



Effects of Climate and Institution Size on Greenhouse Gas Emissions from Colleges and Universities in the United States

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Abstract

Emissions of greenhouse gases (GHG) associated with buildings may constitute as much as 40 percent of total emissions by the United States. Data on GHG emissions for 238 institutions, including doctorate-granting universities, master's institutions, and baccalaureate colleges, were acquired from the American College & University Presidents' Climate Commitment (ACUPCC). A regression model that included gross building area, July mean temperature, and January mean low temperature was used to predict GHG emissions ($R^2 = 0.911$). A similar model was developed for emissions as a function of full-time equivalent (FTE) students, but the fit was poorer ($R^2 = 0.693$). The percentage of coal in the energy source for electric power generation was also a factor, with higher percentages resulting in higher emissions. Institutions with high percentages of coal as their electricity source also experienced low January temperatures, making it difficult to distinguish the effects of energy source from winter climate. For doctorate-granting universities, emissions scaled with gross building area with an exponent of ~ 1.1 , indicating that emissions per unit building area increased with institution size. For master's and baccalaureate institutions, GHG emissions increased as a linear function of institution size.

Keywords: Climate, greenhouse gas, institutions

Introduction

Emissions of greenhouse gases (GHG) associated with buildings may constitute as much as 40 percent of total emissions by the United States.¹ Thus, buildings provide one of the more promising avenues for reduction in GHG emissions.² Colleges and universities typically consist of a mixture of buildings used for offices, residences, classrooms, and laboratories. They therefore can provide guidance as to how reductions can be achieved.

More than 625 colleges and universities have signed the American College & University Presidents'

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Climate Commitment (ACUPCC), which mandates that the institutions carry out an inventory of GHG emissions.³ Although the reported emissions estimates use a variety of approaches and are often incomplete, it is timely to examine these results for overall trends. Such an analysis establishes a baseline for evaluating future efforts to reduce GHG emissions at colleges and universities and may be helpful to planners who seek to estimate their institution's GHG emissions before doing an inventory. It should also provide a useful perspective for university planners and other administrators when setting priorities for efforts to reduce GHG emissions.

Reporting for the ACUPCC is aligned with the WBCSD/WRI GHG protocol,⁵ which divides emissions measurement into three categories: Scope 1 emissions come from sources on-campus; Scope 2 emissions result from purchased electricity generated off-campus; and Scope 3 emissions derive from all other sources.^{3,4} Here I analyze Scope 1+2 emissions estimates for 237 U.S. campuses for the period July 2006 to July 2008³; emissions estimates were a function of climate and size of institution, which was measured by either the total area of the buildings or the number of full-time equivalent (FTE) students.

GHG emissions depend mostly on energy consumption. A question that has not received sufficient attention is how energy consumption scales with institution size. To address this issue I use the exponential model:

$$E = aS^b \quad (1)$$

where E is GHG emissions, S is institution size as measured by gross building area or number of FTE students, and a and b are constants. If the exponent b is greater than 1, large institutions are expected to have greater emissions per unit size than small ones; if b is less than 1, small institutions will have greater emissions per unit size than large ones.

Methods

Emissions estimates from 238 campuses in the United States were analyzed for the period from



July 1, 2006 to July 1, 2008; data were obtained from ACUPCC Reporting System (<http://acupcc.aashe.org/>), which is associated with the American Association for Sustainability in Higher Education. Institutions ranged from 309 to 64,394 FTE students in size, and were distributed over 45 states. The data were uploaded by individuals at different campuses who were performing budgets of GHG emissions. The estimates are based largely on utility bills, as well as computing distances and other energy-requiring activities. Activities that produce GHGs besides CO₂ are also included in the estimates, although the amounts are generally small.

Emissions estimates are divided into the following categories: Scope 1, emissions that come from sources on-campus (natural gas for heating); Scope 2, emissions that are used on campus but purchased from off-campus sources (electricity); Scope 3, emissions that are not used directly on campus but occur as a result of institutional activities. The most important items falling under Scope 3 are emissions associated with commuting and resulting from air travel for institutional business. Because of variations in reporting practices for Scope 3 emissions, the present study considers Scope 1+2 emissions only.

In 85 percent of the cases, the method used for calculating emissions was the Campus Carbon Calculator developed by Clean Air-Cool Planet,⁵ which provided some consistency in methodology across the institutions. Data were organized according to classifications established by the Carnegie Commission on Higher Education into the institutional categories of doctorate-granting universities, master's colleges or universities, or baccalaureate colleges.

Climate data were collected using mean temperatures collected from a weather website (The Weather Channel, www.weather.com). A ZIP code for each institution was entered into the site, which produced a page with 30 year monthly mean temperatures from the National Climatic Data Center for the city where the institution is located. Climate variables included mean high and low temperatures in January and July and the mean temperatures for January and July.

Another factor that can significantly influence greenhouse emissions is the source of energy used to generate electricity. Conventional coal generation produces higher emissions per kilowatt than other sources.⁶ The percent of electricity that was generated from coal in each state where an institution was based was calculated from data listed for April 2008, which was downloaded from the Energy Information Administration.⁷

Data were analyzed for all institutions as well as for each Carnegie classification using stepwise multiple regression. Data were used "as is" (without audit-

ing or verification), although one college reporting anomalously low electricity use was dropped from the analysis. Two universities that did not report gross building area were excluded from the analysis based on that variable. Predictor variables included all temperature variables as well as gross square meters of buildings and number of FTE students. The response variable was emissions under Scope 1+2 (ion-campus consumption + purchased energy). Emissions, gross building area, and number of FTE students were log-transformed to stabilize variance and improve fit. Alternative models were evaluated using the Akaike Information Criterion with the program JMP (v 8, SAS Institute, Cary, NC).

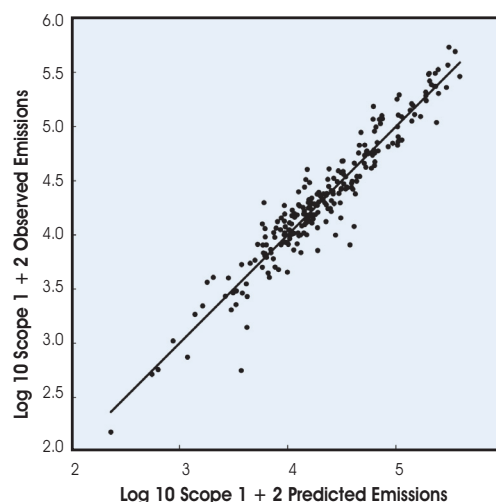


Fig. 1. Actual versus predicted emissions (log₁₀ metric tons of CO₂ equivalent) under Scope 1+2 using log₁₀ gross building area as a predictor for 237 institutions of higher education.

Results

For all institutions, emissions were strongly correlated with the log₁₀ gross building area (Fig. 1, Table 1). Emissions scaled with institution size with an exponent (b) of ~1.1, meaning that emissions per unit building area increased with the size of the institution. Another important factor was July mean temperature, which was positively correlated and presumably reflects increased emissions associated with air conditioning. The third significant factor was mean low temperature in January, which was negatively correlated, reflecting increased need for heating (Table 1). The coefficient for the effect of July temperature was almost five times the coefficient for January temperature, suggesting that emissions are more sensitive to cooling than to heating needs.

The percent of electricity that came from coal in states where institutions were based was negatively correlated with mean January temperature ($r = -0.268, p < 0.0001$). When percent coal was included as an independent variable in the analysis, it gener-



A factor that can significantly influence greenhouse emissions is the source of energy used to generate electricity.



Larger doctorate-granting institutions contributed more GHG emissions per unit building area than smaller ones.

Table 1. Variables and Coefficients for Regression Equations for Scope 1+2 Emissions as a Function of Gross Building Area and January and July Temperatures

Institutional Carnegie Classification	Sample Size	Variables	Coefficients	R ² (RMSE)
All	237	Intercept Gross building area July mean January mean low	-2.284 1.1328 0.02830 -0.005868	0.911 (0.1751)
Doctorate	68	Intercept Gross building area July mean January mean low	-2.420 1.1396 0.03344 -0.006526	0.898 (0.1454)
Master's	87	Intercept Gross building area July mean January mean low	-1.684 1.0337 0.02164 -0.01113	0.821 (0.1871)
Baccalaureate	80	Intercept Gross building area July mean	-1.841 1.0840 0.02189	0.768 (0.1763)

Scope 1+2 emissions, log10 metric tons of CO₂ equivalent; gross building area measured in log10 square meter; temperatures in degrees Celsius; RMSE, root mean square error.

ally replaced January temperature (Table 2). More complete data and further analyses are necessary to distinguish the role of energy source from winter temperatures on GHG emissions, although multiple regression analysis of the two largest components of Scope 1+2 emissions (stationary emissions and purchased electricity) suggests that winter climate has a significant effect. Both stationary emissions and purchased electricity showed a significant relationship with gross area. After removing the effect of building area, log10 stationary emissions were negatively correlated with January temperature (overall R² = 0.636), but July temperature showed no correlation. Log10 emissions from purchased electricity were only correlated with July temperature (overall R² = 0.750).

Because large doctorate-granting universities had a strong influence on the overall results, the data on emissions were analyzed for each Carnegie classification (Table 1). The most important predictor of GHG emissions for the doctorate-granting institutions was gross building area, followed by July mean temperature and January mean low temperature. As expected, July temperature was positively correlated with emissions while January temperature was negatively correlated with emissions. This is consistent with increased energy demands for both heating and cooling. However, when percent coal was included in the analysis, it replaced January temperature (Table 2), so the effect of energy source for electric power may be equally important.

For the master's institutions, the overall fit for log-transformed emissions was poorer (Table 1). The

best predictor was gross building area, followed by January mean low temperature and July mean temperature. When percent coal was included as an independent variable, January mean low temperature was still significant (Table 2). This suggests that for master's institutions nighttime temperatures in winter had an impact on emissions regardless of the energy source.

For the baccalaureate colleges, gross building area was the greatest contributor to emissions, followed by July mean temperature, which had a positive effect on emissions (Table 1). The effect of January temperature was not significant. Percent coal was significant (Table 2), suggesting that for these schools energy source was more important than January temperature.

Although GHG emissions depended strongly on gross building area in all three Carnegie classifications, there appear to be some important differences in the scaling of energy demand with institution size. For the doctorate-granting universities, the slope of the log-log regression (b) was 1.140, which was significantly greater than 1 (t-test, p < 0.01). This means that larger institutions contributed more GHG emissions per unit building area than did smaller ones. On the other hand, the slopes for the master's and baccalaureate institutions (1.034 and 1.084, respectively) were not significantly different from 1, suggesting that these institutions did not produce more emissions per unit area as they became larger.

Furthermore, the relationship of emissions to climate and energy source was slightly different for



Table 2. Variables and Coefficients for Regression Equations for Scope 1+2 Emissions as a Function of Gross Building Area, Energy Source for Electricity, and July Temperature

Institutional Carnegie Classification	Sample Size	Variables	Coefficients	R ² (RMSE)
All	237	Intercept Gross building area July mean Percent coal	-2.039 1.1294 0.01641 0.002042	0.915 (0.1708)
Doctorate	68	Intercept Gross building area July mean Percent coal	-1.1960 1.09734 0.02161 0.002348	0.910 (0.1368)
Master's	87	Intercept Gross building area July mean January mean low Percent coal	-1.6428 1.05134 0.01413 -0.00735 0.001718	0.828 (0.1846)
Baccalaureate	80	Intercept Gross building area July mean Percent coal	-1.7368 1.0741 0.01732 0.001146	0.775 (0.1749)

Scope 1+2 emissions, log₁₀ metric tons of CO₂ equivalent; gross building area measured in log₁₀ square meter; temperatures in degrees Celsius; RMSE, root mean square error.

each of the classifications. For the doctorate-granting universities, January temperature and percent coal appeared to have an approximately equivalent effect on emissions. For the master's institutions, both percent coal and January temperature were important factors. For the baccalaureate colleges, January temperature did not seem to affect emissions.

For all three types of institutions, the number of FTE students was also a significant predictor of emissions

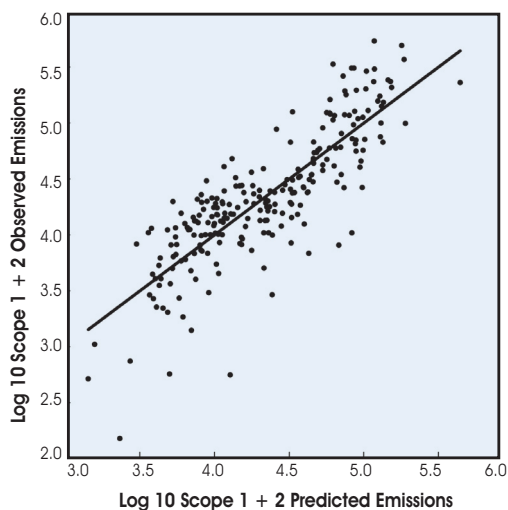


Fig. 2. Actual versus predicted emissions (log₁₀ metric tons of CO₂ equivalent) under Scope 1+2 using log₁₀ FTE as a predictor for 237 institutions of higher education.

but the fit of the regression model was poorer (Fig. 2, Tables 3 and 4). The fit was best for the doctorate-granting universities and master's institutions, with R² values ranging from 0.631 to 0.679, while for the baccalaureate colleges it was quite poor, with values less than 0.35. Energy source expressed as percent coal entered the regression model for doctorate and baccalaureate institutions, as well as for all institutions combined (Table 4). It did not enter the model for master's institutions, however.

For all institutions combined, GHG emissions scaled with the number of FTE students with a slope (*b*) of 0.926, which is marginally less than 1 (*p* < 0.1). There were marked differences between Carnegie classifications, however. The slopes for the doctorate-granting and baccalaureate institutions were not significantly different from 1, whereas the slope for the master's institutions was significantly less than 1 (*p* < 0.01). Large master's institutions appear to have fewer emissions per student than do smaller ones, but this is not the case for doctorate-granting universities and baccalaureate colleges.

Discussion

The results of this study have important implications for institutions interested in reducing GHG emissions. To a large extent the GHG emissions footprint of a university is influenced by its size, measured as gross area of buildings or by number of students. Size reduction of the institution appears to be one effective pathway for achieving significant decreases

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Table 3. Variables and Coefficients for Regression Equations for Scope 1 +2 Emissions as a Function of Number of FTE and January and July Temperatures

Institutional Carnegie Classification	Sample Size	Variables	Coefficients	R ² (RMSE)
All	237	Intercept Log10 FTE July mean high January mean	-0.04987 0.9260 0.03348 -0.007930	0.693 (0.3240)
Doctorate	70	Intercept Log10 FTE July mean low January mean	-0.4238 1.2062 0.01732 -0.01060	0.636 (0.2773)
Master's	87	Intercept Log10 FTE July mean January mean	0.6752 0.7861 0.02497 -0.01860	0.631 (0.2690)
Baccalaureate	80	Intercept Log10 FTE July mean	0.3688 0.8297 0.04319	0.321 (0.3017)

Scope 1 +2 emissions, log10 metric tons of CO₂ equivalent; FTE, full-time equivalent students; temperature in degrees Celsius; RMSE, root mean square error.

Table 4. Variables and Coefficients for Regression Equations for Scope 1 +2 Emissions as a Function of FTE, Energy Source for Electricity, and July Temperature

Institutional Carnegie Classification	Sample Size	Variables	Coefficients	R ² (RMSE)
All	237	Intercept Log10 FTE July mean high Percent coal	0.3508 0.9412 0.01682 0.002211	0.712 (0.3138)
Doctorate	70	Intercept Log10 FTE Percent coal	0.08652 1.1467 0.002582	0.679 (0.2583)
Baccalaureate	80	Intercept Log10 FTE July mean Percent coal	0.5723 0.8315 0.03246 0.001391	0.345 (0.2981)

Scope 1 +2 emissions, log10 metric tons of CO₂ equivalent; FTE, full-time equivalent students; temperature in degrees Celsius; RMSE, root mean square error.

in institutional GHG emissions. Any reductions in gross building area that can be achieved without impacting the institution's effectiveness should produce a beneficial effect on GHG emissions.

Another important factor is climate. Both warm and cold climates contribute significantly to emissions, although the contribution of cold winters is somewhat unclear due to the confounding effect of coal as an energy source for electricity. Institutions in

regions with hot summers have higher GHG emissions than do institutions of the same size in regions with cooler summers. Furthermore, doctorate-granting universities have a steeper slope for emissions as a function of temperature than do master's and baccalaureate institutions (Table 1). The current trend toward increased use of campuses during the summer may have the consequence of increased GHG emissions, at least on campuses located in warmer climates.



Much of the variation in GHG emissions among colleges and universities is explained by factors that are intractable to administrative control, such as climate, or that require difficult decisions about the size and future needs of the institution. One area that is subject to control is the source of fuel used to generate electricity. If institutions can reduce the amount of coal in their energy mix, they should be able to reduce GHG emissions.

As building standards change to allow for energy conservation, the coefficients of the regression models presented here should change as well. A lower value for the intercept (a in Eq. 1) would reflect overall improvement in energy efficiency, while lower values for the coefficients would reflect changes in the dependency of emissions on building size and climate. Some of the higher emissions at large institutions may result from the increased energy demands associated with research production. Careful attention should be paid to devices such as fume hoods, computers, and other building components that can contribute disproportionately to energy use.

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