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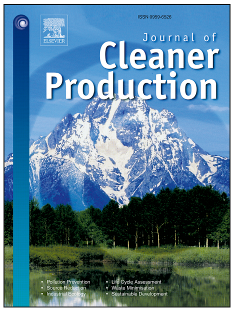

Assessing the carbon footprint of a university campus using a life cycle assessment approach

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Assessing the carbon footprint of a university campus using a life cycle assessment approach

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Abstract

To respond to anthropogenic effects on the global climate system, higher education institutions are assessing and aiming to reduce their greenhouse gas emissions. The objective of this paper was to evaluate the carbon footprint of Clemson University's campus using a streamlined life cycle assessment approach. The carbon footprint sets a baseline for source specific evaluation and future mitigation efforts at Clemson University. Greenhouse gas emission sources presented in this carbon footprint include steam generation, refrigerants, electricity generation, electricity life cycle, various forms of transportation, wastewater treatment, and paper usage. This case study describes the approach used to quantify each greenhouse gas emission source, and discusses data assumptions and life cycles phases included to improve carbon footprint comparison with other higher education institutions. Results show that Clemson University's carbon footprint for 2014 is approximately 95,000 metric tons CO_2-equivalent, and 4.4 metric tons CO_2-equivalent per student. Scope 1 emissions accounted for about 19% of the carbon footprint, while Scope 2 and 3 emissions each contributed nearly 41%. The largest sources of greenhouse gas emissions were electricity generation (41%), automotive commuting (18%), and steam generation (16%). Electricity generation from coal was 29% of the electricity generation resource mix and accounted for three-quarters of Clemson University's GHG emissions associated with electricity.

Keywords

Life cycle assessment approach

Carbon footprint

Higher education institution

University

1 Introduction

Increased greenhouse gas (GHG) emissions coupled with other anthropogenic drivers are extremely likely to be the dominant cause of recent and expected global warming (Stocker, et al., 2013). This paper assesses the GHG emissions of a large university, which can generate a GHG emissions profile similar to that of a small city (Knuth, et al., 2007). The U.S. alone hosts approximately 4,600 degree-granting postsecondary institutions which enroll nearly 20 million students (Snyder, et al., 2019). As society moves towards GHG emissions reduction, universities can play an active role through education and by presenting themselves as a model (Geng, et al., 2013; Clarke & Kouri, 2009).

In the past, higher education institutions (HEIs) have participated in environmental sustainability declarations such as the Talloires, Halifax, and Kyoto Declarations (Evangelinos, et al., 2009). More recently, many HEIs have adopted 'green' initiatives and have signed focused commitments such as the prominent American College & University Presidents' Climate Commitment (ACUPCC) (Sharp, 2002; Cleaves, et al., 2009). Since its inception, the ACUPCC has evolved into three Presidents' Climate Leadership Commitments. Each commitment requires a climate action plan, and two of the commitments require the signatory HEI to complete a comprehensive inventory of its GHG emissions and set a target date for achieving carbon neutrality (Second Nature, 2018a).

Currently, over 400 institutions have signed a Presidents' Climate Leadership Commitment, many reporting their GHG emissions inventory utilizing the Sustainability Indicator Management and Analysis Platform (SIMAP), (which was previously the Clean Air-Cool Planet Campus Carbon Calculator) while others use their own custom tools, or contract outside firms to create their carbon footprint (CF) (Second Nature, 2018b; UNH Sustainability Institute, 2018). In the quest to quantify GHG emissions, several HEIs have also used a life cycle assessment (LCA) approach (Lukman, et al., 2009; Baboulet & Lenzen, 2010; Guereca, et al., 2013). LCA methods vary, some apply environmentally-extended input-output (IO) analysis (Townsend & Barrett, 2015; Larsen, et al., 2013; Thurston & Eckelman, 2011; Gómez, et al., 2016), while others use an approach similar to a process analysis (PA) 'bottom-up' method (Letete, et al., 2012; Klein-Banai, et al., 2010; Li, et al., 2015).

As more HEIs quantify their GHG emissions, transparent models are needed to illustrate carbon footprinting approaches and enable clearer comparison between HEI. Evaluating similarities or differences in HEI's major GHG emissions sources can help concentrate goals, strategies, and policies to reduce emissions. However, comparisons are difficult as institutions have ranging population sizes, GHG emission sources, and variations in their CF methodology. Comparison of HEI CFs can be challenging as the GHG emission sources included are not always consistent, particularly regarding the inclusion of Scope 3 emissions. In some HEIs it has been suggested that indirect emissions can account for up to 80% of their CF (Ozawa-Meida, et al., 2013; Gómez, et al., 2016). While in other studies, Scope 3 emissions makeup as little as 18% of the CF (Klein-Banai, et al., 2010). This has been recognized as an issue by environmental practitioners, some have even expressed concern that their institution may be portrayed unfairly due to differential reporting in indirect emissions (Robinson, et al., 2017).

As a contribution to efforts quantifying GHG emissions in HEIs, this study evaluates Clemson University (CU), a public university in South Carolina. This case study builds a CF of CU using a streamlined LCA approach to quantify its GHG emission sources. In this case study, the GHG emission sources and the life cycle phases included in the assessment are explicitly stated, along with assumptions, quantified flows, and data sources. It is the hope of the authors that this study aids other HEIs to consider the impact of various GHG emission sources and phases included in their own CFs, as well as highlight data sources they may need. Furthermore, by describing each GHG source data source and system boundary this paper aims to enable more accurate comparison between HEIs.

2 Case study: Clemson University

CU resides in the northwest corner of South Carolina and is the second largest university in the state. The university offers over 80 majors, 75 minors, 110 graduate degree programs, and recently reached the R1 Carnegie classification as a highest research activity doctoral university (Clemson University, 2017a). This case study focuses on data gathered in 2014, thus Table 1 summarizes the characteristics of CU for the 2013/2014 academic year.

Table 1. Clemson University characteristics for 2013/2014

Total academic building area	613,816 m^2
Annual budget[a]	$907 million
Undergraduate students	17,260
Graduate students	4,597
Faculty	1,388
Administrators	208
Staff	3,304
Student faculty ratio	17:01
Research program funding[a]	$148 million
Average journal publications per year	1,221

Sources: Clemson University, 2014; Clemson University, 2017c, 2017d, 2017e

[a]Proposed operating budget for 2013/2014

In 2007, CU signed the ACUPCC and set long-term goals to increase renewable energy sourcing to 10% by 2025, and to become carbon neutral by 2030 (CU President's Commission on Sustainability, 2011). Currently the major sources of GHG emissions related to campus operations include electricity, steam generation, and transportation associated with the university. Many of the energy-related processes are controlled by CU Facilities, including the on-campus natural gas-fired steam generation plant. To reduce its CF, the university has switched from coal to natural gas for steam generation, and has worked to increase efficiency of electricity appliances and equipment on campus. As a state organization, new buildings and renovations are also required to meet at least Leadership in Energy and Environmental Design

(LEED) Silver standards. However, indirect emissions from transportation such as commuting and university related travel are more difficult to control, so overall additional projects are needed for the university to reach carbon neutrality.

2.1 Scope and boundaries

CU has several buildings outside of its main campus, including off-campus department buildings, and additional remote facilities throughout South Carolina e.g., in Greenville, Greenwood, Columbia, and Charleston (Clemson University, 2017a). This study is bound by GHG emission sources and buildings on or related to CU's main campus, with the inclusion of the Madren Conference Center and CU Wastewater Treatment Plant, which are located near the main campus. The principal data collected to quantify the GHG emissions of CU for this study stem from systems operating in 2014, and in cases where data were unavailable for this year, it was assumed that data and supporting surveys available from 2015 to 2017 could be used to characterize the system. The ACUPCC does not consider existing forests to be carbon offsets as they not a GHG emissions reduction action above normal operations, therefore CU's 70 square kilometer experimental forest was not included in this study (Clemson University, 2017b).

Figure 1. General boundary of Clemson University's main campus delineated by black line

3 Approach

3.1 Greenhouse Gas Selection

Carbon footprinting attempts to capture the total GHG emissions that are directly and indirectly caused by a human activity, including those accumulated over the life stages of a product (Wiedmann, 2009). The Intergovernmental Panel on Climate Change (IPCC) recognizes that many gases have global warming potential (GWP) (Stocker, et al., 2013), however there is not a consensus on the spectrum of GHGs that should be included in a CF (Wiedmann & Minx, 2008). Under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, only six GHGs; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are considered (UNFCCC, 2008). The ACUPCC signatories are expected to track and report emissions of the six Kyoto GHGs; focusing on CO_2 (Dautremont-Smith, et al., 2007). The case study of CU includes emissions of these six Kyoto GHGs, with the addition of hydro-chlorofluorocarbon (HCFC) from refrigerants on campus.

3.2 Scopes and Phases Considered

GHG emissions can be broken down into three scopes as defined by the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBSCD) Greenhouse Gas Protocol Corporate Standard (WRI & WBCSD, 2004). Scope 1 emissions include direct GHG emissions that occur from sources that are owned or controlled by the organization (i.e. from CU-owned facilities), Scope 2 emissions consist of upstream emissions from the generation of purchased electricity, and Scope 3 emissions are indirect emissions from sources owned or controlled by another entity (WRI & WBCSD, 2004).

To quantify CU's GHG emissions, a CF was created utilizing a LCA based approach. For each source, a streamlined LCA method was used to estimate emissions for life cycle phases with high potential emissions (e.g. fuel combustion), and additional emissions sources were evaluated based on data availability. Data for the use phase at CU was available to quantify the CF contribution for most GHG emissions sources. However, the streamlined LCA approach was applied to include other significant life cycle phases for each GHG emissions source. Evaluating past CF for HEIs guided the selection of phases included in CU's CF. This case study was further streamlined since only select environmental impacts (e.g. GWP) were considered in the LCA approach.

This case study applied a top-down approach for the estimation of emission factors, while using a bottom-up approach for the accounting of activity intensities. The advantage of this streamlined life cycle assessment approach over using a GHG inventory tool was that it was able to be catered to incorporate the available site-specific data for each GHG emission source. For example, calculating the GHG emissions associated with steam generation was more rigorous than just applying an emission factor to the volume of natural gas consumed. CO_2 combustion emissions were quantified using the chemical composition of the natural gas provided to CU (using stoichiometric relations) and incorporated the efficiency of the boilers used. Similarly, automotive commuting emissions utilized commuter survey data and specific fuel economy to characterize GHG emissions from fuel consumption. In addition, waterwaster treatment sought out an emissions factor that aligned with the specific wastewater treatment process used.

Most of the data available for CU were recorded in the terms of energy and mass units, except for university-related travel which was reported in monetary terms. However, usually only data for the use phase were recorded by CU, so upstream emissions were estimated under the use of openLCA 1.7 (Di Noi, et al., 2017) with Ecoinvent database version 3.3 (Wernet, et al., 2016) or gleaned from literature. If GHG emission sources did not have specific data available or recorded, then estimates gathered from literature or generic data were used. Indirect emissions were particularly difficult to quantify as data for these GHG emission sources (e.g. paper use) originates from different parties, and records for various phases of the life cycle are not always available to the university. This study preferentially used LCA literature data representative of the U.S. market, however when no data for the U.S. were available (e.g. for wastewater chemicals), then data from the European or global markets were used.

CF case studies do not always detail their assumptions and the life cycle phases evaluated for each GHG emission source. Utilizing a process-based LCA approach is also limited in that process based LCAs often fail to account for all of the activities associated with a final demand and systematically underestimates environmental impacts (Majeau-Bettez, et al., 2011). Since the life cycle phases included in the CU CF differ between GHG emissions sources, Table 2 is provided. This table aims to avoid reader assumptions and aid in HEI CF comparisons by illustrating where there are potentially additional GHG emissions associated with each source.

Table 2. Emission types and data sources considered for carbon footprint

Emission Type	GHG Emission Source	Phase	Flow	Data Source
Scope 1 Direct emissions	Steam generation	Production	Natural gas combustion	CU Facilities
	Refrigerants	Use	HFCs and HCFC releases	CU Facilities
	University owned vehicles	Use	Gasoline & diesel combustion	CU Parking and Transportation Services, CU Police Department
	University owned aircraft	Use	Jet fuel combustion	CU Chief Pilot
	Fertilizer application	Use	Fertilizer nitrification and denitrification	CU Facilities
	Wastewater treatment	Use	Aerobic digestion of sludge	CU Facilities
Scope 2 Indirect emissions	Electricity generation	Production	Coal, gas, & oil combustion in power plants	CU Utility Services, EPA eGRID
Scope 3 Indirect emissions	Electricity life cycle	Cradle to grave	Plant, construction, operation, materials, and decommissioning	Literature
	Transmission and distribution losses	Distribution	Coal, gas, & oil combustion in power plants	EPA eGRID
	Automotive commuting	Use	Gasoline combustion	CU Parking and Transportation Services
	Clemson area transit bus system	Use	Electricity use & diesel combustion	Clemson Area Transit
	University related travel	Use Cradle to consumer	Gasoline combustion Air transportation	CU Facilities
	Paper	Cradle to gate	Office paper, paper towels, & bathroom tissue	CU Facilities
	Natural gas leakage	Cradle to gate	Natural gas leakage associated with steam generation	Literature
	Refrigerants	Cradle to gate	HCFC-22 only	CU Facilities
	Waste and recycling transportation	Post-use transportation	Gasoline combustion	CU Recycling Services
	Wastewater Treatment Chemicals	Cradle to consumer	Chemicals	CU Facilities
	Water treatment	Chemical production, transportation of materials, and plant	Chemicals & operation	CU Wastewater Treatment Plant

operation

3.3 Methods

To estimate the CF, this research applied a consumption-based hybrid LCA (HLCA) approach. HLCA methods are appropriate to calculate organizational footprints because they produce complete results whilst being application-specific (Baboulet & Lenzen, 2010). To quantify the effects of these GHG emissions, the 100-year time horizon GWP was used based on the values defined in the IPCC Fifth Assessment Report (AR5) (Stocker, et al., 2013), and the total CF was expressed in CO_2 equivalent (CO_2-e) emissions. GHG emissions were calculated for each source using the following formula.

$$E_G = S \times EF_A \quad (1)$$

Here, the GHG emissions emitted from a specific source (E_G) can be quantified by combining S, which represents the source expressed in units, with its respective GHG emission factor (EF_A). Examples of a source's units include cubic meters of gasoline and kilograms of fertilizer. Emission factors for specific GHG emission sources were adopted from literature, and fuel combustion emissions factors originated from the U.S. Energy Information Administration (EIA) (EIA, 2016). Once the total GHG emissions from all sources were found, they were summed to quantify the total CF in metric tons of CO_2-e.

3.4 Scope 1

Scope 1 emissions encompass direct GHG emissions occurring from sources that are owned or controlled by CU. In this CF, emissions were analyzed from the operational phase for CU's steam generation, refrigerant use, vehicles, aircraft, fertilizer, and wastewater treatment.

3.4.1 Steam generation

CU's on-campus steam plant uses natural gas boilers to generate steam for space heating, domestic hot water, dehumidification, and other processes. Natural gas consumption and steam production quantities were obtained from plant records, which was collected on hourly intervals every day. To determine GHG emissions, the composition of the natural gas was obtained from the supplying pipeline company. In a properly tuned boiler nearly all the carbon fuel in the natural gas (99.9%) is converted to CO_2 during combustion (EPA, 1998), so complete combustion was assumed. Then, stoichiometric equations for the hydrocarbons constituting the natural gas were used to determine the CO_2 produced annually from natural gas combustion. Uncertainty in these calculations stems from the assumption that boilers were performing complete combustion and the composition of the natural gas. The composition of the gas delivered varies slightly each day, and an average was calculated using daily chromatography data over three months as data beyond this range was unavailable from the natural gas provider.

3.4.2 Refrigerants

This analysis evaluated the refrigerant fluid leaking from air conditioning units into the atmosphere. Substantial refrigerant leaks are reported and fixed, however many small leaks are "topped off" if the leak is not significant enough to repair. The leakages of hydro-chlorofluorocarbon (HCFC-22) and hydro-fluorocarbons (HFC-404A and HFC-410A) were quantified by weighing drums of refrigerant before and after refrigerant was added to top off units. The refrigerant added to units was assumed to be the amount leaked out into the atmosphere in this year. Over 96% of the refrigerant released during this period was HCFC-22.

3.4.3 University owned vehicles

CU owns a variety of vehicles that aid in campus operations. A shuttle service called Tiger Transit provides a daily park and ride service for students parking on the outskirts of campus. CU's Police Department (CUPD) also utilizes multiple vehicles to patrol daily. Total fuel usage for Tiger Transit was recorded by Parking and Transportation Services, while the CUPD fleet coordinator provided information about vehicle usage and patrol distance to estimate fuel consumption. From this, the consumption of gasoline and diesel from these vehicles was determined. The university also owns several golf carts which are used intermittently. Due to a lack of data, it was assumed the electricity used by electric golf carts was included in the total campus electricity consumption, while potential emissions from any gasoline powered carts and other miscellaneous facilities vehicles were not quantified. Note that CU also produces its own biodiesel to fuel CU Facilities trucks on campus, and these emissions were assumed to be carbon neutral.

3.4.4 University owned aircraft

CU has two private aircraft; a 2008 Citation CJ3 jet, and a 1998 Beechcraft King Air C90B Turboprop. The Chief Pilot for CU provided information about the average annual time each vessel was flown, and the fuel consumption rates, which together were used to estimate the total fuel. For future analysis, detailed data recording the total annual fuel used and specific combustion statistics for the aircrafts is preferential since jet fuel consumption can be influenced by the number of factors; including frequency of takeoffs and landings, wind speed and direction, weight carried, and flying altitude.

3.4.5 Fertilizer

CU Facilities records the amount of nitrogen fertilizer used on its campus landscaping, the Walker Golf Course, and at the Madren Conference Center. The application of this fertilizer increases the available nitrogen in the soil, which enhances nitrification and denitrification rates and in turn increases the production of N_2O (De Klein, et al., 2006). Emissions from fertilizer application varies due to differences in soil type, moisture, temperature, season, plant type, and management practices (EPA, 1996). However, these data were unavailable, so direct atmospheric emissions associated with denitrification and nitrification after fertilizer application were quantified using an average emissions factor of 0.01 kg N_2O–N per kg N applied (De Klein, et al., 2006). Indirect emissions from potential leeching and runoff were not considered, nor were possible emissions associated with machinery used in fertilizer application.

3.4.6 Wastewater treatment

CU owns and operates its own wastewater treatment plant (WWTP). The main unit operation at the plant is a sequencing batch reactor. The U.S. Environmental Protection Agency (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 (EPA, 2010). However, the values needed for these calculations could not be obtained for the CU WWTP. Therefore, GHG emissions were estimated using a procedure outlined by Monteith et al. (2005) for various wastewater treatment processes when facility-specific data are unknown. Sequencing batch reactors are a version of the activated sludge process, so the CU system was assumed to be similar enough to a conventional activated sludge process to quantify emissions for this study. An average of their estimated CO_2 emissions for conventional activated sludge treatment processes was applied to the wastewater treated by CU. This estimate did not account for solid waste disposal or electricity for operation, however, WWTP electricity is already included in CU's total electricity consumption.

3.5 Scope 2

Scope 2 emissions consists of the upstream emissions from the generation of purchased electricity. CU's electricity is provided by Duke Energy Carolinas, LLC, whose service territory covers the western portions of North and South Carolina.

3.5.1 Electricity generation

Emissions from purchased electricity generation were calculated using data from CU Facilities and the U.S. EPA Emissions & Generation Resource Integrated Database (eGRID). The eGRID database contains data for electricity generating plants that supplied power to the electric grid in 2014, including each plant's net generation and associated environmental emissions (EPA, 2017b). This dataset was filtered to include only plants operating under CU's electricity provider Duke Energy Carolinas, LLC, and then was further sorted by each plant's primary fuel. GHG emissions from electricity generation were quantified for plants with primary fuels of coal, gas, and oil, and it was assumed that were no direct GHG emissions associated with electricity generation from biomass, hydro, nuclear, or solar fuel sources. Next, GHG emissions were allocated based on CU's proportional use of electricity, which was 0.11% of the total generation from Duke Energy Carolinas, LLC

Table 3 compares the electricity generation resource mix supplied to CU by Duke Energy Carolinas, LLC to the average for its SERC Reliability Corporation (SERC) area and the U.S. national average. The SIMAP tool utilized by many HEIs applies the eGRID sub-region unless the user knows the specific utility resource generation mix. To demonstrate the significance of using the specific electricity generation resource mix, both the SERC and U.S. generation resource mix output GHG emissions rates were applied to CU's CF. Within CU's electricity generation, coal plants were responsible for 79% of overall GHG emissions even though it accounted for only 29% of the resource mix. By applying the SERC value rather than the more specific electricity provider's value, Scope 2 GHG emissions became almost 21% greater in magnitude, and increased CU's CF by about 8%. Furthermore, applying the national average generation resource mix increased total CU's Scope 2 GHG emissions by nearly 59% and increased its CF by about 24%.

Table 3. Comparison of electricity generation resource mixes

Generation Resource Mix (%)	Clemson University[a]	SERC Virginia/Carolinas[b]	U.S.[b]
Coal	28.99	31.7	38.7
Oil	0.06	0.6	0.7
Gas	15.14	20.8	27.5
Other fossil	0	0.3	0.5
Nuclear	52.61	42.2	19.5
Hydro	2.27	1.3	6.2
Biomass	0.69	2.9	1.6
Wind	0	0	4.4
Solar	0.24	0.2	0.4
Geothermal	0	0	0.4
Other unknown/purchased fuel	0	0.1	0.1
Output emission rate CO_2-e (kg/MWh)	323	391	513

[a] CU resource generation mix is based on Duke Energy Carolinas, LLC eGRID data
[b] Generation resource mixes and emissions rates based on eGRID summary tables (EPA, 2017a)

3.6 Scope 3

Scope 3 emissions includes all indirect emissions that come from sources owned or controlled by outside entities, excluding Scope 2 emissions. The inclusion of GHG emissions sources in this scope was guided by previous CFs of HEIs, and was also based on data availability. CU's Scope 3 emissions analyzed the life cycle of electricity generation, electricity transmission and distribution, various forms of commuting, university related travel, natural gas leakage associated with steam generation, paper usage, waste and recycling transportation, wastewater treatment chemicals, and water treatment.

3.6.1 Electricity life cycle

Electricity has indirect emissions associated with processes such as raw materials extraction, materials manufacturing, component manufacturing, materials transportation, and infrastructure construction. Since there are numerous plants included in the electricity generation of Duke Energy Carolinas, life cycle emission factors were taken from literature for each electricity generation source. The National Renewable Energy Laboratory (NREL) conducted a meta-analytical review and harmonization of LCAs for several electricity generation technologies. This process evaluated and disaggregated emissions estimates based on the life cycle stages they included, and then adjusted all the studies to have consistent boundaries for comparison (Whitaker, et al., 2012). The median life cycle emissions factors for coal, gas, nuclear, and solar were gleaned from these studies (Whitaker, et al., 2012; Heath, et al., 2014; Warner & Heath, 2012; Kim, et al., 2012). Median life cycle emissions from biomass and hydropower were taken from the IPCC's Fifth Assessment report (AR5) (Edenhofer, et al., 2014), while oil did not have a harmonized emissions factor, so its value was adopted from Sovacool (2008). Each respective emissions factor was applied to the total generation and electricity mix percentages for CU. The emission factors used for this analysis did not break down the estimated life cycle emissions by phase, so the emissions from electricity generation found in Scope 2 were removed from this total to avoid double counting. Considering CU's two largest resources for electricity generation, it is noteworthy that the harmonized median life cycle GHG emissions across technologies was significantly higher for coal-fired electricity generation (980 g CO_2-e/kWh) than for nuclear (12 g CO_2-e/kWh) (Whitaker, et al., 2012; Warner & Heath, 2012). Subsequently, the life cycle GHG emissions from coal accounted for 77% of CU's electricity life cycle emissions.

3.6.2 Electricity transmission and distribution losses

To determine electricity lost in transmission and distribution from the power plant and its customers the following equation was adapted from eGRID methodology (Diem & Quiroz, 2012).

$$E_{TD} = E_{Clemson}\left(\frac{1}{1-GGL} - 1\right) \quad (2)$$

Here, E_{TD} is the electricity lost in transmission and distribution, $E_{Clemson}$ is the amount of electricity used by CU annually, and *GGL* is the eGRID grid gross loss factor. The grid loss factor for the Southeastern U.S. Virginia/Carolina where CU resides is 5.82% (Diem & Quiroz, 2012). The emissions associated with lost electricity were determined by applying the same method described for Scope 2 emissions.

3.6.3 Transportation

Indirect GHG emissions from transportation can be a significant aspect of a HEI's CF. At CU this includes commuting via personal vehicles and the local bus system, along with university related travel for employees and students.

3.6.3.1 Student and employee commuting

Automotive commuting included daily travel using a personal vehicle to reach campus during the workweek. For this analysis, data were obtained for the 16,521 full-time campus parking permits. Each permit recorded either the type of commuter (e.g. student commuter, resident, or employee) or in certain cases the type of vehicle used (light electric vehicle, motorcycle, etc.). Resident parking permits were not included in the analysis as it was assumed this population would walk to campus. The majority of permits record vehicle make, model, and year, so an average fleet fuel economy was found using vehicle-specific fuel economy data from the EPA and the Department of Energy (DOE) (EPA & DOE, 2017). A survey recording weekly commuting frequencies and distance driven was analyzed for 2,259 students and employees.

When compared to the total number of commuters, this survey produced a margin of error of 1.92% at a 95% confidence level. The surveyed distance commuted and driving frequencies by students and employees were applied with the number of parking permits and the average fleet fuel economy data to determine CO_2 emissions from fuel combustion.

There were several sources of uncertainty in the data that should be acknowledged for the readers. The average fuel economy value used assumed city driving, which may not accurately reflect all commuter habits. Also, employee vehicle registration did not distinguish between faculty and staff, so a shared average fuel economy for both groups was applied to the survey data. Furthermore, it is also a possibility that survey respondents were not fully honest when describing their driving habits, or that their driving patterns may have changed throughout the semester. There is input uncertainty as it is possible some students may not have a permit and park off-campus or are dropped off on campus by someone with an unpermitted vehicle. Another consideration not accounted for is that commuters may drive around campus for extended periods of time searching for a place to park during peak hours. These details are difficult to capture or estimate and would require more in-depth surveying in future studies.

3.6.3.2 Clemson area transit bus system

Clemson area transit bus system (CATBUS) is a fare-free public transit system that has routes on-campus and in the towns surrounding the university. CATBUS is widely used by students, employees, and local citizens, and is transitioning to an all-electric bus fleet, however in 2014 the majority of its buses were fueled by diesel. Annual reports of the fuel consumption and mileage for the diesel bus fleet were acquired from the CATBUS transit supervisor. The total electricity consumption for their electric bus fleet was obtained using monthly records projected to estimate annual electricity used for charging. The CATBUS facility is outfitted with photovoltaic solar panels, so it was assumed that the electricity generation from these panels would be applied to offset electricity used by the electric fleet, while the remaining electricity needed is provided by Duke Energy Carolinas, LLC. GHG emissions from electricity generation and incorporated transmission and distribution losses were accounted for. The on-campus routes are known to have 99% student ridership, so this was assumed for all other routes to allocate emissions to CU.

3.6.3.3 University related travel

CU administrators, faculty, and staff frequently travel for administrative purposes, to attend conferences and meetings, conduct field work, visit collaborators, and to present their research. In this analysis, expenses related to university travel were analyzed for employees and students. Transportation is the most significant source of GHG emissions in university-related travel, so emissions from food and accommodations were not included. The employee mileage driven for university related activities was determined using CU's known mileage reimbursement with the total charges. Then, this was applied with the average fuel economy found for vehicles registered by faculty and staff. Since the cost of commercial and charter flights were recorded in monetary terms for a fiscal year, the Carnegie Mellon Economic Input-Output Life Cycle Assessment (EIO-LCA) tool was used to estimate the GHG emissions resulting from spending in the air transportation sector of the U.S. economy (Carnegie Mellon

University , 2010). The 2002 U.S. purchaser price model was used (Weber, et al., 2010) and 2014 fiscal year expenditures were converted to U.S. 2002 dollars using the U.S. Consumer Price Index Inflation Calculator (BLS, 2018). Expenses incurred by university employees were detailed, however student travel expense data were aggregated and not appropriately described. Therefore, it was assumed that the average student trip would be three days, consisting of driving to an airport, a flight, accommodations, and per diem based on typical conference travel. This assumption was a source of uncertainty, and it is recommended that expenses be recorded by the university in more detail for future analysis. Furthermore, the EIO-LCA tool used for flights considered upstream materials and energy resources throughout the supply chain for the air transportation sector as a whole (Weber, et al., 2010). In this GHG emissions from jet fuel combustion were not quantified as most expense data had no information regarding travel destinations or the type of aircraft used.

3.6.4 Paper

CU uses a variety of copy paper, paper towels, and bathroom tissue. Emission factors for these products were adopted from comprehensive LCAs that quantified cradle-to-gate GHG emissions (The American Forest & Paper Association, 2010; Environmental Resources Management, 2007). The functional units from the LCA studies (e.g. 55.1 kg CO_2-e/40,000 sheets bathroom tissue) were applied to CU's product use (e.g. rolls of bathroom tissue used by CU were converted to total sheets). Paper towels and bathroom tissue products came in varying dimensions to accommodate different paper product dispensers around campus. Using known length and width for products, the overall paper use was compared to its literature reference flow.

3.6.5 Natural gas leakage

Natural gas fuels steam generation on CU's campus. Brandt et al. (2014) estimated leakage from North American natural gas systems using the EPA's GHG Inventory. Emissions associated with possible leakage during production, processing, transmission, storage, and distribution of natural gas were estimated to be 1.78% of end use gas consumed plus net storage (Brandt et al., 2014). This estimation was used along with the composition and density of the natural gas obtained from CU's natural gas transmission company to quantify methane emissions associated with leakage.

3.6.6 Refrigerants

OpenLCA was used to quantify the upstream cradle-to-gate GHG emissions associated with refrigerants replaced on campus in 2014. Ecoinvent only had data available for HCFC-22, which was 96% of the quantity of refrigerants leaked and replaced on campus. Therefore, upstream cradle to gate impacts for HFC-404A and HFC-410A were not evaluated.

3.6.7 Waste and recycling transportation

Waste and recycling are collected on campus and transported to the appropriate facilities. The frequency of pickup and the distance transported were reported by the CU Recycling Services operator and used in conjunction with the average fuel economy of a refuse truck (DOE, 2015).

3.6.8 Wastewater treatment chemicals

Already, emissions from the CU WWTP treatment processes and electricity use were used to estimate GHG emissions, however, known quantities of chemicals are also used to treat wastewater and are considered Scope 3 emissions. The WWTP provided annual usage of alum, sulfur dioxide, and chlorine, along with each chemical's supplier and manufacturing specifications. The Ecoinvent database was then utilized to examine cradle to gate life cycle inventory for each chemical (Wernet, et al., 2016), and transportation from the supplier was added through openLCA.

3.6.9 Water treatment

The university obtains water from Anderson Regional Joint Water System, however since this water treatment system is outside of CU's control, data was limited to the volume of water recieved. Therefore, surrogate data was adopted from a study by Denholm and Kulcinski (2004) to estimate the GHG impact of potable water production, including chemical production, transportation of materials, electricity, and water treatment plant operation.

4 Results and discussion

The total CF for CU was estimated to be 95,418 metric tons CO_2-e. This included Scope 1, 2, and 3 emissions, which were 18,041, 38,718, and 38,659 metric tons CO_2-e, respectively. The emissions estimated from each source are presented in Table 4, and their overall contributions are illustrated in Figure 2, which excludes GHG emission sources that constitute less than 1% to the CF. Overall, the de-minimis emissions together totaled 1,321 metric tons CO_2-e, and accounted for less than 2% of the total CF.

Table 4. Greenhouse gas emissions for Clemson University

	Source	**GHG Emissions (metric tons CO_2-e)**
Scope 1	Steam generation	15,522
	Refrigerants	143
	University owned vehicles	1,669
	University owned aircraft	515
	Fertilizer	19
	Wastewater treatment	173
	Sub-total	**18,041**
Scope 2	Electricity generation	38,718
	Sub-total	**38,718**
Scope 3	Electricity life cycle	5,207
	Transmission and distribution losses	2,393
	Automotive commuting	16,738
	Clemson area transit bus system	1,180
	University related travel	10,014
	Paper	150
	Natural gas leakage	2,656
	Refrigerants	139
	Waste and recycling transportation	27

Wastewater treatment chemicals	2
Water treatment	153
Sub-total	**38,659**
TOTAL	**95,418**

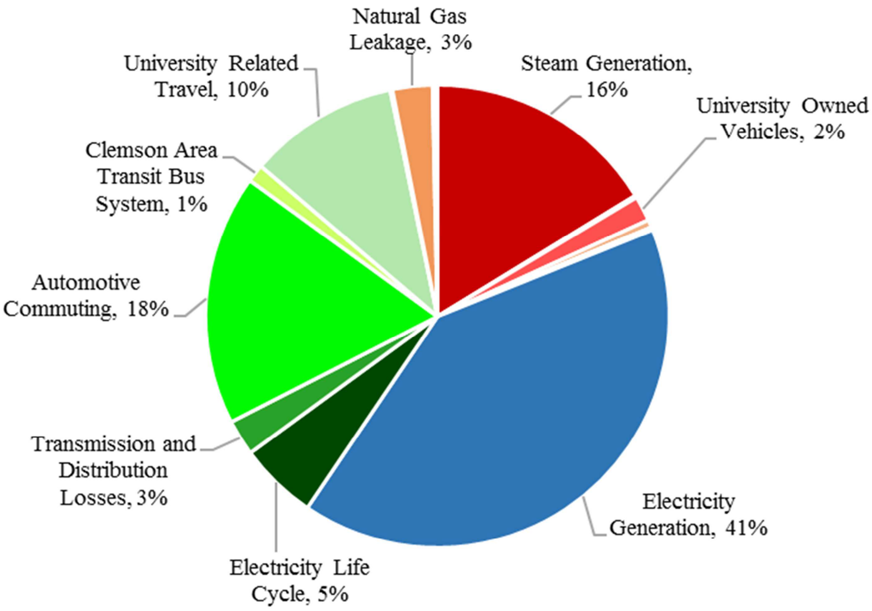

Figure 2. Clemson University's carbon footprint by source

4.1 Benchmarking

The case study of CU found that Scope 1 emissions accounted for about 19% of the CF, while Scope 2 and 3 emissions each contributed nearly 41% to the CF. Considering the listed HLCA studies in Table 5, several other HEIs besides CU have looked at heating from natural gas (Lukman, et al., 2009; Ozawa-Meida, et al., 2013; Riddell, et al., 2009), and emissions from university owned vehicles in their Scope 1 emissions (Baboulet & Lenzen, 2010; Ozawa-Meida, et al., 2013). After examining available data for specific GHG emission sources, many of CU's emissions were of similar magnitude to other HEIs. CU's Scope 1 steam generation in 2014 used about 9.5 million cubic meters of natural gas and subsequently produced 15,522 metric tons CO_2. Rowan University used about 10 million cubic meters of natural gas in their plant to create steam and cogenerate electricity, and this produced about 19,000 metric tons CO_2 (Riddell, et al., 2009). Also, CU's commuting was responsible for approximately 18% of the total CF, which is comparable to the University of Illinois at Chicago and De Montfort University, where commuting contributed 16% and 18% of their CF, respectively (Klein-Banai, et al., 2010; Ozawa-Meida, et al., 2013). Since HEI CFs often include many of the same substantial GHG emitting sources (energy consumption, transportation, etc.), comparing the CF per student (including undergraduate and graduate students) can begin to relate institutions of varied sizes. When normalized, CU has an annual CF of nearly 4.4 metric tons CO_2-e per student. This falls slightly below the average of CFs per student as seen in Table 5. Note that several HEI studies presented CFs ranging over several years, and Table 5 lists the CF from the most recent year given.

Table 5. Comparison of carbon footprints in higher education institutions

Case study	Method	Number of students	Total GHG emissions (metric tons CO_2-e)	Metric tons CO_2-e/student	Year(s) of data collection	Source
Institute of Engineering at the National Autonomous University of Mexico, Mexico	PA	581[a]	1,577[a]	2.7[a]	2010	Guereca, et al., 2013
Tongji University, China	PA	47,000	NA	3.8	2009-2010	Li, et al., 2015
The University of Cape Town, Africa	PA	21,175	84,926	4.0	2007	Letete, et al., 2012
University of Illinois at Chicago, USA	PA	25,125	275,000	10.9	2008	Klein-Banai, et al., 2010
University of Sydney, Australia	HLCA	NA	20,000[b]	NP	2008	Baboulet & Lenzen, 2010
University of Maribor, Slovenia	HLCA	3,800[a]	974[a,c]	NP		Lukman, et al., 2009
De Montfort University, England	HLCA	21,585	51,080	2.4	2008-2009	Ozawa-Meida, et al., 2013
Rowan University, USA	HLCA	9,600	38,000[c]	4.0	2007[d]	Riddell, et al., 2009
Clemson University, USA	HLCA	21,857	95,418	4.4	2014-2017	-
University of Castilla-La Mancha, Spain	IO	NA	23,000[b]	2.13	2013	Gómez, et al., 2016
Yale University, USA	IO	NA	874,000	NP	2003-2008	Thurston & Eckelman, 2011
The Norwegian University of Technology & Science, Norway	IO	20,000	92,000	4.6	2009	Larsen, et al., 2013
University of Leeds, England	IO	30,761	161,819	5.3	2010-2011	Townsend & Barrett, 2015

PA: Process analysis
HLCA: Hybrid life cycle assessment
IO: Input-Output
NA: Not available
NP: Not presented due to study limitations
[a] Engineering departments only
[b] Approximation based on given data in study
[c] Limited GHG emission sources included
[d] Fiscal year

4.2 Addressing electricity

One of the greatest contributors to the CFs of HEIs is GHG emissions associated with electricity. At CU, about 41% of emissions attributed to electricity generation, 5% emissions from electricity generation's life cycle, and about 3% from transmission and distribution losses. Table 3 shows the significant influence the electricity generation resource mix has on a HEI's potential CF, and the authors strongly encourage HEIs to investigate and describe their specific electricity generation resource mix when calculating their own CF. For example, due to its higher emissions factors, electricity generation from coal accounted for about three-quarters of CU's GHG emissions associated with electricity even though it is only about 29% of the electricity generation resource mix. Acknowledging the impact of varying electricity generation resources adds understanding to comparisons between HEIs Scope 2 emissions and overall CF. As an example, consider comparing Scope 2 GHG emissions between CU and a similarly sized HEI in Washington State. The HEI in Washington may consume greater electricity per student, but since their electricity generation is dominated by hydropower, they would have less associated Scope 2 contribution to their overall CF than CU.

Insight on the GHG impact of electricity generation sources is also valuable when developing climate action plans to decrease a campus's CF. While the electricity generation itself is often outside of a HEI's control, implementing campus based renewable energy alternatives may be a method to decrease GHG emissions associated with grid electricity generation comprised mainly of fossil fuels. As a major electricity customer, HEI can also encourage and even partner with energy providers to add more renewable energy to their electricity generation resource mix as a method to dramatically decrease their CF.

4.3 Uncertainty

Uncertainty is inherent in any emissions accounting. Therefore, the authors would like to identify elements of uncertainty in GHG emissions estimates so they can be reduced in future studies. Most uncertainty studies in LCA quantify only parameter (input data) uncertainty, though it can also arise from scenario (normative) choices and the models themselves (Lloyd & Ries, 2007). Using CU as an example, we can see that these sources of uncertainty can all be improved upon by recording more detailed data. Parameter uncertainty relates to incomplete knowledge about inputs and can stem from imprecise measurements and expert estimations (Huijbregts, 1998). In this study, this included the assumptions used for travel distances for CU's vehicles, aircraft, and waste and recycling transportation. This study also experienced scenario uncertainty emerging from system boundaries as the CF was constrained to only CU's main campus due to data unavailability from remote campus facilities. Additionally, model uncertainties were present under the assumption that emissions from LCA studies (e.g. paper usage and wastewater treatment) are similar to that of CU. Being able to recognize these sources of uncertainty can enable a feedback process to improve recording keeping and improve future CFs.

4.4 Recommendations for Future Studies

Data unavailability was the largest obstacle in this research as pointed out in individual sections. Future studies may want to have the foresight to choose between IO, PA, or HLCA approaches and determine appropriate GHG emission sources to advise more comprehensive record keeping at their university. Due to the varied operations at HEIs, it is encouraged that future CF studies report all their GHG emission sources, discuss data assumptions, and state the life cycle phases included in their evaluation. This will enable more thorough comparisons and benchmarking between HEI's CFs.

At CU there are many GHG emission sources that could be evaluated for future CFs, many related to Scope 3 emissions coming from sources owned or controlled outside the university. Additional GHG emission sources that could be assessed include composting, agriculture, food, beverages, furniture, laboratory supplies, maintenance supplies, machinery, infrastructure, and construction activities. GHG emission sources already evaluated in this study could be expanded to include additional upstream life cycle phases to Scope 1 GHG emission sources such as raw materials extraction, processing, and transportation of fertilizer and fossil fuels used. Downstream impacts such as GHG emissions associated with landfilling and recycling, and the disposal of construction and demolition materials would also be insightful to add to CU's CF. Additionally, the inclusion of carbon offsets such as purchased credits or forestry management.

4.5 Conclusions

This paper demonstrated that comparing the CFs of HEI is difficult since each have incorporated different GHG emission sources in their scopes, have varying population sizes, and often use differing methodology. As discussed, even by normalizing differences in student population the metric tons CO_2-e per student varied from 2.13 to 10.9 between the compared HEI. In some cases, similarities were found such as between CU and the Norwegian University of Technology & Science which had comparable student population and CFs. However, this case is starkly contrasted by other HEI such as the University of Illinois at Chicago which also had a similar student population, but reported a CF nearly threefold greater. This example illustrates the importance of listing the GHG emission sources included so that HEI are not compared unfairly.

Overall, the CF of CU resulted in a more complete understanding of the impact of university operations and identified significant GHG emission sources such as electricity generation and transportation. This information can help educate stakeholders about the impact of their daily activities and influence changes in campus operations. As anthropogenic GHG emissions continue, it is likely that more HEI respond with GHG emission reduction commitments. Despite their limited scope, it is important to continue discussing HEI CFs to establish baselines for future improvements and create a body of knowledge for comparative assessments.

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Total academic building area	613,816 m^2
Annual budget[a]	$907 million
Undergraduate students	17,260
Graduate students	4,597
Faculty	1,388
Administrators	208
Staff	3,304
Student faculty ratio	17:01
Research program funding[a]	$148 million
Average journal publications per year	1,221

Sources: Clemson University, 2014; Clemson University, 2017c, 2017d, 2017e

[a]Proposed operating budget for 2013/2014

Emission Type	GHG Emission Source	Phase	Flow	Data Source
Scope 1 Direct emissions	Steam generation	Production	Natural gas combustion	CU Facilities
	Refrigerants	Use	HFCs and HCFC releases	CU Facilities
	University owned vehicles	Use	Gasoline & diesel combustion	CU Parking and Transportation Services, CU Police Department
	University owned aircraft	Use	Jet fuel combustion	CU Chief Pilot
	Fertilizer application	Use	Fertilizer nitrification and denitrification	CU Facilities
	Wastewater treatment	Use	Aerobic digestion of sludge	CU Facilities
Scope 2 Indirect emissions	Electricity generation	Production	Coal, gas, & oil combustion in power plants	CU Utility Services, EPA eGRID
Scope 3 Indirect emissions	Electricity life cycle	Cradle to grave	Plant, construction, operation, materials, and decommissioning	Literature
	Transmission and distribution losses	Distribution	Coal, gas, & oil combustion in power plants	EPA eGRID
	Automotive commuting	Use	Gasoline combustion	CU Parking and Transportation Services
	Clemson area transit bus system	Use	Electricity use & diesel combustion	Clemson Area Transit
	University related travel	Use Cradle to consumer	Gasoline combustion Air transportation	CU Facilities
	Paper	Cradle to gate	Office paper, paper towels, & bathroom tissue	CU Facilities
	Natural gas leakage	Cradle to gate	Natural gas leakage associated with steam generation	Literature
	Refrigerants	Cradle to gate	HCFC-22 only	CU Facilities
	Waste and recycling transportation	Post-use transportation	Gasoline combustion	CU Recycling Services
	Wastewater Treatment Chemicals	Cradle to consumer	Chemicals	CU Facilities
	Water treatment	Chemical production, transportation of materials, and plant operation	Chemicals & operation	CU Wastewater Treatment Plant

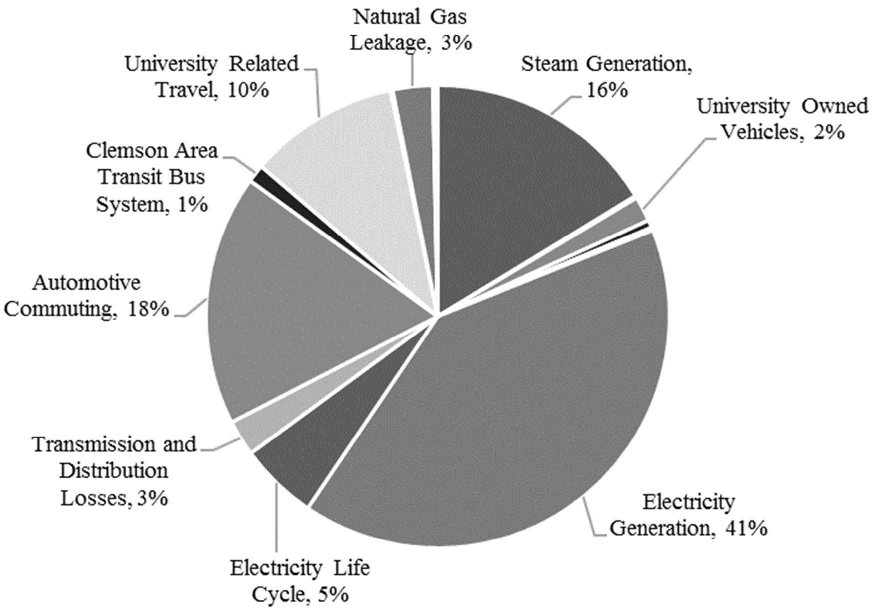
Generation Resource Mix (%)	**Clemson University**[a]	**SERC Virginia/Carolinas**[b]	**U.S.**[b]
Coal	28.99	31.7	38.7
Oil	0.06	0.6	0.7
Gas	15.14	20.8	27.5
Other fossil	0	0.3	0.5
Nuclear	52.61	42.2	19.5
Hydro	2.27	1.3	6.2
Biomass	0.69	2.9	1.6
Wind	0	0	4.4
Solar	0.24	0.2	0.4
Geothermal	0	0	0.4
Other unknown/purchased fuel	0	0.1	0.1
Output emission rate CO_2-e (kg/MWh)	323	391	513

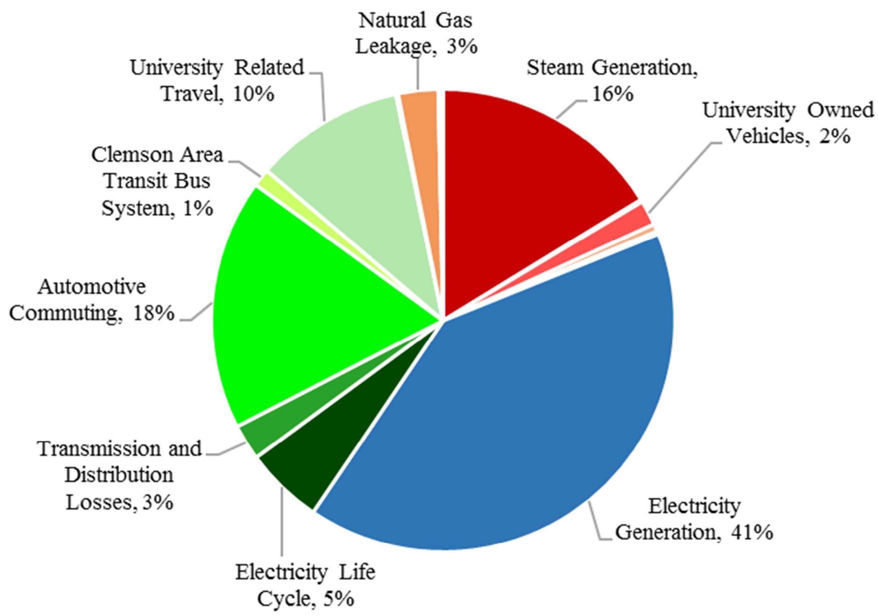
[a] CU resource generation mix is based on Duke Energy Carolinas, LLC eGRID data
[b] Generation resource mixes and emissions rates based on eGRID summary tables (EPA, 2017a)

	Source	GHG Emissions (metric tons CO_2-e)
Scope 1	Steam generation	15,522
	Refrigerants	143
	University owned vehicles	1,669
	University owned aircraft	515
	Fertilizer	19
	Wastewater treatment	173
	Sub-total	**18,041**
Scope 2	Electricity generation	38,718
	Sub-total	**38,718**
Scope 3	Electricity life cycle	5,207
	Transmission and distribution losses	2,393
	Automotive commuting	16,738
	Clemson area transit bus system	1,180
	University related travel	10,014
	Paper	150
	Natural gas leakage	2,656
	Refrigerants	139
	Waste and recycling transportation	27
	Wastewater treatment chemicals	2
	Water treatment	153
	Sub-total	**38,659**
	TOTAL	**95,418**

Case study	Method	Number of students	Total GHG emissions (metric tons CO_2-e)	Metric tons CO_2-e/student	Year(s) of data collection	Source
Institute of Engineering at the National Autonomous University of Mexico, Mexico	PA	581[a]	1,577[a]	2.7[a]	2010	Guereca, et al., 2013
Tongji University, China	PA	47,000	NA	3.8	2009-2010	Li, et al., 2015
The University of Cape Town, Africa	PA	21,175	84,926	4.0	2007	Letete, et al., 2012
University of Illinois at Chicago, USA	PA	25,125	275,000	10.9	2008	Klein-Banai, et al., 2010
University of Sydney, Australia	HLCA	NA	20,000[b]	NP	2008	Baboulet & Lenzen, 2010
University of Maribor, Slovenia	HLCA	3,800[a]	974[a,c]	NP		Lukman, et al., 2009
De Montfort University, England	HLCA	21,585	51,080	2.4	2008-2009	Ozawa-Meida, et al., 2013
Rowan University, USA	HLCA	9,600	38,000[c]	4.0	2007[d]	Riddell, et al., 2009
Clemson University, USA	HLCA	21,857	95,418	4.4	2014-2017	-
University of Castilla-La Mancha, Spain	IO	NA	23,000[b]	2.13	2013	Gómez, et al., 2016
Yale University, USA	IO	NA	874,000	NP	2003-2008	Thurston & Eckelman, 2011
The Norwegian University of Technology & Science, Norway	IO	20,000	92,000	4.6	2009	Larsen, et al., 2013
University of Leeds, England	IO	30,761	161,819	5.3	2010-2011	Townsend & Barrett, 2015

PA: Process analysis
HLCA: Hybrid life cycle assessment
IO: Input-Output
NA: Not available
NP: Not presented due to study limitations
[a] Engineering departments only
[b] Approximation based on given data in study
[c] Limited GHG emission sources included
[d] Fiscal year


Natural Gas Leakage, 3%
Steam Generation, 16%
University Owned Vehicles, 2%
Electricity Generation, 41%
Electricity Life Cycle, 5%
Transmission and Distribution Losses, 3%
Automotive Commuting, 18%
Clemson Area Transit Bus System, 1%
University Related Travel, 10%



Natural Gas Leakage, 3%
Steam Generation, 16%
University Owned Vehicles, 2%
University Related Travel, 10%
Clemson Area Transit Bus System, 1%
Automotive Commuting, 18%
Transmission and Distribution Losses, 3%
Electricity Life Cycle, 5%
Electricity Generation, 41%

Assessing the carbon footprint of a university campus using a life cycle assessment approach

Raeanne Clabeaux, Michael Carbajales-Dale, David Ladner, and Terry Walker

Highlights:

- A case study of Clemson University presents a streamlined life cycle assessment approach to quantify the campus's carbon footprint.
- Life cycle phases and data assumptions for each greenhouse gas emission source are discussed to provide a basis for comparison to other higher education institutions.
- Scope 1 emissions accounted for about 19% of the carbon footprint, while Scope 2 and 3 emissions each contributed nearly 41% to the carbon footprint.
- Applying the electricity provider's specific electricity generation resource mix has a significant impact on the final carbon footprint.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: