacity of 48 million gallons (MG) a day, and it provides water regularly to Anderson, Big Creek, Broadway, Clemson, Hammond, Homeland Park, Pendleton, Powdersville, Sandy Springs, Starr-Iva, West Anderson, and Williamston [109].

4.4.9.2 Data

Data was received from Clemson Faculties regarding the waste used. This data was given per month for 2014 as seen in the table below.

Table 4-51. Clemson University Water Use in 2014

Date	Water (MG)
14-Jul	25.74
14-Aug	25.77
14-Sep	37.71
14-Oct	32.08
14-Nov	26.75
14-Dec	18.58
15-Jan	24.14
15-Feb	21.46
15-Mar	23.94
15-Apr	27.87
15-May	23.33
15-Jun	27.89
Total	**315.25**

Data Quality

Table 4-52. Data Quality for Water Use in 2014

Indicator Score	Score	Explanation
Reliability	1	Data based on measurements
Completeness	1	Data are for all water used by Clemson University
Temporal correlation	1	Data are from 2014
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data are specific to enterprises under study

Emissions Factor

Data could not be obtained from the Anderson Regional Joint Water System to estimate lifecycle emissions. Therefore, surrogate data was used. A LCA study by Denholm& Kulcinski (2004) estimated the GHG impact of potable water production for a large North American city by tracing major energy flows [110]. In this LCA, the phases analyzed were chemical production, transportation of materials, and water treatment plant operation. In operation, electricity is needed in WTP to pump water and chemicals, and in treatment systems. The emissions factor used also included electricity for administrative and laboratory activities, and building maintenance [110]. Overall, it was estimated that 128.13 g CO2-e were emitted per a cubic meter of water treated [110].

Data Quality

Table 4-53. Data Quality for Water Treatment Emissions Factor

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations
Temporal correlation	4	Less than 15 years of difference to year of study
Geographical correlation	3	Data pertains to similar water treatment process water production for a large North American city
Further technological correlation	3	Data from processes and materials under study but from different enterprises and technology

4.4.9.3 Methods

The following equation was used to determine the emissions associated with Clemson's potable water use.

$$(EF)(CF)(W_{Clemson}) \tag{21}$$

Here, *EF* is the emissions factor, *CF* is the conversion factor from m^3 to MG, and $W_{Clemson}$ is the amount of water used by Clemson in a year. This calculation produced the results shown in Table 4-54.

Table 4-54. Emissions Associated with Water Use in 2014

Date	Emissions (metric tons CO_2-e)
14-Jul	12
14-Aug	12
14-Sep	18
14-Oct	16
14-Nov	13
14-Dec	9
15-Jan	12
15-Feb	10
15-Mar	12
15-Apr	14
15-May	11
15-Jun	14
Total	**153**

4.4.9.4 Conclusions and Recommendations

Overall, 153 metric tons CO2-e were estimated to be associated with Clemson's potable water. Some uncertainty arises since this is not plant specific emissions data from Anderson Regional Joint Water System. There is also uncertainty due to changing water demands. For instance, and colder year might require more steam generation, and therefore increase water demands. This will create to higher associated emissions corresponding with increased chemical use, chemical transportation, and energy.

Reducing water consumption can decrease over associated emissions. This can be achieved by installing using more water efficient appliances and plumbing fixtures (e.g. toilets, faucets) or by encouraging more efficient behavior (e.g. shorter showers). Another method to reduce water consumption is to implement greywater recycling practices, or by collecting rainwater for watering activities.

4.5 Campus Solar PV Suitability

4.5.1.1 Background

The ACUPCC challenges institutions to measure their GHG emissions and develop a plan to become climate neutral. Increasing renewable energy sourcing to 10% by the 2025 fiscal year is one of Clemson University's long term goals. One step towards this goal has been the production of biodiesel from campus waste oils. However, there are other opportunities to pursue further renewable energy sources on campus. Electricity generation was the highest contributor to Clemson's carbon footprint (about 40,000 metric tons CO_2-e in 2014), so there is potential to decrease emissions through increased renewable energy sourcing. Currently, about 3% of the energy generation provided to Clemson by Duke Energy comes from renewable resources: 0.69% biomass, 2.27% hydro, and 0.24% solar. Duke Energy plans to reduce the carbon emissions of their electricity generation by 40% from 2005 levels [85]. This will help the university lower its carbon footprint. While Clemson can encourage Duke Power to decrease their emissions from generation, another possibility to increase renewable sourcing is to install on-site power generation at the university. Even though energy technologies like utility-scale wind or concentrated solar power are estimated to have larger technical potentials, decentralized rooftop PV offers benefits which centralized ‘clean energy’ systems lack [111]. Decentralized rooftop PV capitalizes on unused ‘rooftop real estate’ and can provide significant energy potential even in places with modest solar resources [111]. This analysis is meant to demonstrate the geographic potential for rooftop solar PV modules within the campus boundaries and motivate future investigations to install such a system. Figure 19 displays the boundary of rooftops analyzed, and also labels rooftops of interest that will be discussed later on.

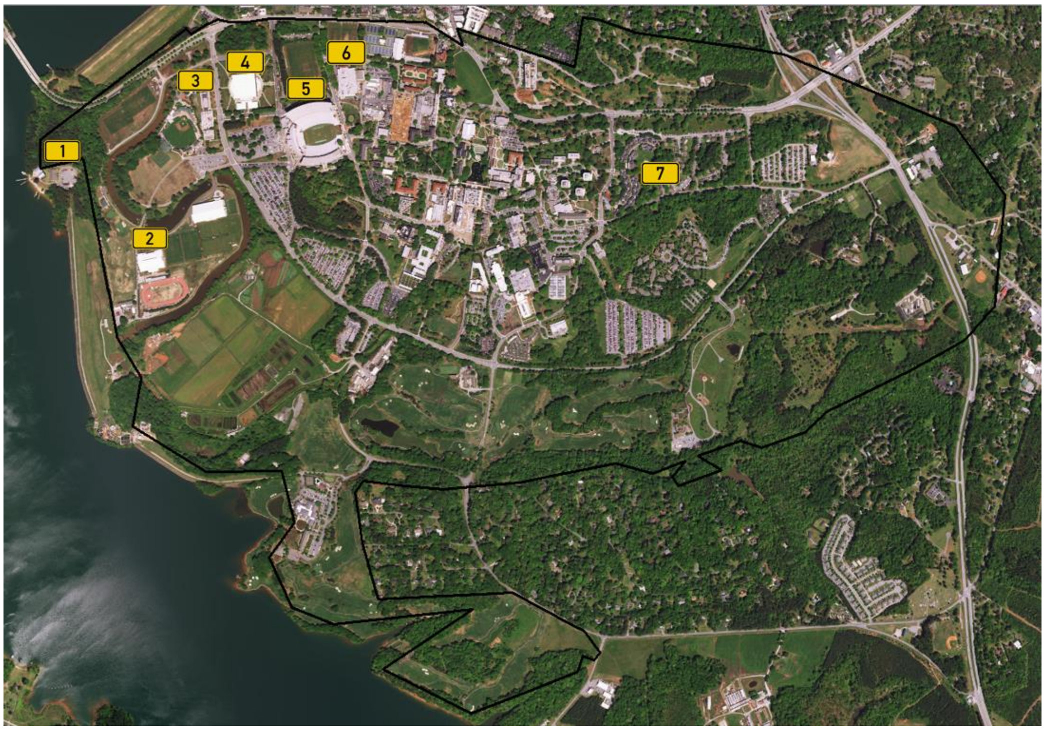

Figure 19. Clemson University Rooftops of Interest

Map Labels:

1. Clemson Rowing Boathouse
2. Clemson Indoor Track Facility
3. Athletic building row of McFadden, Jervey Athletic Center, and Jervey Gymnasium

4. Littlejohn Coliseum
5. Death Valley Stadium
6. Fike Recreation Center
7. Calhoun Courts Apartments

4.5.1.2 Data

Data was obtained from the South Carolina Department of Natural Resources, who commissioned aerial photos for the entire state. Point-cloud data collected on March 19th, 2011 was downloaded from the NOAA Digital Coast website for Pickens County, SC. The data was given in the NAD 1983 StatePlane South Carolina FIPS 3900 (meters) coordinate system. It was stored in the form of LAS files, the standard format to store airborne light detection and ranging (LiDAR) data. LiDAR data collects multiple returns from a location. The first return reflects the tallest features, and subsequent returns will be from lower elevations. This illustrates the natural and built features on the surface layer such as trees and buildings.

Data Quality

Table 4-55. Data Quality for LiDAR data

Indicator Score	Score	Explanation
Reliability	1	Verified data based on measurements
Completeness	1	Representative data from a several paper manufacturers to even out normal fluctuations
Temporal correlation	2	Data are from 2011, which is less than six years difference, however new buildings may have been erected in that time
Geographical correlation	1	Data from area under study
Further technological correlation	1	Data from enterprises under study

4.5.1.3 Methods

This analysis used geographic information systems (GIS) and LiDAR data to determine the solar PV potential on Clemson rooftops. The following figure demonstrates the tools used, which are described further in this section.

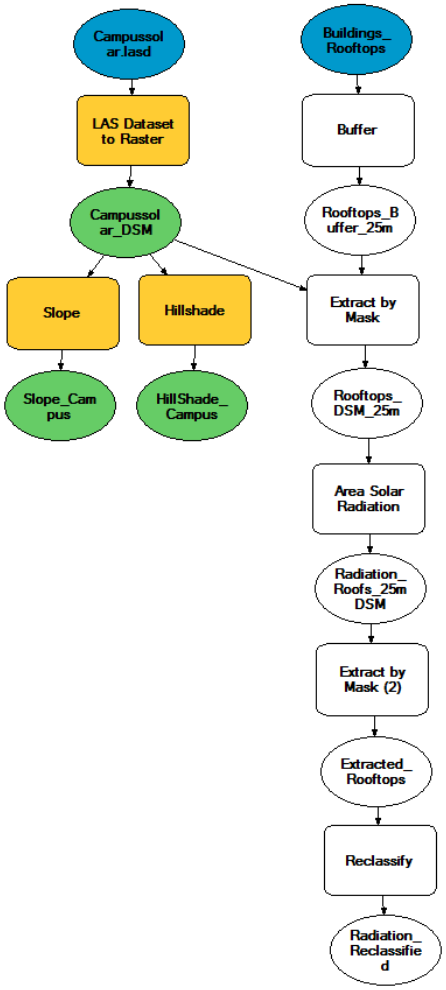

Figure 20. Model of GIS tools used in Clemson Rooftop Solar PV Study

Raster

Seven files consisting of 26,542,566 points were used to form a LAS dataset of the main campus, which had an average point spacing of about 0.712 meters. The LAS dataset of seven files was converted to a digital surface model (DSM) raster based on the first point returns. This was performed using a binning interpolation method that assigned cells based on average value and filled voids linearly. The output was designated to have a 1 meter cell size since the space between points was typically less than 1 meter. The elevation was also created in meters, which created the following figure.

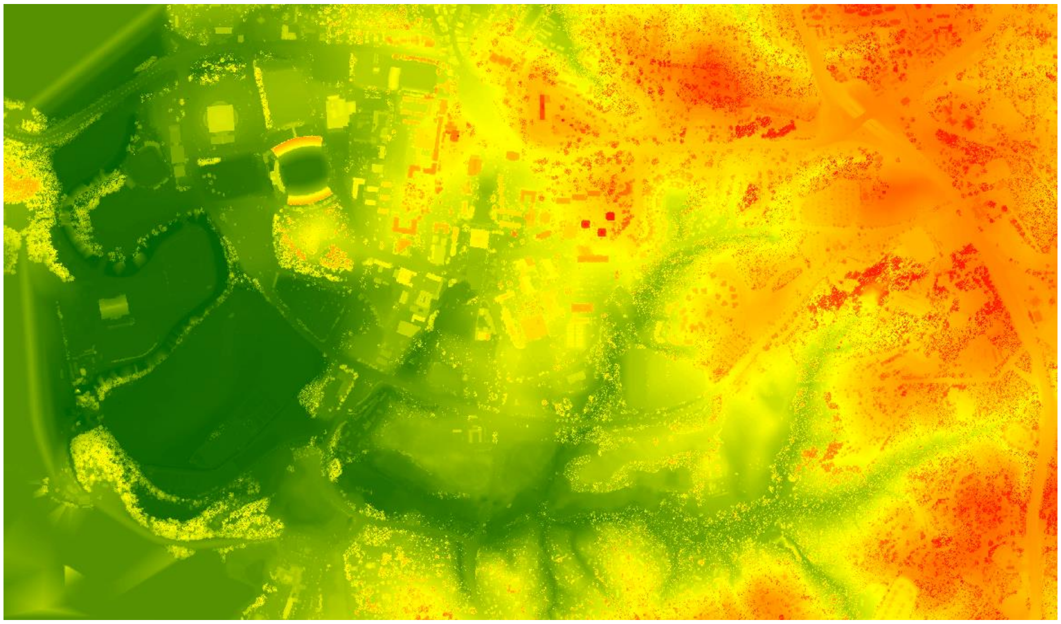

Figure 21. Raster Digital Surface Model of Clemson University's Campus

Rooftop Suitability

For this analysis, only existing rooftops on the main campus were considered for solar panel implementation. A polygon feature map of rooftops from 2016 was provided by the Clemson Geospatial Center. The rooftops analyzed include campus buildings, residential buildings, athletics stadiums, stands, and even sheds. In total, the area of rooftop analyzed was 273,324 square meters. Next, suitable solar radiation needed to be found for rooftops. However, calculating insolation can be very time consuming, so before solar radiation was found, the rooftop areas were buffered by 25 meters (rather than running this tool for the entire DEM of campus). Using this buffer was recommended by the Geospatial Center since adjacent landscape and obstructions are considering in solar radiation calculations. Therefore, it was assumed that built and natural features over 25 meters away would not be need obstruct solar radiation on rooftops. Next, the energy from sunlight was measured using the area solar radiations tool. This tool simulates sun movement over the geographic area (e.g. raster surface) for a chosen time interval. Notably, at our latitude, solar resource is not significantly depleted until slope surpasses 30 degrees [112]. However, slope was not used as a constraint as it already factored into annual solar radiation calculations. Since this analysis is evaluating future potential, each monthly interval of solar radiation for the year of 2017 was analyzed with daily 0.5 hour intervals. This calculated the sunlight delivered over time, in watt hours per square meter (Wh/m^2). The maximum solar radiation varied over the year, as seen in Figure 22, and had a monthly average of 130 kWh/m^2.

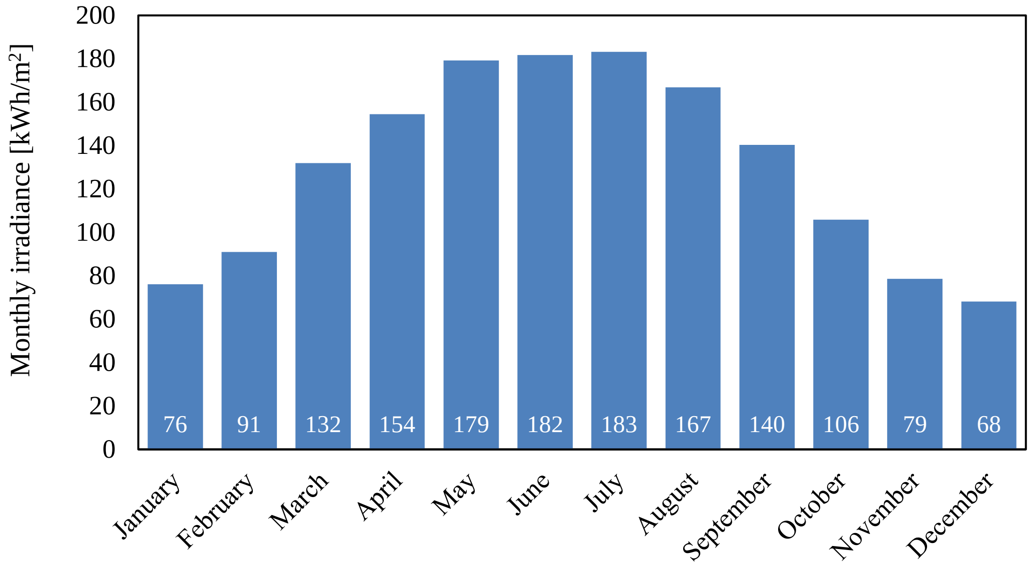

Figure 22. Monthly Maximum Solar Radiation for Clemson Rooftops

The solar radiation on the rooftops was mapped for each month, (see Appendix). However, the solar radiation in the highest month (July) and lowest month (December) are shown as Figure 23 and Figure 24 respectively. According to The National Renewable Energy Laboratory (NREL), the direct normal radiation at moderate resolution in the Clemson area receives an approximate yearly average of 4.5-5 kWh/m^2 per day [113]. Assuming 4.5 kWh/m^2 per day, this would amount to 135 kWh/m^2 per month, aligning with the data obtained from GIS for solar radiation that had a monthly average of 130 kWh/m^2.

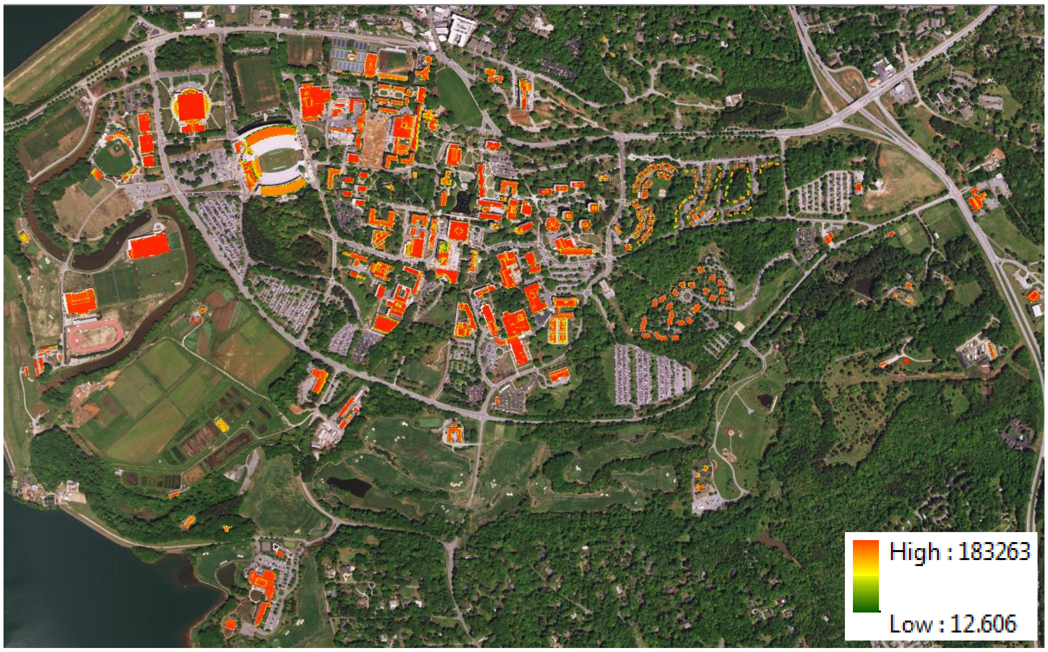

Figure 23. Clemson Rooftop Solar Radiation Potential for July (Wh/m^2 per month)

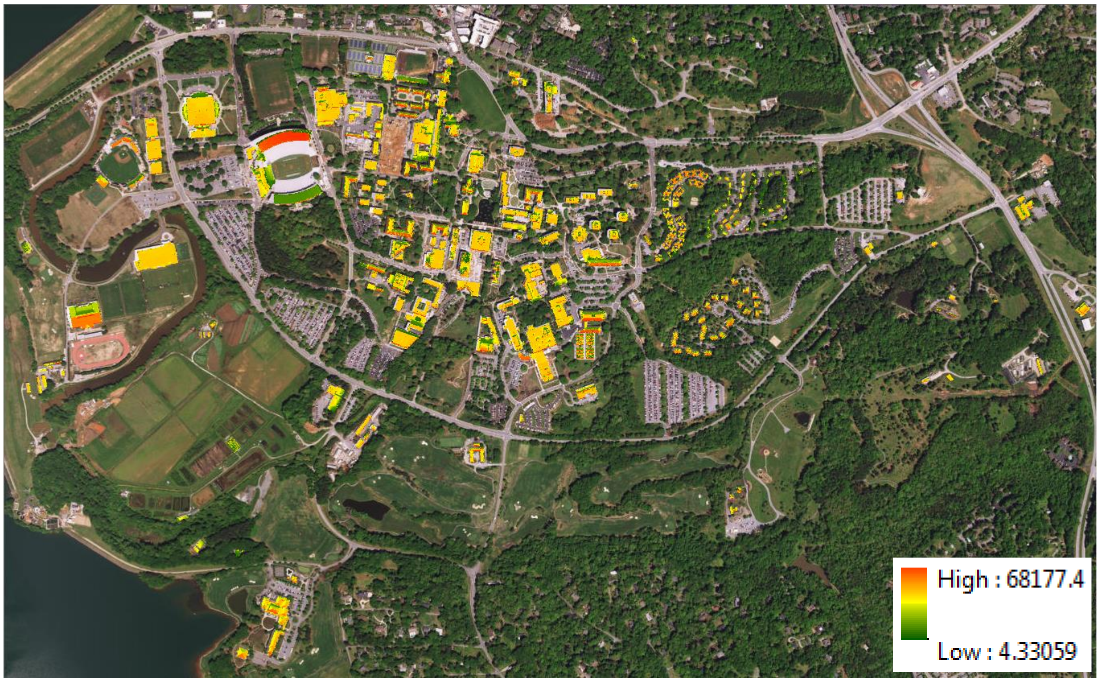

Figure 24. Clemson Rooftop Solar Radiation Potential for December (Wh/m^2 per month)

Solar Radiation Suitability

From this analysis, as would be expected, most rooftop area received higher solar radiation during July than in December, which has less daylight hours. Using the solar radiation tool to produce monthly estimations only allowed one day of the month to be evaluated. Therefore, the annual solar radiation was calculated using smaller time intervals to increase the accuracy of the results. This analysis was run for the entire year at 2 week intervals, with daily 0.5 hour intervals analyzed. Next, the analysis accounted for rooftop space needed for maintenance accessibility and infrastructure. Therefore, the suitable rooftop space was decreased by 1 meter around the perimeter of the roof using the buffer tool.

Many buildings around campus received solar radiation with an upper range of 1,200 – 1,500 kWh/m^2 annually. To validate this estimate, NREL's value of 4.5 kWh/m^2/day can be used for 365 days to find that this area should receive approximately 1,645 kWh/m^2 annually [113]. Since this value is an estimate at moderate resolution for the South Carolina area, the slightly lower annual solar radiation found using GIS seems reasonable. A figure showing this final product is shown in Figure 25. Here, the red illustrates the rooftop that receives 1,200 – 1,500 kWh/m^2 solar radiation annually.

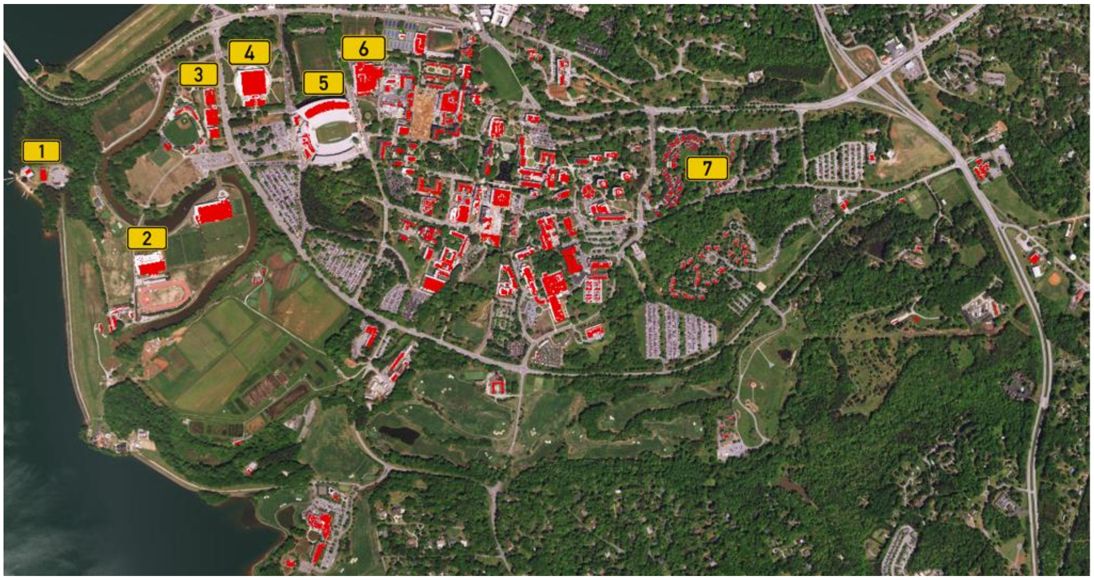

Figure 25. Clemson University Annual Rooftop Solar Radiation (1,200 – 1,500 kWh/m^2)

There were many rooftops that received 1,200 – 1,500 kWh/m^2 throughout campus, however, some of the larger rooftop area was on athletic facilities. Therefore, they pose significant potential for solar PV installation. The Clemson Rowing Boathouse (1), the Clemson Indoor Track Facility (2), the athletic building row of McFadden, Jervey Athletic Center, and Jervey Gymnasium (3), Littlejohn Coliseum (4), Death Valley Stadium (5), and Fike Recreation Center (6) are highlighted in the figure above. As can be seen, many other campus buildings show suitability for solar, and even smaller buildings such as Calhoun Courts Apartments (7) have suitable area for a PV array on each rooftop.

Conventionally, the best direction to face solar panels in the Northern Hemisphere is to the south, as this direction receives the most sunlight. Thus, the maximum annual solar radiation from this calculation (1,486 kWh/m^2 per year) was found on south facing roofs. This is displayed by the indoor track facility (2), the Littlejohn Coliseum (4). Littlejohn has a flat roof and receives the same irradiance across the whole surface. Meanwhile, the indoor track facility has a sloped roof that aligns east-west, so the north-facing slope receives less sunlight. This is also displayed by the south facing stands of Death Valley Stadium (5). While this stadium does not possess a roof, there is potential to add solar PV panels if a south facing stadium facade were added; a similar installation has been installed on the Philadelphia Eagles Stadium [114]. A one meter buffer was considered along the outer edge of every rooftop for maintenance and infrastructure. With this considered, it was determined that approximately 163,000 m^2 of rooftop receive solar radiation within the 1,200–1,500 kWh/m^2 range annually. To assess photovoltaic potential and determine annual electricity output, *E*, for a system, Hofierka and Kanuk (2009) used the following equation [115].

$$\mathrm{E} = \mathrm{A_e \eta_e G} \tag{22}$$

Here, *Ae* is the total surface area of solar cells (m^2), η_e is the performance ratio, and *G* is the annual solar irradiation (Wh/m^2). Also following Hofierka and Kanuk (2009), it can be conservatively assumed that the installation of a 1-kWp PV system with an array of solar modules requires about 10 m^2 of free roof area [115]. The power density of the sun was assumed to be the standard 1,000 W/m^2 [116]. Hence, the system has an efficiency of 10% or 0.1 kW/m^2. This value is a conservative assumption that considers the many losses that occur in the system. The power conversion efficiency coefficient used by NREL PVWatts photovoltaic system calculator is 0.77, and considers losses from factors such as soiling, shading, snow, wiring, and degradation [117]. However, this 0.1 kW/m^2 assumption also accounts for losses from solar panel spacing across the areas of the solar array.

Next, it was determined that all buildings with potential for solar panels had at least 10 m^2 of free roof area to accommodate an array. Then, the value of 0.1 kW/m^2 was used to represent the performance (η_e) of a given rooftop surface area (*Ae*). The annual solar irradiation for the surface area is assumed to be 1,200 kWh/m^2, which is the lower value in the upper range. Considering all 163,000 m^2 of available rooftop area is being covered with PV solar panels, the potential capacity of this system would be 16,300 kW. Since the surface solar radiation is 1,200 kWh/m^2/yr from 1,000 W/m^2 solar irradiance, their annual output is 1,200 h/yr. This equates to almost a 14% capacity factor for the system per year, and a total potential electricity generation of about 19,560 MWh/yr.

4.5.1.4 Conclusions and Recommendations

Solar PV modules are a viable option for emission-free and renewable electricity to decrease Clemson's carbon footprint. Solar power is sustainable, reduces vulnerability of the grid, and increases self-sufficiency of the campus. The purpose of this analysis to display the potential for solar on Clemson's rooftops and provide a general estimation of potential electricity generation from widespread solar PV modules. This analysis evaluated 273,324 m^2 of rooftops, and determined that 163,000 m^2 received solar radiation within the 1,200–1,500 kWh/m^2 range annually after accounting for space needed around the roof perimeter. Overall, if this entire rooftop area found viable in this analysis was covered with solar PV modules, it could generate approximately 19,560 MWh annually.

The LiDAR data used in this analysis was from 2011, therefore it does not include new buildings such as the Watt Center, the Clemson Indoor Practice Facility, CORE Campus, additions to Littlejohn Coliseum, or residence halls currently under construction. The rooftop outline included the Clemson Indoor Practice Facility, which was built in 2012, so it was not included in the LiDAR data. However, the rooftop of this building is flat, so the solar radiation calculated for this area is assumed to stay consistent with the GIS calculations.

There was uncertainty stemming from accuracy of point cloud data, the DSM it created, and the rooftop outlines. Closer examination found that for some buildings, suitable rooftop area was scattered across some roofs that appeared flat. However, with the naked eye it is difficult to determine if there were structures, slopes, or shade on the roof that may reduce the feasibility of solar panel installation when calculated with GIS. If the slope of the roof is steep, it may make it harder to install and service the solar arrays. Therefore, it is recommended that the rooftops be physically inspected on a building-by-building basis for a more thorough assessment of suitability. Also, the Clemson Geospatial Center is actively pursuing the acquisition of new LiDAR data for campus. This could be used in future studies to validate the results of this analysis and to evaluate further rooftop PV viability on new buildings.

There is also potential to study potential rooftop suitability in more depth. Choi et al. (2011) argue that simplistic electricity generation formulas like that proposed by Hofierka and Kanuk (2009) do not account for intermittent behavior of solar irradiance and the dynamic performance of PV systems [118]. They also recommend that users should consider different PV technologies for the annual mean power conversion efficiency coefficient [118]. Therefore, the suitability results of this analysis could change if more specifications were known about desired PV technology and incoming solar radiation. Therefore, future studies could optimize incoming solar radiation and investigate the potential electricity generation from various PV technologies.

There are also some practical considerations that must accompany the installation of solar PV modules. One consideration is that the roof can support the weight of a solar array, and that the panels don’t interfere with existing structures such as HVAC or drainage. However, there are also some structural benefits to adding solar panels to roofs. Solar panels intercept solar radiation, keeping the building slightly cooler than if the roof was exposed, which would reduce cooling costs. Panels can also help hold heat in, which can reduce heating costs in winter.

Future studies should perform a cost-benefit analysis of rooftop solar implementations. This should estimate the potential savings of such a system and compare it to the cost of the solar panels, inverters, infrastructure, labor, maintenance, and cost of connecting to the grid. If installing PV panels is a lucrative option, future studies may also investigate the possibility of implementing solar modules over parking lots, stadium stands, the experimental forest, and on other undeveloped university owned land. It must also be acknowledged that solar radiation varies seasonally, and can be affected by changes in weather (e.g. cloud cover). Since solar generates electricity during daylight hours, daily electricity loads for campus should be analyzed and there may be potential to provide electricity to the grid and receive credits to use during nighttime.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This research conducted LCAS to build a carbon footprint for Clemson University's main campus. This section discloses the results of Clemson University's carbon footprint, and provides recommendations for improvement and future studies. As previously discussed, continued GHG emissions increase the likelihood of severe and irreversible impacts for people and ecosystems [8]. The current atmospheric concentration of CO_2 has already reached over 408 ppm [10], and to limit the increase of future global warming to 2 °C above pre-industrial levels, the atmospheric concentration of CO_2 must be stabilized to about 450 ppm equivalent [20]. In response, GHG initiatives have developed, creating a need for higher education institutions such as Clemson University to develop a transparent inventory of GHG emissions.

5.2 Clemson Carbon Footprint Results

This research built a carbon footprint for Clemson University's campus through a series of LCAs described in chapter 5. The total carbon footprint for Clemson University was 94,903 metric tons CO_2-e. The inventory of these results is shown in Table 5-1 on the following page.

Table 5-1. Carbon Footprint for Clemson University Campus

Activity		Emissions (metric tons CO_2-e)
Scope 1		
Steam Generation		15,522
Refrigerants		143
University Owned Vehicles	Tiger Transit	1,597
	CUPD	72
University Owned Aircraft	2008 Citation CJ3 Jet	402
	1998 Beechcraft King Air C90B Turboprop Airplane	113
Fertilizer		19
Wastewater Treatment		173
Scope 2		
Electricity Generation		38,718
Scope 3		
Electricity Life Cycle		5,207
Transmission and Distribution Losses		2,393
Automotive Commuting		16,738
Clemson Area Transit	Electric Fleet	81
	Diesel Fleet	1,099
University Related Travel	Student Driving	249
	Student Air Travel	5,175
	Employee Driving	1,550
	Employee Air Travel	5,320
Paper Usage	Office paper	1
	Washroom Towels	70
	Bathroom Tissue	79
Waste and Recycling Transportation		27
Wastewater Treatment	Chemicals	2
Water Treatment		153
Scope 1		**18,041**
Scope 2		**38,718**
Scope 3		**38,144**
TOTAL		**94,903**

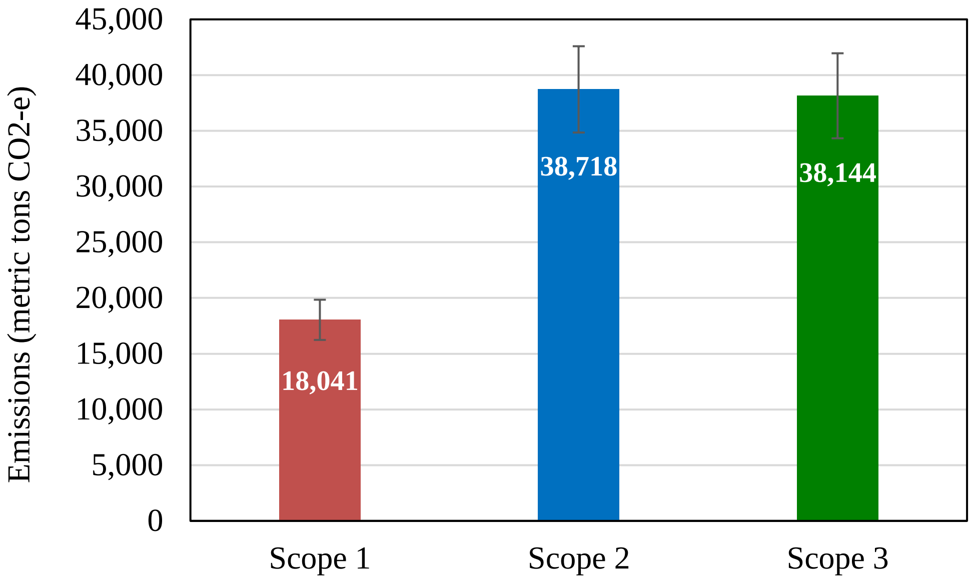

Figure 26. Clemson University Carbon Footprint by Scope

As seen in Figure 26, the scope 2 and scope 3 emissions are nearly double the magnitude of the scope 1 emissions. On this figure 10% error in the overall calculations has been assumed to represent uncertainty. Most uncertainty studies in LCA quantify only input data uncertainty, though it can also arise from the functional unit, characterization factors, scenario uncertainty, and model uncertainty [68]. Due to available information and time considerations, this study focused on characterizing input data uncertainty in the inventory. The five independent data quality indicators used to describe the aspects of data quality were; reliability, completeness, and correlations temporally, geographically, and technologically [68]. These indicators cannot be used quantitatively, and due to the nature of the data, a Monte Carlo analysis could not be performed. With the assumption of 10% error in the overall calculations, the estimated uncertainty creates a range of 85,413 to 104,393 metric tons CO_2-e for the overall carbon footprint with scope 1, scope 2, and scope 3 emissions ranging from 16,237-19,845, 34,846-42,590, and 34,330-41,958 metric tons CO_2-e, respectively.

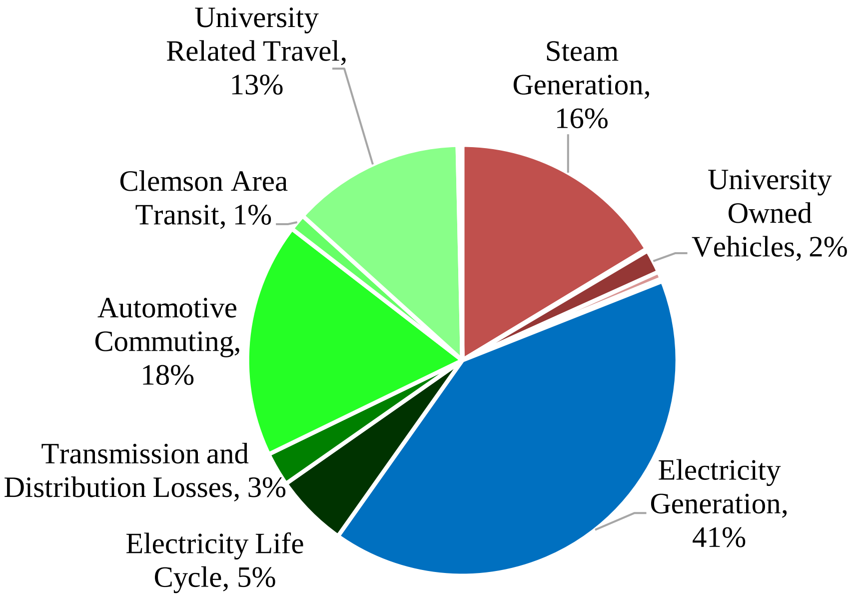

Figure 27. Pie Chart of Clemson University's Carbon Footprint

Figure 27 displays the contributions of each activity to the overall carbon footprint. Any activity contributing less than 1% had its percentage excluded from the figure. Here, the red shaded activities are related to scope 1 emissions, which had a total contribution of 19%. Electricity is the only scope 2 emission, and contributed 41%. The scope 3 emissions are shaded green, and together accounted for 40%. The activities with the highest emissions were related to fossil fuel combustion, including electricity (41%), automotive commuting (18%), steam generation (16%), and university related travel (13%). Overall, emissions related to electricity generation were the highest GHG emitting activity, being 41%. Electricity also had another 5% life cycle emissions, and 3% attributed from losses in transmission and distribution.

5.3 Recommendations

5.3.1 Reducing Carbon Footprint

Creating a GHG inventory is essential to create strategies to improve Clemson University’s campus carbon footprint. To optimize carbon footprint reductions, the activities with the highest emissions should be prioritized. Examining the Scope 1 emissions, the activity with the highest contributor was steam generation. Here, it is recommended that demands are reduced for hot water use, dehumidification, and space heating. This could be achieved with methods such as low-flow showerheads, faucet aerators, shortening showering times, or reducing temperatures on clothes washers. Adjusting set temperatures in buildings and applying passive heating strategies to new building design could further help to reduce future heating loads. Furthermore, lower GHG steam generation sources such as biogas or solar thermal panels could be used in the future to meet the university's increasing heating needs. The other scope 1 activities had less than 3% contributor cumulatively. However, several recommendations were made to decrease the emissions of these activities. One recommendation is that fertilizer use could be reduced or eliminated completely. In the future, the university should seek to purchase CUPD and Tiger Transit vehicles with higher fuel economy or electric charging capability or electric charging capability. Also, university owned aircraft travel could be reduced by using commercial flights, alternative transportation, or video conferencing instead. Scope 2 emissions from electricity generation contributed 41% to the overall carbon footprint. If this is combined with scope 3 emissions from electricity generation's life cycle (5%) and transmission and distribution losses (3%) this altogether accounts for nearly half of Clemson's campus carbon footprint. As discussed in Section 4.5, Clemson University has a large area of rooftop that could be used for solar PV panels. This section demonstrated the geographic potential for rooftop solar PV modules within the campus. As a renewable energy source, solar PV has no emissions associated with operation, and it would have less transmissions and distribution losses. Therefore, a transition to solar PV or another renewable energy source is recommended to significantly reduce campus carbon emissions. The other scope 3 activities with high GHG contributions were automotive commuting (18%) and university related travel (13%). Emissions from automotive commuting could be reduced by encouraging carpooling or commuting via walking, biking, or CATBUS. This may require an increase in bike paths in sidewalks to accommodate students. While CATBUS is outside the control of Clemson University, their efforts to install solar PV panels and make an entirely electric fleet can reduce Clemson's associated emissions. Students may be more likely to choose this mode of transportation if CATBUS runs buses more frequently. Other university related travel (e.g. conferences) could be reduced by setting up carpools for travel, using videoconferencing, and traveling by alterative transport rather than plane.

To make significant changes in the campus's overall carbon footprint, a holistic approach to future planning should be applied. Carbon emissions must either be reduced or offset to reach Clemson's goal of carbon neutrality. Each activity that contributes to Clemson's carbon footprint has specific recommendations to improve, however changes in operation, technology, and behavior are reoccurring themes. For instance, lowering water use can decrease emissions associated with water treatment and wastewater treatment. Decreasing heated water use will also lower steam generation demands. A few methods to reduce water use are to install timed showers, low-flow showerheads, or encourage students to take shorter showers. These are all changes in operation, technology, and behavior that could be utilized, most effectively in conjunction, to lower water use and associated emissions. Changes in operation and technology are often driven by cost-benefits, but in many cases this goes hand in hand with carbon emissions as lower resource and energy use (e.g. steam, electricity) lowers costs for the university. These changes may also be made to promote the university as being "green" to attract potential students, or in response to pressure from stakeholders. Furthermore, increasing education for students and employees about the value of GHG reductions is highly recommended so that they can advocate for GHG improvements on campus. An educated campus community can help promote operational and technological changes, and may also be more prone to change their behavior to decrease GHG emissions as well.

5.3.2 Sensitivity Analysis

It is also recommended that a sensitivity analysis be performed for Clemson University's carbon footprint. There was uncertainty related to data quality which is rated for each data source. There were also many assumptions made related to functional units (e.g. paper use) and for the IO analysis (e.g. university related travel). These sources of uncertainty are discussed further in the section 5.5.

5.3.3 Data Reporting

To become carbon neutral it is essential that the necessary data is available to monitor emissions progress. Finding the proper channels to gather data was difficult, and it is recommended that the university create a directory of contacts for campus related activities. Another recommendation is that operations make data available to students and employees as it could be used for instructional purposes while simultaneously raising awareness of energy and material use on campus. Overall, this research unveiled limited recorded data to build the carbon footprint. Facilities had detailed data for energy consumption, steam generation, and other processes that include meters. However, there were several activities that did not record detailed information. It would be useful to have building specific data so that the carbon footprints could be created and compared for buildings around campus. This could drive investigations to determine what building specific designs and behaviors contribute most to the carbon footprint.

There was also variability in data recorded for each campus activity. Clemson’s police department and aircraft provided estimates of fuel use, but in the future, specific consumption would be beneficial to build the carbon footprint. During the data acquisition phase of this research, the benefits of gathering more detailed data in the future were communicated. This had positive results as the Clemson wastewater treatment plant started keeping records of daily chemical in January of 2017 after several inquiries on the subject. However, in many cases, only an annual or monthly average for a material or energy flow was given and this could not be amended before this research was conducted. For this analysis, it would have been beneficial to simulate a range of possible outcomes for decision making and to understand the variability in a process. Unfortunately, the data did not have enough quantity to create an uncertainty distribution with Monte Carlo. In the future, a large dataset is needed to determine distribution parameters for each input. Therefore, it would be preferred if data from facilities and administrators recorded trends over time for each input. For instance, rather than providing an annual value for paper towel usage or Tiger Transit fuel consumption, this data could be recorded at weekly intervals. This could help aid investigation to determine what month is our carbon footprint highest, and even be used to highlight connections in consumption patterns.

5.4 Comparison to other Studies

5.4.1 Previous HEIs

It is difficult to compare the results of this study to other studies conducted for HEIs. Each study has incorporated different activities in their scopes, has varying population sizes, and variations in their methodology and emissions factors. However, comparing available data for specific activities, many of Clemson University's emission trends are of the same magnitude of other HEIs. The Norwegian University of Technology & Science had about 22,000 students and 5,500 employees and found a carbon footprint of 92,000 metric tons CO_2-e [30]. Meanwhile in 2014 Clemson also had about 22,000 students, 5,000 employees, and had a carbon footprint of nearly 95,000 metric tons CO_2-e [6] [7]. Clemson's steam generation in 2014 used about 337 million cubic feet of natural gas and subsequently produced 15,522 metric tons CO_2. Rowan University used about 354 million cubic feet of natural gas in their plant to create steam and cogenerate electricity, and this produced about 19,000 metric tons $CO_{2.}$ Also, Clemson's commuting was responsible for 18% of the total carbon footprint, which is comparable to previous HEIs. At the University of Illinois at Chicago commuting was 16% of their carbon footprint, while it at De Montfort University it was 18% [39] [64]. Though it should be recognized that the commuters at different universities may drive different types of vehicles. One way to compare the Clemson University study to previous studies is to normalize the carbon footprint by the number of students the intuition serves. Thus, finding the carbon footprint per student can relate institutions of different sizes. The outcome of this comparison is shown in Table 5-2 and either given values or based on study information. Clemson falls within the range of carbon footprints per student, though it should be noted that each study includes different activities and may have higher emission intensities from energy use. For example, De Montfort University has nearly 22,000 students and had a footprint of about 51,000 metric tons CO_2-e with 34% of emissions originating from energy use [64]. This resulted in a per student carbon footprint of 2.4 metric tons CO_2-e per student. Meanwhile, the University of Illinois at Chicago has about 20,000 students and had a carbon footprint of 275,000 metric tons CO_2-e, 63% of this footprint was attributed to campus power plants [33]. This caused them to have a per student carbon footprint of 8.8 metric tons CO_2-e per student.

Table 5-2. Carbon Footprint per student for Higher Education Institutions

Case Study	Method	MTCO$_2$-e/student
Institute of Engineering at Universidad Nacional Autónoma de México, Mexico	PA	NA
The University of Cape Town (UCT), Africa	PA	3.2
Tongji University, China	PA	3.8
University of Illinois at Chicago (UIC), USA	PA	8.8
University of Sydney (USyd), Australia	HLCA	NA
University of Maribor (Engineering Campus only), Slovenia	HLCA	NA
De Montfort University (DMU), England	HLCA	2.4
Rowan University, USA	HLCA	4.0
Clemson University (CU), USA	**HLCA**	**4.3**
Yale University (YU), USA	IO	NA
The Norwegian University of Technology & Science (NTNU), Norway	IO	4.6
University of Leeds (UoL), England	IO	5.3

5.4.2 Sightlines

The Sightlines presentation for 2014 determined that Clemson University emitted almost 160,000 metric tons CO2-e, which is much higher compared to the nearly 95,000 metric tons CO2-e calculated in this study [119]. Sightlines found that 22% of total emissions were scope 1, 46% were scope 2, and 32% were scope 3. This varies to the results from this research, which found scope 1 emissions to be 19%, with scope 2 and 3 emissions being 41% and 41%, respectively. The Sightlines methodology to calculate this is not known since they are an independent consulting service. They included a different of the same activities in their study; on-campus stationary combustion of natural gas, vehicle fleet, agriculture, refrigerants, purchased electricity, commuting, employee air travel, student study abroad, solid waste, wastewater, purchased paper, transmission and distribution losses [119]. The emissions from some activities were quantified, but the inputs and emissions factors used were not all specified. The largest discrepancy was in emissions related to purchased electricity. They found that 73,020 metric tons CO2-e were emitted, while this study determined 38,718 metric tons CO2-e were emitted. Since this study only included electricity used by the main campus, Sightlines may have used the total electricity purchased from Duke Energy in 2014. The total electricity purchased was 149,803,619 kWh, which would translate to 48,453 metric tons CO2-e using the methodology outlined in section 4.3.1. This methodology is based off plant specific data from the Duke Energy Carolinas balancing authority in the eGRID database, which was not released until January of 2016. Another possible discrepancy is that Sightlines based their calculations off of a different electricity mix that what was found in this study or used average emission factors for electricity generation. According to eGRID, the national average emissions factor is 0.52 kg CO2-e/kWh with an average electricity mix of approximately 20% nuclear, 39% coal, and 28% gas. The average emission rate for the SERC Virginia/Carolina subregion is 0.39 kg CO2-e/kWh since this region has an electricity mix of about 43% nuclear, 32% coal, and 20% gas. Meanwhile, the Duke

Carolinas electricity mix found for Clemson University has an emissions rate of 0.32 kg CO2-e/kWh since it has about more nuclear (53%), 29% coal, and 15% gas. Using the information provided in the Sightlines report, their emissions rate translates to about 0.49 kg CO2-e/kWh, which falls close to the national average.

5.5 Uncertainty

This research performed streamlined LCAs, therefore, phases were left out of the analysis. This leaves room for uncertainty as it is likely that these phases would have contributed more to the carbon footprint. There is also uncertainty in representativeness of the carbon footprint for 2014. While this footprint was mainly used data from 2014, data for activities such as CATBUS and wastewater chemicals used more recent data. Since year-to-year trends may vary, annual trends are needed for future analysis. For example, annual steam generation could be affected by weather and heating needs, and the 2014 values may deviate from the norm. There has also been slight monetary inflation from the 2014 data to the current day, which may impact the IO analysis for university related travel. Some activities also were based on assumptions from operators such as for the CUPD distance patrolled and university aircraft use. More precise data could be gathered for future studies.

The methods used to determine GHG emissions also contributed to uncertainty in the final carbon footprint. For each activity, a hybrid LCA was conducted using as much process specific data as possible. However, in many cases average emissions factors and surrogate data was used. In reality, the average emission factors may vary, for instance diesel combustion was based on an average of diesel combustion from several modes of combustion. There was also surrogate data used for several studies, including wastewater treatment operation, water treatment, paper usage, and the electricity life cycle emissions. From surrogate data, the most relevant and intensive LCA study available was used. Then, if multiple values were presented the value corresponding with the process used by Clemson was used, or else a median value was chosen. However. the emissions factors from LCA studies had varying locations and often a range of processes or products. From this there is uncertainty, and obtaining LCA data for the specific products and processes used by Clemson may provide better insight to the GHG emissions from these activities.

Several significant assumptions contribute to uncertainty in the carbon footprint. First, university related travel data was limited, so the emissions attributed to this activity were based on assumptions outlined in section 4.4.5. Since more detailed information for costs were not given, the GHG estimations for student travel were based on the cost of travel to a conference. However, it is likely that students traveled for other purposes besides conferences, and for varying periods of time. Thus, this estimation is a source of notable uncertainty.

The life cycle emissions from electricity are also an activity with great uncertainty. The life cycle emissions applied were averages based on LCA studies for each generation energy source. The majority of the life cycle emission factors were obtained from the IPCC or NREL's extensive studies. However, the emissions included electricity generation, which were already calculated using data from Duke Energy and eGRID. To find the emissions associated with the lifecycle outside of operation, the electricity generation estimate was subtracted from the overall life cycle estimates. These are two different data sources, and the overall emissions factors found by the IPCC and NREL were not as specific as the plant operations emissions data. Therefore, sensitivity analysis for these sources of uncertainty are recommended.

5.6 Future Studies

5.6.1 Expanding Current System

The largest obstacle in this research with the unavailability of data. One recommendation for future studies is to perform a sensitivity analysis. Future studies may also want to specifically seek out more detailed information for university owned vehicles and aircraft, and waste and recycling transportation, as their emissions estimates were based on operator’s assumptions rather than recorded data. Also, student and employee commuting contributed a large portion of the campus carbon footprint. The frequency and distance traveled to commute were based off Parking and Transportation Services data. Further studies may want to re-survey for consistency or perform a sensitivity analysis on this data specifically.

There are also many activities that could be added to the carbon footprint in future studies. The Scope 3 emissions that come from sources owned or controlled outside of Clemson University open many possibilities for evaluation. Further activities that could be assessed are emissions associated with composting, agriculture, experimental forest management, housing, food, beverages, furniture, laboratory supplies, machinery, infrastructure, and construction.

Activities already evaluated in this study could be expanded to include additional life cycle phases to scope 1 activities such as raw materials extraction, processing, and transportation of fertilizer, refrigerants, and fossil fuels used in steam generation and in vehicles. Including upstream impacts could be especially significant for steam generation and life cycle emissions from natural gas electricity generation. Fracking for natural gas can produce small leakages of methane from the production and delivery system, which can have a great climate impact due to methane’s higher GWP. This possible leakage has been estimated that a natural gas system can have an excess percentage leakage of 1.8% to 5.4% of end use gas [94]. However, this leakage is not included in the steam generation calculations or in NREL's harmonized value for life cycle emissions. Therefore, it is recommended that future studies investigate this leakage and add it to the carbon footprint.

The bounds of scope 3 activities could also be further expanded. Clemson separates large amounts of cardboard, paper, compost, and scrap metal, and recently started recycling Styrofoam. The GHGs from landfilled waste and recycling processes could be investigated by reaching out to the facilities that receive these materials.

5.6.2 Expanding Current System

Future studies can also be conducted to appraise the effect of changes in behavior and operations. This study highlights the possibility of CATBUS commuting replacing personal vehicle commuting if the bus schedule becomes more frequent. The change in GHG from such a transition could be quantified in future studies. Studies could also explore the impact of a change such as electric hand dryers replacing paper towels, or installing low flow shower heads. Using the baseline established in this study, these future investments can then be weighed in a cost-benefit analysis to determine what changes will most effectively lower the campus carbon footprint.

Another aspect that can be evaluated is how the carbon footprint of Clemson's main campus will change year to year. With this, it may be worthwhile to project Clemson's gross carbon footprint if operations continue with current conditions. Then, future studies can study the projected impact as the student population grows, new buildings are constructed, new technology is installed (e.g. motion lights), and behavior changes (e.g. commuting habits). Comparing buildings may also be another useful study. For example, the Lee III building was designed to be zero net-energy and has a green roof, a geothermal heat pump, and a deliberate natural ventilation design. This building could be compared to older building that don't have this technology and planning.

The inventory analysis of this study focused on flows contributing emissions to air; specifically, GHGs. However, expanding the impact assessment could potentially include other environmental impacts. Future studies may want to assess impacts related to Clemson University such as resource depletion, ozone depletion, smog potential, human carcinogenicity, ecosystem toxicity, nanoparticle pollution, and waste generated. The significant quantities of water and fossil fuels used to support campus operations contribute to resource depletion. Smog potential would also be interesting to quantify as is created from pollutants released from volatile organic compounds, nitrogen oxides, and sulphur dioxide. These emissions can stem from vehicle combustion, industry, and power plants, all which support Clemson’s activities.

5.6.3 Comparing to Previous Studies

Comparing carbon footprints between HEIs is difficult as each institution has varying population size and activities contributing to their operations. Furthermore, some of the carbon footprints were limited to just a few main activities, resulting in a lower overall footprint. Transparency should be encouraged in reporting activities inputted to the footprint. This leads to the question “what is an appropriate functional unit for comparison between very different institutions?” There are several functional units that have been proposed. This study has quantified the carbon footprint per student served. This could be expanded to create a carbon footprint per capita, which would include employees working on campus. Another metric that could be used to compare is an overall carbon footprint per square foot of building space. Also, if building specific material and energy flows were obtained, then departments could also be compared. Departments with intensive laboratory activities will likely have higher emissions associated with equipment electricity needs and manufacturing of laboratory chemicals. However, the design and age of the building itself will also influence departmental GHG emissions. For example, Lee III serves the College of Architecture, Arts, and Humanities, and was designed to be zero net-energy, so the departments located in this building would likely have a lower carbon footprint compared to others. A further metric to compare HEIs would be to quantify the carbon footprint per research dollar spent, or per publications. This functional unit could also be applied to compare the carbon footprint between departments, as the departments with carbon intensive laboratory activities may also have more publications. Another functional unit could even compare carbon footprints for graduate students, undergrad students, and faculty.

Another future study may be conducting a detailed comparison of the systems within each university's carbon footprint. Each HEI has a different electricity generation resource mix, which impacts their overall footprint. They might also have differences in other activities such as how they heat their buildings, the types of cars driven for commuting, type of paper used, and university related travel policies.

5.6.4 Carbon Neutrality Goal

Clemson University has set a target to become carbon neutral by 2030. There is not one solution, however there are several methods that can be employed in combination to achieve this. For instance, switching to 100% renewable energy is not financially feasible, plus there are emissions associated with other activities (e.g. fertilizing) that will not be eliminated. Overall, a comprehensive approach with significant operational and behavioral changes is required. First, energy use can be decreased with increased energy efficiency in buildings, transportation, and operations. Energy and carbon emissions are directly related, so increased energy efficiency can lower associated emissions without interfering with current operations. Second, conservation of resources and reduced waste can decrease emissions upstream emissions associated with acquisition and downstream emissions associated disposal. This will require behavioral and possibility even cultural change. These strategies can be used to optimize Clemson’s system and reduce emissions. However, to become carbon net-zero, carbon-free energy sources or carbon offsets should be sought after by the university. Renewable energy, such as wind, solar, biofuel, and hydroelectric power are all potential carbon-free energy sources that could be used in the future to offset energy demands. Purchasing renewable energy credits is also an option. The Clemson Experimental Forest cannot be counted as a carbon offset with the ACUPCC as offsets must produce additional GHG emissions reductions to “business as usual.” Thus, carbon sequestered with existing forest management practices are not considered an offset. However, strategies that count for “additionality” would be reforestation in areas that have been cut down, or afforestation of lands that have not had trees for more than a generation. Future studies could evaluate strategies to recommend a comprehensive plan to achieve carbon neutrality.

APPENDIX

Hillshade and Slope

Hillshade creates a grayscale 3D representation of the surface, and considers the Sun’s position to shade the image. When combined over the Raster, a map can be created to better illustrate campus buildings and geographic features in 3D.

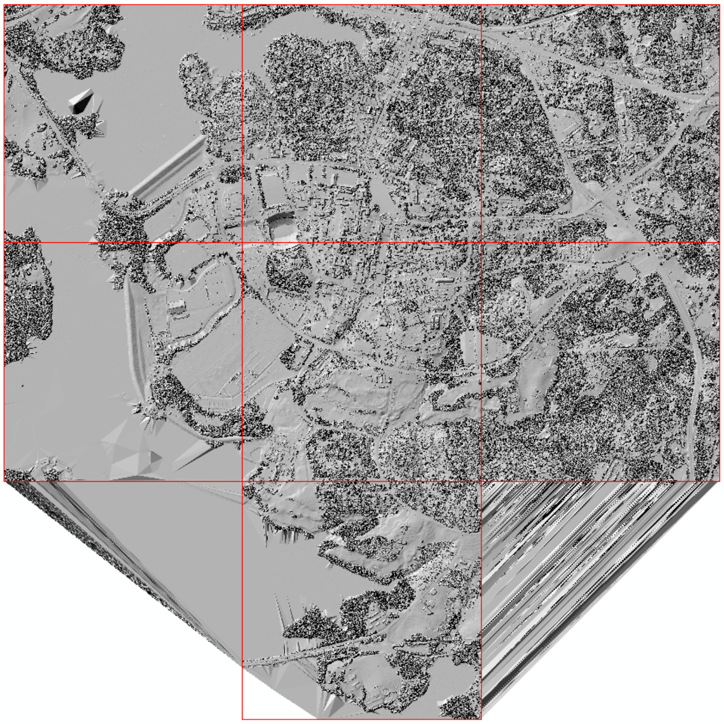

Figure 28. Hillshade of Clemson's Campus

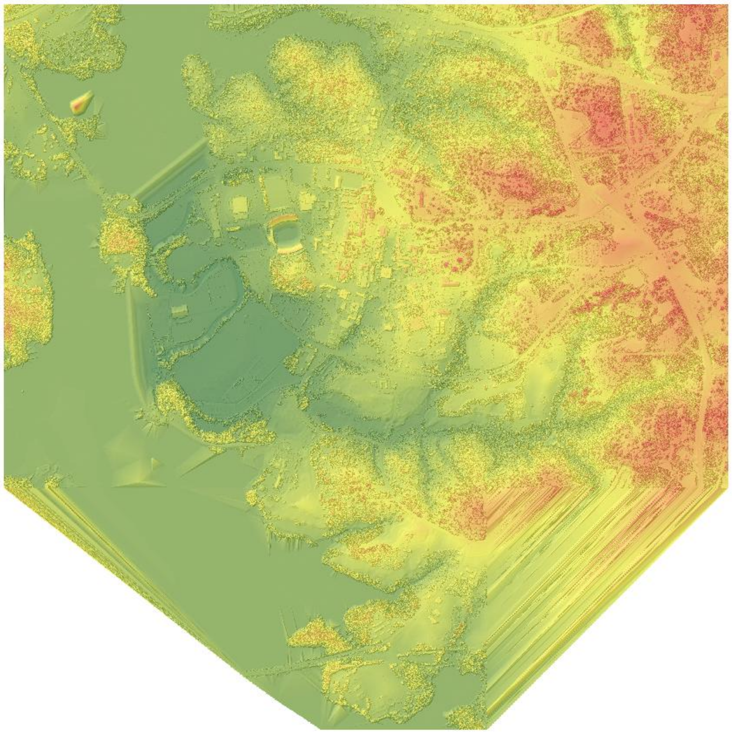

Figure 29. Raster with Hillshade of Clemson's Campus

Monthly Solar Radiation Potential

The solar radiation on the rooftops was mapped for each month, as seen in the following figures.

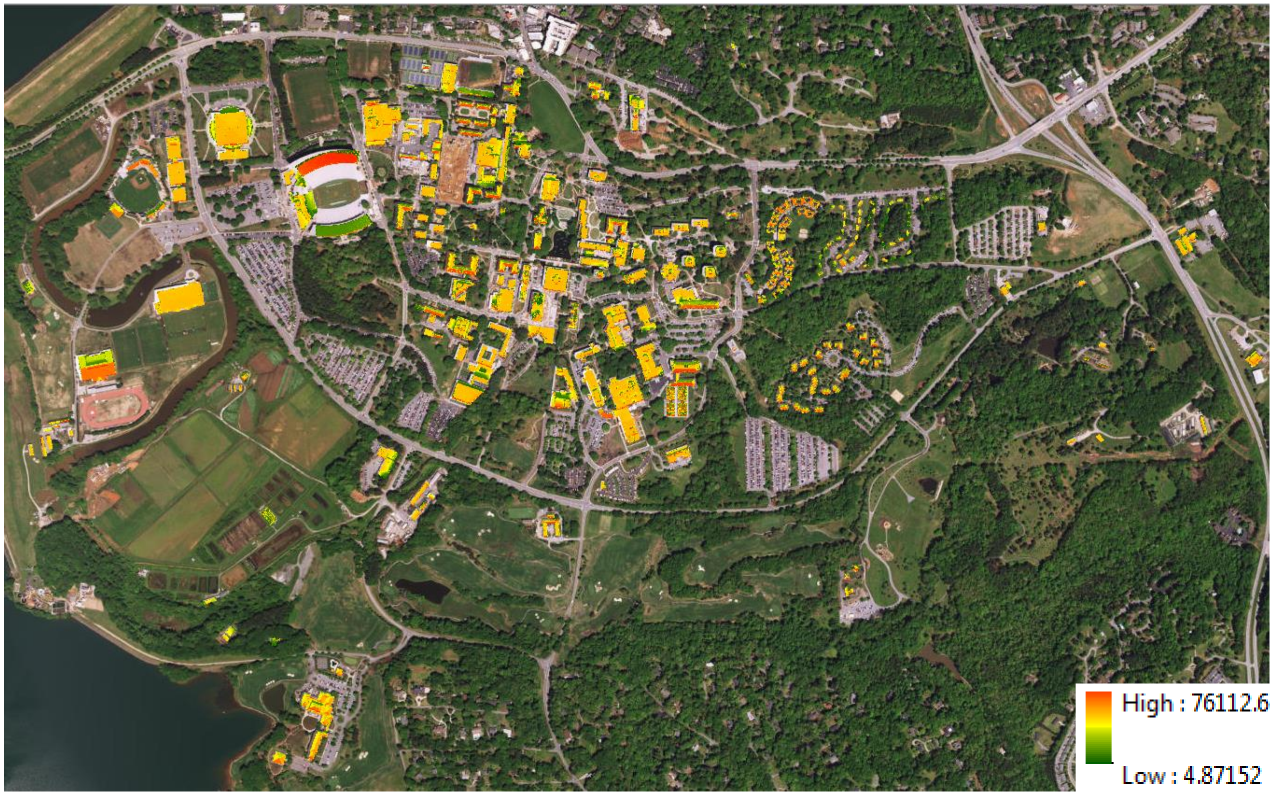

Figure 30. Clemson Rooftop Solar Radiation Potential for January (Wh/m^2 per month)

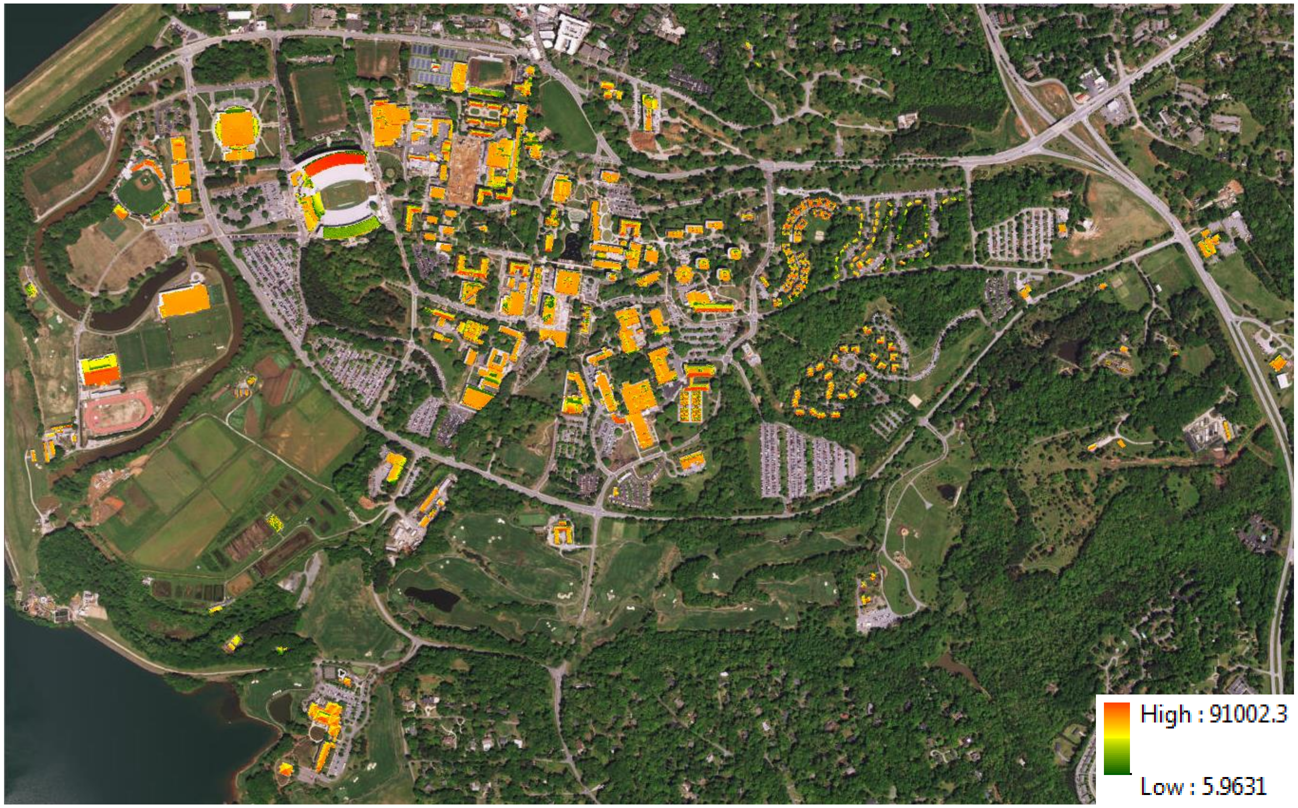

Figure 31. Clemson Rooftop Solar Radiation Potential for February (Wh/m^2 per month)

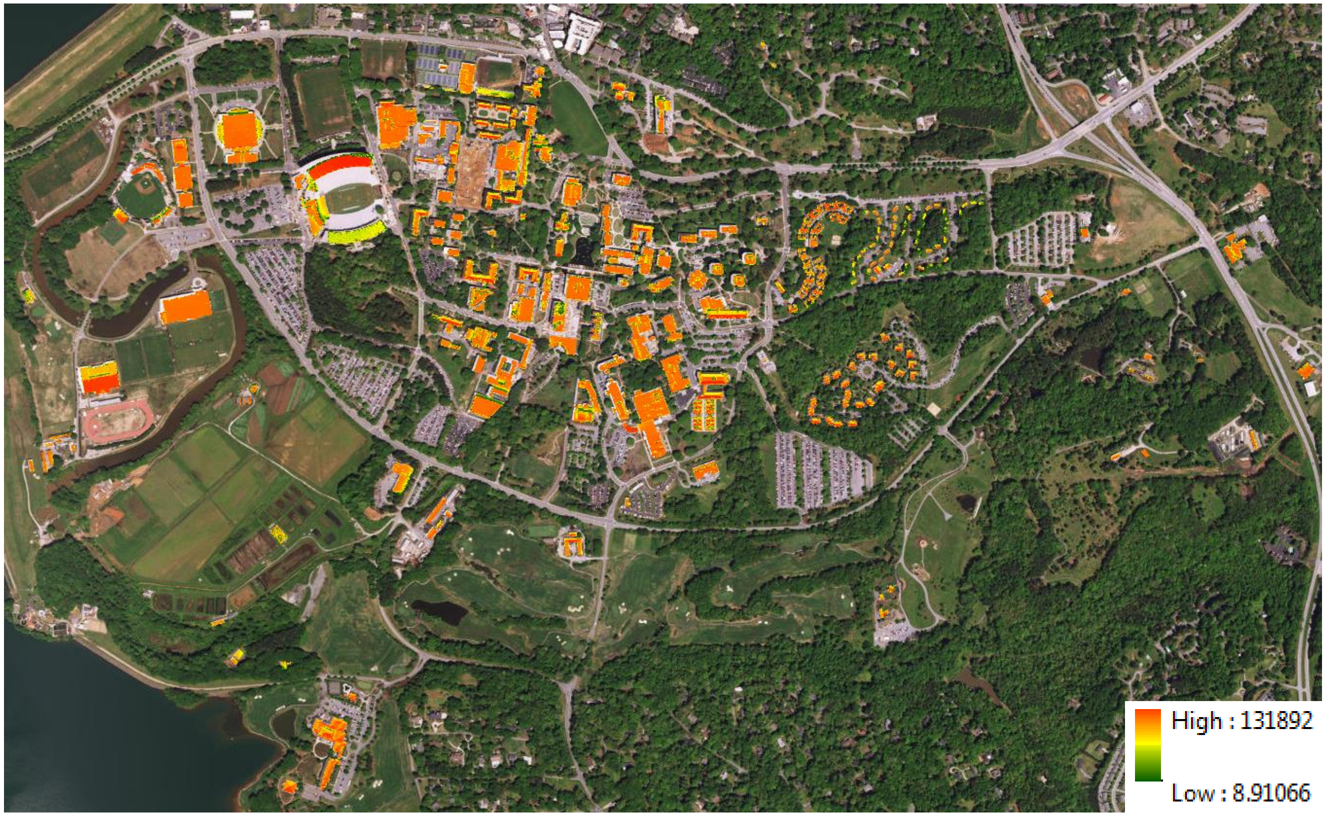

Figure 32. Clemson Rooftop Solar Radiation Potential for March (Wh/m^2 per month)

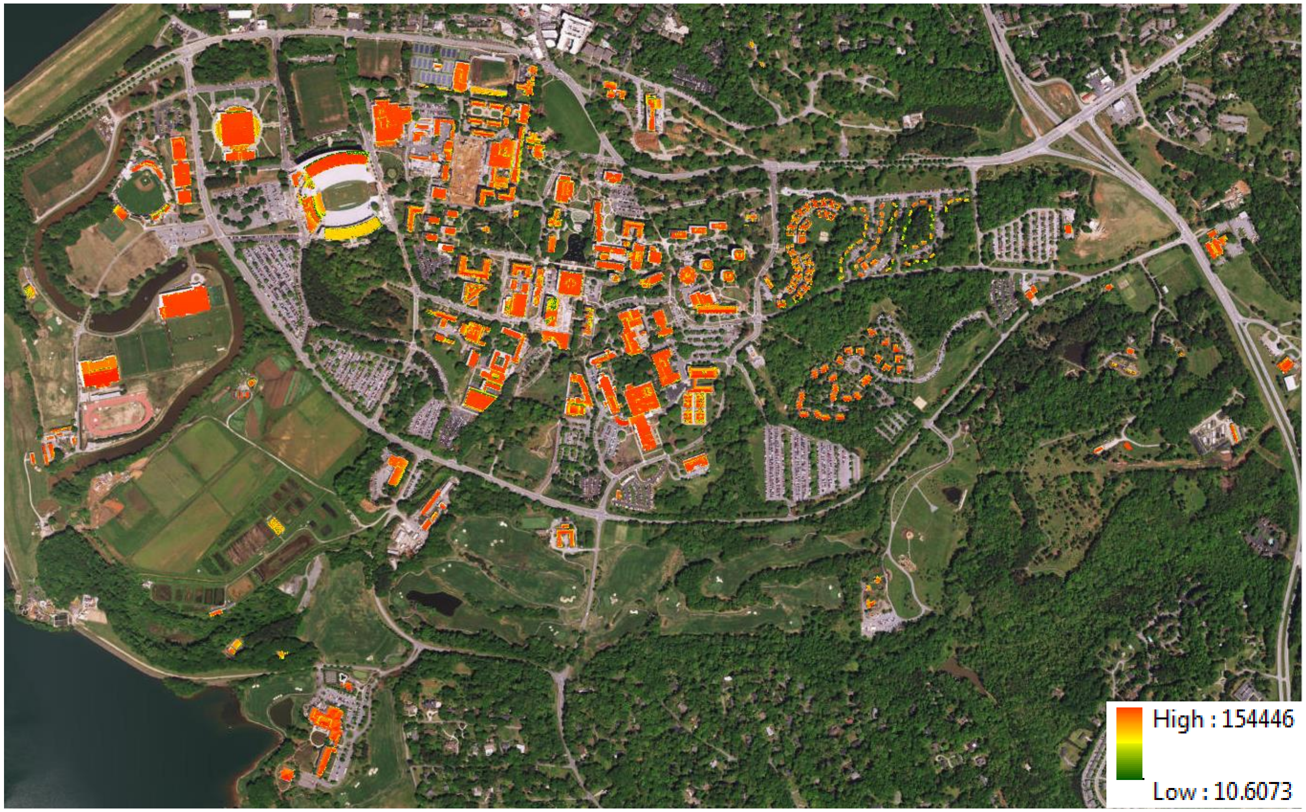

Figure 33. Clemson Rooftop Solar Radiation Potential for April (Wh/m^2 per month)

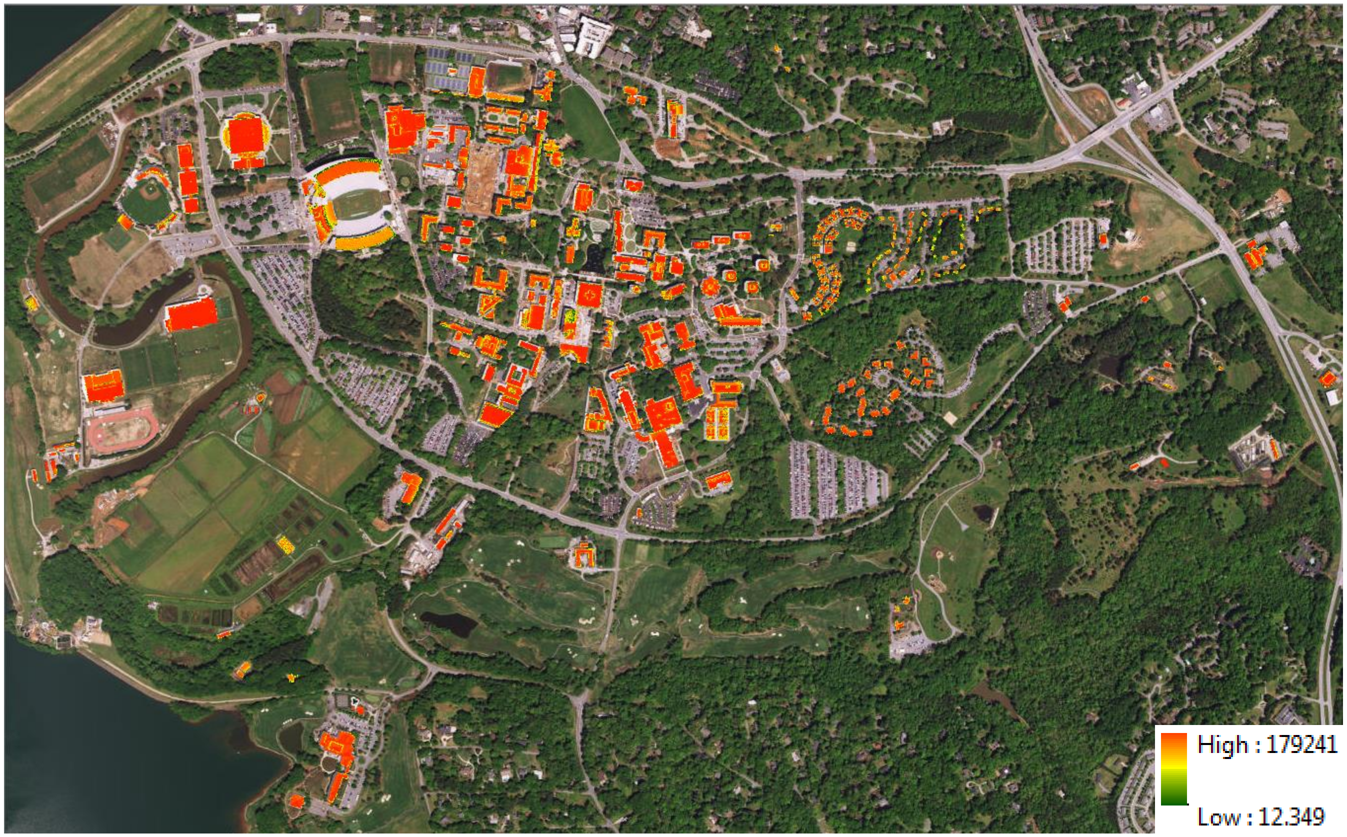

Figure 34. Clemson Rooftop Solar Radiation Potential for May (Wh/m^2 per month)

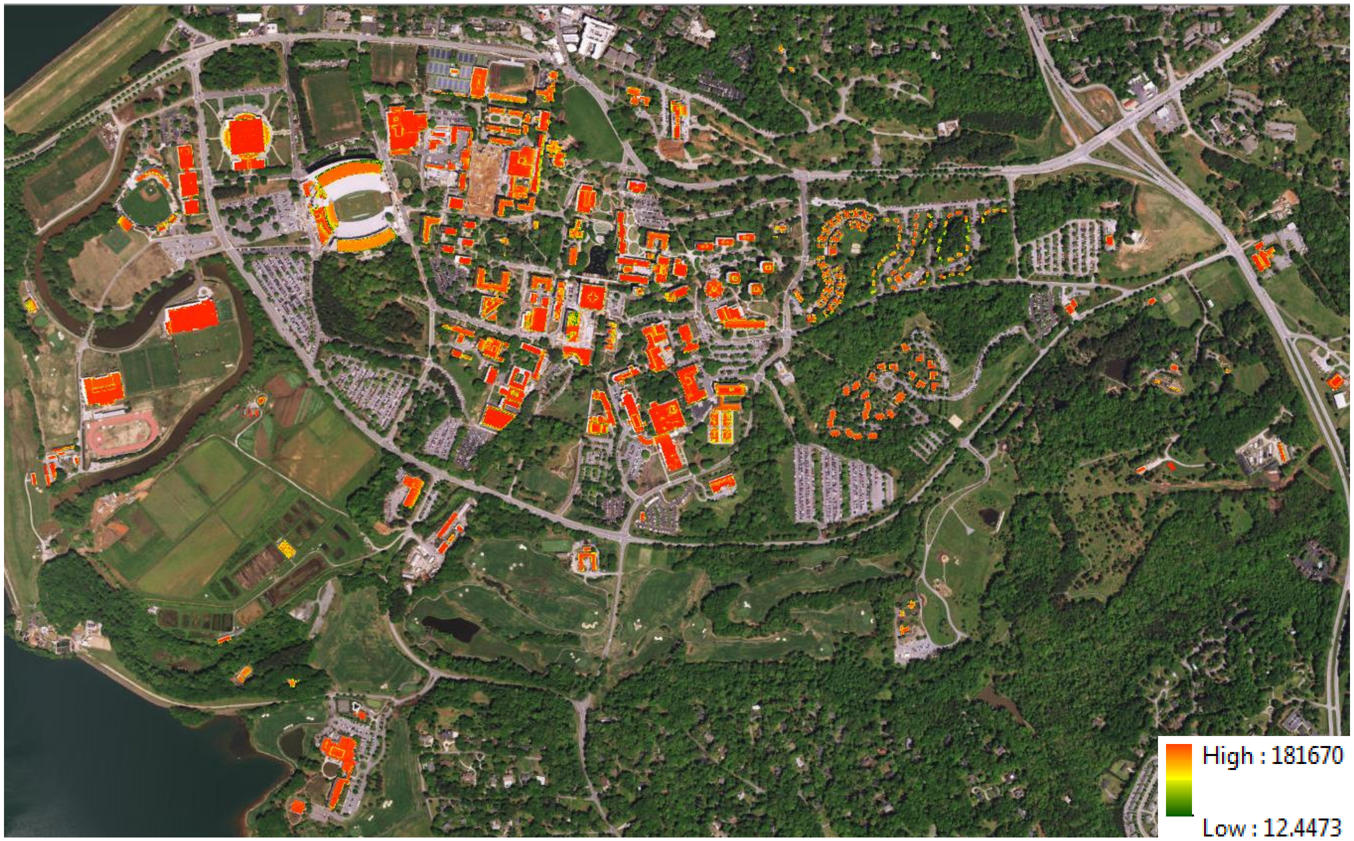

Figure 35. Clemson Rooftop Solar Radiation Potential for June (Wh/m^2 per month)

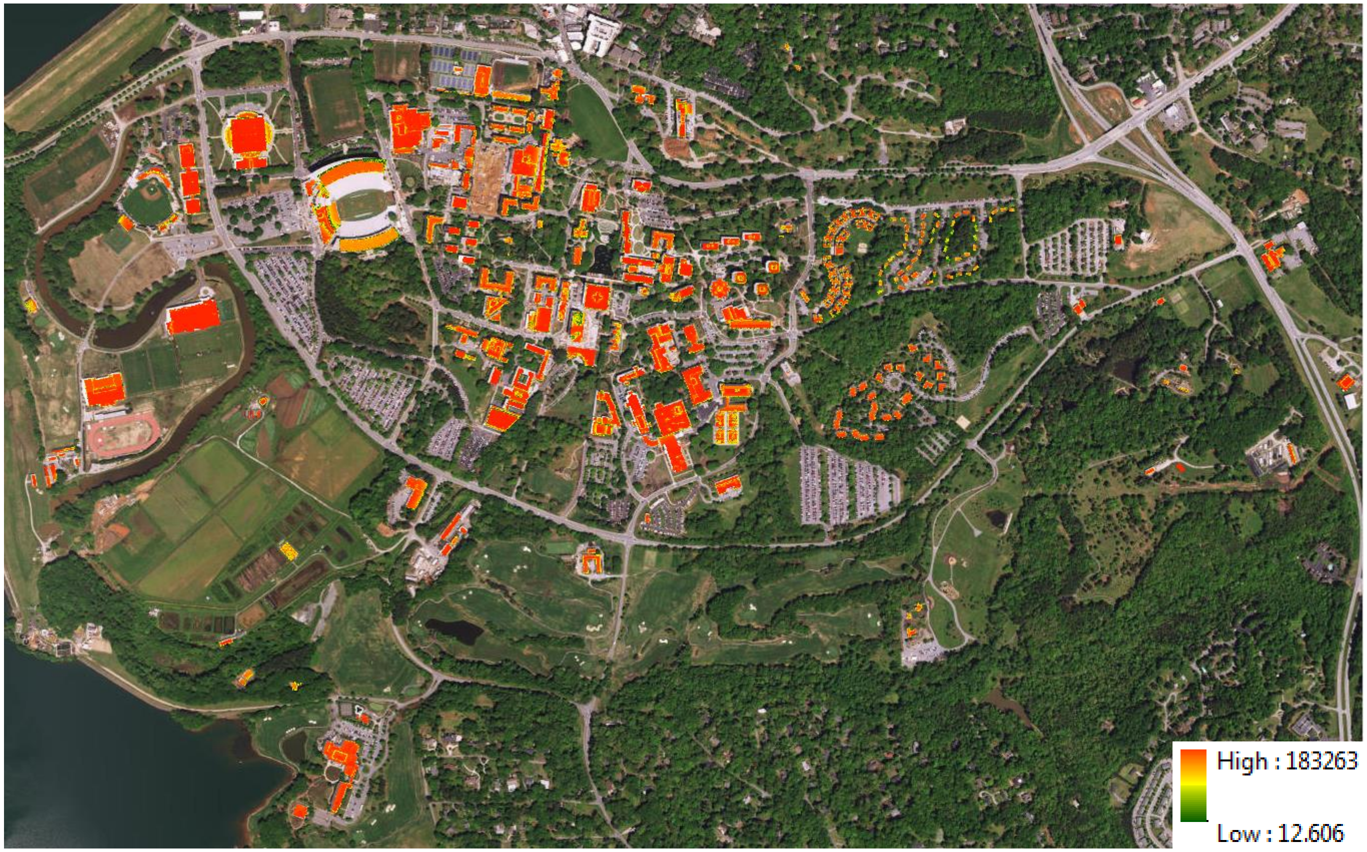

Figure 36. Clemson Rooftop Solar Radiation Potential for July (Wh/m^2 per month)

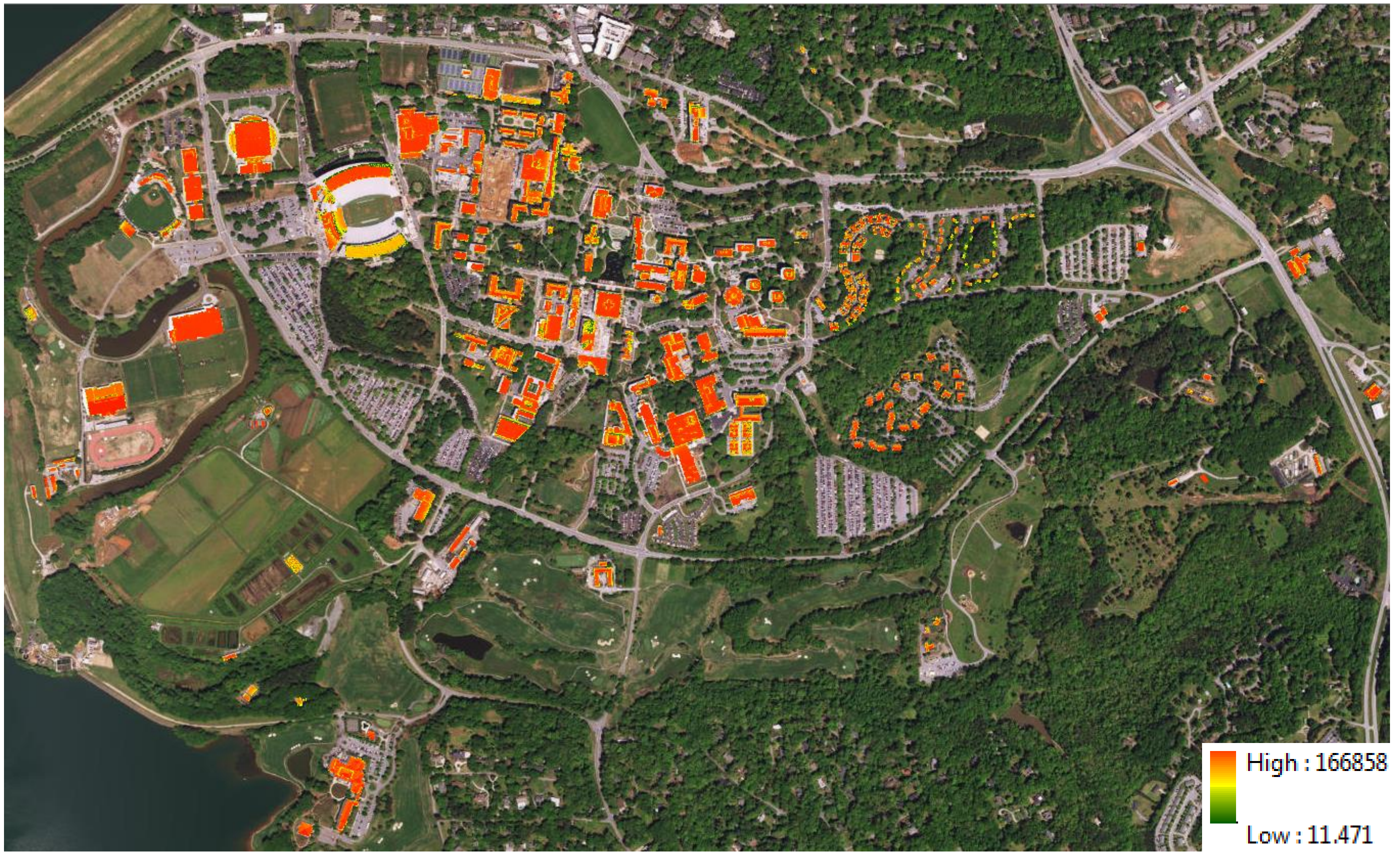

Figure 37. Clemson Rooftop Solar Radiation Potential for August (Wh/m^2 per month)

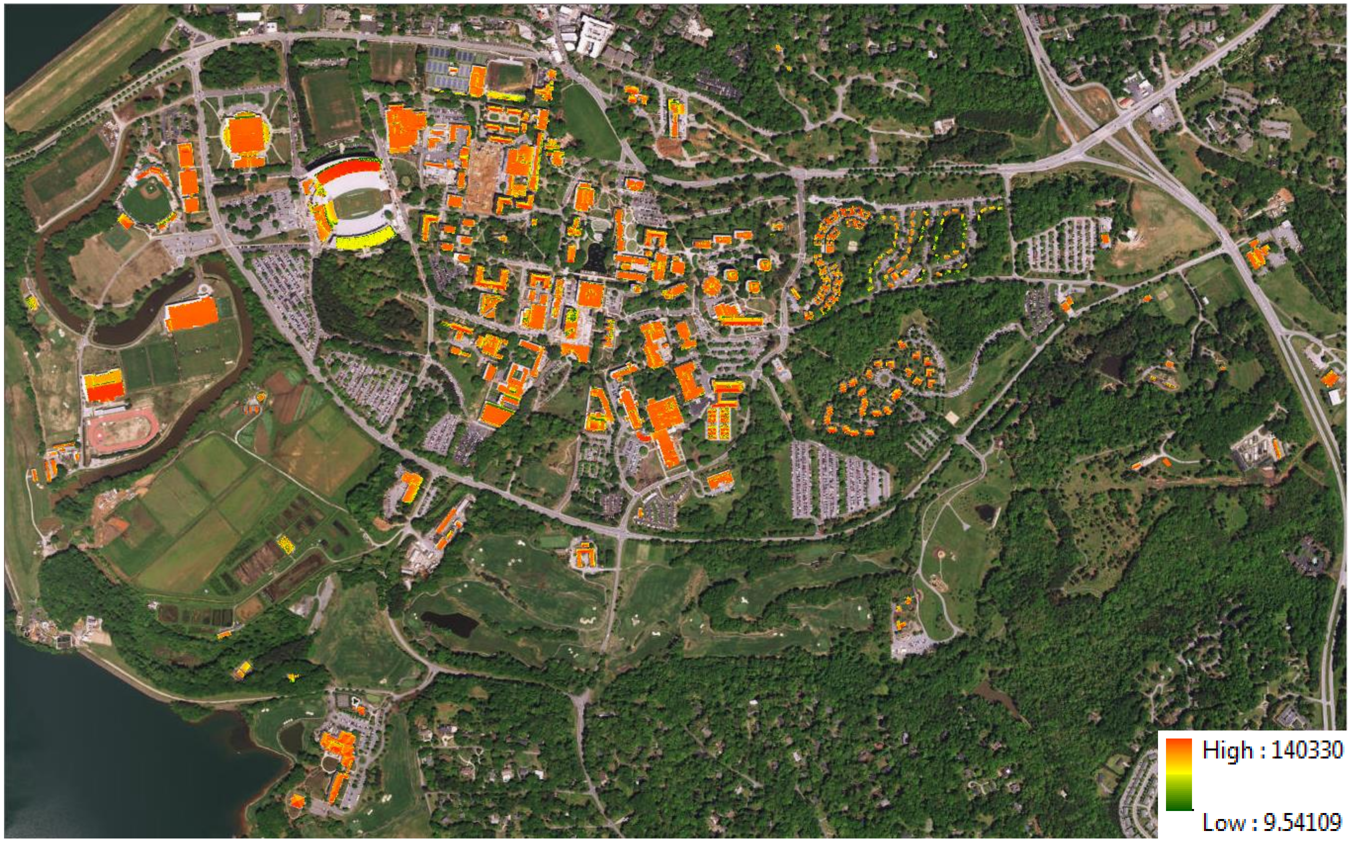

Figure 38. Clemson Rooftop Solar Radiation Potential for September (Wh/m^2 per month)

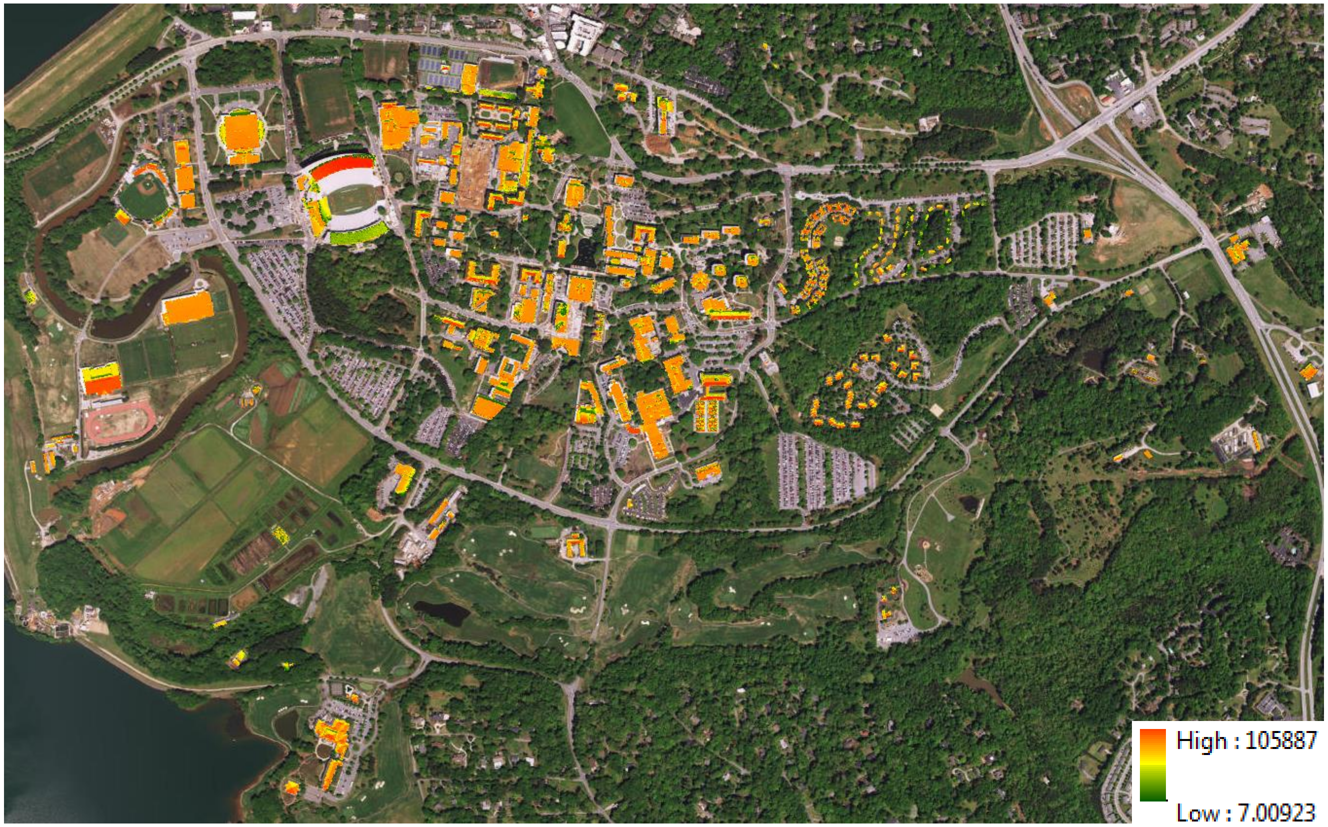

Figure 39. Clemson Rooftop Solar Radiation Potential for October (Wh/m^2 per month)

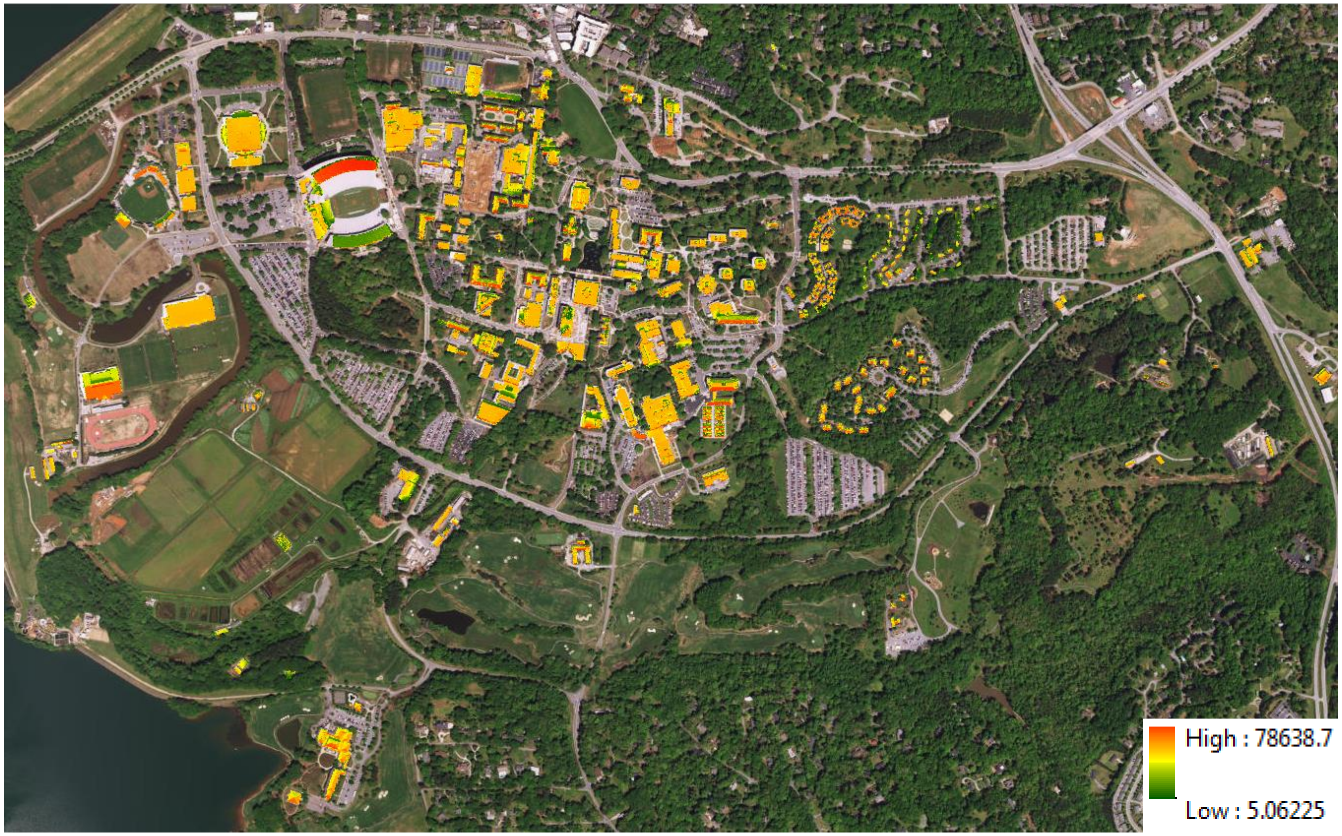

Figure 40. Clemson Rooftop Solar Radiation Potential for November (Wh/m^2 per month)

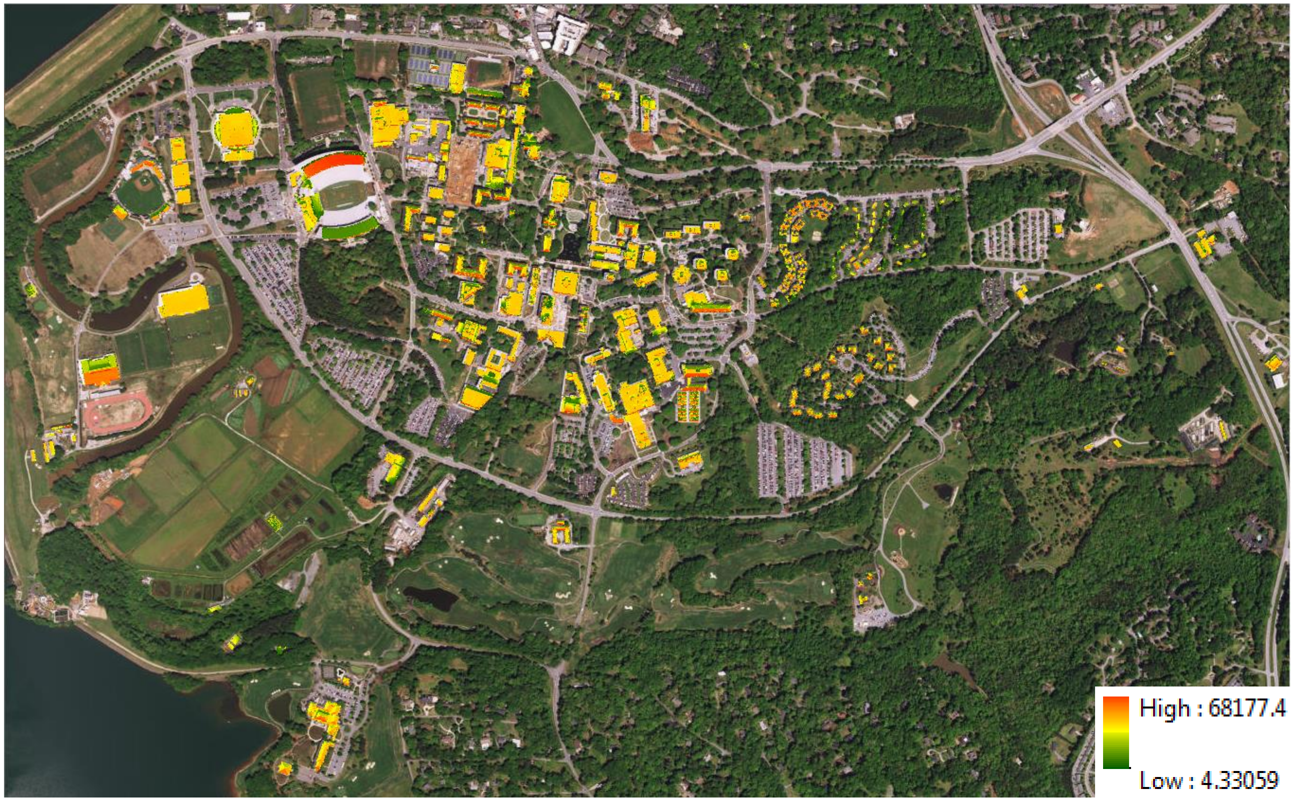

Figure 41. Clemson Rooftop Solar Radiation Potential for December (Wh/m^2 per month)

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