It’s Not Easy Being Green

Assessments and Strategies for Sustainable Institutions

Department of Engineering and Public Policy
Department of Social and Decision Sciences
H. John Heinz III School of Public Policy and Management

Carnegie Mellon University
Pittsburgh, PA 15213

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Disclaimer and Explanatory Note

Please do not cite or quote this report, or any portion thereof, as an official Carnegie Mellon University report or document. As a student project, it has not been subjected to the required level of critical review.

This report presents the results of a one-semester university project involving students from the Department of Engineering and Public Policy, the Department of Social and Decision Sciences, and H. John Heinz III School of Public Policy and Management at Carnegie Mellon University and the Department of Chemical and Petroleum Engineering at the University of Pittsburgh. In completing this project, students contribute skills from their individual disciplines and gain experience in solving problems that require interdisciplinary cooperation. The project is managed by graduate students and monitored by faculty advisors. An advisory panel of academic and industry experts provides suggestions, information, and expertise.

Project Participants

This project is jointly conducted by students of the Department of Engineering and Public Policy (EPP), the Department of Social and Decision Sciences (SDS), and the H. John Heinz III School of Public Policy and Management (PPM) at Carnegie Mellon University.

Students

Social Sciences

Social and Decision Sciences

Yoonseong Choe
Irene Choi
Julia Ende
Alexander Kalke
Yongwoo Kim
Jee Sun Lee
Keith Menchin
Jennifer Park
Asa Wattan
Adam Young
Ayu Yu

Public Policy and Management

Ryan Menefee
Matthew Schneider

Engineering and Public Policy

Chemical Engineering

Chisom Amaechi
Catherine Dorsi
Michaelangelo Tabone
Taha Udyawar

Civil and Environmental Engineering

Mary Ashe
Dan Cox
Maria Pantelaros
Corey Tucker

Electrical and Computer Engineering

Alvin Tan
Doug Robl

Mechanical Engineering

John Bistline
Julie Cone
Michael Cushman
Takahiro Matsuura
Sarat Mikkilineni
Mike Ricci

Project Managers

Inês Lima Azevedo	Engineering and Public Policy
Adam Newcomer	Engineering and Public Policy

Faculty

Paul Fischbeck — Engineering and Public Policy, Social and Decision Sciences
pf12@andrew.cmu.edu

H. Scott Matthews — Civil and Environmental Engineering, Engineering and Public Policy
hsm@cmu.edu

Project Review Panel

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Marty Altschul – University Engineer, Carnegie Mellon University

Rosemary Capo – Associate Professor, Department of Geology and Planetary Sciences, University of Pittsburgh

Caren Glotfelty – Director of Environment Program, The Heinz Endowments

Stan Kabala – Adjunct Research Professor, Bayer School of Natural and Environmental Sciences, Duquesne University

Mark Kamlet – Provost, Carnegie Mellon University

Barbara Kviz – Environmental Coordinator, Facilities Management, Carnegie Mellon University

Francis McMichael – Walter J. Blenko, Sr. Professor of Environmental Engineering; Professor, Engineering and Public Policy and Civil and Environmental Engineering, Carnegie Mellon University

Indira Nair – Vice Provost for Education, Professor, Engineering and Public Policy, Carnegie Mellon University

Allison Robinson – Director of Environmental Initiatives, UPMC

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Executive Summary

Institutions and campuses are increasingly focusing on environmental and sustainability issues in response to climate change and related ecological concerns. Such actions are diverse and range from signing commitments for greenhouse gas emissions reductions to adding sustainability courses to the curriculum. Best practices for identifying areas of significant impact and ideal decision frameworks for effecting change are not yet clear.

This study provides a coherent framework and set of tools to allow institutions to understand their environmental impacts in relation to their peers, to determine appropriate sustainability goals and targets, and to identify and implement cost-effective programs to achieve these goals. The general methods and tools developed in this report are applicable to any institution, but the framework is applied here to the Carnegie Mellon campus.

An evaluation of existing carbon footprint calculators for institutions was performed and several inconsistencies were found. The six calculators assessed in detail differed substantially on the number of required inputs, ranging from 4 to 70. The three most significant calculator inputs for the Carnegie Mellon campus case study (which represent approximately 93 percent of all estimated emissions) were electricity, steam, and faculty/student air travel. Based on these key inputs, a simplified carbon footprint estimator was developed. Using this tool, the annual carbon footprint of Carnegie Mellon was estimated to be approximately 164,000 metric tons of carbon dioxide equivalent (MTCDE).

In addition to greenhouse gas emissions, there are other considerations that affect the overall sustainability of campuses. These impacts are assessed using an ecological footprint calculation and life cycle analysis of a university's operations. The overall ecological footprint was estimated to be 300,000 acres, with the major contributors being the built environment, goods, and transportation. This value corresponds to over 2,100 times the actual Carnegie Mellon campus area. For the life cycle analysis of campus operations, indirect carbon emission impacts of the production chain are approximately 3.5 times larger than the direct impacts from campus power generation purchases.

When deciding on campus strategies for climate change mitigation and for broader sustainability initiatives, active participation from the entire campus population is a key determinant for success. However, in order to do so, it is crucial to understand perceptions and attitudes of the total campus community before any implementation efforts are undertaken. For such purposes, the opinions and outlooks of the Carnegie Mellon campus were assessed first by analyzing previous surveys and then by conducting one specifically tailored to the Carnegie Mellon community. This survey was designed and distributed to the campus population to gauge attitudes and knowledge about sustainability issues and solutions. Over 2,000 surveys were completed, and the key findings were that there is a significant correlation between taking environmental courses and student concern toward environmental issues and that there is a significant discrepancy between perceived and actual cost-effectiveness of mitigation options. This gap points to the need for more environmentally-oriented courses and programs at institutions but also to the importance of university involvement in broader community education.

General carbon mitigation options for institutions were investigated ranging from conservation programs to purchasing renewable energy credits (RECs) to on-site electricity generation through renewable resources. A mitigation cost curve specific to the Carnegie Mellon campus was

compiled, which identifies the cost and reduction potential for a variety of abatement options. The most cost-effective mitigation options for the Carnegie Mellon campus were determined to be using wood/coal co-firing at the Bellefield Boiler, switching to biodiesel for the campus transportation fleet, powering down cluster computers, and installing occupancy sensors. Also, the options that would provide the largest emissions reductions were window replacements throughout campus, encouraging low-carbon behavior (e.g., energy conservation and reducing beef consumption), using natural gas at the Bellefield Boiler, and powering down computers across campus. One of the key conclusions from this analysis was that, in order to achieve more than an eight percent reduction in current emission levels, Carnegie Mellon would necessarily need to buy RECs or carbon offsets.

A key issue when establishing sustainability targets is benchmarking performance with other comparable institutions. However, in order to perform fair assessments, similar schools need to be evaluated. A method for identifying sustainability peer groups among institutions was defined, which allows for a unified and fair system for comparison. After selecting four-year institutions, with campus housing, in an urban area, private, non-profit, with greater than 5,000 students, with at least 50 PhDs, and in a similar climate zone, a sustainability peer group of 24 universities was obtained for Carnegie Mellon. When comparing with these peers, Carnegie Mellon ranks fourth in the top tier of schools along with the University of Rochester and Syracuse. A comprehensive examination of the sustainability initiatives undertaken by these peer institutions was also performed. Although this analysis showed that Carnegie Mellon outpaces a majority of its peers by performing internal audits and offering an environmental housing option for students, the university is not doing a few important initiatives that a majority of its peers are doing like retrofitting utilities and adding motion sensors.

Since only a small percentage of universities have publicly available emissions assessments, a method for estimating electricity and energy use and the carbon footprint of 1,600 universities was developed. In order to do so, publicly available regional and sectoral data were used. It was estimated that the 90^{th} percentile confidence interval of Carnegie Mellon's electricity use ranges from 38-165 GWh using square footage data and from 45-181 GWh using a regression-based model. The accuracy of the results improved with increased information about institutions (e.g., square footage of campus buildings).

Given the overall analysis described above, a set of recommendations for Carnegie Mellon was developed, and an overall framework to be used by other institutions was designed.

1. Introduction

1.1. Motivations

Institutions and campuses are increasingly focusing on environmental and sustainability issues in response to climate change and related ecological topics. As environmental concerns increase, efforts to raise awareness on sustainability issues are gaining more support from the higher education. Campuses are mobilizing to integrate environmental considerations into their operation and education to promote actions that minimize harmful impacts on the environment.

Universities are important for their large direct impacts as well as their indirect impacts. The large direct energy and environmental impacts of campuses and the concentrated body of faculty, staff, and students that populate them is evidenced by the fact that education is responsible for over eight percent of electricity consumption from the U.S. commercial sector (EIA 2006).

As institutes of higher education, universities also have considerable indirect impacts, as they assume particular social responsibilities and leadership roles within society. Demonstrating exemplary environmental stewardship is a vital part of the broader endeavor to be societal leaders. Reflecting sustainability in their operations and educational efforts is essential for institutions to improve the community and to encourage others to follow their example. In this manner, universities can motivate their students and employees to contribute to ongoing efforts to improve the environment by examining their ecological impacts and striving to improve environmental performance.

Education is a highly effective tool for delivering messages to the broader community and for making strong impacts, which is why universities are constantly striving to be trailblazers and change agents in important areas of society. Universities are committed to molding students' values and aiding them as they gain the knowledge and skills that they will take with them into broader society. Raising student awareness on environmental issues will enhance the education for students while better equipping them with the skills to become leaders in promoting environmentally sustainable practices. Ultimately, environmental education will not stop when students leave the university. They will carry on the values and knowledge instilled in them through their education, as they become citizens who are capable of making a difference in the larger world. This aspect of teaching and research has one of the most important impacts in broadening a student's educational experience while furthering more far-reaching societal goals.

There has been a wide range of actions to date by institutions and campuses as the focus on environmental and sustainability issues increases. Such actions are diverse and range from signing commitments for greenhouse gas emissions reductions to adding sustainability courses to the curriculum. Best practices for identifying areas of significant impact and ideal decision frameworks for effecting change are not yet clear.

This study provides a coherent framework and set of tools to allow institutions to understand their environmental impacts in relation to their peers, to determine appropriate sustainability goals and targets, and to identify and implement cost-effective programs to achieve these goals. The general methods and tools developed in this report are applicable to any institution, but the framework is applied here to the Carnegie Mellon campus.

1.1.1. Sustainability

Sustainability has many different meanings. A succinct definition is meeting the "needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). Since many natural resources are finite, the current rates of energy and material use may not be possible to sustain indefinitely into the future. Therefore, incorporating sustainability considerations into individual and institutional decision-making processes at places like universities is important.

1.1.2. Climate Change

The large direct and indirect contributions to climate change are additional drivers for analyzing and addressing sustainability issues for campuses. The large direct energy and environmental impacts of campuses and the concentrated body of faculty, staff, and students that populate them is evidenced by the fact that education is responsible for over eight percent of electricity consumption from the U.S. commercial sector (EIA 2006). In 2007, the total enrollment in institutions of higher education was 18 million, which represented about six percent of the total U.S. population (NCES 2008). Since enrollment is expected to reach 20.5 million by 2016 (NCES 2008), educating students on sustainability issues will also have an increasingly important indirect impact as well by affecting society at large for years to come.

1.1.3. Other Ecological Considerations

Addressing sustainability goes beyond just looking at carbon dioxide. Sustainability requires systems-level planning that accounts for all significant inputs, taking into consideration things such as biodiversity. Natural resources, such as fresh water, play a central role in the Earth's ecological stability and the ability for organisms to survive. Other factors central to humanity's continued existence also have ecological implications, such as food supplies. Differences in the bioproductivity of land and land use have significant ecological impacts. For instance, one acre of farmland growing wheat and one acre of pasture for grazing cattle produce food at very different rates. The number of mouths that they are able to feed is also quite different, as farmland produces more than pastureland. However, it is difficult to quantify total environmental impacts due to the expansive scope of ecological issues and the high degree of interplay between differing ecosystems. As discussed in Chapter 3, Wackernagel and Rees attempted to resolve this dilemma by creating the notion of an ecological footprint. This metric takes a range of readily available data and each ecosystem's bioproductivities and condenses them into one measure of aggregate ecological impact. Ultimately, the use of this tool can help to make better-informed policy decisions at institutions like universities.

1.1.4. Recent University Attention

There is growing action to address sustainability issues on university campuses. Efforts to quantify and rank sustainability programs and other environmentally-oriented initiatives on college campuses have increased in recent years. For example, the Association for the Advancement of Sustainability in Higher Education (AASHE) recently released their Sustainability Tracking, Assessment, and Rating System (STARS), a tool that allows colleges and universities to conduct an assessment of their sustainability initiatives and compare themselves to other schools (AASHE 2008). The Princeton Review will begin offering ratings of schools on their green practices (Carlson 2008). These scores are based on a 30-question survey that is sent to the schools (Carlson 2008). This method may not be the best way to measure the sustainable practices of a university, as it allows schools to interpret the questions however they want. Others recommend that universities use the STARS program because it allows a greater degree of transparency (Carlson 2008).

1.1.5. Commitments and Petitions

Actions taken by universities to address sustainability issues are varied. Some institutions have tried to show themselves as leaders in sustainability by signing one of the various climate commitments. The most popular is the American College and University President's Climate Commitment (PCC 2008), but others include the Talloires Declaration and various other regional commitments. However, just as various assessment strategies are open to interpretation by the institutions, so too are these commitments. The Talloires Declaration does not specify concrete goals. Rather, it suggests the establishment or expansion of programs in several abstract areas without mandating levels that would be categorized as successful (ULSF 2008).

The PCC is much more specific, requiring a committee to be formed, an inventory to be taken within one year, and an action plan for climate neutrality to be established within two years, as shown in the decision-making framework for the PCC in Figure 1.1.1. However, schools often sign these commitments and are unaware of the level of dedication necessary. The commitment is typically signed before a university calculates its own carbon footprint and before it determines a list of feasible and cost-effective mitigation options or of peer institutions for benchmarking.

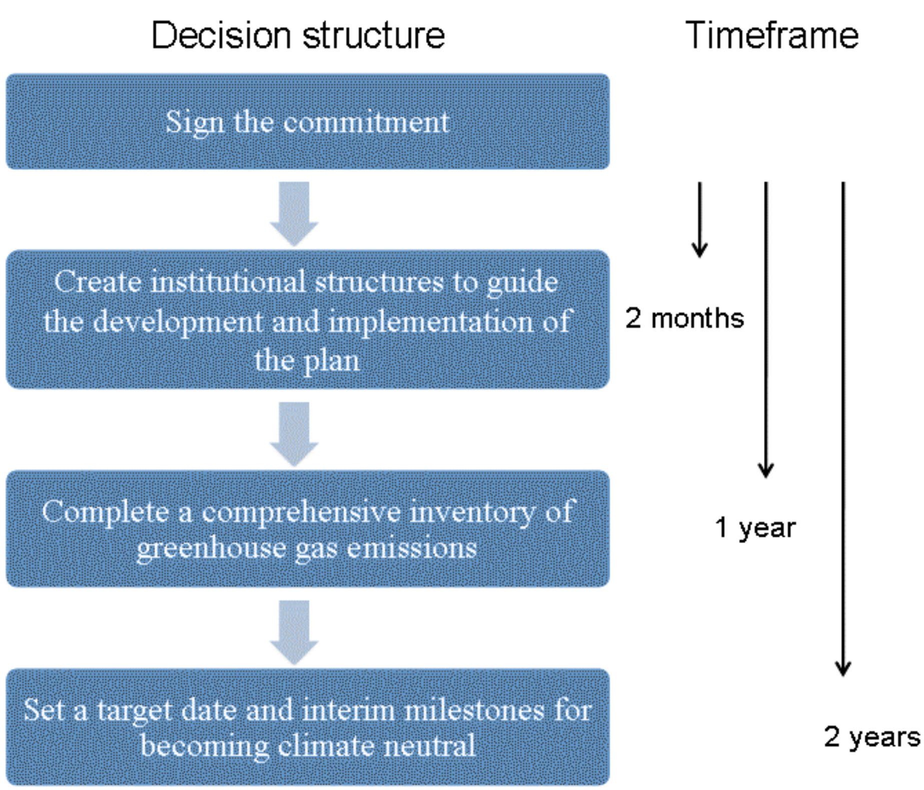

Figure 1.1.1 – Diagram of the PCC decision-making process

Moreover, some PCC requirements may not even have a large contribution to addressing sustainability. For instance, to show immediate success in the area of Leadership in Energy and Environmental Design (LEED) construction, an institution needs only to supply a written commitment stating the university's commitment to meeting the standards of LEED, but actually meeting those standards is not required (ACUPCC 2008). The same is true for carbon offsets for air travel and ENERGY STAR appliance purchasing policies (ACUPCC 2008). Additionally, while the requirement is quite clear in the PCC for an action plan for climate neutrality, there is no required completion date, nor is there any penalty for missing targets. Even "climate neutrality," the scope of what is meant by this term, and what parties are responsible for the carbon dioxide emitted, is not clear. An article in *The Chronicle of Higher Education* states that Universities are frequently confused about these questions, and while there is pressure on the part of the universities to join the PCC, it offers few answers (Carlson 2008).

Some campuses have signed commitments to reduce their greenhouse gas emissions in responses to petitions. At Carnegie Mellon, a petition was sent out to the campus community by the members of Sustainable Earth during the 2006-2007 academic year aiming to "increase the amount of alternative electrical energy purchased by the campus to 51% of its annual usage" by 2010. The petition reads:

> We, the members of Sustainable Earth and the greater campus community, request that Carnegie Mellon University achieve the following: (1) increase the amount of alternative electrical energy purchased by the campus to 51% of its annual usage; (2) seek out diverse and locally provided renewable energy sources; (3) reduce electrical energy consumption and (4) accomplish these goals by the year 2010. While we recognize that the University's current purchase of 20% is an excellent step toward sustainability, we believe a further increase of 31% would demonstrate a continuing commitment to fight global warming and reduce air and water pollution, while acting as a role model for students and peer institutions. With an increase of a little under $45 a year in tuition, Carnegie Mellon can afford this increase to 51% alternative energy. If you are a CMU undergraduate student, graduate student, or alumnus and would like to get involved and support our campaign, you can help tremendously by signing a petition. Petitions are hanging up on the bulletin board of the Green Room in the UC. If you would like a petition for yourself to pass out yourself (in class, on your floor) email sustain@andrew.cmu.edu. Thank you for your support. Together we can achieve a greener, cleaner future.

Several thousand students signed the petition, and the administration took it very seriously. However, the phrasing of the petition was vague and the administration was unsure about the proper reaction to the petition. The administration looked for guidance from faculty and from around the university. They wanted to address the petition and be financially responsible as well. Since the original petition came out, Sustainable Earth has moved on and created a new petition that is more detailed and is more specific than the first petition.

One of the objectives of this work is to figure out ways to address this original petition. Due to recent efforts by groups like Sustainable Earth to have Carnegie Mellon become a signatory to the PCC, this work will also present a coherent framework to address whether it would be advisable for the university to sign the PCC or similar commitments. From a broader perspective, this work provides a coherent framework and set of tools to allow institutions to understand their environmental impacts in relation to their peers, to determine appropriate sustainability goals and targets, and to identify and implement cost-effective programs to achieve these goals.

1.2. Organization of Report

The subsequent chapters of the report examine in depth the project's motivations, methods, results, conclusions, and recommendations. Each section of the report is designed to assess Carnegie Mellon University's standing on sustainability initiatives, to find available sustainability programs and footprint reduction methods, and to determine the most feasible recommendations specific to Carnegie Mellon while also providing a general methodological framework for other institutions to follow. Chapter 2 analyzes methods for calculating an overall carbon footprint and estimates Carnegie Mellon's current carbon footprint. Chapter 3 addresses sustainability issues beyond carbon and how they can be measured. Using an ecological footprint calculator, Carnegie Mellon's ecological footprint is estimated to determine what the school should concentrate on to minimize its overall environmental impact. Chapter 4 proposes realistic steps the campus could take to further its commitment to sustainability, based on surveys that measure Carnegie Mellon community's perceptions and willingness to make the campus more sustainable. Chapter 5 examines available mitigation options and the effectiveness of abatement methods. Chapter 6 presents sustainability programs undertaken by other universities and colleges that can assist Carnegie Mellon in adopting initiatives, while a tool that allows institutions to identify its sustainability peers is also developed. Chapter 7 discusses data collection which served to define peer groups and a metric that assess institutions' energy and electricity consumption levels. Based on the information provided by the previous chapters, Chapter 8 summarizes the report with proposals for what type of future investments Carnegie Mellon should make to increase environmental sustainability.

Chapter 1 References

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2. Carbon Footprint and Calculator Assessment

2.1. Introduction

Before a university or any organization can responsibly set goals to reduce carbon emissions or commit to a carbon reduction program, it is necessary for the institution to know their emissions or carbon footprint by completing an emissions inventory. Although it would be extremely difficult and costly for a large university to calculate emissions down to the nearest metric ton of carbon dioxide equivalent, the best that can be done is to estimate emissions with as low of an uncertainty as possible.

An emissions inventory is a list of all of the major sources of emissions, along with an estimate of the magnitude of those emissions. For example, a greenhouse gas emissions inventory would include estimates for electricity, natural gas, steam and chilled water usage, transportation emissions, and waste. However, this list is by no means comprehensive. There are several other contributors to a carbon footprint that will be mentioned later on.

A "footprint" is the amount of emissions that a particular entity creates and has become synonymous for the impact of that entity on the environment and on climate change through its emissions. A common way to calculate a carbon footprint is in units of metric tons of carbon dioxide equivalent (or MTCDE), which is a useful way to measure the relative effects of many different types of greenhouse gases. Emissions-emitting activities do not emit any one particular greenhouse gas but rather emit a variety of gases, with the most common being carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Using carbon dioxide as the base for metric tons emitted, other gases are multiplied by a coefficient to convert these emissions into carbon dioxide equivalent emissions. The carbon dioxide equivalent metric allows for easier comparison across different category emitters (e.g., energy and transportation), as well as across total emissions from different entities (e.g., for comparison between universities).

There are many tools available for completing an inventory or calculating a footprint. However, each has limitations, and calculated emissions can vary wildly depending on the particular calculator. Since the choice of mitigation strategy can depend on the carbon footprint, it is important to minimize uncertainties when calculating footprints. To this end, the primary goal of this research is to understand the requirements and limitations of existing carbon footprint calculators, to estimate sources of uncertainty, to develop an improved method of estimating carbon footprints, and to estimate the carbon footprint for Carnegie Mellon University by completing an inventory.

One of the main goals of this research was to estimate the carbon footprint for Carnegie Mellon University. The primary objective of this analysis is to provide an accurate measurement of the annual carbon footprint of the university. Once the carbon footprint is well-known, it is easier to develop mitigation strategies for the university to undertake. The carbon footprint of Carnegie Mellon was used as a baseline to compare all of the calculators to one another.

A second goal was to determine the best overall method for carbon footprint estimation. The calculator research was one of the first completed tasks. The calculators were organized and compared with one another, since there are several different types of calculators that are designed for different uses. One of the goals was to find the best overall calculator for institutions like Carnegie Mellon.

A related goal was to provide a complete analysis of Carnegie Mellon's carbon footprint. Not only is it important to determine an overall value for the university's annual emissions, but it is imperative that the most significant greenhouse gas emission sources be identified along with optimal and cost-effective ways to provide emissions reductions. Analyzing the carbon footprint and the causes of greenhouse gas emissions is an important first step in establishing a satisfactory mitigation strategy.

Another primary objective was to document the data collection method. Keeping a thorough and transparent account of the data collection was an ongoing process throughout the project. It is important to provide accurate and comprehensive documentation of all data collection methods to facilitate measurements of the university's footprint in the future.

The final goal of the research was to design an improved carbon estimator. After researching current greenhouse gas assessment tools, a simple carbon calculator was designed and applied to the Carnegie Mellon campus as a case study. A description of what a good comprehensive carbon calculator should look like and what features it should have was also provided. The best program currently available for universities, the Clean Air-Cool Planet calculator, requires over 80 individual inputs. By reverse-engineering the coefficients used in the program, a simple one-sheet calculator with fewer than ten inputs uses the CACP framework to arrive at an emissions estimate accurate within 7-10 percent of CACP's emissions estimate.

2.2. Review of Existing Calculators and Inventories

There are many tools available for calculating a footprint. A systematic and comprehensive survey was performed on these existing calculators in addition to an extensive search of available online calculators. Using Google to search the Internet was the first strategy used. Entering search terms like "carbon emissions calculator" or "carbon footprint tool," many results were retrieved. Changing the wording of searches sometimes yielded additional hits, as there is no universally accepted nomenclature for tools to measure emissions. Table 2.2.1 shows a more complete summary of these searches.

Table 2.2.1 – Summary of search terms and corresponding Google hits

Search Terms	Google Hits
"carbon footprint tool"	2,010,000
"carbon emissions tool"	1,860,000
"carbon emissions estimator"	1,760,000
"footprint estimator"	585,000
"carbon emissions calculator"	263,000
"footprint calculator"	212,000
"emissions calculator"	151,000
"carbon footprint calculator"	101,000

Also, calculators were found by searching other college's websites. Many schools have a "Green Practices" (or similar) homepage, which may have been involved with taking an inventory of their own institution's emissions. The results of their inventories (specifically the MTCDE output) would prove to be useful in the analysis of Carnegie Mellon's emissions. At the outset of the project, several university inventories were surveyed to analyze the methods of data collection and reporting. Surprisingly, many of these universities are not transparent about their data collection or calculation methods, and fully documented results of these inventories are not often available without an extreme burden to the user. For instance, one university has the entire results of their emissions inventory available exclusively in hard copy at the university library.

After learning little from other university inventories, this project became committed to being fully transparent about detailing data collection methods, documenting assumptions, and providing a full emissions output and analysis of Carnegie Mellon's footprint that would be available to the public. The contents of this report reflect this commitment.

Searching the Internet for available carbon emissions tools, it became evident that many calculators would be available with a wide range of intended applications. The Clean Air-Cool Planet calculator (hereafter referred to as "CACP") and similar calculators were defined as "comprehensive," meaning that the user is able to provide inputs across multiple categories of emissions contributors. Examples of non-comprehensive calculators are those that calculate emissions exclusively from auto travel or exclusively from electricity consumption while ignoring the overall footprint of a person, household, university, or similar entity.

The category contributors that have the most impact on calculated emissions are electricity and/or steam usage, transportation, and waste. A comprehensive calculator is one that includes all three of the major categories plus any variety of other inputs. Calculators that include inputs for only one of these categories were termed as "category-specific."

After performing Internet searches for calculators, different varieties of emissions estimators were found. For example, within the comprehensive calculators, calculators differ in presentation (e.g., a web-based application or a downloadable Excel macro), the intended audience (e.g., universities, offices, a family, or a single person), varying degrees of specificity required for inputs (e.g., exact grid-mix by source or state of residency), and even the units required for inputs which required manual conversion outside of the calculator program (e.g., pounds of waste or short tons of waste). A pool of 50 emissions calculators was compiled and, given the degree of variation, was "profiled" in a spreadsheet. It includes information such as calculator type, inputs required, and a web link to the calculator.

An observation worth noting here is the misleading nature of defining these programs as carbon or emissions "calculators," and not "estimators." In Section 2.5, the substantial variation between the outputs of these programs will be shown, but before knowing this analysis, any user of these programs should be aware that the inputs provided to the calculators are often not exact. These data are typically estimated figures for the kilowatt-hours of electricity consumed in a given year or the number of pounds of waste sent off to landfills. The programs themselves take these numbers and frequently apply an averaged coefficient (e.g., CACP uses 22.1 mpg as the average miles per gallon efficiency of all cars, whereas for any particular university, the number is certain to be higher or lower than 22.1 mpg) to arrive at an overall carbon footprint estimate (usually expressed in terms of MTCDE). It is not possible, then, to *calculate* emissions but only to *estimate* emissions with low uncertainty. Since many of these tools (such as CACP) refer to themselves as "calculators," this report will continue with that terminology to avoid confusion. However, the improved program created for this project will be more accurately termed an emissions "estimator."

Of the calculators that were located and profiled, CACP was found to be the most comprehensive calculator available. CACP is able to use over 80 individual inputs in a downloadable Excel macro that has nearly 100 individual sheets, some requiring inputs and some only containing the underlying assumptions used by the macro to calculate emissions on other sheets. CACP is also a relevant calculator for universities calculating their footprint, as the inputs are broken into faculty, staff, and student inputs, among other inputs unique to a university campus. The CACP website reports that over 150 universities are now using their "Campus Climate Action Footprint," of which the CACP emissions calculator is a part (CACP 2008).

While the comprehensive nature of the CACP calculator is certainly an asset, it also has major drawbacks. The CACP calculator is difficult to navigate and not accessible to the average user. Despite the good intentions to provide transparent documentation of the assumptions underlying the calculator, those assumptions are not always easily located. The complicated format of the calculator may, in fact, deter its use by institutions with limited time or labor resources.

These existing emissions calculators all have limitations. Some calculators require very few inputs to calculate emissions (as low as four inputs in some cases). Others require data that are not easily accessible or hard to find without the cooperation of university administrators who are willing to release potentially sensitive data (e.g., for this project, university administration graciously agreed to provide the home ZIP code of every faculty and staff member at Carnegie Mellon, without identifying information, to provide an accurate estimate for transportation emissions). Over the course of this project, it took nearly four months to collect the data required for the Clean Air-Cool Planet calculator to achieve the most accurate measurement of emissions. It was not possible to fill in every input in the CACP calculator, as some of the inputs were not applicable to Carnegie Mellon (e.g., information about co-generation plants and agricultural programs).

Table 2.A.2 in Appendix 2.A lists the inputs required for a broad range of calculators used for comparison analysis, and Table 2.A.3 lists the web addresses, number of inputs, and type for each of the calculators.

2.3. Baseline Carnegie Mellon Inputs

Before collecting inputs for Carnegie Mellon, it was important to decide on a boundary for what would be considered Carnegie Mellon's footprint. Carnegie Mellon has campuses all over the world, including California, Portugal, Qatar, and Australia, among others. This analysis focuses only on Carnegie Mellon's main campus in Pittsburgh. One reason for this choice is that the main campus is the only one for which a comprehensive set of inputs is available (some of the global campuses are not owned by Carnegie Mellon *per se* but by governments). Drawing the boundary at the Pittsburgh campus lowers the total emissions footprint for the university. However, in addition to comprehensive data being readily available only for the main campus in Pittsburgh, focusing on the main campus alone allows for better comparison with other universities in the U.S.

A standard set of Carnegie Mellon data was compiled that would apply to all calculators. Table 2.3.1 provides the full list of inputs required in the CACP calculator, and the specific inputs supplied for Carnegie Mellon.

Table 2.3.1 – CACP categories of inputs and Carnegie Mellon values*

CACP input category	Carnegie Mellon Value	Units**	Note
Energy Budget	12,534,026	$	-
Full-time Students	10,120	Persons	-
Faculty	1,501	Persons	-
Staff	3,673	Persons	-
Total Building Space	4,724,720	ft^2	-
Purchased Electricity	100,862,648	kWh	-
% Coal	41.4%	%	-
% Nuclear	41.4%	%	-
% Renewable	17.2%	%	Wind
Purchased Steam	382,577	MMBTU	-
Chilled Water	189,541	MMBTU	2007 value
Air miles: Faculty/Staff	45,000,000	miles	-
Air Miles: Student Programs	39,000,000	miles	Includes travel to/from campus
Student Commuting by Personal Vehicle	20%	%	-
Total students driving alone	20%	%	-
Total students carpooling	0%	%	-
Trips per Day	1	trips/day	-
Days per Year	160	days/year	-
Miles per Trip	1	miles/trip	-
Faculty Commuting by Personal Vehicle	100%	%	-
Total Faculty Driving Alone	100%	%	-
Total Faculty Carpooling	0%	%	-
Trips per Day	1	trips/day	-
Days per Year	260	days/year	-
Miles per Trip	15	miles/trip	-
Staff Commuting by Personal Vehicle	100%	%	-
Total Staff Driving Alone	100%	%	-
Total Staff Carpooling	0%	%	-
Trips per Day	1	trips/day	-
Days per Year	260	days/year	-
Miles per Trip	15	miles/trip	-
Landfilled Waste (No CH_4 Recovery)	3,102	short tons	-

* Categories with no meaningful input for Carnegie Mellon are omitted here
** CACP required value

The following sections elaborate on the data collection method and any assumptions made for the inputs. Unless otherwise noted, all data used in this exercise were from 2006.

2.3.1. Energy Consumption Inputs

The facilities management services (FMS) department at Carnegie Mellon provided the consumption of electricity in kilowatt-hours for all of Carnegie Mellon's Pittsburgh campus for 2006 and 2007. The 2006 figures were used, because they were more complete than the figures for 2007. FMS also provided the electricity grid mix for the university, which helps to have a more accurate emissions estimate (CACP otherwise provides a state average electricity grid mix to calculate emissions). FMS also supplied the amount of steam and chilled water (2007 value for chilled water) in thousands of pounds (Mlb). CACP requires that steam be input in British Thermal Units (MMBTU) and does not have a built-in conversion. This required manual conversion before inputting steam into the CACP calculator. A Tufts University report on their greenhouse gas emissions provided the following conversion: "1.19 million BTU (MMBTU) is required to produce 1,000 pounds (Mlb) of steam" (Gloria 2001).

2.3.2. Total Building Space

Facilities Management also provided the square-footage of each building on campus. CACP differentiates between "building space" and "research space," but Carnegie Mellon does not. Therefore, the entire area of Carnegie Mellon was included in the building space input.

2.3.3. Campus Population Data

Publicly available numbers from Carnegie Mellon's website were used to find the number of faculty, staff, and students within the predefined boundary. The permanent home ZIP codes (or country, as appropriate) for all faculty, staff, and students at Carnegie Mellon were acquired after receiving approval for an Institutional Review Board (IRB) request. The home ZIP code data for faculty and staff were supplied by the Human Resources Department (HRIS system), and student data were extracted from the Student Information System (SIS). This data set was used extensively for other inputs into the CACP calculator. Those specific uses will be elaborated in detail when appropriate.

To report the campus population accurately, individuals who work at or attend the university away from Carnegie Mellon's main campus in Pittsburgh (i.e., those people at other campuses in places like California, Portugal, Qatar, and Australia) were excluded. Although this lowers the emissions footprint for the university by excluding those community members, comprehensive data are readily available only for the main campus in Pittsburgh. Thus, focusing on Pittsburgh alone allows for better comparison with other institutions.

2.3.4. Faculty and Staff Air Miles

From the Carnegie Mellon accounting administrators, two different sets of data were acquired. One set of data was an Oracle accounting system data export, by department, of faculty and staff travel reimbursed by Carnegie Mellon for university business. This data set was not very helpful for this exercise, since the only consistent information for each reimbursed trip was the dollar value of the trip. For each line-item, there was an optional comment field that sometimes had the departing/arriving cities for travel with varying degrees of detail (e.g., some lines showed layovers, some only showed the final destination, and some lines showed nothing at all). The data set also was separated by department, and was only accessible one department at a time. This data set could be extraordinarily helpful if the accounting system required the user to input the destination airport for each line-item of travel. Also, if this data was made available in one printout of all university-reimbursed travel, the data analysis could be completed in minutes, rather than weeks.

The second data set proved very helpful for this exercise. This data set, provided by Carnegie Mellon administration and prepared by the university's preferred third-party travel agency, was the end-of-year report of all faculty and staff travel reimbursed for university business through that agency. This report provided an accurate breakdown of the frequency and magnitude of flights by Carnegie Mellon personnel. It included statistics on the number of flights taken in 2007, where those flights originated and terminated, a list of the top city pairs ranked by number of segments flown, and a list of the top airlines flown ranked by segments flown. The major drawback to this data was that, at the time it was acquired, the third-party travel agency reported that they thought the information in their report represented only 46 percent of travel. This statement was not qualified with a reference to a dollar basis or a mile basis. As a consequence, it was assumed that the data represented 46 percent of travel for the year 2007, and the data was scaled up to 100 percent.

Given the extensive shortcomings of the first data-set and the ease of using the second, the second data set exclusively was used to estimate faculty/staff travel for 2007. Assuming that air travel frequency would remain the same for the unaccounted 54 percent of the data, the provided data was extrapolated to represent the entire year and showed 45 million miles of air travel in 2007.

2.3.5. Student Air Miles

CACP provides an input for "student program," which likely refers to athletic travel. However, Carnegie Mellon, like many other universities in the country, attracts a student population from across not only the United States but also from around the world. Thus, the emissions inventory was able to achieve a more accurate carbon footprint calculation for Carnegie Mellon when the number of miles that students fly to campus was incorporated into the analysis.

For this input, two sets of data were acquired. The first data set (which ultimately was not used in this analysis) was a small survey (approximately 180 Carnegie Mellon students) of flying habits throughout the academic year, conducted for use in a course unrelated to this project. This survey asked participants to report the number of times they flew each year and to list their top destinations. The data included flights to and from students' homes both for the beginning and end of the school year and for holidays, as well as travel to spring break destinations and other trips. The mean mileage for survey participants was calculated and then multiplied by the total student population at Carnegie Mellon (10,120 students) to arrive at 18 million miles.

The data set ultimately used in this analysis was the previously-mentioned data set that included the home ZIP code or country of every student (undergraduate and graduate) at Carnegie Mellon. Students who lived in Pennsylvania, Ohio, Maryland, and New York were excluded from this analysis under the assumption that they drive and do not fly to and from campus at the beginning and end of each academic year.

An assumption was made that each student who does fly makes only one round-trip flight per year from their nearest airport to Pittsburgh International Airport each school year. This assumption was made for two reasons. First, this assumption makes analysis of student flying much more straightforward. Second, there is an important question of the amount of student flying that should be counted toward the university's carbon footprint (i.e., those flights that are the responsibility of the university). This estimation exercise draws the line at students' personal travel to and from home at the beginning and end of each school year and arguably (though not included in this analysis) students' travel home for holidays. Student travel that is not the responsibility of the university includes students' travel to visit friends or to spring break destinations (these would be considered part of the student's personal carbon footprint) and travel for job interviews (which would add to the carbon footprint of the company requiring the travel).

Having made these assumptions, the next step was to calculate the distance by air to Pittsburgh International Airport for all students. This required breaking students into two groups: domestic and international. For domestic students, the distance by air for each student (outside of the excluded states) from their permanent home ZIP code to Pittsburgh International Airport was used. For international students, data on the number of students from each international country for the 2007-2008 academic year was taken from the same data set. Carnegie Mellon has a sizeable international student population (2,496 international students in 2007-2008), with the largest representation from India (535 students), South Korea (435 students), and China (253 students). Overall, Carnegie Mellon hosted students from 100 countries for the 2007-2008 academic year. For each of the 18 countries sending the largest number of students to Carnegie Mellon (the cutoff was Indonesia, which sent 20 students), the round-trip air miles from that country's main airport to Pittsburgh International Airport was estimated and then multiplied by the number of students from that country. For countries with multiple possible points of departure (e.g., students from China could reasonably be flying to the U.S. from either Beijing or Shanghai), one airport was arbitrarily selected (in the case of China, Shanghai) as the point of departure for all students from that country. To calculate the round-trip air distance, the WebFlyer online web application was used (WebFlyer 2008).

Countries sending fewer than 20 students were grouped into regional areas, and an assumption was made that all students from surrounding countries flew from one airport central to that region. For instance, students from Middle Eastern and North African countries were assumed to fly from Dubai International Airport, while students from Europe were assumed to fly from Frankfurt International Airport.

Table 2.3.2 – Descriptive statistics for student air travel data

	Median	Mean	SD	n
Student Round-Trip Flights	14,580	13,628	3,385	2,496

Overall, it was estimated that Carnegie Mellon students fly 39 million miles to and from Carnegie Mellon. Keeping mind that the first set of acquired data revealed that many students fly home for holidays (and that this is within the boundary of the assumptions of this research), it is expected that 39 million miles is an underestimate of the number of miles actually flown each year by Carnegie Mellon students but is nevertheless a reasonable best-guess estimate for this analysis.

2.3.6. Faculty and Staff Commuting

CACP asks for the percentage of faculty and staff members traveling to campus by car and then for the percentage of those who travel to campus alone or in a carpool. It also asks for the number of faculty/staff who ride the bus to commute to work, but this analysis assumes that 100 percent of faculty and staff commute by car, alone, each of 260 days per year.

Using the home ZIP code information for all faculty/staff supplied by Carnegie Mellon, any faculty and staff who do not work at the Pittsburgh campus of Carnegie Mellon (which does not exclude those faculty and staff who live across state lines and commute to work each day) was filtered out. The mean round-trip drive to campus for a given faculty or staff member is estimated as 15 miles.

Table 2.3.3 – Descriptive statistics for auto transportation data

	Median	Mean	SD	n
Faculty/Staff Round-Trip Daily Commute	4.5	14.0	12.0	5,144
Student Round-Trip Daily Commute	3.7	2.2	2.3	2,496

There is another set of data available for Carnegie Mellon that would help to refine the estimate of travel for faculty and staff in particular. In the past two years, a survey has been distributed to all members of the Carnegie Mellon community who apply for a parking permit on campus. This survey accurately captures a large number of all commuters to Carnegie Mellon daily. In addition to eliciting information about the frequency and distance of commute to campus, it also gathers data regarding alternate modes of transportation that may be used by faculty and staff.

The major drawback to this data set is that there is not enough parking available on campus for all of the faculty and staff who request a permit, so there are people who commute to campus frequently and park off-campus who cannot be counted in the data set. Ultimately, auto travel accounts for a relatively small part of the Carnegie Mellon footprint, and more refined numbers for faculty and staff auto travel will not make a substantial difference to the overall footprint.

2.3.7. Student Commuting

Student commuting was one of the more difficult inputs for which to find a reasonable estimate. Many students cannot obtain or afford campus parking, and those who drive are likely to park in the campus parking garage (which cannot distinguish between students, faculty, staff, or visitors), or at metered spaces operated by the City of Pittsburgh. For a crude estimate, the number of students who live in campus housing was found, and that number was subtracted from the total student population. An assumption was then made that even though students may own a car, it is likely that they live close enough to campus that they can either walk or take a bus to commute each day (given the lack of parking spaces available to students).

Ultimately, it was roughly estimated that 20 percent of Carnegie Mellon students commute daily to campus. It was also estimated that the average round-trip for those students is approximately one mile, since students are unlikely to live in the suburbs and are more likely to live in Pittsburgh proper. Another assumption was made that these students commute 160 days per year, which is the average total number of class days during the fall and spring semesters.

2.3.8. Waste

According to the Carnegie Mellon Green Practices website, “approximately 17,000 pounds of garbage is sent to landfills every day” (Carnegie Mellon 2008b). When this number is multiplied by the days per year and then converted from pounds to short tons (2,000 lbs. = 1 short ton), a total of 3,102 short tons of waste sent to landfills each year.

2.4. Comparison of Calculator Outputs

The next step was to use this data collected for the CACP calculator and input identical Carnegie Mellon numbers into the selected comprehensive calculators to compare the outputs. The observation that propelled the comparison exercise was the difference in the number of required inputs for each calculator. Since the comprehensive calculators allegedly measure the same thing, it was expected that the number of inputs would be similar across calculators. Further, since some calculators ask for four or five inputs while others ask for eighty, this analysis investigated the degree to which the output of these calculators varied given the same inputs.

For this analysis, the CACP calculator was used as a baseline for two reasons. First, it asked for the most inputs, so collecting a complete set of inputs for CACP would allow using those same numbers for calculators requiring fewer inputs. Second, CACP is specifically designed for universities, and the data available for Carnegie Mellon aligns well with the specific required inputs for CACP.

Figure 2.4.1 shows the conceptual model of inputting Carnegie Mellon's standard input set into other comprehensive calculators for the purpose of comparing emissions results.

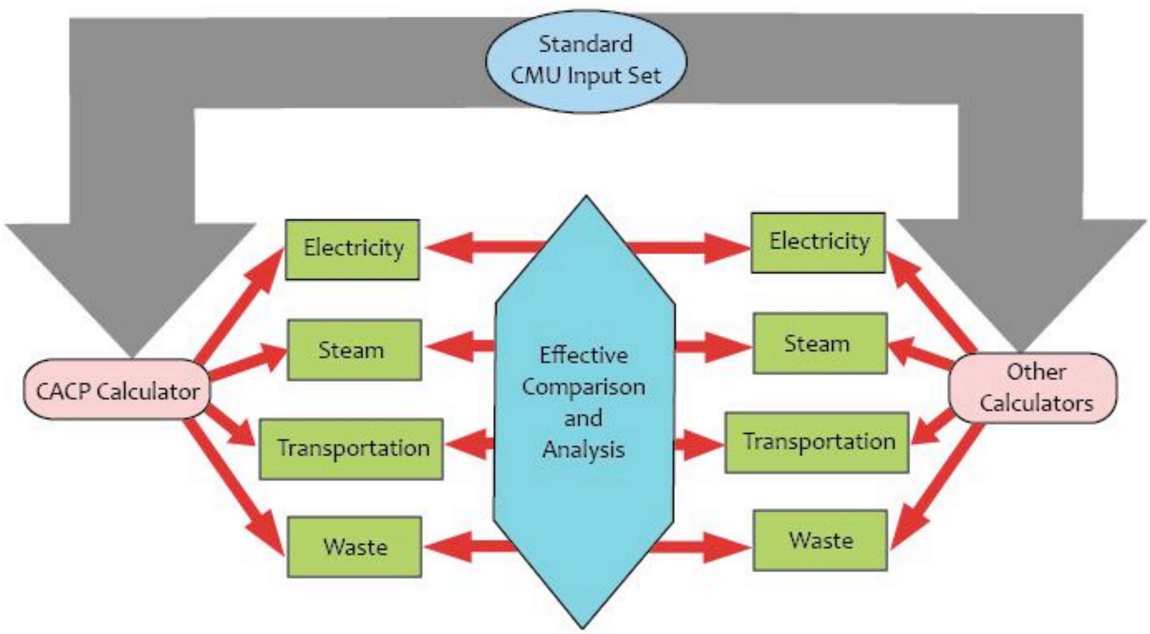


Figure 2.4.1 – Conceptual model of calculator comparison

Though the initial search for calculators turned up many viable options, some calculators were excluded from this analysis. One calculator, CarboNZero, gave wildly different outputs each time identical numbers were put into the calculator. Another, ICLEI, only gave one number for overall emissions but did not break it down into categories (e.g., auto transportation and electricity) and could not be used for cross-category analysis.

The initial list was narrowed to five comprehensive calculators, excluding the CACP calculator. Each of the five other comprehensive calculators was very different from the CACP calculator. The number of inputs ranged from as low as 4 (GreenTagsUSA, Nature Conservancy) to as high as 70 (Penn State). Table 2.4.1 below shows the required inputs for the six comprehensive calculators. Table 2.A.2 (as found in Appendix 2.A) shows this information for the complete set of carbon calculators.

Table 2.4.1 – Inputs required across six comprehensive calculators

	CACP	Green TagsUSA	PG&E	PSU	EPA	Nature Conserv
Calculator Type	Campus	Household	Personal	Campus	Personal	Household
Number of Inputs	80	4	5	70	5	4
Energy Budget	•					
Full-Time Students	•					
Faculty	•					
Staff	•					
Total Population					•	
Total Building Space	•					
Purchased Electricity	•	•	•	•		
Grid Mix	•			•		
Purchased Steam	•			•		
Chilled Water	•					
Air Miles	•	•				•
Auto Travel:						
No. of Commuters	•					
Fuel Efficiency	•					
Trips per Day	•					
Days per Year	•					
Miles per Trip	•					
Total Distance		•	•	•	•	•
Waste	•			•		

In addition to each calculator requiring different inputs, many of the calculators required different units for these inputs or would not allow the inputs with a magnitude as large as those required for Carnegie Mellon. In many instances, a total figure (e.g., electricity) was divided by the total population to find the electricity consumption for one person. Next, the output from the calculator was re-multiplied by the total population at Carnegie Mellon to find an estimate for the calculated carbon footprint for campus. Table 2.4.2 shows these input values.

Table 2.4.2 – Inputs for each comprehensive calculator

	CACP	Green TagsUSA	PG&E	PSU	EPA	Nature Conserv
Energy budget	$12,534,026					
Full-time students	10,120					
Faculty	1,501					
Staff	3,673					
Total population		(1)[b]			15,294	
Total building space	4,724,740 sqft					
Purchased electricity	100,862,648 kWh	9,967 kWh	8,405,220 kWh[c]	100,862,648 kWh	[d]	
Purchased steam	382,577 lbs.			382,577 lbs.		
Chilled water	189,541 lbs.					
Air miles	84,000,000 miles	8,300 miles				280,000 flights[e]
Auto travel:						
No. of commuters	7,198					
Fuel Efficiency	22.1 mpg					
Trips per day	[a]					
Days per year	[a]					
Miles per trip	[a]					
Total distance		2,011 miles	20,346,846 miles	20,346,846 miles	20,346,846 miles	20,346,846 miles[f]
Waste	3,102 short-tons			3,102 short-tons		
Output (per year)	**163,680 MTCDE**	**289,985,037 lbs.**	**70,792,637 lbs.**	**76,966 MTCDE**	**157,152,114 lbs.**	**126,765 short-tons**

[a] Different for each of faculty, staff, and students. See table 3.2.1 for specific inputs

[b] Implied

[c] Per month

[d] Chose "electric heat"

[e] Total miles divided by 300 miles/flight = 280,000 short flights

[f] Chose "mid-size" vehicle

2.5. Differences across Calculators

After putting the required data into each of the six comprehensive calculators, each calculator gave significantly different outputs for carbon emissions.

2.5.1. Total Emissions and Category Contributions across Calculators

Figure 2.5.1 shows the total emissions output for each of the six comprehensive calculators (including the CACP calculator).

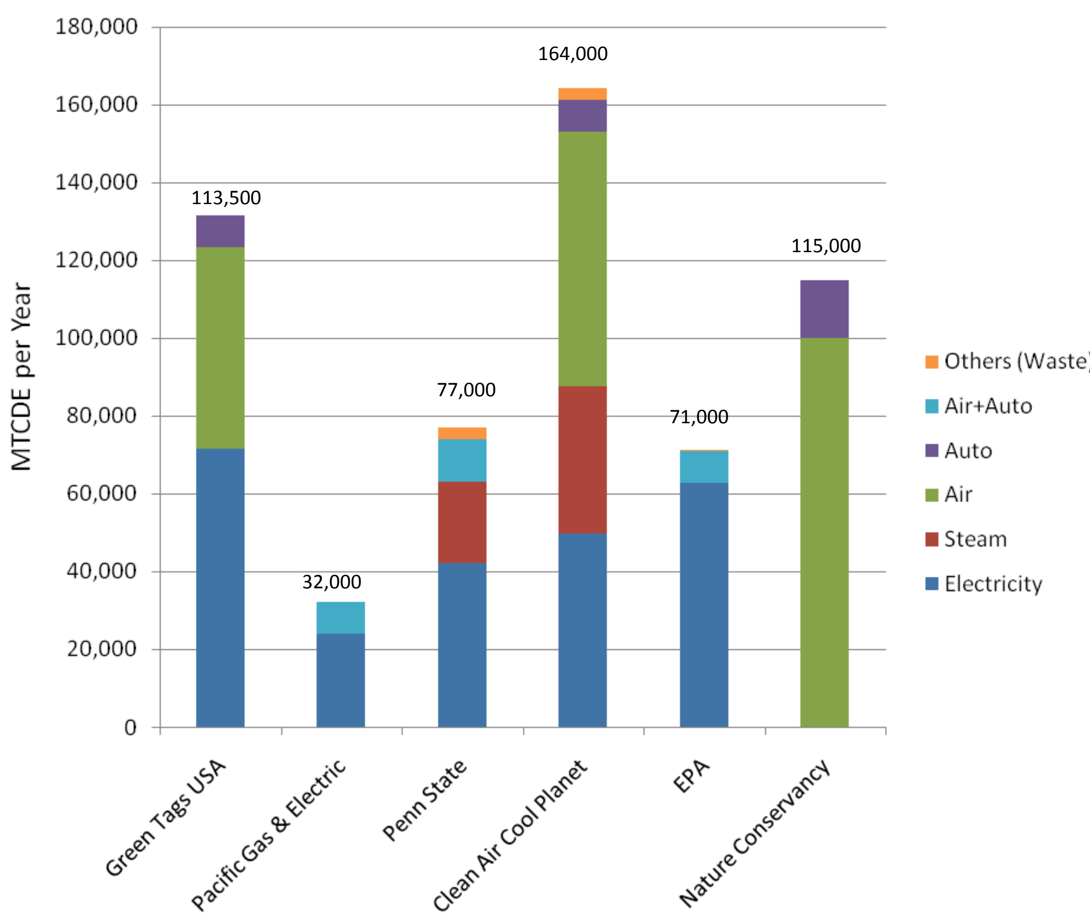


Figure 2.5.1 – Total emissions for six comprehensive calculators divided by category contribution

Two observations regarding these outputs are readily apparent. First, the total emissions output of each calculator varies greatly. The calculator with the largest estimated MTCDE per year (CACP) is 460 percent greater than the calculator with the smallest (Pacific Gas & Electric). This trait is partly due to differences in the number of inputs. Second, even within individual categories, there is an enormous range of variation for that particular category's contribution to the overall Carnegie Mellon footprint. For example, the estimated MTCDE from electricity ranges from about 25,000 MTCDE per year to slightly over 70,000 MTCDE per year. It is important to bear in mind that identical inputs for Carnegie Mellon were used for each of the six calculators. Another important observation is that only two of the calculators (CACP and Penn State) explicitly ask for an input and provide an output for steam usage.

2.5.2. Implications

Not all carbon calculators are created equal, and the choice of calculation method may greatly affect the reported emissions. There are a few important lessons from this exercise. First, universities may incorrectly estimate their emissions if they simply use a calculator they find online. It is assumed that universities would perform a search similar to the one carried out for this analysis: after first searching for university-specific calculators, the search was then broadened with Google searches (see Section 2.2 for more information). For the six calculators comprehensive calculators found, these estimators gave very different emissions measurements despite using identical numbers for inputs.

A corollary of this first observation is that a university can locate a calculator that will provide a predetermined emissions output. Using this analysis, a university that wishes to illustrate that it has a low carbon footprint can use the Pacific Gas & Electric or the EPA calculators. Universities that want to find a calculator that will report all categories of information at a deflated level from the so-called "gold standard" from this study can use the Penn State calculator instead of the CACP calculator.

The CACP was selected as the model calculator in this analysis for a number of qualitative reasons, including its focus on universities and the comprehensive range of inputs for a calculation of campus emissions. Relative to all other comprehensive calculators, the CACP calculator seems to give the most reasonable estimate of Carnegie Mellon's footprint, though the actual value for the university's annual greenhouse gas emissions is not known precisely beforehand. However, other calculators indicate that air travel emissions per person may lower by up to a factor of four (Climatecrisis.net 2006).

Overall, this analysis demonstrates that CACP can and should be used as a baseline measure of carbon emissions. However, the CACP calculator is not easy to use. Section 2.7 has an improved carbon estimator that works with CACP's underlying assumptions but is much more accessible than the original CACP calculator. It is recommended that universities use this improved carbon estimator to estimate their emissions quickly and accurately.

2.6. Estimation of Carnegie Mellon's Carbon Footprint

In this section, an estimate of Carnegie Mellon University's carbon footprint for 2006 using the inputs above and the CACP calculator is summarized.

2.6.1. Emissions by Category

Four major categories exist across all emission sources for Carnegie Mellon's carbon footprint. The category of waste accounted for less than 5 percent of emissions and does not affect total emissions greatly. Total emissions using the CACP calculator were calculated to be 163,680 MTCDE. Of this total, CO_2 emissions were 159,948 MT, CH_4 emissions were 140 MT, and N_2O emissions were 2 MT. Total equivalent CO_2 emissions were calculated by giving greater weights to CH_4 and N_2O emissions; however, both emissions sources only accounted for 3,732 MTCDE or 2.3 percent of the total eCO_2 emissions. All categorical emissions from the CACP calculator were shown to be in the form of X_i MTCDE per unit of input, where i represented each category.

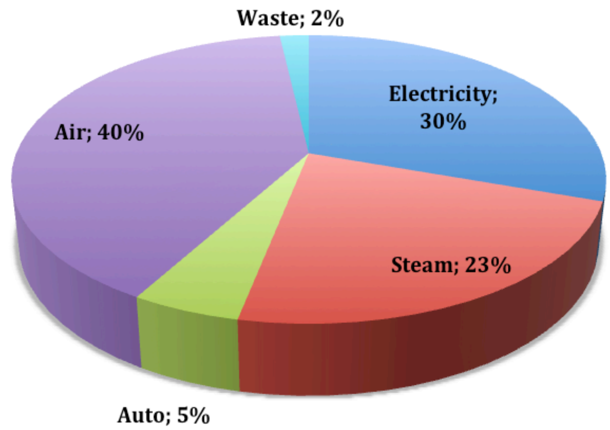


Figure 2.6.1 – CACP-calculated percent category contribution to overall Carnegie Mellon footprint

2.6.1.1. Electricity

Emissions from purchased electricity were 49,553 MTCDE, which represented 30.3 percent of the total emissions. For Carnegie Mellon, the power generation portfolio mix is assumed to be 41.4 percent coal, 41.4 percent nuclear, and 17.2 percent renewables. Electricity generation from nuclear and renewable sources accounted for zero percent of emissions from electricity. Purchased electricity included chilled water.

2.6.1.2. Steam

Emissions from steam and chilled water accounted for 37,539 MTCDE, which represented 22.9 percent of total emissions. Power sources had no effect on emissions from steam. For every 100,000 MMBTUs of purchased steam, 9,812 MTCDE were emitted and 123,201 MMBTUs were consumed. Although no details were given in the CACP calculator, a higher consumption of MMBTUs versus purchased MMBTUs was assumed to be due to plant efficiency.

2.6.1.3. Transportation

Emissions from total transportation (car and air travel) were 73,578 MTCDE, which represented 44.9 percent of total emissions.

Emissions from total car travel (student and faculty/staff commuters) were 8,262 MTCDE, which represented five percent of total emissions. The CACP calculator assumed that each mile of car travel emitted 0.000404 MTCDE.

Emissions from total air travel (official and student air travel) were 65,256 MTCDE, which represented 39.9 percent of total emissions. The CACP calculator assumed that each mile of air travel emitted 0.000777 MTCDE. 46.4 percent of air travel was due to student air travel and 53.6 percent of air travel was due to official air travel.

2.6.1.4. Waste

Emissions from waste were 3,069 MTCDE, which represented 1.9 percent of total emissions. Waste emissions were entirely composed of emissions from CH_4, which amounted to 134 MT. Equivalent MT of CO_2 emissions were calculated by multiplying MT of CH_4 emissions by 23.

Of all inputs, purchased electricity (included chilled water), purchased steam, and air travel were defined as the most significant inputs when calculating Carnegie Mellon's carbon footprint. These three inputs accounted for 93.1 percent of total emissions, while car travel and waste accounted for only 6.9 percent of total emissions.

2.6.2. Demographic Emissions Summary

When considering Carnegie Mellon's total carbon footprint, it averaged 16 MTCDE per student, 11 MTCDE per person (faculty, staff, and students), and 0.035 MTCDE per square foot. If only electricity was considered as a source of emissions, Carnegie Mellon University had 5.0 MTCDE per student, 3.0 MTCDE per person, and 0.010 MTCDE per square foot.

2.6.3. Sensitivity Analysis

In order for campuses to begin analyzing mitigation strategies, a sensitivity analysis was conducted. Total emissions were previously calculated as 163,680 MTCDE, and emissions contributions by input were shown in Figure 2.6.1. Specifically, an X percent reduction in total emissions required an X percent * (100 percent/Y percent) reduction in an input, where Y percent represented that input's percentage contribution toward total emissions. For example, an analysis of each input's percentage change required for a 10 percent reduction in total emissions is shown in Table 2.6.1.

Table 2.6.1 – Sensitivity analysis results

Category	Category Input	Current Emissions (MTCDE)	10 Percent Total Emissions Reduction	Reduced Input
Electricity	100.0 million kWh	49,600	33%	36 million kWh
Steam/Chilled Water	383,000 MMBTU	37,500	34%	378,000 MMBTU
Waste	3,100 short tons	3,000	Not possible	-
Faculty/Staff Gasoline	20 million miles	8,000	Not possible	-
Student Air	39 million miles	30,300	60%	16 million miles
Faculty Air	45 million miles	35,000	52%	22 million miles

2.6.4. Athletic Department Comparison

As mentioned, accurate data on air and auto travel was hard to find due to the scarce information that provided by the Oracle accounting system. Due to this difficulty, a new approach had been created to find sufficient data on Carnegie Mellon's travel history. The best option was to acquire travel information for individual departments and use this data to compare the campus on a whole. Unfortunately, this would have taken up too much time, so it was decided to find one department that would be thought to have a sufficient amount of travel and compare that to the total estimates made.

The athletic department is unique from others since it can be assumed that overall athletic travels made will remain fairly constant from year to year. Therefore, this value will be a constant input in air and auto travel. The data received is from the academic year of 2006-2007 and is of total travels made by all teams on campus in addition to individual travels made by the faculty and staff for recruiting and conferences.

The information was obtained by contacting the Associate Department Head of the athletic department, Joan Maser. She was able to give information on all team-related travels. Specific itineraries for every trip made in this one year were obtained and analyzed in order to decipher the correct amount of people and how many buses being used in addition to the route taken by the buses and any layovers made for flights. Additionally, access was given to all expense reports for the same year, which showed all individual travels made. In these receipts, mileage was calculated, and all flights were looked examined. Next, each individual's team affiliation was found. The majority of the travel was for recruitment purposes but some were due to conferences and other events.

The analysis was broken up to examine the impact that each team makes in addition to an overall comparison to the collective campus. Below is a breakdown of all the air and ground miles traveled by each team in one academic year and it is followed by a breakdown of the total emissions produced by the athletic department.

Table 2.6.2 – Athletic department ground transportation data

	Individual Auto Miles	Personal Team Bus Miles	Total Ground Miles
Track	5,411	118,662	**124,073**
Football	9,563	96,562	**106,125**
Swim	2,542	35,488	**38,030**
Conference, Clinic, etc.	1,635	0	**1,635**
Soccer	5,171	42,428	**47,599**
Golf	759	8,962	**9,721**
Tennis	3,662	52,678	**56,340**
Volleyball	754	20,150	**20,904**
Basketball	9,674	127,047	**136,721**
	39,171	***501,977***	***541,148***

In order to compare the bus miles with the automotive miles traveled, the miles of each team were recorded and multiplied by the average number of athletes that traveled per event for each team. After this, the miles were converted to what the number would have been if each individual was traveling in a car with a fuel economy of 22.1 miles per gallon. This step was done by knowing that the average person gas mileage of a bus is 32 miles per gallon, which is the average fuel economy of every person traveling on the bus (Ambassatours 2008).

Overall, the distance traveled by ground transportation came to a total of 541,148 miles, which is a small fraction of the total miles (20.4 million miles) estimated in Section 2.3.

Table 2.6.3 – Athletic department air travel data

	Individual Air Miles	Team Air Miles	Total Air Miles
Track	5,080	125,850	**130,930**
Football	16,132	104,000	**120,132**
Swim	6,512	0	**6,512**
Conference, Clinic, etc.	19,888	0	**19,888**
Soccer	11,464	75,718	**87,182**
Golf	5,524	32,152	**37,676**
Tennis	5,216	83,200	**88,416**
Volleyball	4,196	35,188	**39,384**
Basketball	3,654	130,065	**133,719**
	77,666	***586,173***	***663,839***

For air travel, a similar approach was taken to find out the number of miles traveled. In this case, the number of miles flown by a particular team was simply multiplied by the number of athletes present on each flight.

The total distance of 663,839 miles turns out to be not even one percent of the 84 million miles traveled by the campus annually.

Table 2.6.4 – Athletic department transportation emissions data

	Ground Travel Emissions (MTCDE)	Air Travel Emissions (MTCDE)	Total Emissions (MTCDE)
Track	50	102	**152**
Football	43	93	**136**
Swim	15	5	**20**
Conference, Clinic, etc.	1	15	**16**
Soccer	19	68	**87**
Golf	4	29	**33**
Tennis	23	69	**92**
Volleyball	8	31	**39**
Basketball	55	104	**159**
	218	***516***	***734***

If each individual team were to be compared, it would be seen that the basketball team has the largest emissions in the athletic department, with the track team close behind. In total, the above analysis demonstrates that the athletic department as a whole creates around 734 MTCDE per year, which is not much in compared to the entire university.

2.7. Designing an Improved Emissions Estimator

2.7.1. Motivation

The CACP calculator has over 80 inputs that must be inputted manually by the user. Examples of such inputs included are the number of goats (livestock), quantity of fertilizer use, and number of faculty. Additionally, the CACP calculator came in the form of an excel spreadsheet that was over four megabytes in size, included macros, and had nearly 100 sheets within the spreadsheet. In general, this format was considered very cumbersome to the user. Hence, it is unlikely that many people would use all of the inputs.

Also, key assumptions were hard to find in the CACP calculator, and some were questionable. For instance, the CACP calculator used a measure of 0.000777 MTCDE per mile of air travel per person. Most online sources including Climatecrisis.net used a measure that was less than 25 percent of CACP's assumption. Since air travel accounted for 40 percent of total emissions for Carnegie Mellon University, revised assumptions would result in air travel accounting for ten percent of total emissions.

The goal was to design a simplified calculator that could reasonably estimate a university's carbon footprint, based on CACP's engine.

2.7.2. Design

The design of an improved emissions calculator aimed to have outputs that were easily presentable, inputs that were significant (greater than five percent of total emissions for most institutions) and all in one place, a downloadable file that was less than 100 kilobytes, and a built-in sensitivity analysis that also was adaptable.

Only five groups of inputs (electricity, steam, chilled water, air travel, and auto travel) that were typically the main emissions sources for institutions like Carnegie Mellon were used in the design of the new calculator. Also, the new calculator allows the user to pick a custom electricity generation grid mix, state-specific grid mix, or national average grid mix. The total file size was less than 50 kilobytes, and a screenshot of the new Excel file is shown in Figure 2.7.1. A new feature (not included in the CACP calculator) was a built-in sensitivity analysis where the user could input the percentage reduction (defaults provided to show immediate results) in total emissions desired, and the user will then be given the percentage reduction required from each categorical input.

University Carbon Footprint Calculator (CACP Mini)

Inputs by Category		Units
Electricity	101,000,000	kwh
Steam	382,000	mmBTU
Chilled Water	0	mmBTU
Air Travel	84,600,000	miles
Auto Travel	22,100,000	miles

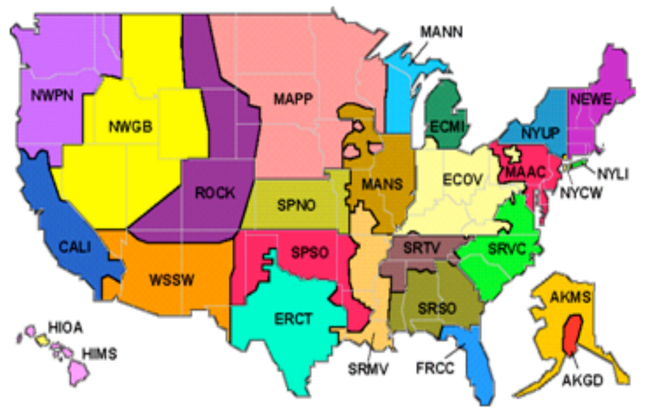
Ouputs by Category		Units
Electricity	72,626	MT eCO2
Steam/Chill Water	37,483	MT eCO2
Air Travel	65,722	MT eCO2
Auto Travel	8,935	MT eCO2
Total	184,765	MT eCO2

*If you wanted to decrease your **Total Emissions** by ...*	5%
*Then **Electricity** would have to be reduced by ...*	13%
*Or **Steam/Chill Water** would have to be reduced by ...*	25%
*Or **Air Travel** would have to be reduced by ...*	14%
*Or **Auto Travel** would have to be reduced by ...*	Not Possible

How do you want to select your Electricity source mix? Custom

Pick a Region
FRCC

OR



Electricity Custom Mix	
Natural Gas	17.0%
Coal	50.0%
Oil	3.0%
Nuclear	20.0%
Hydropower	7.0%
Renewables	2.0%
Total	99.0%

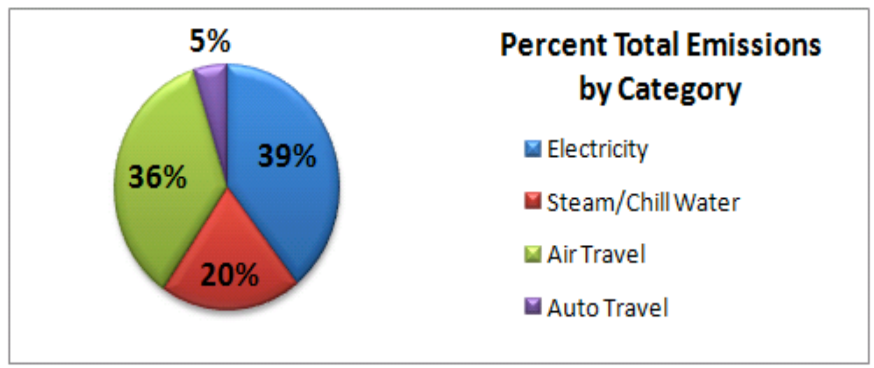


Figure 2.7.1 – Screenshot of improved greenhouse gas emissions estimator

2.8. Conclusions and Recommendations

2.8.1 Conclusions

The annual carbon footprint of Carnegie Mellon was found to be approximately 164,000 MTCDE as of 2006 after thorough research and the use of the CACP calculator. Although other calculators were assessed, the Clean Air-Cool Planet calculator was the most comprehensive, and it generally had the most accurate assumptions. The CACP calculator was also judged to be the best suited greenhouse gas emissions estimator for Carnegie Mellon and other institutions. The analysis showed that the four major contributors to the carbon footprint of Carnegie Mellon are electricity, steam, faculty air travel, and student air travel. A more intuitive and user-friendly carbon calculator was developed so that other institutions can determine their annual emissions in a shorter amount of time and with less strenuous effort. After a detailed carbon footprint assessment is performed, an institution can begin to make mitigation strategies that will successfully reduce its greenhouse gas emissions.

2.8.2 Recommendations

It is very important that, once an institution begins to assess its carbon footprint thoroughly, there is a simple strategy to perform a similar assessment on a yearly basis. The recommendations of this work are aimed to expedite data collection and analysis of Carnegie Mellon's footprint over time as well as any other institutions that are striving to do likewise. This carbon footprint analysis took approximately four months to perform. It should now take Carnegie Mellon only a few hours to do the same if the new calculator is used properly and if data gathering systems are improved and made more accessible.

2.8.2.1 The Big Four

One recommendation is to focus on measuring the largest contributors to the carbon footprint. The four largest emission sources at Carnegie Mellon are electricity, steam/chilled water, and the air travel of faculty and students. These categories make up the majority of the carbon footprint. Although it is good to reduce waste, auto travel, and other small contributors, an institution should focus on the primary contributors to the carbon footprint if it wants to make significant reductions. The "Big Four" at Carnegie Mellon are electricity, steam/chilled water, faculty air travel, and student air travel. The "Big Four" here may not be the same as the "Big Four" at other institutions. The important point is to find the largest contributors and to reduce as much from them as possible.

2.8.2.2 Future Data Tracking

Another recommendation is to improve university accounting systems to track data more easily, especially within the primary emission source categories. After the "Big Four" emissions sources are determined for a particular institution, it is advisable to find a way to track the numbers needed, so that data for these large contributors can be found easily and can be updated at least annually (or quarterly if possible). Having an easy way to track the "Big Four" will make it easy to assess the school's progress once mitigation strategies are in place. An easy way to track faculty air travel at Carnegie Mellon is through the Oracle accounting system. When faculty purchase flights, writing down the destination along with the normal required information should be made mandatory. This system will make it easier to estimate faculty air travel as well as air travel for many other organizations.

2.8.2.3 Excel-Based Calculator

The final recommendation from this research is to create a simple Excel-based calculator with simplified inputs and outputs that are accurate within seven to ten percent of the actual carbon footprint for an institution. No two institutions are exactly alike. Once the initial carbon footprint assessment is completed, an institution should create a calculator that fits its particular needs. Simplicity should be kept in mind so that it can be used by faculty, staff, students, and administrators. Absolute accuracy is not as important as the ease of use, as long as emissions estimations are within a reasonable range so that an institution can have a relatively good approximation of its annual greenhouse gas emissions. The Excel-based calculator developed in this study can be used as a model, since it improves upon the CACP calculator interface by improving the overall ease of use. This calculator was designed to estimate Carnegie Mellon's footprint quickly and easily from significant emissions contributors. However, what works for Carnegie Mellon may not work for another institution, so an accurate and detailed assessment should first be performed before trying this calculator.

Chapter 2 References

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3. Beyond Carbon: Ecological Footprint

3.1. Introduction

The Earth is finite in terms of both land area and natural resources. Therefore, the Earth's stability is dependent on the balance between human population and resource demand, and a breaking-point is reached if these conditions exceed Earth's limits. An ecological footprint attempts to calculate the human demand on the planet's ecosystems and natural resources by comparing consumption with the Earth's ecological capacity to renew these resources and absorb resulting waste. The ecological footprint particularly of developed nations has shown that the current demands on the Earth are threatening the ability of future generations to sustain a lifestyle similar to the one at present. Now is the time for this challenge to be met in order to ensure the preservation of the Earth and its resources for continued use well into the future.

3.1.1. Ecological Sustainability Summary

Humans need a variety of natural resources to live; however, many individuals do not realize how utilizing exorbitant amounts of these resources impacts the environment. Moreover, at a current world population of 6.67 billion people (Census 2008), the per capita biocapacity is at 1.8 hectares (4.5 acres), and the Earth's population is ever increasing. The current global ecological footprint is 23 percent larger than what the Earth is able to renew, meaning that it now takes more than 14 months for Earth to regenerate what humans use in a single year. In terms of the average ecological footprint of one human being, the current ecological footprint is 2.3 hectares, meaning that it would take 1.5 Earths in order to sustain this level of consumption. Americans have one of the largest ecological footprints at 9.6 hectares (23.7 acres) per person. It is estimated that approximately five Earths would be needed if everyone in the world consumed at the same rates as U.S. citizens. China, on the other hand, stands at 1.4 hectares (3.5 acres). However, the national consumption of fuel by China is only four percent of what America uses currently (Sod-Hoffs 2008). In the future, if Chinese levels of consumption reach the equivalent of American levels now and the Chinese population increases to over 1.5 billion, one can easily imagine the type of ecological trouble humans and numerous other species would experience. Without the implementation of preventative policies, an overall Chinese consumption increase to United States levels would require 25 Earths to meet all resource demands (Adbusters 2008). By measuring the ecological footprint of a population (whether it is a university, city, nation, or the world), an individual can adequately assess over-consumption or "overshoot" by this population and in turn can help policymakers manage ecological assets more effectively.

3.1.2. Motivation

Carnegie Mellon University aspires to be part of the movement to make this world cleaner and "greener" by tracking the natural assets that people consume on campus and by being responsible for its ecological impact. This analysis aims to track ecological assets through an ecological footprint assessment, which is a resource accounting tool that quantifies human demand on Earth. The results of this analysis can be used to give specific recommendations that allow students, faculty, and staff to make more informed environmental choices. A step of this kind is necessary to secure the means for well-being while still maintaining the ability of future generations to live on an Earth where human consumption has not fully depleted what nature can regenerate. Furthermore, as current community leaders and as future change agents in the world, campus populations are most capable to begin guiding and shaping policies to engender a more ecologically sustainable world.

3.2. Ecological Footprint Overview

3.2.1. Scope

Carbon dioxide is the primary concern of many of today's environmental engineers and policymakers. Although there are many significant reasons for this attention, it is important not to neglect the larger problem of "meeting the needs of the present without compromising the ability of future generation to meet their own needs," which is one definition of sustainability (Brundtland 1987). Other decisions, not directly related to the emissions of greenhouse gases, also play roles in the ability to provide for future generations. Since the overarching goal of sustainable development entails many complex and interconnected ecological facets, it would be a mistake to direct all attention and efforts toward a single environmental concern.

3.2.2. Consumption

Modern societal demand is comprised of global consumers. Not only has the amount of consumption increased, but the distance between producers and consumers has increased as well. Purchased goods commonly must travel halfway around the globe before reaching the consumer. Many individuals do not take into consideration the effects that buying such goods will have upon the environment and do not think about how consumption choices are equally as bound to an intricate web of ecological ramifications as they are to economic and social ones. Consumers often do not consider or understand the supply chain process, and it is easy in modern society to forget that ground beef does not originate from the supermarket. For this reason, metrics such as an ecological footprint allow for a broad base of goods to be condensed into a single value that allows for a quantitative comparison of ecological fitness.

3.2.3. Carrying Capacity "on its Head"

In order to understand the notion of an ecological footprint, one should consider the concept of carrying capacity. This sustainability metric was designed to measure how many people or organisms could live within a certain area boundary without facing losses. However, as seen today in places like Singapore, the number of organisms, namely humans, that are able to live in a certain area is no longer bounded by such restrictions. Although technology has allowed a larger population to live comfortably on a smaller piece of land, this arrangement does not imply sustainability. Wackernagel and Rees took the idea of carrying capacity and literally turned it "on its head." Since humans were able to use technology to make any space livable at rates much higher than such an area could naturally provide, Wackernagel looked at the amount of land needed to provide a similar lifestyle for one person or population of people. To better understand this notion, one can imagine that a giant bubble has been placed over the city of Pittsburgh and all its inhabitants. This bubble allows for sunlight, rain, and other ecological functions to occur but does not allow for outside goods or people to cross its boundaries (Rees and Wackernagel 1995). How long could Pittsburgh sustain itself? One year? One month? With current consumption levels, Pittsburgh requires additional land and goods beyond the city's boundaries to sustain itself. Thus, an ecological footprint for Pittsburgh would be a bubble sufficiently large enough to keep the city and all its inhabitants alive and healthy indefinitely.

3.2.4. Assumptions

In brief, an ecological footprint is "an accounting tool" that includes a variety of factors about consumption and waste, showing a quick "balance sheet" of current usage-flows. Such a tool is helpful, since most Western consumers do not always consume from local sources. However, with an ecological footprint, individuals are able to calculate clearly the amount of land they require. In order to calculate an ecological footprint, six basic ideas must be assumed (Rees and Wackernagel 1995):

- The majority of the resources people consume and the wastes they generate can be tracked.
- Most of these resource and waste flows can be measured in terms of the biologically productive area necessary to maintain flows. Resource and waste flows that cannot be measured are excluded from the assessment, leading to a systematic underestimate of humanity's true ecological footprint.
- By weighting each area in proportion to its bioproductivity, different types of areas can be converted into the common unit of global hectares, hectares with world average bioproductivity.
- Since a single global hectare represents a single use and all global hectares in any single year represent the same amount of bioproductivity, they can be added up to obtain an aggregate indicator of ecological footprint or biocapacity.
- Human demand, expressed as the ecological footprint, can be directly compared to nature's supply, biocapacity, when both are expressed in global hectares.
- Area demanded can exceed area supplied if demand on an ecosystem exceeds that ecosystems regenerative capacity (e.g., humans can temporarily demand more biocapacity from forests, or fisheries than those ecosystems have available). This situation, in which an area's ecological footprint exceeds available biocapacity, is known as "overshoot."

With these assumptions, the ability to calculate an institution's ecological footprint is possible.

3.3. Ecological Calculator

3.3.1. Search Method and Results

Determining the ecological footprint of Carnegie Mellon's campus began with a search for appropriate ecological footprint calculators. The search method was similar to that used for finding carbon calculators (see Section 2.2) using Internet search engines like Google was used to locate a straightforward and precise calculator that could be applicable to campuses. However, unlike carbon calculators (which appear in a wide array of options on the Internet), comprehensive ecological calculators were much harder to find. This difficulty is due to the absence of a specific and widely-accepted method for calculating a carbon footprint, whereas an ecological footprint has a specific method that has been developed, researched, and analyzed in detail. Search results proved to be somewhat unsatisfactory with the large majority of calculators designed for individual use and stemming from the same central source (e.g., Redefining Progress/Our Ecological Footprint). Common questions included in these calculators were: "How many miles a week do you drive?" and "How much food do you buy locally?" (Redefining Progress 2008). While these calculators may be useful on an individual basis, it was unlikely to be informative for a campus community, as they were too simplistic to offer any real basis for analysis. In order to be used on a campus scale, the calculator would need to take into account the size of the campus, energy requirements on campus, and the amount of food eaten on campus in the form of the ecological footprint outlined by Wackernagel and Rees.

3.3.2. Description and Applicability of All Calculators

The small number of calculators that were found did, however, have a surprising amount of variety in their scope, application, and complexity. The inputs for these calculators ranged from questions that were very specific and quantitatively driven to multiple choice questions with little or no quantitative data needed. The most simplistic of the calculators found was the WWF calculator that was primarily aimed at giving an individual a rough estimate of his or her ecological footprint. Questions were based upon a basic grouping of the categories into food, travel, home, and "stuff" (e.g., goods). Although this calculator effectively encapsulated the idea of Wackernagel and Rees, it was not conducive to large institutions like a college campus. Multiple choice questions such as "How would you best describe your diet" were answerable by the following: meat and/or fish eater, vegetarian, or vegan. Such basic answers would not be serviceable in the context of a college or university.

Two other calculators, Redefining Progress and Global Footprint Network, were slightly better, requiring more exact data inputs in addition to qualitative multiple choice questions. Both Redefining Progress and the Global Footprint Network were web-based applets geared toward individual use. However, despite such compelling indications of quality, these calculators were also unfit for the broad scope of a campus setting. The quantity of a university's consumption exceeded the input capacity of the calculators, and although more exact than the previous calculator, the questions were not the most precise. Examples like "Which best describes your home?" (Redefining Progress 2008) and "Does your home have electricity?" (Global Footprint Network 2008) were not adequate for determining the ecological footprint for an institution, since they are primarily aimed toward assessing individual footprints.

A very precise ecological footprint calculator was found through the U.S. Environmental Protection Agency (EPA). This tool had a variety of different formations of an ecological footprint that were designed for specific purposes ranging from individuals to retail centers (and even included a sector designed for schools). Unfortunately, no direct model for colleges and universities were available. Nonetheless, the EPA calculator required very precise, quantitative data to calculate footprints, which allowed for a calculation that would be precise and scalable for a large institution beyond normal individual calculators. Moreover, the questions were also based heavily upon inputs similar to those necessary in a college or university. However, questions that asked for the specific quantity of electricity used and copy paper used per year would have been helpful in determining an exact footprint. Therefore, despite the very well designed and preciseness of the EPA calculator, it was ultimately decided against due to limitations of the web-based applet.

Considering that further analyses other than the simple calculation of the footprint were to be performed, it was decided that an Excel-based spreadsheet calculator like Redefining Progress' household calculator would be far more efficient in providing an accurate ecological footprint and simple sensitivity analyses. A detailed description of the Redefining Progress household calculator can be found in the subsequent sections of this chapter.

In addition to the calculators discussed above, other less significant calculators were also found but were not noteworthy in their precision or their applicability to a large institution. Thus, these tools were not considered in the process to determine which calculator would be used to calculate Carnegie Mellon's ecological footprint.

Table 3.3.1 – Search results by calculator with consideration of applicability to campus setting

Calculator	Description	Website URL
Redefining Progress (Household)	• Comprehensive calculator using Excel format, based heavily on the work of Wackernagel • Inputs are broad, varied, and allow for formatting to campus proportions	www.sbs.utexas.edu/resource/WhatIs
EPA	• Web-based applet with a variety of different formations from individual to retail locations but none available specifically for campus settings • Has a comprehensive list of inputs similar to Redefining Progress but without the ability to format directly for college campuses	www.epa.vic.gov/ecologicalfootprint
WWF	• Web-based applet with basic questions regarding food, travel, home, and stuff • Appropriate for individual use but not large enough in scope to handle a college campus setting	footprint.wwf.org.uk
Global Footprint Network	• Web-based applet designed specifically for individual households • Although comprehensive in its scope for individuals, it does not allow formatting for the larger scope of a college	www.footprintnetwork.org
Redefining Progress (Individual)	• Web-based applet version of the household version above that is configured specifically for individuals with a consideration of the individual's country of origin • Although very good for individual use, it cannot be reconfigured for a campus setting very easily	www.rprogress.org

3.3.2. Chosen Calculator

The calculator that was chosen to estimate the ecological footprint of Carnegie Mellon's campus was designed by Redefining Progress, a public policy think tank, and was based on Wackernagel's work (Wackernagel and Yount 1998). The calculator includes six broad categories: food, housing, goods, services, transportation, and waste. Within these broader categories, there are individual inputs. These inputs are requested in monthly values, and the calculator uses this information to calculate the ecological footprint. As detailed in Section 3.3, this particular calculator was chosen due to its simplicity and its applicability for institutions like university campuses. Although originally designed for an individual household, modifications were made to this calculator to make it appropriate for the size and scope of a campus setting, with the shift from the housing category to the built environment category being the most significant. This category then took into account the square footage of the every campus building and the acreage of the entire campus. Additional changes had to be made to account for steam. Since a significant amount of steam is used on Carnegie Mellon's campus, neglecting such a large input would have had a very large influence on the size of the university's footprint. In order to account for the quantity of steam used, the amount of carbon dioxide released as a result of the steam was calculated. A back calculation was then performed to calculate the amount of electricity that would produce that same amount of carbon dioxide. The steam could then be an equivalent input to electricity. Another back calculation was performed to determine the amount of electricity that would produce that same amount of carbon dioxide. Ultimately, the steam proved to be a substantial piece of the total ecological footprint.

Since only one calculator aligned with the objectives of this research, another round of searches was performed to ensure that this tool was the most effective and accurate calculator for the campus ecological footprint. The first search centered on Wackernagel and Rees book *Our Ecological Footprint* to check whether the inputs of the calculator were similar to the original conception. Only slight differences were found. For instance, in the Wackernagel and Rees work, the "garden" category was found inside of the broader heading of "food," and "built environment" was fused with "energy land" to create a more intuitive household calculator. Next, a higher order search was performed using various online media-catalogues like MetaLib to determine if other variations of the same calculator existed. While many of the searches pointed to the same calculator, a couple results showed that new calculators also had been made. However, these calculators were not appropriate for use in this study. One newer calculator was designed specifically for Australia, and another calculator was designed for an entire nation, which was too large in scope due to its inputs for values such as imports, exports, and other such measures (EPA 2005). Although this calculator was not utilized in this study, there were differences between the calculator used in this analysis and the newer calculators. The newer calculators included a more biodiversity friendly approach and a new measure for the potential of land called net primary productivity (NPP). Nonetheless, despite these improvements in the EPA calculator, substantiation of the Redefining Progress calculator for the purpose of calculating a campus ecological footprint proved successful.

The Redefining Progress calculator was useful, because it required inputs that generally were recorded by Carnegie Mellon. However, inputs that required information that was not detailed in inventory records were estimated using either national per capita averages or calculated estimations. One such category was food, since the ecological footprint calculator required detailed knowledge of several very specific inputs like amount of beef that was either grain fed or pasture fed. Naturally, such detailed information was not kept by the university. Other inputs included the percentage of food eaten on campus that is wasted and a broad approximation of how much food is locally produced. Other categories such as built environment were more easily accounted for, since inputs like the square feet of campus and living areas is readily documented. Another important input was the electricity purchased and the grid mix associated with this electricity purchase. Goods were measured using inputs such as kilograms of paper used and the amount of janitorial products to calculate the footprint. Waste had the most obvious inputs with kilograms of paper, aluminum, magnetic metal, glass, and plastic wastes for the calculations. Transportation inputs such as airplane, car, and public transportation travel and service inputs such as laundry and postal services were also accounted for and were generally speaking calculated using estimates. The total number of inputs was approximately 60. Table 3.3.2 shows the break down of the inputs between categories, a description of the units used, and examples for each of the categories from the calculator.

Table 3.3.2 – Summary of inputs needed for ecological footprint calculator

Categories	Number of Inputs	Units	Examples
Food	21	kg, l, $, m^2, number	Meats, liquids, cereals, garden, eggs, and cheese
Housing	17	m^2, $, kWh, m^3, l, kg	Living area, hotels, electricity, gas, coal, and utilities
Transportation	10	pers*km, km, pers*hrs, kg	Public transportation, private transportation, airplane, and repairs
Goods	11	kg	Clothes, tobacco, leather, glass, and other products
Services	8	kg, $(telephone)	Postal, laundry, and telephone
Wastes	5	kg	Paper, glass, and plastics

3.4. Ecological Footprint Calculation

3.4.1. Land Use Categories

In order to break down consumption into one measure, consumption must first be divided into four different categories, which is further separated into a total of eight "land use categories" (Rees and Wackernagel 1995). This step is taken due to the fact that different ecosystems produce at different rates and must be accounted for as such. Table 3.4.1 shows the varying land-use categories.

Table 3.4.1 – Eight main land and land-use categories for ecological footprint assessments

I) Energy Land:	a.) land "appropriated" by fossil energy use	(ENERGY OR CO_2 LAND)
II) Consumed Land:	b.) built environment	(DEGRADED LAND)
III) Currently Used Land:	c.) gardens	(REVERSIBLY BUILT LAND)
	d.) crop lands	(CULTIVATED SYSTEMS)
	e.) pasture	(MODIFIED SYSTEMS)
	f.) managed forests	(MODIFIED SYSTEMS)
IV) Land of Limited Availability	g.) untouched forests	(PRODUCTIVE NATURAL ECOSYSTEMS)
	h.) non-productive areas	(DESERTS, ICECAPS)

Of the above categories, one of the most difficult to conceptualize is the notion of energy land. Fossil fuels are being consumed at a far faster rate than they can be replenished, but another environmental concern is the amount of greenhouse gases that is emitted from burning of such fuels. In order to allow for proper absorption of this carbon in various waste sinks, Wackernagel and Rees estimated the amount of forest required to sequester the amount of carbon made. In *Our Ecological Footprint*, this value was set at 100 gigajoules per hectare (Rees and Wackernagel 1995). Modifications to this conceptual framework have been made since its initial formulation, as technology and knowledge of carbon sequestration have increased. Another important factor in carbon sequestration is the category of untouched (i.e., virgin) forests, which could lead to "a massive net CO_2 release that would be recovered only after 200 years" (Rees and Wackernagel 1995) if harvested. The other categories provided for in the footprint are far more straightforward like the built environment, which represents land that has been paved over or has had buildings built upon it. This value signifies land that would require a very long time to return to being ecologically productive again. Currently used land includes such activities as gardening, farming (crop lands), animal husbandry (pasture), and foresting (managed forests). These activities exert limited strains on the environment compared with other more land-intensive activities but nonetheless can have a negative impact.

3.4.2. Yield Factors

After the categories are divided to define where different products go and what kind of land each product will be using, the analysis must also bring them back together into one measure: a global hectare or global acre. The method for accomplishing this task is through an equivalence or yield factor. In order to understand the notion of a yield factor more clearly, one can imagine an apple tree in two separate ecosystems: a desert and a forest. The apple tree will not be able to grow the same in either ecosystem, since there is a difference in each of the ecosystem's bioproductivity, which represents "the amount of biological productivity required to renew the biotic resources humans use (food, timber, etc.) and to absorb their waste" (Lenzen et al. 2006). The yield factor normalizes varying bioproductivities, so that they emulate the global average biomass productivity and can allow for global comparisons.

3.4.3. Example of Ecological Footprint Calculation for Goods

In order to calculate the footprint of the goods that individuals consume (including many different natural and synthetic products), it is necessary to calculate the strain that the various land use categories place upon the environment (NCCSTS 2008). Energy in the form of fossil fuels is used to make many goods. Additionally, although the standard formula (shown in Figure 3.4.1) for fossil fuel land is used, each product will have its own unique energy intensity ratio. This ratio describes how certain goods (e.g., medicine and tools) require a higher demand for energy to run machinery and labs than other goods. Other goods (e.g., cotton and tobacco) require a large ratio of arable land to harvest such products. Some examples of the amount of land needed to produce cotton clothes and tobacco products illustrate just how much land humans require for their consumption, as 10,000 m^2 of arable land will only grow 636 kg of cotton or only 1,600 kg of tobacco. Animal goods are even more land-intensive, requiring pastureland to raise animals such as sheep and cattle for wool and leather. The same amount of land as above will only produce 10 kg of wool or 57 kg of leather. Thus, animal products are considerably less productive per unit area than plants. Paper products are produced through the harvesting of trees. In order to calculate the land area needed for paper (expressed in m^2 per year), roundwood productivity (expressed in m^2 land per m^3 wood) is multiplied by paper conversion efficiency (expressed in m^3 wood per kg paper), consumption quantity in metric or U.S. standard (kg paper), metric conversion factor and waste factor (kg wood harvested per kg wood used to make paper). One cubic meter of roundwood can produce about 1,000 kg of paper. Since not all parts of the wood are used in making paper products, waste factors are used to account for losses in the final product in addition to accounting for many indirect sources of production associated with the final product. It is important that all associated life cycle activities are converted properly into the corresponding ecological footprint land area. Wackernagel uses several assumptions in terms of aggregate built up industrial and commercial land and aggregate data of population in the United States. In order to calculate built land, he assumed that "the amount of built up land is directly proportional to the fossil energy area needed to manufacture the good" (Wackernagel and Yount 1998). The equation is as follows for the built up land area: fossil energy land is multiplied by built up land (1,100 m^2)/fossil energy required for built up land (1,324 m^2 + 1,196 m^2), then divided by the bioproductivity of land (i.e., 3.5). 1,100 stands for estimation of per capita built up land component of goods including wastes, and 1,324 and 1,196 account for fossil fuel areas of goods and waste, respectively. Dividing the outcome by 3.5 permits standardization for the average productivity of land under the assumption that most built up land is located on bioproductive land rather than arable land. Combining these values allows for the final analysis result to be in units of global hectares or global acres, which can then be used to analyze the consumption habits of the population in question. Calculations of this sort are then carried out for each of the categories of built environment, goods, transportation, food, services and wastes.

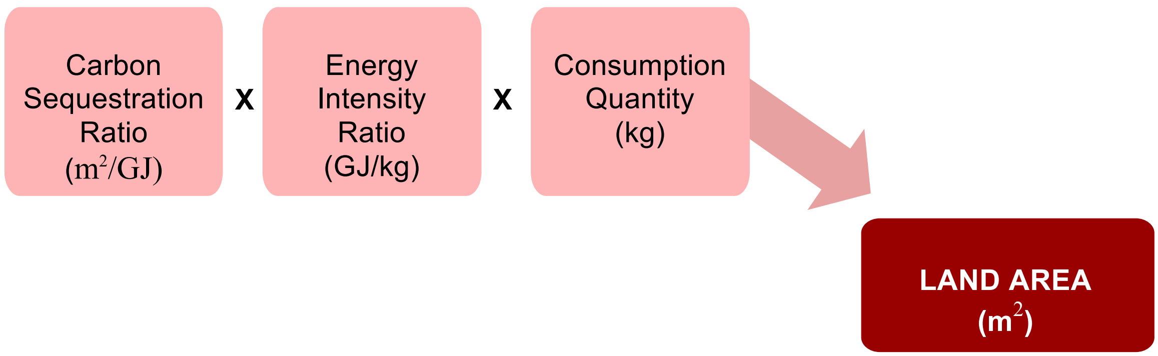

Figure 3.4.1 – Graphical representation of energy land use calculation

3.5. Ecological Footprint Results

3.5.1. Carnegie Mellon's Ecological Footprint

Using the ecological footprint calculator designed by Redefining Progress, the Carnegie Mellon ecological footprint was found to be 300,000 acres, as shown in Figure 3.5.1. Given that the area of the campus itself is 140 acres, the results of the analysis imply that it would take the space of nearly 2,150 campuses to support Carnegie Mellon's lifestyle. The 300,000 acre ecological footprint can also be divided into 20-30 acres per capita, depending on the scope of the campus community included in the calculation. If only undergraduate and graduate students are included in the calculation, the footprint would be 30 acres per capita. However, if the students, faculty, and staff are included, the ecological footprint would be 20 acres per person.

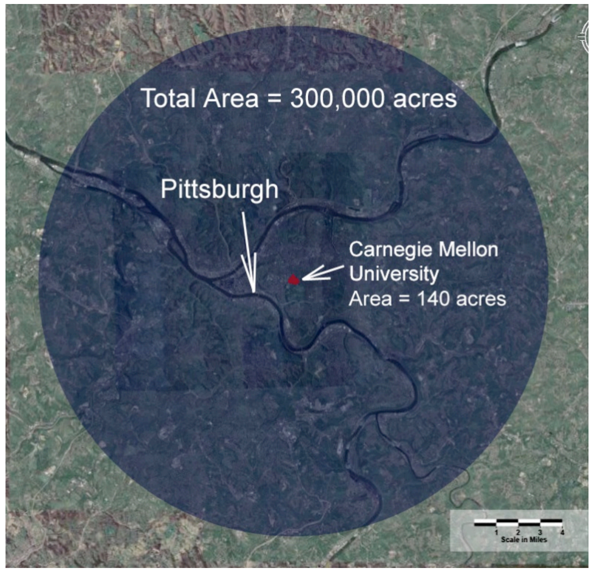

Figure 3.5.1 – Relative area of ecological footprint in comparison to Carnegie Mellon campus

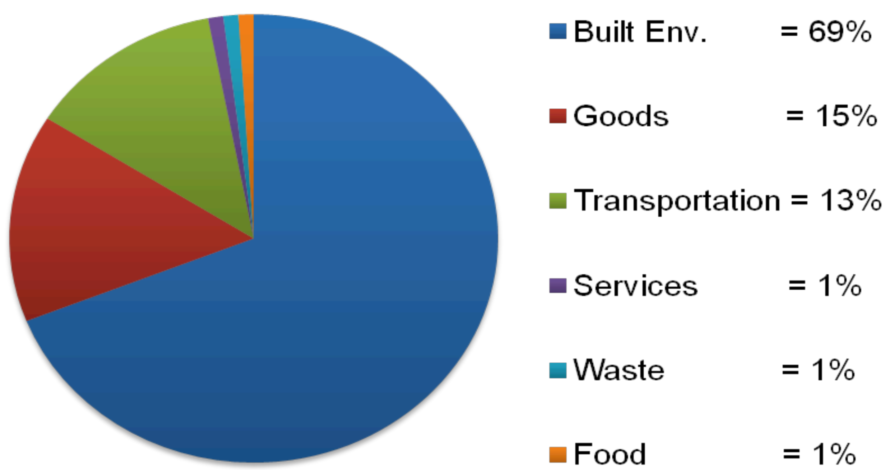

Figure 3.5.2 – Categorical percentage share of Carnegie Mellon's ecological footprint

Figure 3.5.2 shows the break down of the Carnegie Mellon ecological footprint based on the six categories included in the calculator. The built environment category has the most impact at 69 percent of the total. Given the carbon footprint analysis in Chapter 2, this result is not surprised, since this category takes into account all of the electricity and energy used on campus. The somewhat surprising result of the calculator was that the goods category had a significant impact as well, as it comprised 15 percent of the campus total (and was followed by the transportation category at 13 percent). Goods include everything that is purchased on campus, which includes computers, lab equipment, and desks. It is surprising that a category made up of purchased goods could have a larger impact than transportation or waste. The three categories that made up one percent of the total ecological footprint each (i.e., services, waste, and food) are relatively inconsequential in the overall ecological footprint.

3.5.2. Sensitivity Analysis

While the ecological footprint was dominated by the built environment category, it was still important to investigate the impacts of the other categories and how changes in these values can affect the total footprint. A sensitivity analysis of the various categories was completed to assess these potential impacts. Each category is determined by a subset of individual inputs. By making small changes to the inputs, predictably minimal changes in the impacts of the categories result. This behavior indicates that the built environment still dominates the overall footprint. For instance, in the waste category, the most sensitive input was paper. When this input was changed to a value larger by one order of magnitude, there was a change in the overall ecological footprint of slightly less than five percent. A change of 100 times the original input value, which is not a likely input in the near future, was needed to see large changes in the overall ecological footprint. While the inputs used in the calculator cannot be guaranteed, the accuracy of these values should be good enough that any minor discrepancy would not have an appreciable change in the results of the analysis. It is unreasonable to think that an input value could be two orders of magnitude away from the true statistic.

For the aforementioned reasons, the sensitivity analysis came to a few key conclusions. First, the built environment will remain the largest contributor to the ecological footprint even with large changes in other categories. Second, the individual inputs for the smaller contributing categories have very minimal impact on the overall footprint. Finally, given the assumed accuracy of the values, small variations in the input values will not significantly impact the output value of the ecological footprint analysis.

3.5.2.1. Analysis of the Effects of Eliminating Categories

The next step was to determine what would happen if Carnegie Mellon were able to implement policies that eliminated certain categories (i.e., to examine the effect of zeroing out specific categories). This analysis was performed by setting specific inputs to zero. An example of a policy that would institute such a change would be if Carnegie Mellon's food services moved to a completely vegetarian plan, as the meat inputs on the ecological footprint calculator would all be zero. This technique was used to examine the overall contribution of specific inputs to the ecological footprint. First, the lower percentage contribution categories were zeroed out using the method outlined above. There were no significant changes to the footprint in zeroing out the services, waste, and food categories. This result reinforces the earlier conclusion that the built environment category dominates the overall footprint. Each category of food, services, and waste make up less than one percent of the total footprint. These three categories contain many individual inputs, meaning that the contribution of these to the overall footprint is even less than this small one percent value. The central categories were goods and transportation, since they had the largest contributions to the footprint. Goods made up approximately 15 percent of the total footprint, with transportation being approximately 13 percent. Zeroing out specific inputs in the goods category resulted in decreases of up to roughly 23,000 acres to the total footprint for each category. Transportation ended up decreasing the total footprint up to roughly 31,000 acres for each input. The largest contributor to the footprint from the transportation category was the air travel input.

After performing the sensitivity analysis and zeroing out analysis, one particularly important conclusion was drawn from the work. For the overall ecological footprint, energy matters the most. The energy that campus used added to the built environment category and dominated the overall ecological footprint. The input for electricity alone accounted for approximately 203,000 acres of the total ecological footprint of roughly 300,000 acres, which represent approximately two-thirds of the total. When this trend is considered, it can be seen that addressing the acquisition and production of electricity can have the greatest effect on the ecological footprint. One way to address this input is by adjusting the grid mix of campuses electricity.

3.5.2.2. Analysis of Grid Mix Possibilities

To further the analysis of what certain policies would have upon Carnegie Mellon's ecological footprint, the effects that changing the grid mix input of the calculator was undertaken. The current grid mix for Carnegie Mellon's campus is roughly 40 percent coal, 40 percent nuclear, and slightly under 20 percent renewables. If Carnegie Mellon did not use any electricity, a huge reduction would take the approximately 300,000 acre footprint by about a third to 96,000 acres. However, since eliminated electricity entirely would be virtually impossible, changes in the relative portfolio shares of the generation mix were made to simulate certain percentages similar to those of the petition (i.e., 50 percent fossil and 50 percent wind, as well as 100 percent wind). These grid mix alterations had a significant impact on the overall footprint, with the 50-50 grid mix resulting in a 220,000 acre footprint. The change to 100 percent wind clearly had a much larger impact reducing the overall footprint to a mere 102,000 acres. However, the interesting conclusion that can be drawn from these numbers is not merely that including renewable energy reduces the footprint. Rather, even with 100 percent renewable energy, an ecological footprint of 6,000 acres still remains for the production of that wind power. This powerful result shows that there is a possibility that, even if the Carnegie Mellon campus can reduce its greenhouse gas emissions to zero, the ecological footprint will remain a problem to be solved.

Table 3.5.1 – Ecological footprint results of a changing grid mix

Grid Mix	Total Ecological Footprint (Acres)	Electricity Portion (Acres)
Current	300,000	203,000
50 Percent Wind/50 Percent Fossil	220,000	125,000
100 Percent Wind	102,000	6,000

3.5.3. Major Uncertainties

The quantitative dependence of the ecological footprint value on the scope of inputs for the calculation sheds light on the conceptual treatment of the ecological footprint and the difficult question of what the bounds of this analysis should be. Individuals and their actions are included when they are on campus. However, when they leave, their actions are no longer included. This issue is accompanied by questions regarding trips taken by faculty and students that are affiliated with the university for leisure and whether such flights should be included in the university's total ecological footprint. Moreover, there are questions concerns whether students who live off campus should also be included. This problem is a question of how far the bounds of the ecological footprint should extend in the context of a campus and what agents should be included in that analysis. However, this complicated issue is brought about by the many complexities inherent in the ecological footprint method itself, since it was originally developed for entire nations or regions and therefore focused upon a much larger scale. For analyses at the university level, the best route is to concentrate on the campus-related factors first and then perhaps to undergo further analysis of off-campus students through self reporting and surveys.

3.6. Beyond Carnegie Mellon: Life Cycle Assessment

3.6.1. Life Cycle Introduction

Life cycles are the process and development needed to produce a product or service. In order to help visualize this, it is best to think of the easiest product possible (e.g., a toothpick) and all the necessary supplies and processes to produce that product. When conceptualized this way, even a simple product like a toothpick suddenly becomes very complicated in its multifaceted production chain, which includes obvious processes like having to cut down trees but also less evident steps like producing the oil that lubricates the spindle of a machine in this process. Life cycle assessment is a method used to assess the environmental impacts associated with a product, process, or service by extrapolating all products and processes that are required like in the toothpick example. This analysis is accomplished by first compiling a list of energy and material inputs and their associated environmental releases. In the case of a toothpick, this would include the wood needed to produce the product itself, all processes required to shape and form the toothpick, and all transportation needed throughout the process. Second, an analysis is performed to evaluate the environmental impacts associated with these inputs and environmental releases. This information is then used to make an appropriate decision about a product or service, which allows for a reasonable decision to be made based on the entire process of production and not simply from the product itself. It is easy to forget how far reaching a product or process might be, and life cycle assessment takes this into account by informing the consumer about all environmental issues associated with the production of a product or carrying out a service.

3.6.1.1. Reasons to Use Life Cycle Assessment

When looking at an institution, it is informative to take a life cycle approach to determine what makes a campus run rather than simply what takes place on campus. Most other assessment models (e.g., carbon footprint and ecological footprint) only take into account what directly happens as a result of campus. The life cycle assessment method examines the entire supply chain of a product or service and thus determines both their direct and indirect impacts. In this case, the direct and indirect impacts of a college or university can be determined.

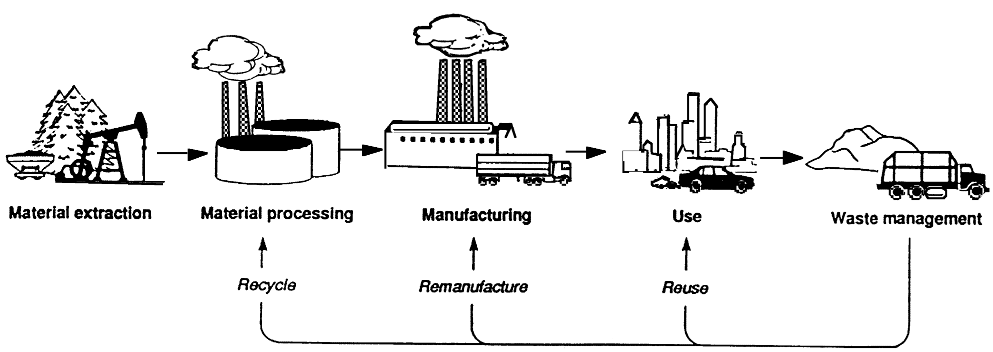

Figure 3.6.1 – Visual representation of the life cycle analysis (OTA 1992)

3.6.2. Life Cycle Assessment Calculations

In order to perform a university life cycle assessment, a specific model must be used. The Economic Input-Output Life Cycle Assessment (EIO-LCA) model, which was designed at Carnegie Mellon, was chosen for this analysis. This model allows for an estimation of the environmental impacts of a certain dollar amount of producing 500 commodities or services in the U.S. and is based on publicly available data. The entire supply chain of requirements is included, but output data is only available for production and does not include the use of the product. The environmental impacts include energy use, air pollutants, hazardous wastes, toxics and dollar amounts of external air pollution costs. This relatively simple model requires an input of a monetary value, which is representative of the monetary value of the output. It also requires that a sector be chosen for the assessment. Further, it requires the choice of a dataset (e.g., carbon emissions or energy usage). This means that if carbon emissions were chosen, all of the direct and indirect carbon emissions that come from the chosen sector would be calculated for the chosen output amount. When performing a life cycle assessment of a university, the "colleges, universities, and junior colleges" sector should be chosen. An appropriate amount of output might be something representative of a student's tuition. For the case study of Carnegie Mellon, the chosen value was $45,000, which is approximately one student's annual tuition. Additionally, for this assessment, four different data sets were chosen along with one data set that remained constant throughout, which was determined to be the economic activity data set. This indicates both direct and indirect economic activity by percentage, and when combined with the other four data sets (i.e., greenhouse gas emissions, pollution, toxic releases, and energy uses), it allows for a determination of direct and indirect emissions, energy use, and other output. This information presents a useful visual representation of the significance of the indirect portion of running a university campus. As illustrated in Figures 3.6.2 through 3.6.5, the analysis suggests that all of the products and processes that are indirectly helping to keep the campus operating proficiently are significant.

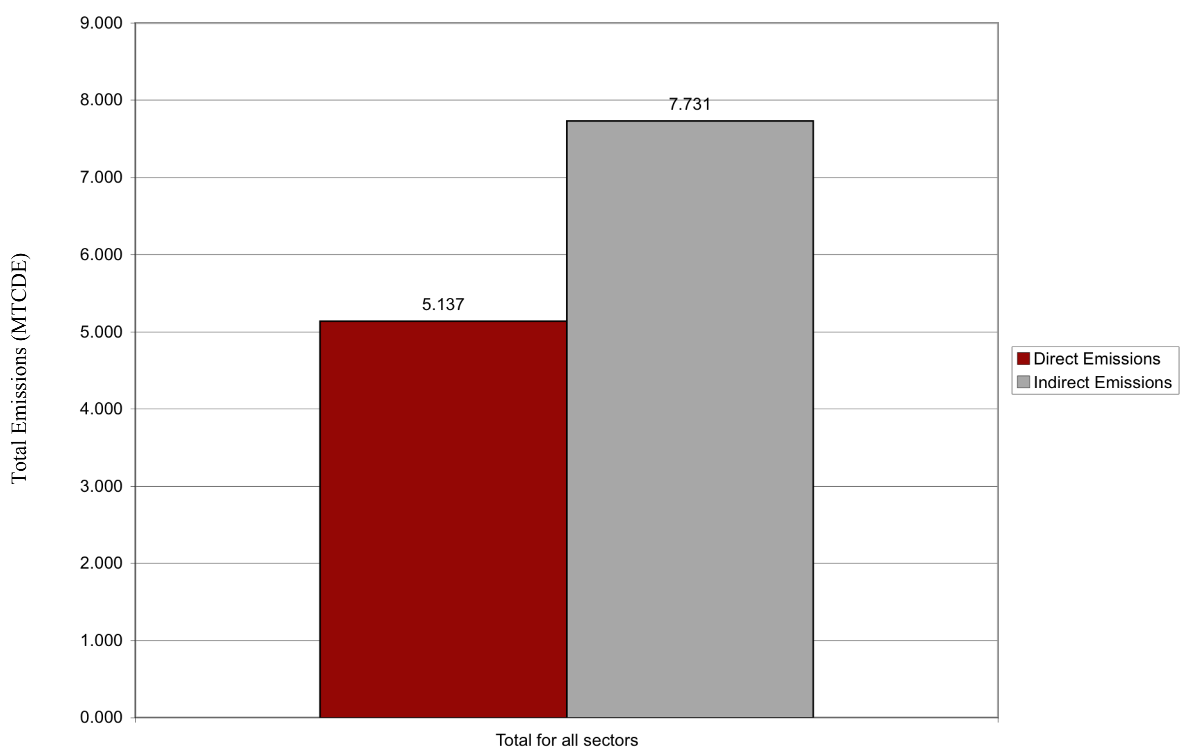

Figure 3.6.2 – LCA comparison of direct and indirect emissions

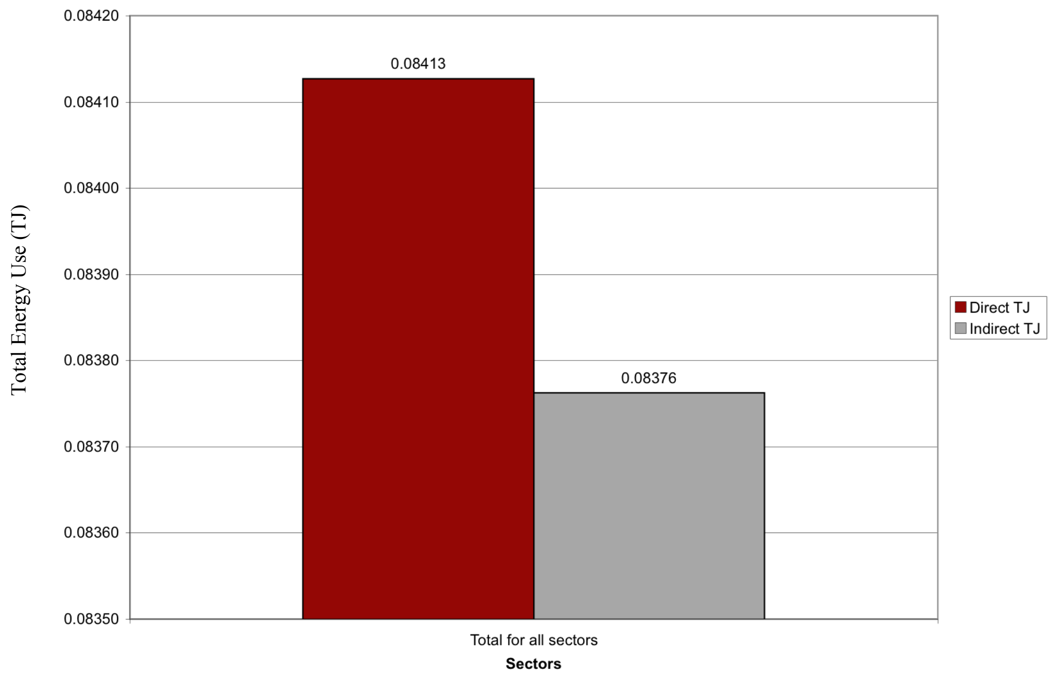

Figure 3.6.3 – LCA of direct and indirect energy use

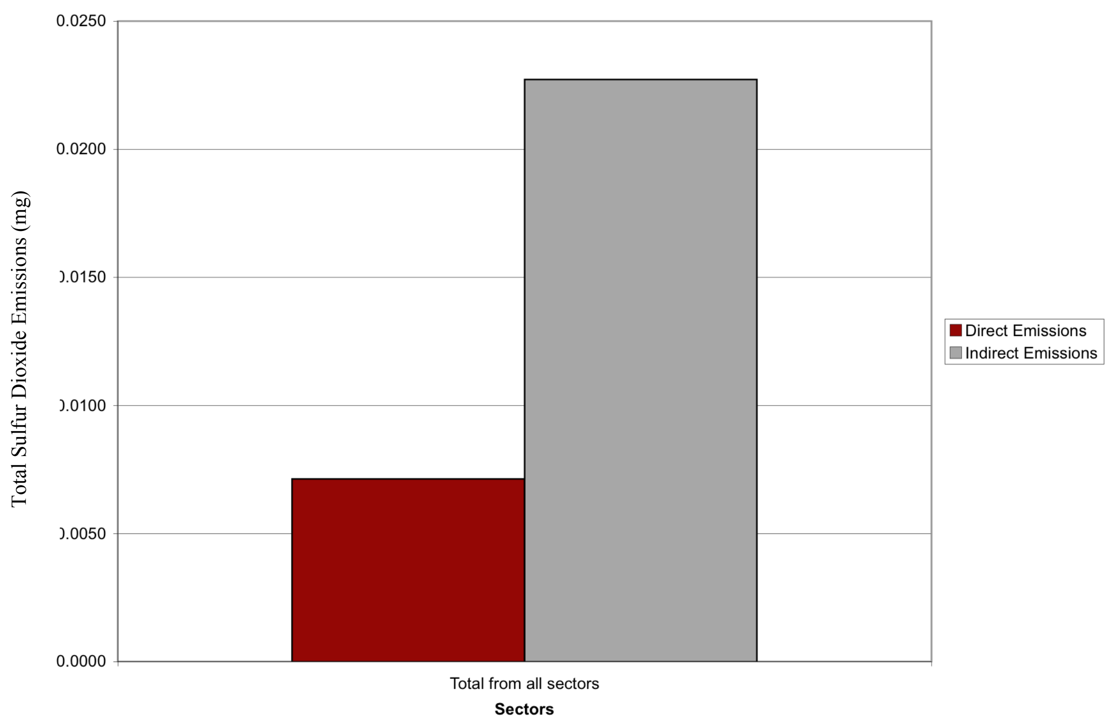

Figure 3.6.4 – LCA of direct and indirect sulfur dioxide emissions

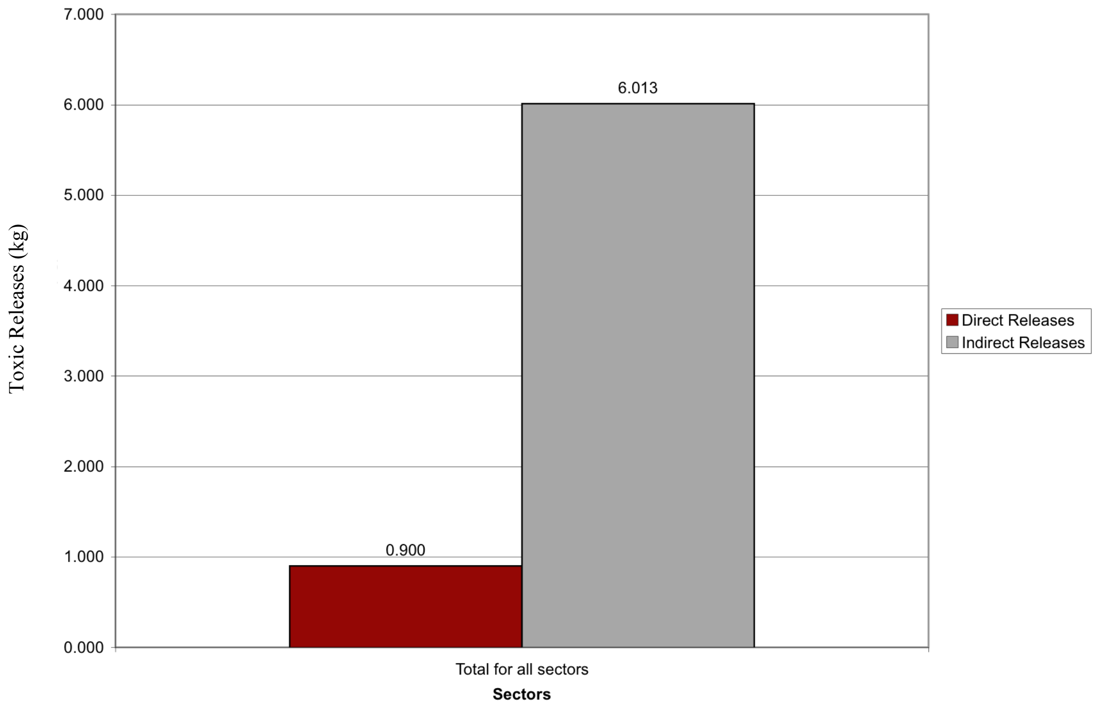

Figure 3.6.5 – LCA of direct and indirect toxic releases

Figures 3.6.2 through 3.6.5 illustrate that data developed through the EIO-LCA model. As shown in Figure 3.6.2, the red bars represent direct emissions from the processes of the university, either the direct emissions by the university or the emissions that result from generating power that is purchased. The gray bars represent the indirect emissions that occur as a result of the running of the university. For example, indirect sources include emissions that result from the power bought by a food processing company with which the university deals, emissions from the power that is bought by the company that makes the machines for the food processing plant, and so on until a specified upper bound is reached. The graphs suggest that the indirect and direct values are often very different, and the indirect emissions are typically larger than the direct emissions. This representation is indicative of an average college campus and is not Carnegie Mellon specific. An assumption that Carnegie Mellon is an average campus allows the EIO-LCA to indicate what can be done at Carnegie Mellon to improve their life cycle impact. This means that, while Carnegie Mellon could significantly change their practices, begin buying all green energy, purchase all local goods, and decrease their direct emissions, the university would still have a very large impact indirectly. This point is critical, because it indicates that a university needs to broaden its scope when examining the environmental impacts of its operations. While it would be extremely difficult to change the practices of every company associated with the university, Carnegie Mellon could potentially have a significant environmental impact through selective buying practices. Preferred purchasing policies like those detailed in Section 3.7 is one method of combating this issue.

3.7. Conclusions and Recommendations

3.7.1. Results and Recommendations from the Life Cycle Analysis

The LCA model suggests that environmental considerations do not stop when goods are consumed or discarded. Although this analysis shows that the Carnegie Mellon's environmental impact extends far beyond the campus itself, the responsibility for decisions regarding consumption must be informed at both individual and institutional levels.

3.7.2. Recommendations from the Ecological Footprint Analysis

The ecological footprint method allows institutions like Carnegie Mellon to locate environmental problems and enact appropriate policies more broadly across various categories of sustainable development. A yearly analysis of the ecological footprint can also be undertaken, which would show the dynamics of the university's consumption and would highlight the university's strengths and weaknesses in these areas. Since all significant data for this analysis is already reported, this task should be easy for the university to accomplish. The continuation of calculations will also permit the administration to diagnose which programs and policies are working effectively. The footprint also helps to advertise the usefulness of performing an ecological footprint by providing a useful jumping ground for other institutions working toward sustainability goals. The following sections detail a number of recommendations (organized by land use categories) developed through the ecological footprint analysis.

3.7.2.1. Recommendations by Land Use Categories

The analysis suggests that Carnegie Mellon's campus is consuming at an unsustainable rate of approximately six times its fair Earthshare (at 4.5 acres per capita). This rate of consumption slightly outpaces the average American. However, by calculating this footprint, the ability to assess the amount of ecological stress the campus places upon the environment is now a possibility for future generations of students. This work has also given insights as to what the main drivers of Carnegie Mellon's ecological footprint are and where the administration would best be able to reduce said footprint.

3.7.2.2. Built Environment with a Focus on Energy

A large contributor to the ecological footprint is the consumption and burning of fossil fuels, which make up for approximately 69 percent (including built environment) of the total Carnegie Mellon footprint. As the Sustainable Earth petition requests (see Section 1.1.5), the recommendation of purchasing more green energy is still very much a valid and viable consideration. Being unable to specify the exact amount of green energy that should be purchased coupled with the realization that certain green energy is not available for purchase in the campus' immediate vicinity, realizing a goal of 51 percent renewable energy by 2010 could prove to be quite difficult problem for the administration to solve. As a result of the location of the main Carnegie Mellon campus, Renewable Energy Certificates (RECs) are the easiest way for the campus to reduce greenhouse gas emissions (see Section 5.3.1). However, such purchases cannot completely eliminate the university's ecological footprint, as consumption of natural resources continues even when energy is not being consumed. If Carnegie Mellon were able to divert money away from consumption toward RECs, there could be potential reductions on both ends. For instance, the dining plan for students at Carnegie Mellon allots money at certain intervals for extra purchases beyond meals called DineXtra. This money must be used before the end of the two-week period and typically is spent in bulk when funds remain toward the end of this period (since these credits would otherwise be lost). Dining Services could offer a small, inexpensive gift (i.e., mints or chocolate) that could be purchased for any leftover DineXtra with the profits from that purchase going toward RECs. This type of green purchasing policy would allow students to feel good about helping the campus environment.

3.7.2.3. Goods

Consumption is a very large facet of an institution's ecological footprint. The purchasing of goods is no different, especially since campus-related purchases can be large appliances that are bought during one's first year at school and later on when moving into off-campus housing. To reduce the impact of university purchases, green purchasing policies should be put into place, such as attempting to make large purchases with companies that have a good environmental record or to purchase energy efficient appliances like ENERGY STAR certified products (see Section 5.4.1.1). However, controlling the spending of a university and being able to direct it toward environmentally friendly policies is ultimately up the administration and can be implemented based on the economic feasibility of the option (as described in Chapter 5). Another difficulty is controlling consumption on the student side, especially since there is an annual turnover with incoming freshmen and outgoing seniors. However, this turnover can be leveraged by enacted a policy that encourages freshmen to purchase needed appliances from upperclassmen who may no longer need them due to relocation or any other reason. Such practices would be greatly beneficial in shrinking the campus' current ecological footprint. A policy of this sort would be a buy-back program that set a specific date for the sale of slightly-used goods offered at reasonable prices. Another purchasing policy that could be introduced to persuade students to buy energy-efficient appliances would be to subsidize a portion of the cost of buying ENERGY STAR certified appliances, especially for students living in on-campus housing. Since the university would benefit from reductions in electricity demand (and consequently smaller utility bills), it would be worthwhile to offer an incentive for students to buy ENERGY STAR devices that consume less energy. Overall, policies regarding environmental purchasing and reducing consumption would help to reduce the overall ecological footprint of campus.

3.7.2.4. Transportation

Although not a major contributor to the campus footprint, transportation nevertheless plays a role in emissions and also in the use and consumption of resources. However, in this category, Carnegie Mellon has already taken a number of important measures, since a large portion of its fleet is currently equipped with biofuels. Furthermore, the arrangement with the Pittsburgh Port Authority that allows students to ride the PAT busses with a flat annual fee greatly reduces the amount of potential emissions that could stem from automobile travel from the campus community. This year also saw the introduction of programs such as Zipcar, which allows students to rent a car. A similar program could also be instituted for bicycles, since many students who would potentially ride bikes around town are unable to store them. This program would allow students to rent bicycles for a specified time period with all relevant insurance and liability issues accounted for in order to allow students to travel emissions-free around campus and Pittsburgh. Moreover, students who are leaving Carnegie Mellon could potentially donate their bikes to the school when they are no longer able to use them, and fines could be placed on bike renters who exceed their time limit with the money from those fines going toward RECs and the maintenance of bikes. Another recommendation to reduce both greenhouse gas emissions and the campus ecological footprint would be to monitor faculty travel so that only absolutely necessary travel (i.e., when videoconferencing is not possible) be allowed. This program could also encourage more environmentally-friendly transportation (e.g., bus or train) when such options are viable. Although such policies are very contingent upon individuals' behavior, having policies in place will hopefully direct those making the decisions toward more environmentally benign choices.

3.7.2.5. Services, Waste, and Food

Although not a dominant facet of the overall Carnegie Mellon footprint, services, waste, and food should not be simply cast aside when planning policies. Every step toward more sustainable operations is an important one, and these three categories (although not quantitatively) large can have very large quality-of-life connotations. The first recommendation concerning these categories is to provide more options for locally grown, fresh produce like those options beginning to appear at on-campus locations like the Entropy+ convenient store. In order to provide more healthy and local food, the university can continue to add more vegetarian options to menus, since fruits and vegetables are typically produced more sustainable than meat products. Waste is another area that improves the general sense of well-being on campus when improved. Currently, the only recommendation would be to continue recycling programs for paper products, ink-cartridges, and other recyclable materials.

3.7.2.6. Other Recommendations

Education is another important facet of moving toward an ecologically sustainable future. Carnegie Mellon should continue to provide students with environmental education options and help to support environmentally conscious groups on campus. Although the benefits from such practices are difficult to quantify, an ecologically-minded citizen is more likely to make decisions that are informed by a wider range of considerations.

3.7.3. Conclusions

Colleges and universities are in a unique position in the world. The collegium that brings students together to learn about a variety of subjects and allows professors to research new ideas can also be used as a conduit to mold future citizens into publicly conscious and socially responsible members of society. The desire for learning coupled with the ability to work toward new ideas allows for innovative thinking to be applied to old problems and drives social change in both thought and behavior. Moreover, as focal points of any community, colleges and universities are able to bring important topics and issues to the forefront of the public arena, propelling change even outside of its campus. These features among others are the reason why college and university campuses must be leaders in the position on the environment and other ecological considerations.

Yet, the importance of ecological considerations is too often overlooked and underappreciated, which is unfortunate given that every day decisions have environmental ramifications that go far beyond greenhouse gas emissions. The importance of these issues are then increased dramatically when taking an EIO-LCA approach, as consumption has ripple effects upon the entire production chain with the resultant environmental strain adding up at each level. Taking such factors into account is central when attempting to lead a more sustainable life. This is why institutions like universities are charged with the tasks of elucidating the importance of ecological considerations and of increasing environmental awareness. As central pillars in communities, universities are apt to help lead the charge in issues concerning the environment and conservation. Projects and research can help students learn to be creative problem solvers and effective leaders and also can teach the greater community about such critical topics like the environment. Colleges and universities must be responsible for helping spread their ideas beyond their campuses alone and into the greater context of the surrounding community.

With their broad scope and staggering complexity, ecological considerations also offer a wide variety of disciplines the opportunity to take part in the process of conserving the environment while providing an impetus for interdisciplinary collaboration. Moreover, there are many opportunities for reductions in regard to individuals' behavioral decisions (especially when consuming natural resources like fuel or water). These small behavioral decisions over time add up to reduce large portions of environmental strain much like the conversely small consumption choices that can add up to contribute to the overall footprint. Again, this is where universities can play an important role in shaping the choices of their students by providing programs that help guide students toward making more environmentally sustainable choices. For example, the bus passes given to every student at Carnegie Mellon help reduce dependence on personal vehicles while promoting mass transit. Additionally, not only do colleges and universities act to create social change in their own student populations, but they also create new ideas through interdisciplinary research and learning. From their positions as teachers of tomorrow's leaders and employers of today's brightest minds, the environment of a college campus is also ripe with opportunity to help formulate creative new ideas about the environment.

Nonetheless, despite their unique position in the world, universities must not lose focus on what gives them that uniqueness: their students. The students are the ones who pay for their education to become leaders of the world. A focus only on the problem can certainly lead to mistaken beliefs, and as such, one must be sure to also look at the solutions to that problem as well. Ecological considerations are also vital in working toward sustainable development goals.

Chapter 3 References

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4. Campus Environmental Survey

4.1. Introduction

Environmental issues are of growing concern and have a large direct impact on university campuses across the nation. The pursuit of sustainability offers the opportunity to lessen and eliminate these environmental consequences. Campuses that utilize sustainable solutions promote the idea of taking environmental considerations into account to students, faculty, and staff when making decisions on consumption and lifestyle choices. By conducting surveys, much can be learned about the campus' perceptions of environmental issues, their understanding of effective mitigation strategies, and their willingness to make behavioral changes. Therefore, it was determined that conducting a campus-wide survey was the best way to reach the Carnegie Mellon community in the shortest amount of time.

The goals of the Sustainable Earth petition, the President's Climate Commitment (PCC), and the relative cost-effectiveness of reduction strategies acted as motivations for the design of the Carnegie Mellon Campus Environmental Survey (see Section 1.1.5 for petition information). It was necessary to create survey questions that would help the university administration develop policies to ensure a more sustainable campus. Therefore, the Carnegie Mellon Campus Environmental Survey specifically focused on determining the knowledge, attitude/opinion, and behavior of students, faculty, and staff on issues including green energy and possible campus mitigation policies. The specific survey goals were as follows:

- Understand what the Carnegie Mellon community is willing to do to make the campus more sustainable.
- Create survey questions that will help the administration develop policies to ensure a more sustainable campus.
- Develop a policy-focused sustainability survey that could be used by the national collegiate community.

The information and data collected from the survey are extremely valuable, and the results should be used as a benchmark to measure changes in campus perceptions in the future.

4.2. Survey Review

In order to create a campus-wide survey that effectively addressed the defined goals, research of previous environmental surveys was conducted to find the best strategies for creating a successful survey. Surveys were searched using the Internet, and only those that contained questions about environmental and sustainability issues were analyzed in depth. Furthermore, the extent of the survey research was not limited to college and university campus surveys but also included environmental surveys conducted by non-governmental organizations and businesses.

4.2.1. Survey Search Methods

The Internet acted as the primary source of information, and two different search methods were used to navigate and filter through to finding the most relevant survey data.

4.2.1.1. Google Search

The first method used for filtering the Internet relied on the Google search engine (www.google.com) and involved a trial and error search technique. A series of word combinations that related to desired survey content were entered into the Google search engine and included phrases such as:

- "environmental survey"
- "sustainable survey"
- "campus survey"

The Google results were searched through up until the twentieth results page. When searching through the results pages, the webpage descriptions provided by Google were read, and a decision was made whether or not to further investigate the result. If the result was considered potentially useful, the website, document, PowerPoint, or PDF file was further explored for survey information. The Google method proved to be a useful way of finding universal surveys that were nonexclusive to academia. However, it was interesting to note that a majority of the surveys found using this method were administered at higher education institutions. A total of 12 surveys were found using this method.

4.2.1.2. Institution Website Search

The second method solely involved searching for surveys administered at academic institutions and was designed to find colleges and universities that were interested in becoming more sustainable. The top 50 of the US News "America's Best Colleges 2008" and the AASHE 92 listed pilot institutions for the STARS program were great resources for finding schools interested in sustainability measures. From US News and AASHE, a list of 142 institutions was obtained, and each of their websites was searched for information on previously conducted environmental and sustainability surveys. For each institution, a similar Google keyword search was used and included the following phrases:

- "sustainability survey"
- "environmental survey"
- "climate survey"
- "student survey"

Only the first page of search results was investigated, and a total of 17 surveys were found using this method. Only the first page was searched as opposed to the twentieth page using the Google Search method, because experience showed that after the first page, the information was no longer relevant.

4.2.2. Survey Search Results

A total of 29 surveys were found, 12 using general Google searches and 17 using institution-specific searches. Below is a list of all the university, college, and organization websites that contained relevant environmental or sustainability surveys.

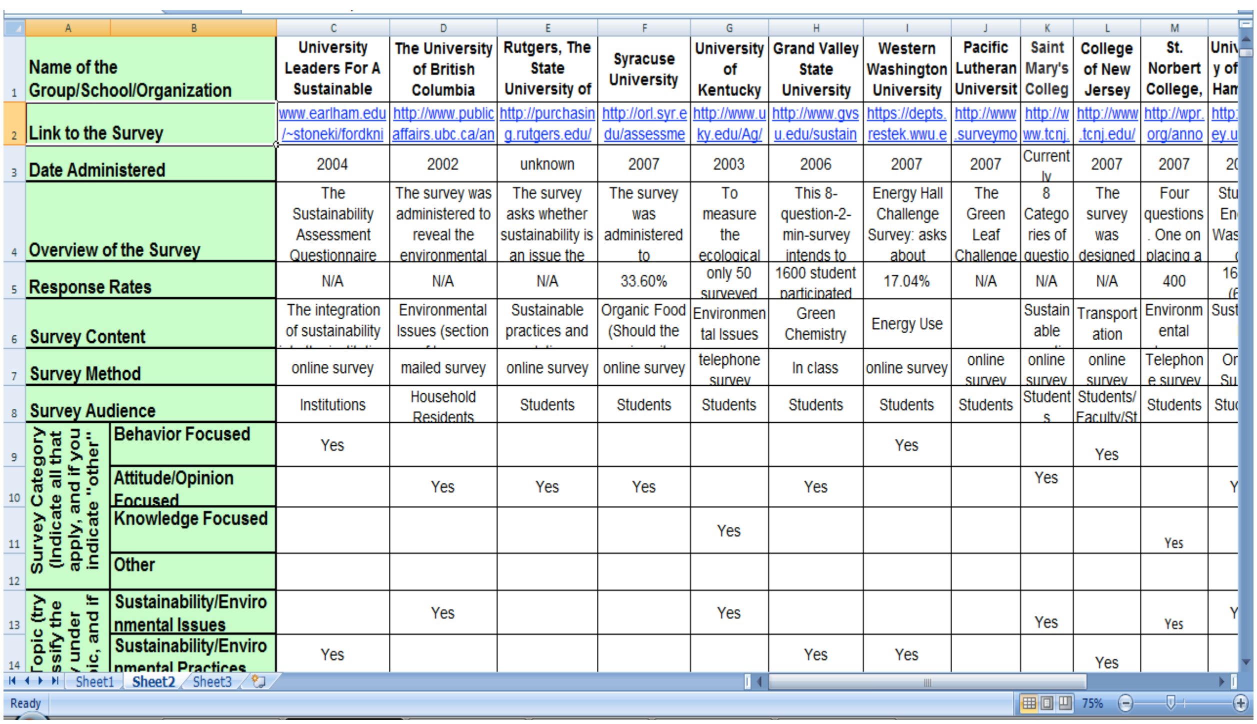
- University Leaders for a Sustainable Future (ULSF)
- University of British Columbia
- Rutgers, the State University of New Jersey
- Syracuse University
- Saint Norbert College-Wisconsin
- University of New Hampshire
- Rice University
- Hamilton College
- University of Kentucky
- Grand Valley State University
- Western Washington University
- Pacific Lutheran University
- Saint Mary's College
- College of New Jersey
- Climate Challenge Survey
- University of Colorado-Boulder
- Cornell University
- Macalester College

- University of Michigan
- University of Minnesota
- University of Wisconsin-Green Bay
- The Global Warming Survey
- Columbia University
- Humboldt State University
- Boston College
- University of Vermont
- Harvard University
- Dartmouth College

4.2.3. Analysis of Search Results

Once all 29 surveys were found, a spreadsheet was created (see Figure 4.2.1) to organize the data gathered from each survey. The survey classification dimensions were listed horizontally in the first row, and the names of the 29 surveys were listed in the first column. The classification dimensions included:

- Date and location of survey administration
- Survey audience (students, faculty, homeowners, etc.)
- Number of respondents
- Response rates
- Number of survey questions
- Results from the survey
- Distribution method
- Demographics
- Administrator feedback



	A	B	C	D	E	F	G	H	I	J	K	L	M	
1	Name of the Group/School/Organization		University Leaders For A Sustainable	The University of British Columbia	Rutgers, The State University of	Syracuse University	University of Kentucky	Grand Valley State University	Western Washington University	Pacific Lutheran Universit	Saint Mary's Colleg	College of New Jersey	St. Norbert College,	Univ y of Ham
2	Link to the Survey		www.earlham.edu /~stoneki/fordkni	http://www.public affairs.ubc.ca/an	http://purchasin g.rutgers.edu/	http://orl.syr.e du/assessme	http://www.u ky.edu/Ag/	http://www.gvs u.edu/sustain	https://depts. restek.wwu.e	http://www .surveymo	http://w ww.tcnj.	http://www .tcnj.edu/	http://wpr. org/anno	http: ey.u
3	Date Administered		2004	2002	unknown	2007	2003	2006	2007	2007	Current ly	2007	2007	20
4	Overview of the Survey		The Sustainability Assessment Questionnaire	The survey was administered to reveal the environmental	The survey asks whether sustainability is an issue the	The survey was administered to	To measure the ecological	This 8-question-2-min-survey intends to	Energy Hall Challenge Survey: asks about	The Green Leaf Challenge	8 Catego ries of questio	The survey was designed	Four questions . One on placing a	Stu En Was
5	Response Rates		N/A	N/A	N/A	33.60%	only 50 surveyed	1600 student participated	17.04%	N/A	N/A	N/A	400	16
6	Survey Content		The integration of sustainability	Environmental Issues (section	Sustainable practices and	Organic Food (Should the	Environmen tal Issues	Green Chemistry	Energy Use		Sustain able	Transport ation	Environm ental	Sust
7	Survey Method		online survey	mailed survey	online survey	online survey	telephone survey	In class	online survey	online survey	online survey	online survey	Telephon e survey	Or Su
8	Survey Audience		Institutions	Household Residents	Students	Students	Students	Students	Students	Students	Student s	Students/ Faculty/St	Students	Stu
9	Survey Category (Indicate all that apply, and if you indicate "other"	Behavior Focused	Yes						Yes			Yes		
10		Attitude/Opinion Focused		Yes	Yes	Yes		Yes			Yes			Y
11		Knowledge Focused					Yes						Yes	
12		Other												
13	Topic (try ssify the y under ic, and if	Sustainability/Enviro nmental Issues		Yes			Yes				Yes		Yes	Y
14		Sustainability/Enviro nmental Practices	Yes					Yes	Yes			Yes		

Figure 4.2.1 – Snapshot of organized survey data spreadsheet

Along with the organizational criteria, a column was developed for listing the most useful and relevant questions within each survey. The template created an efficient way to organize the collected survey data, allowing for general trends to be easily distinguished and conclusions to be made about the effectiveness of each survey.

4.2.3.1. Question Analysis

When analyzing each survey, good and bad types of questions were noted. From the survey administrator feedback, much was learned about the most and least effective surveying techniques, and the new knowledge was used to develop the Carnegie Mellon Campus Environmental Survey.

For example, questions like "Do you recycle?" were labeled as ineffective due to their inability to reveal useful information about the individual taking the survey. When creating a survey question, emphasis needed to be placed on developing more complex questions that would reveal more specific characteristics about the individual. From the question "Do you recycle?," nothing is learned about how often the individual recycles or if they would be willing to recycle more or less given a specific condition.

Unfortunately, all of the analyzed surveys contained ineffective or irrelevant questions, demonstrating that the goals for the Carnegie Mellon Campus Environmental Survey are unique and possibly the first of their kind.

4.2.3.2. Distribution Method

The effectiveness of distribution methods used for the survey was weighed based on accessibility and the response rate. Table 4.2.1 shows the allocation of the different distribution methods used for administering the surveys; only 24 out of the 29 surveys provided this information. The majority of the surveys were administered through the web.

Table 4.2.1 – Table of distribution of survey administering mediums

Online	Mailed	In Class	Handed-Out	Telephone
14	2	2	1	5

4.2.3.3. Survey Audience

Most surveys were given out to students (see Table 4.2.2); however, high response rates also correlated with surveys administered to faculty and staff as well as students. It is important to note that the majority of the surveys administered to faculty and staff were targeted to select individuals and therefore resulted in very high response rates, which lead to higher than expected response rates for the collective faculty, staff, and students. However, it was nevertheless concluded that, in order to receive the highest response rate and to attain more interesting comparisons in the data analysis, the Carnegie Mellon Campus Environmental Survey should be administered to everyone affiliated with Carnegie Mellon University (students, faculty, and staff).

Table 4.2.2 – Survey audience distribution

Student	Student/Faculty/Staff	High School Student	Household Resident
16	8	1	4

4.2.3.4. Other Findings

Some interesting findings discovered from the survey data were that, of the environmental surveys that reported response rates, the average was approximately 30 percent (see Table 4.2.3). Furthermore, surveys comprised of ten or fewer questions resulted in a higher response rate of approximately 35 percent. Therefore, it was inferred that fewer questions on a survey leads to higher response rates. This outcome, along with the fact that most response rates were less than 50 percent, was taken into consideration for the structure and creation of the Carnegie Mellon Campus Environmental Survey. The number of questions on each survey and the distribution of the year when the survey was administered were both noted (see Table 4.2.3).

Table 4.2.3 – Table of survey data

Distribution of Year Survey Submitted											
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
# of Surveys	1	2	1	2	1	2	1	1	5	7	1
Distribution of Number of Questions											
# of Questions	4	5	7	8	10	11-14	15-18	19-22	23-26	27-32	33-35
# of Surveys	1	2	1	5	1	2	3	2	3	2	2
Average Number of Questions (of 25 reports that included survey questions)											
18											
Total Number of Respondants (of 17 surveys that provided this information)											
8114											
Average Number of Respondants											
477											
Average Response Rate											
31.50%											
Average Response Rate for Surveys With 10 Questions or Less											
34.80%											

4.2.4. Lessons Learned

The main benefits of using the two methods and template were to distinguish which types of survey questions have been asked by other institutions and organizations and to determine their relative effectiveness. This process allowed for the development of a more unique and successful survey for the Carnegie Mellon campus.

From the 29 surveys found, a template was created that allowed for the discovery of which types of questions were most efficient as well as what distribution methods were most prevalent and successful. Furthermore, the organizational criteria revealed that Carnegie Mellon Campus Environmental Survey would indeed be unique and original. A majority of the surveys analyzed focused on current community behaviors and did not include dimensions that would help administrators develop more effective environmental and sustainability policies.

The research of previous environmental surveys proved to be a beneficial means for determining the survey audience and most effective distribution method. However, none of the researched surveys exemplified the desired goals for the Carnegie Mellon Campus Environmental Survey. Therefore, a new survey question organization method, described in the next section, was developed to help in the identification and development of the most effective survey possible.

4.3. Organization Method

The assessment of over 400 questions on 29 previously conducted environmental surveys resulted in the development of a question organization method to aid the creation of the Carnegie Mellon Campus Environmental Survey. Since none of the found environmental surveys solely embodied the survey goals for Carnegie Mellon, it was determined that organizing the survey questions individually would be helpful in developing the campus survey. Analysis of the over 400 survey questions revealed distinct similarities in the purpose and subject matter of the survey questions. This discovery allowed them to be organized in two dimensions, denoted as categories and topics.

4.3.1. Categories

The first organizational dimension, categories, determines the type of information that the question obtains from an individual, and classifies it into one of the three subcategories: behavior, attitude/opinion, and knowledge.

4.3.1.1. Behavior

These are questions that obtain information about personal behaviors and include questions that reveal current routines and lifestyle choice, as well as questions that require persons to predict their future actions. Below are examples of behavior questions obtained from previous environmental surveys:

- "I regularly use public transportation." (Pacific Lutheran University)
- "I read books, journals, and online materials, rather than printing them, to save paper (Always, Often, Sometimes, Rarely, Never)." (Clark University)
- "How much would you be willing to pay in additional college fees in order to further sustainable development on campus?" (Rice University)

4.3.1.2. Attitude/Opinion

These are questions that obtain information about a person's opinions and/or attitudes and include questions that reveal willingness and likelihood to commit to an idea as well as an individual's level of agreement with the specified idea. Below are examples opinion/attitude questions obtained from previous environmental surveys:

- "How much do you value environmental sustainability on the Rice University campus?" (Rice University)
- "Are you personally concerned about global warming?" (Global Warming Survey)
- "Do you feel that recycling in the dorms is convenient?" (University of Colorado-Boulder)

4.3.1.3. Knowledge

These are questions that obtain information about a person's knowledge and include questions that reveal a person's exposure to and/or understanding of a specified topic. Below are examples knowledge questions obtained from previous environmental surveys:

- "From what fuel source does UK produce its electricity and heat?" (University of Kentucky)
- "How much do LED or compact fluorescent replacements cost?" (University of La Verne)
- "Can you name two tree species found on campus that are native to Kentucky? (University of Kentucky)

4.3.2. Topics

The second organizational dimension, topics, organizes the subject matter or content of the question, and classifies it into one of the three subtopics: issues, practices, and solutions.

4.3.2.1. Issues

These are questions that inquire about a specified issue or debatable topic in areas such as politics, society, economics, security, and/or the environment. Below are examples of issues questions obtained from previous environmental surveys:

- "How well informed would you say you are about global warming?" (University of Wisconsin)
- "How important is it to you for CU to be a leader in campus environmental management?" (University of Colorado-Boulder)
- "Can you name one current pressing environmental issue in Kentucky?" (University of Kentucky)

4.3.2.2. Practices

These are questions that inquire about common practices defined as the current or past activities observed by individuals, organizations, and/or governments. Below are examples of practices questions obtained from previous environmental surveys:

- "How often do you recycle?" (Rice University)
- "Have you, or are you currently, taking or teaching courses that include topics on practices and/or policies that support an environmentally sustainable lifestyle?" (Clark University)
- "How sustainable is CU's waste management program (purchasing, waste prevention, reduction, recycling)? Rank 1 to 5" (Columbia University)

4.3.2.3. Solutions

These are questions that inquire about possible solutions that address a specified issue. Solution questions propose future mitigation strategies in the form of policies and/or practices. Below are examples of solutions questions obtained from previous environmental surveys:

- "Do students support proposals to raise Minnesota's gas tax? Do students think that raising the gas tax will affect driving habits?" (University of Minnesota)
- "Will including sustainability as a theme in new student orientation and the first-year experience increase environmental literacy?" (Saint Mary's College)
- "Would you be willing to reduce the amount of disposable goods (i.e., paper cups, plastics, printer paper/photocopies, etc.) that you use in order to positively contribute to a 'greener' campus?" (Rice University)

4.3.3. Categories and Topics Combinations

The two organizational dimensions, categories and topics, can be combined for a total of eight possible survey question classifications. Each of the 29 previous environmental surveys was organized into one category and topic combination to help determine the most common and effective types of survey questions. The relationship between the organizational dimensions is seen in Figure 4.3.1.

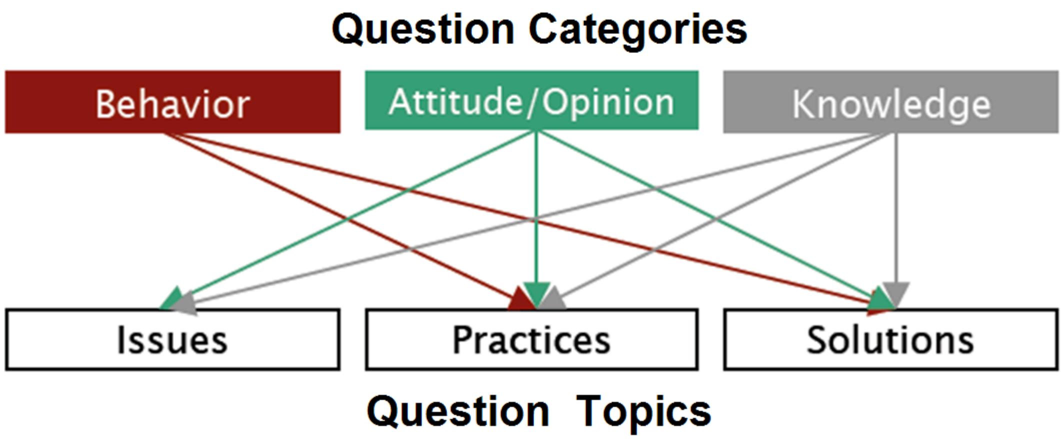


Figure 4.3.1 – Illustration of the eight possible survey question combinations

The surveys were classified based on which category and topic combination was most prevalent. Therefore, if a majority of the questions on a survey were classified as the combination behavioral-practices, then the survey as a whole was classified as this combination. Furthermore, as seen in Figure 4.3.1, the only combination of categories and topics that cannot be made is behavior-issues. None of the questions from the previous environmental surveys could be classified into this combination; therefore, it was not included as a combination option.

After analyzing the 29 previous environmental surveys, it was determined that the most common question category and topic combination was behavioral-practices, with approximately 30 percent of the surveys having a majority of this question combination. The combinations of attitude/opinion of issues and attitude/opinion of solutions were also prevalent, with each representing approximately 20 percent. The data obtained from the organizational analysis of the previous environmental surveys were then used to formulate effective and concise survey questions for the Carnegie Mellon Campus Environmental Survey.

4.4. Carnegie Mellon Campus Environmental Survey

Using the research conducted on previous environmental surveys in conjunction with the developed question organization method, a campus environmental survey was created that demonstrated the following goals:

- Understand what the Carnegie Mellon community is willing to do to make the campus more sustainable
- Create survey questions that will help the administration develop policies to ensure a more sustainable campus

- Develop a policy-focused sustainability survey that could be used by the national collegiate community

The campus environmental survey needed to determine the opinions of students, faculty, and staff on environmental issues and solutions to aid the Carnegie Mellon administration in the development of campus sustainability policies. Therefore, the most prevalent question combinations, behavioral-practices, attitude/opinion of issues, and attitude/opinion of solutions were considered when developing the goals and objectives for the survey. The question category knowledge was also considered despite its lower representation on previous environmental surveys, because this type of question could be successful at estimating a community's overall understanding and exposure to the central ideas of sustainability.

4.4.1. Survey Development

The survey development involved a lengthy process of generating numerous questions and then revising or eliminating them based on their ability to exemplify the survey goals. Multiple survey drafts were tested to determine the most transparent wording and formatting styles as well as to obtain preliminary survey results.

4.4.1.1. Survey Testing

The campus environmental survey was submitted to three separate test groups before the final submission via SurveyMonkey (www.surveymonkey.com). The first and second test groups were given paper copies of the survey, and the groups consisted of 14 and 23 Carnegie Mellon students, respectively. The students were asked to give their comments on the survey while completing the survey and were specifically asked to comment on any misunderstandings they encountered. The two test groups were extremely helpful and aided in revising the survey to improve question wording, ordering, and formatting.

The third test group consisted of 48 Carnegie Mellon students who completed an online trial version of the SurveyMonkey campus environmental survey. This group of students was unaware that they were testing a survey and were not asked to make any comments about the survey quality. The purpose of this test group was to ensure that the written format of the questions was translated into a representative online electronic format and that SurveyMonkey interpreted the survey data correctly.

4.4.1.2. Final Survey Questions and Formatting

The final version of the campus environmental survey consisted of 16 environmental questions and 8 demographic questions for a total of 24 questions (a copy of the survey can be seen in Appendix 4.A). The survey contained a variety of different question formats including multiple choice, fill-in-the-blank, and rating options. A variety of question category and topic combinations were utilized, and the distribution of the used combinations can be seen in Table 4.4.1.2.1.

Table 4.4.1 – Classification of final survey questions using the survey organization method (includes only the 16 environmental questions)

Category and Topic Combinations	Number of Questions Classified
Behavior → Practices	0
Behavior → Solutions	1
Attitude/Opinion → Issues	**3**
Attitude/Opinion → Practices	2
Attitude/Opinion → Solutions	**3**
Knowledge → Issues	1
Knowledge → Practices	1
Knowledge → Solutions	**5**
Total Number of Questions	**16**

The different category and topic combinations utilized demonstrate that the survey focuses on the combinations attitude/opinion on issues, attitude/opinion on solutions, and knowledge of solutions. Furthermore, the distribution reveals that the survey represents the stated goals by including questions that determine the respondents' opinion and knowledge of environmental issues and solutions.

4.4.2. Survey Distribution Method

The final survey was distributed to the Carnegie Mellon community using the online survey tool, SurveyMonkey. An e-mail containing a link to the survey was sent to all Carnegie Mellon students, faculty, and staff, and it explained that the survey takes about ten minutes to complete and that results would be used by the university administration to inform campus-wide policies. The e-mail also advertised that persons who completed the survey would be entered in a raffle to win a $99 Amazon.com gift card and that the drawing would be held Friday, April 18, 2008. The e-mail was written with the intent to increase participation by emphasizing the potential importance of the survey and by offering the opportunity to win a prize as compensation for the time and effort spent completing the survey.

4.5. Results

4.5.1. Statistics

The survey was a great success and exceeded all prospects, resulting in 1,700 responses within the first three hours of being released and with 70 percent of surveys completely answered.

4.5.1.1. Response Rates

The survey was left active on SurveyMonkey.com for one week, resulting in a total of 2,820 survey responses and 2,023 complete responses. A survey qualifies as being complete if all questions are answered where choices are provided. However, if a question has more than one part where the respondent can pick a choice but only answers part of the question, it is still considered as complete. Thus, 72 percent of the total submitted surveys were considered complete. Only 1,924 of the total submitted responses were analyzed due to a series of filters that sorted out all incomplete responses. This process allowed for a standard formatting that reduced the variability and difficulty of the data analysis.

Furthermore, the Carnegie Mellon community consists of approximately 14,000 students, faculty, and staff, which implies the survey received an average response rate of 20 percent, while the average response rate for the researched previous environmental surveys was approximately 30 percent. However, the average survey population audience for these previously conducted surveys was only 1,700 people. This demonstrates that the scope of the Carnegie Mellon Campus Environmental Survey extends far beyond that of any of the researched surveys, and the 20 percent response rate demonstrates a phenomenal success. Furthermore, a 20 percent response rate is generally good, regardless of the size of the audience.

4.5.1.2. Demographics

Questions 1 through 3 asked about gender, U.S. citizenship, and age. Of the 1,924 respondents, 47 percent were female and 53 percent were male, while 81 percent of respondents were United States citizens. The average age of the respondents was 28 with a standard deviation of 11, implying that 68 percent of respondents were between the ages 17 and 39.

Question 4 inquired about the respondents' affiliation with the university and particularly which their school (Carnegie Institute of Technology, College of Fine Arts, Tepper School of Business, and others).

Table 4.5.1 – Affiliation at Carnegie Mellon of survey respondents

Affiliation									
CIT	**CS**	**CFA**	**Heinz**	**H&SS**	**MCS**	**Multiple**	**None**	**Tepper**	**Total**
452	243	153	122	269	183	231	101	170	1,924
23%	13%	8%	6%	14%	10%	12%	5%	9%	100%

Question 5 of the survey asked about the respondent's affiliation status to determine students' level of completion (freshman, sophomore, etc.), or whether they were a faculty or staff member.

Table 4.5.2 – Position at Carnegie Mellon of survey respondents

Position							
Freshman	**Sophomore**	**Junior**	**Senior**	**Graduate**	**Faculty**	**Staff**	**Total**
233	191	170	204	570	130	419	1,917
12%	10%	9%	11%	30%	7%	22%	100%

It was necessary to obtain this demographic information to make comparisons between respondents, because these questions provide a variety of group classifications. Trends within each group can be analyzed and then compared to other groups to attain information like the environmental knowledge of freshmen students compared to that of graduate students.

Question 6 inquired about the number of classes the respondent had taken at Carnegie Mellon that dealt specifically with sustainability or environmental issues.

Table 4.5.3 – Number of environmental courses taken at Carnegie Mellon by survey respondents

Environmental Courses Taken	Number of Respondents	% of Respondents
0	1,465	76%
1	271	14%
2	82	4%
3 or More	106	6%

Question 7 asked whether the respondent was involved in any environmental groups at Carnegie Mellon, and **Question 8** asked the respondent to list those groups to which he/she belonged.

Table 4.5.4 – Respondent membership in environmental groups

In an Environmental Group	Not in an Environmental Group
202	1,722
10.5%	89.5%

4.5.1.3. Environmental Questions

Question 9 had the respondents indicate which of the given energy production methods were examples of "green energy" sources, and the respondents were able to choose more than one option if desired. However, the respondents were unable to indicate that they believed none of the options were "green energy" sources without being filtered as an incomplete survey. Therefore, these responses were not included in the results analysis. Further, research of the survey results will include filtering the survey results to include these respondents.

Table 4.5.5 – Whether a choice was considered "green energy"

	Hydro	Wind	Fuel Cell	Solar	Coal	Natural Gas	Nuclear	Biofuel
No	458	61	907	72	1,891	1,764	1,491	1,110
Yes	1,466	1,863	1,017	1,891	33	160	433	814

Question 10 asked the respondents to specify what percentage of Carnegie Mellon's total electricity use should come from green energy and obtained an average response of 58 percent.

Questions 11, 12, and 13 assumed that Carnegie Mellon increased its purchases of "green energy" to 50 percent. Question 11 then asked how many tons of CO_2 would be prevented from entering the atmosphere. Question 12 asked how much per student would the university need to charge annually if the students absorb the additionally energy costs. Finally, Question 13 asked how much the respondent would be willing to pay in order to increase Carnegie Mellon's "green energy" purchases.

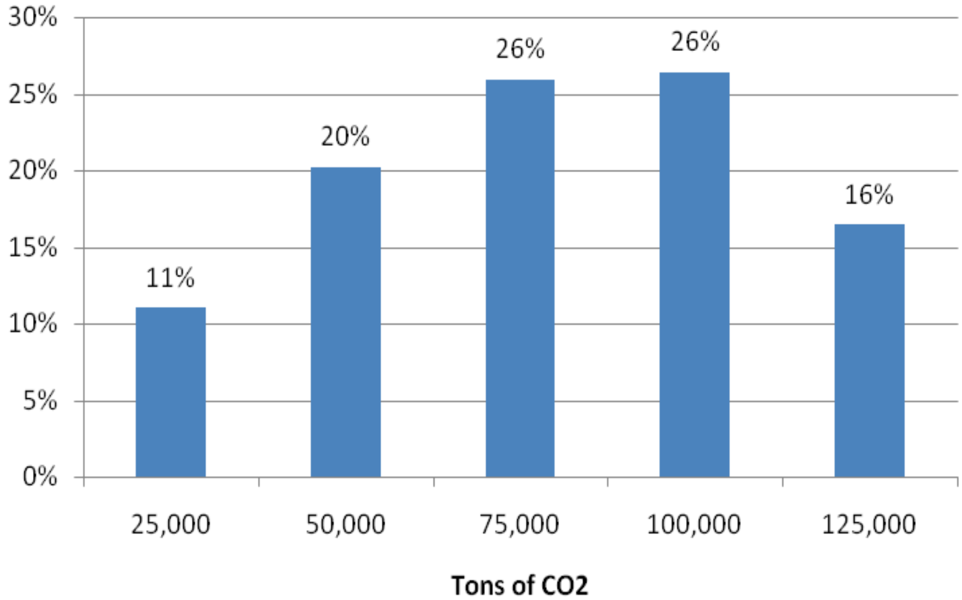


Figure 4.5.1 – Illustration of the amount of CO_2 prevented from entering the atmosphere if 50 percent of Carnegie Mellon's energy was "green energy"

For **Question 12**, respondents said that each student would have to pay an average of $85 to increase "green energy" purchases to 50 percent, with the maximum input $275 and the minimum input being $3.

For **Question 13**, it was found that the average amount a person would be willing to pay was $84 a year. The distributions of the entered amounts can be seen in Table 4.5.6.

Table 4.5.6 – Amount of money respondents were willing to pay

$/year	Number of Respondents	Percentage (%)
Blank	39	2.1
0	**334**	**17.6**
0-50	474	25.0
50	**286**	**15.1**
50-100	66	3.5
100	**384**	**20.3**
Over 100	310	16.4

From Table 4.5.6, it can be seen that the responses had a wide variation, ranging from respondents who were willing to pay nothing to $5,000 per year for "green energy." Furthermore, the three bolded amounts indicate that there are three distinct price ranges that include over half of the respondents. These price distinctions demonstrate a wide variety of willingness among the Carnegie Mellon community and possibly indicate that the campus is undecided about the importance of purchasing "green energy." However, interestingly enough, 14 respondents were willing to pay $1,000 per year in order to make the Carnegie Mellon campus more sustainable.

Table 4.5.7 – Amount of money the undergraduate students were willing to pay

$/year	Number of Undergraduate Respondents	%
Blank	16	2.0
0	**130**	**16.3**
0-50	203	25.4
50	**129**	**16.2**
50-100	27	3.4
100	**160**	**20.1**
Over 100	133	16.7

Table 4.5.7 shows the willingness to pay for just undergraduate students, in order to change to 50 percent "green energy" at Carnegie Mellon. The same trends occur in the undergraduate students as did in the entire population of respondents. The high end for the range of willingness to play was only $2,100, and six of the 14 respondents who were willing to pay $1,000 were undergraduate students.

In **Question 14**, the respondents were asked to identify which of the following groups ought to pay the additional costs associated with purchasing "green energy" at Carnegie Mellon. The option choices included the Federal government, the state government, the local government, Carnegie Mellon, and the Carnegie Mellon students.

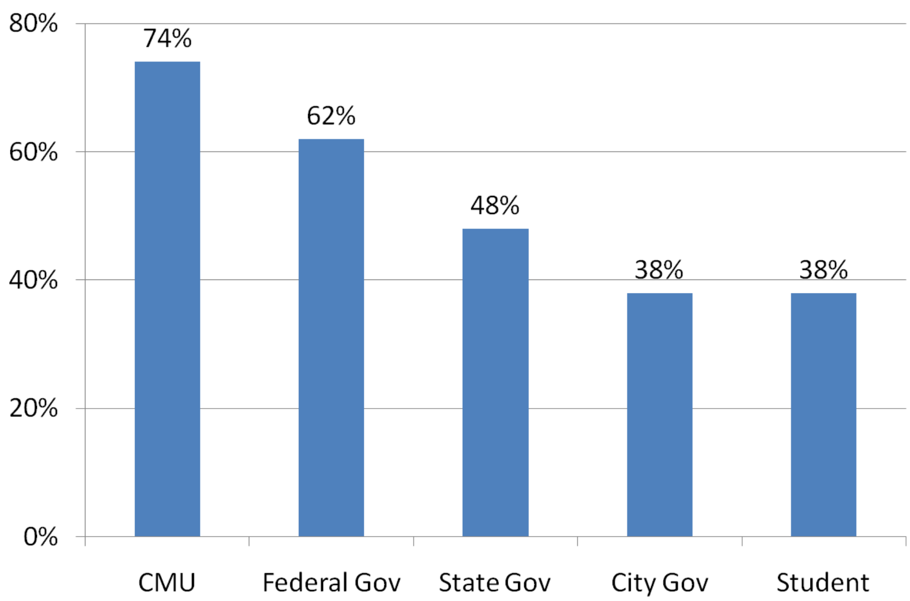


Figure 4.5.2 – Illustration of who should pay for additional costs from purchasing "green energy"

From Figure 4.5.2, it is evident that a large portion of the Carnegie Mellon community believe that the university should pay for the additional costs of "green energy," while a minority of respondents believed that students should pay the additional costs. Furthermore, it was worth noting that many of the respondents believed that the Federal government, second to Carnegie Mellon, should absorb the additional costs associated with Carnegie Mellon purchasing more "green energy."

Question 15 asked respondents to estimate what percent of Carnegie Mellon's carbon dioxide emissions were produced by undergraduate activities. The average response was that 43 percent of the total carbon dioxide emissions are produced by undergraduate activities.

For **Questions 16 through 21**, the respondents were asked to complete a series of questions in which they indicated their level of agreement, ranging from "Strongly Disagree" to "Strongly Agree." Question 16 stated, "I fully understand the meaning of the term 'sustainability.'"

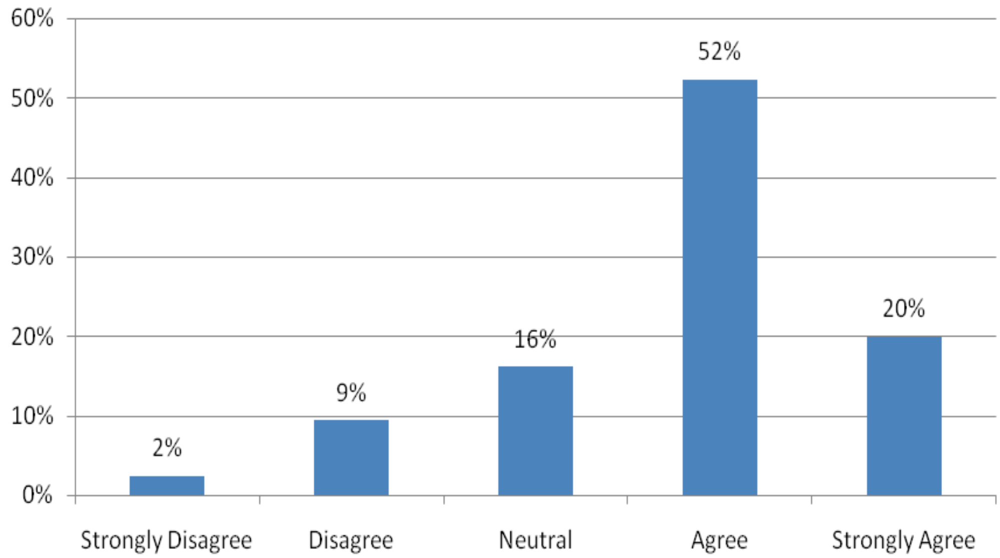


Figure 4.5.3 – Illustration of respondents' full-understanding of the term "sustainability"

From this graph, it can be seen that a majority (52 percent) of the surveyed population believes they have a good understanding of term sustainability.

Question 17 stated that unless dramatic steps are taken, global warming will cause significant irreversible damage to global ecosystems and human populations.

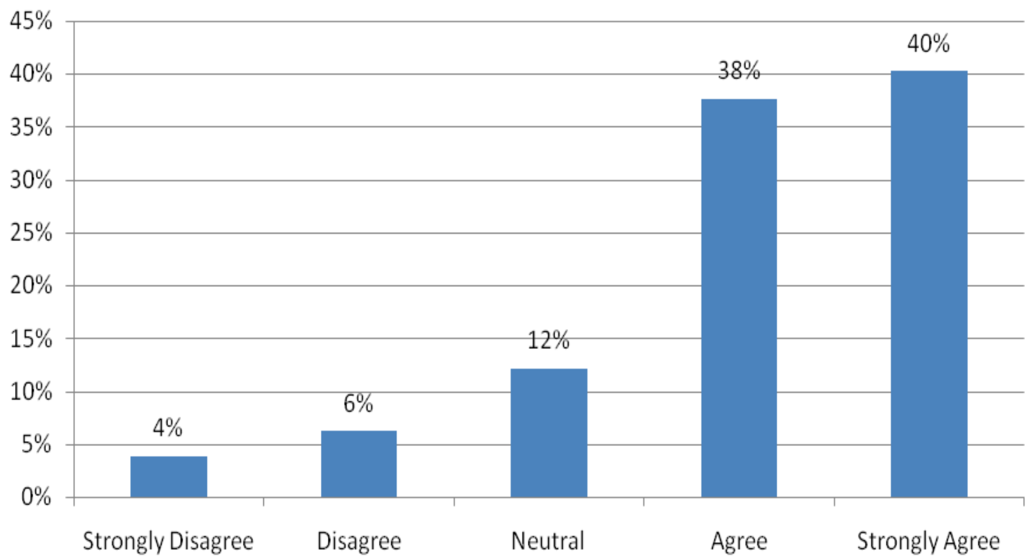


Figure 4.5.4 – Illustration of respondents' beliefs of impacts of global warming on the environment

The data in Figure 4.5.4 demonstrates that most of the Carnegie Mellon community believes that global warming will have a significant effect on the world's environment.

Question 18 asked the respondents to indicate their level of agreement with the following statement, "My concern toward environmental issues has grown due to Carnegie Mellon events, activities, and/or courses."

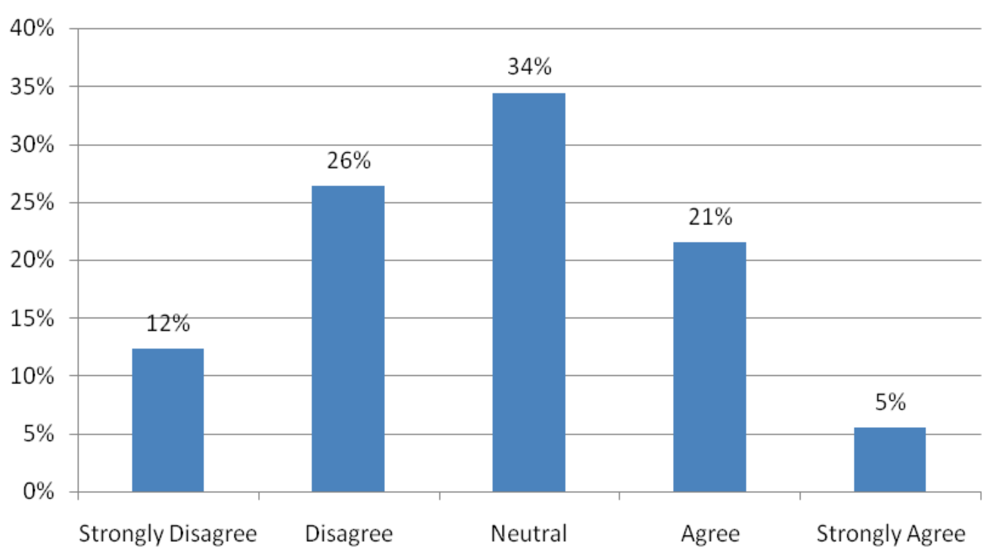


Figure 4.5.5 – Illustration of respondents' agreement of the increase in concern toward environmental issues due to Carnegie Mellon

Figure 4.5.5 demonstrates that many of the respondents concern of environmental issues have not grown due to Carnegie Mellon events, activities, or courses.

Question 19 inquired whether the respondents believe Carnegie Mellon to be leader in sustainable practices among other universities.

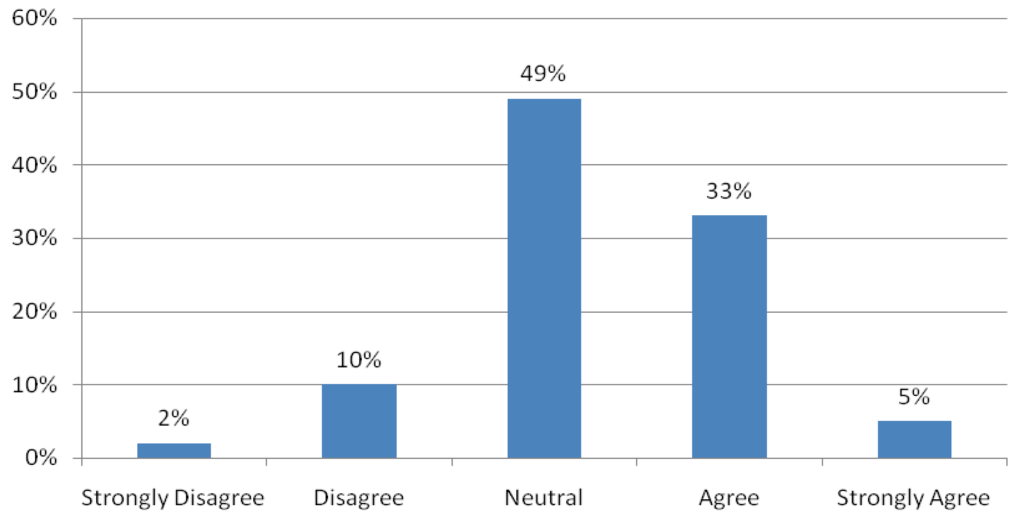


Figure 4.5.6 – Illustration of respondents' view of Carnegie Mellon as a leader

From the Figure 4.5.6 it can be seen that many of the respondents believe that Carnegie Mellon's leadership in sustainable practices is only a little above average compared to other universities.

Questions 20 asked the respondents for their level of agreement with the following statement, "The Carnegie Mellon community is well informed about what is being done to make the campus more sustainable." **Question 21** asked respondents to determine whether they agreed that university stakeholders should be consulted about sustainable decisions surrounding plans for new campus developments.

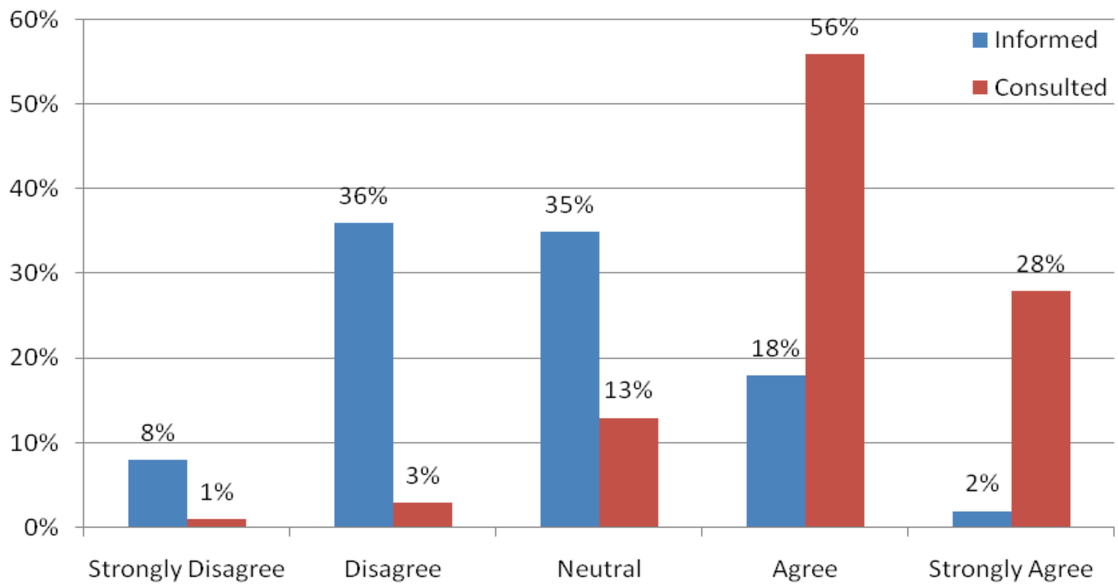


Figure 4.5.7 – Illustration of community knowledge versus how much they should be consulted

Figure 4.5.7 illustrates the perceptions of how well informed the Carnegie Mellon community is about campus sustainability initiatives and is represented by the blue bars. The red bars indicate how important it is that all university stakeholders be consulted about campus sustainability initiatives. It can be seen that the Carnegie Mellon community believes they are much less informed and involved compared to the level they should be.

Questions 22, 23, and 24 asked the respondents to rate a series of 16 proposals to help reduce the environmental impacts of the Carnegie Mellon campus. The 16 proposals are as follows:

1. Purchase ten percent of campus electrical power from hydropower sources
2. Purchase ten percent of campus electrical power from wind power
3. Purchase ten percent of campus electrical power from fuel cells/hydrogen power
4. Purchase ten percent of campus electrical power from nuclear power
5. Purchase ten percent of campus electrical power from solar power
6. Install a cogeneration plant to provide both electricity and heat for Wean Hall
7. Install highly efficient windows in Baker/Porter Hall
8. Use biofuels to power all university vehicles
9. Reduce beef products sold on campus and served in dining facilities by 50 percent
10. Eliminate “sleep mode” on campus computers, so they turn-off instead
11. Install motion detectors on lights in public spaces
12. Permit only compact fluorescent bulbs in dormitories and offices
13. In the winter, lower thermostat settings in campus buildings by 3° F
14. Reduce the number of parking spaces on campus by 20 percent
15. Eliminate paper newspapers distributed on campus (online campus news only)
16. Purchase offsets (pay other organizations to reduce their emissions)

Question 22 asked the respondents to rate the proposals in terms of their effectiveness to reduce Carnegie Mellon’s carbon dioxide emissions.

Question 23 requested that respondents rate the proposals according to their relative cost-effectiveness (i.e., which proposals would result in the greatest money savings).

Question 24 then asked the respondents to consider their answers to questions 22 and 23 and then rate the proposals based on their personal preference.

After examining the data, it became evident that respondents who believed a proposal would effectively reduce carbon dioxide emissions also rated the proposal high in terms of their personal preference. This same correlation did not exist for relating cost-effectiveness and personal preference. However, the data also indicates that respondents were not well informed about certain proposals. Respondents assumed offsets were very cost ineffective and showed a disliking for Carnegie Mellon to implement this option. Further discussion in Section 5.3.1.1 will demonstrate that carbon offsets are in fact relatively cost effective and are not an unreasonable carbon mitigation strategy.

The two graphs below illustrated in Figures 4.5.8 and 4.5.9 respectively demonstrate that the proposal to reduce parking spaces on campus is the least favorable option and also is believed to be highly cost ineffective. Furthermore, respondents chose installing highly efficient windows as the most preferred option, even though it received a high rating in terms of cost-effectiveness. However, lowering thermostat settings received the highest rating in terms of cost-effectiveness but only received an average rating in terms of personal preference.

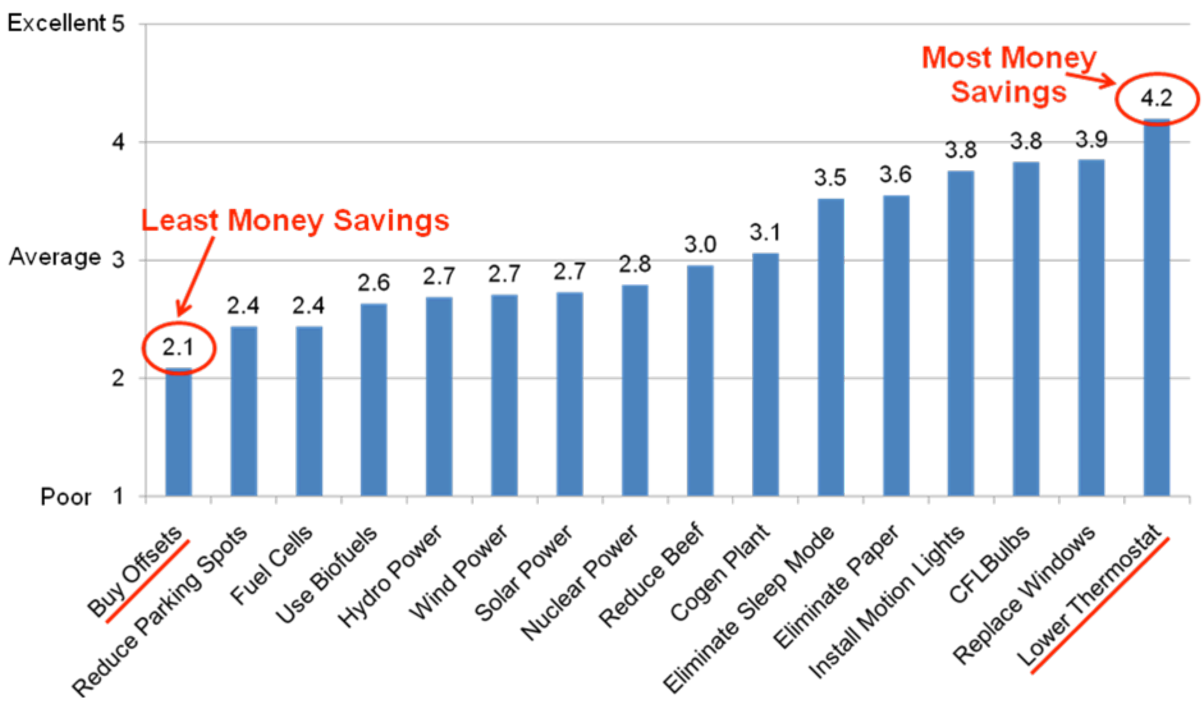


Figure 4.5.8 – Illustration of cost-effectiveness of green alternatives

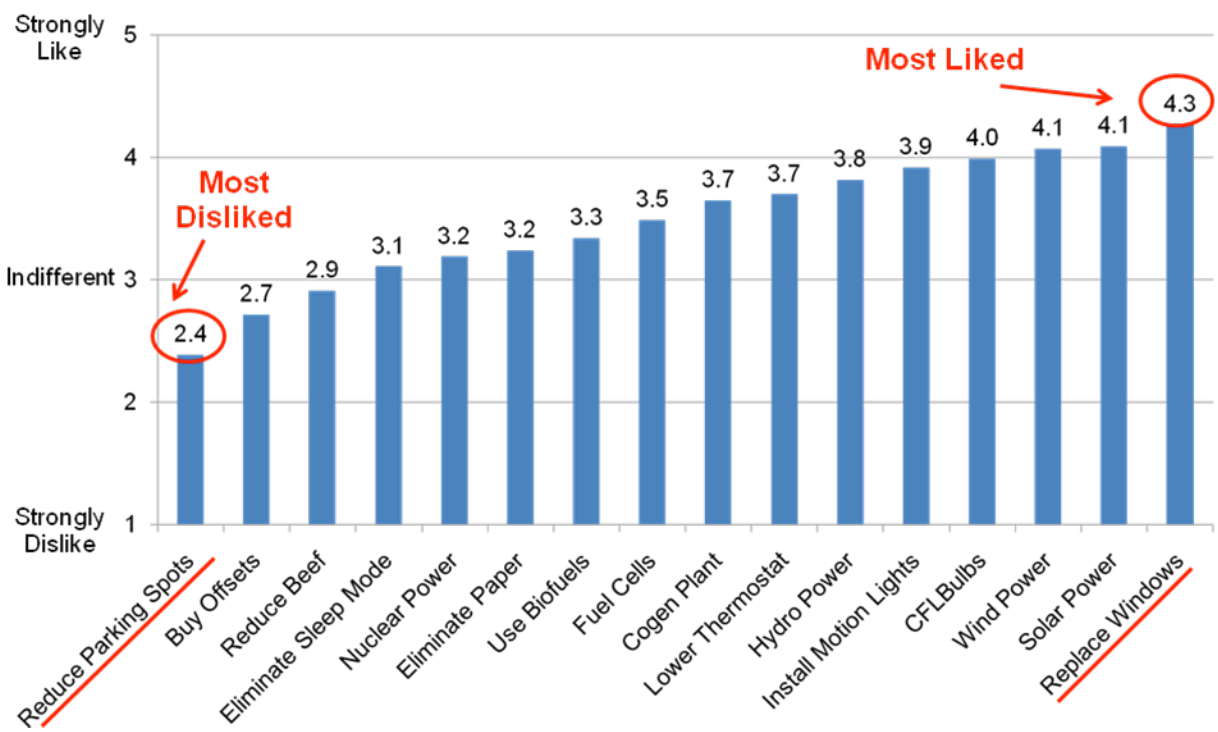


Figure 4.5.9 – Illustration of preference of green alternatives

4.6. Discussion of Survey Results

After finding the initial results from the survey data, more in-depth calculations and analyses were conducted by comparing results across questions. Due to time constraints on the project, only a limited amount of the most pertinent and interesting findings were able to be correlated and discussed in this section. Further analysis of the survey results will be conducted by a team of research students in the summer of 2008.

4.6.1. Comparisons

4.6.1.1. Affiliation

As mentioned in Section 4.5, the Carnegie Mellon Campus Environmental Survey received an astounding amount of respondents who were then divided into four groups of community affiliation, undergraduate students, graduate students, faculty, and staff.

The Sustainable Earth petition acted as a large motivator for the project and stated that Carnegie Mellon should increase the amount of “green energy” electricity purchased by the campus to 51 percent of its annual usage. From the graph depicted in Figure 4.6.1, it can be seen that the petition underestimated the campus community desires. The average percent of “green energy” that all the respondents believed should be pursued by the university was 58 percent. However, graduate students and faculty desired Carnegie Mellon to pursue an even higher percentage of “green energy” purchases compared to that of undergraduate students and staff.

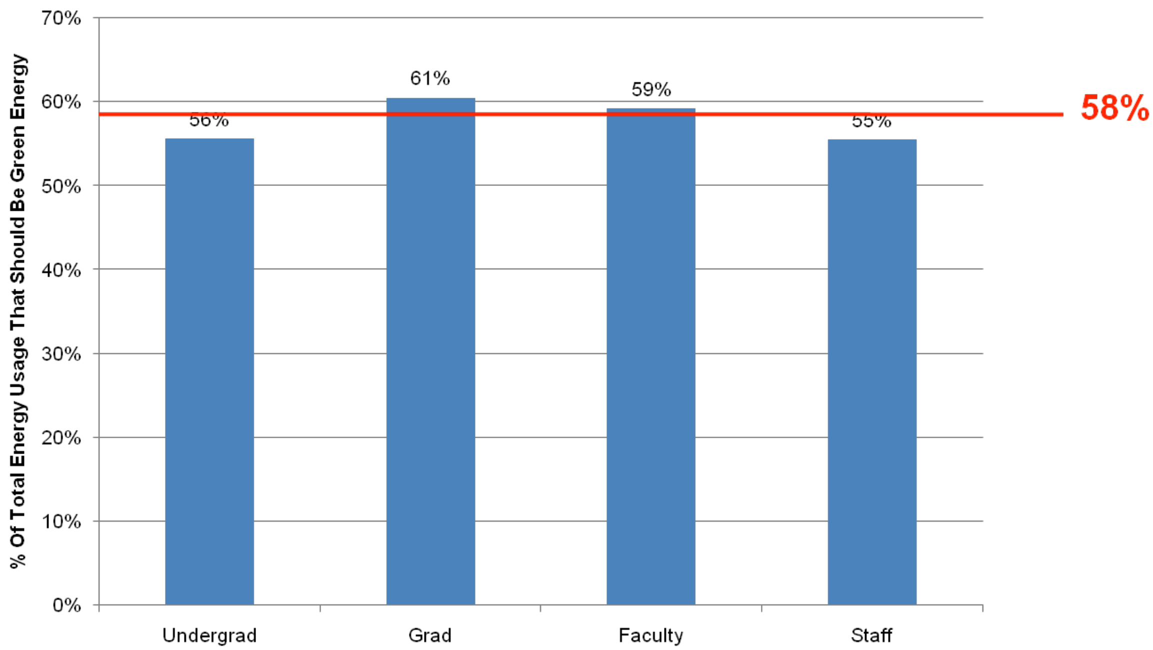


Figure 4.6.1 – Illustration of the percent of Carnegie Mellon energy that should be "green"

One of the most interesting survey questions asked the respondents what their willingness to pay for increasing "green energy" purchases to 50 percent of the total campus electrical energy usage.

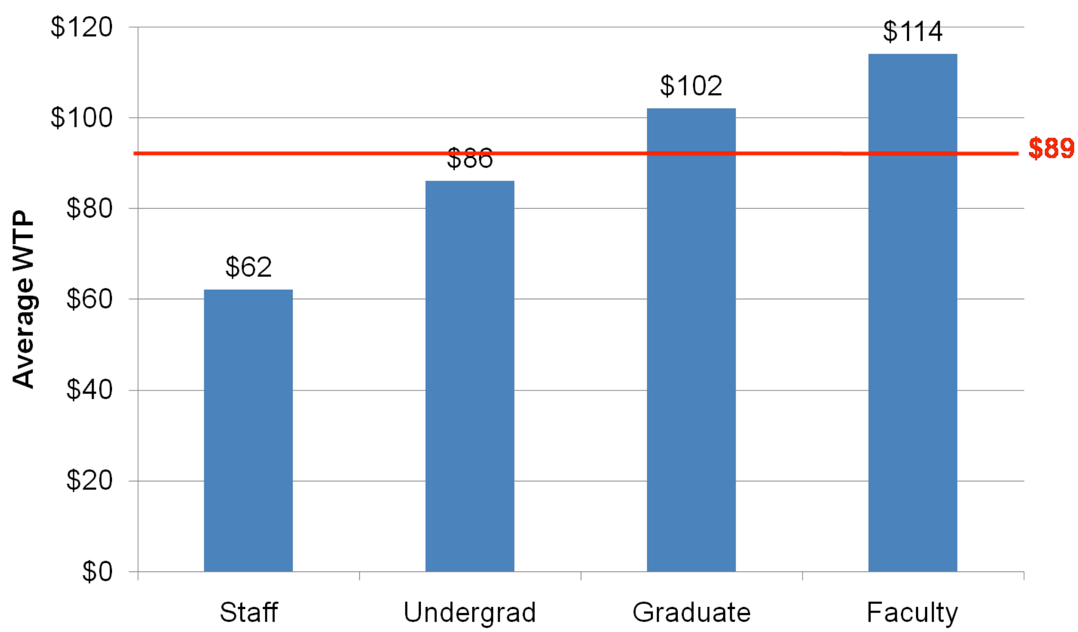


Figure 4.6.2 – Illustration of average willingness to pay across different positions

The graph in Figure 4.6.2 demonstrates a comparison between Carnegie Mellon affiliation and the average willingness to pay to increase "green energy" purchases. The analysis reveals that faculty are willing to pay the most (at $114 per year) followed by graduate students (at $102 per year) and undergraduate students (at $86 per year), while staff were willing to pay the least amount at $62 per year. Therefore, Carnegie Mellon faculty members are willing to pay almost twice as much as the staff. The average amount that all respondents are willing to pay to increase "green energy" purchases to 50 percent is approximately $89 per year.

4.6.1.2. Global Warming

Another major issue addressed in the Carnegie Mellon Campus Environmental Survey was global warming. Global warming is still a controversial topic, and there is national discrepancy between its meaning and its effects. Therefore, due to of the nature of the topic, it was desired to determine the Carnegie Mellon community perceptions of global warming.

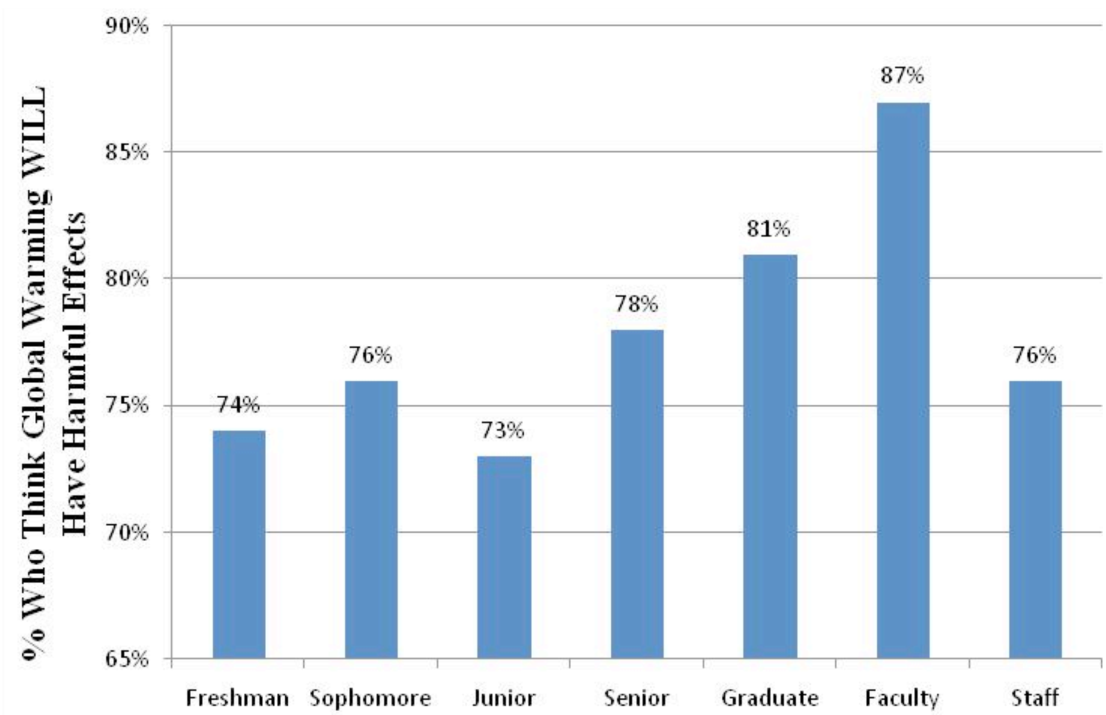


Figure 4.6.3 – Illustration of percentage of respondents who believe global warming will have harmful effects

The purpose of the graph in Figure 4.6.3 is to determine the Carnegie Mellon community's perceived existence of global warming and demonstrates that all campus affiliates believe to some extent that global warming will result in irreversible harmful environmental effects. However, it can be seen that faculty members have the greatest representation of respondents that believe global warming will have harmful effects, which is followed by graduate students and senior students.

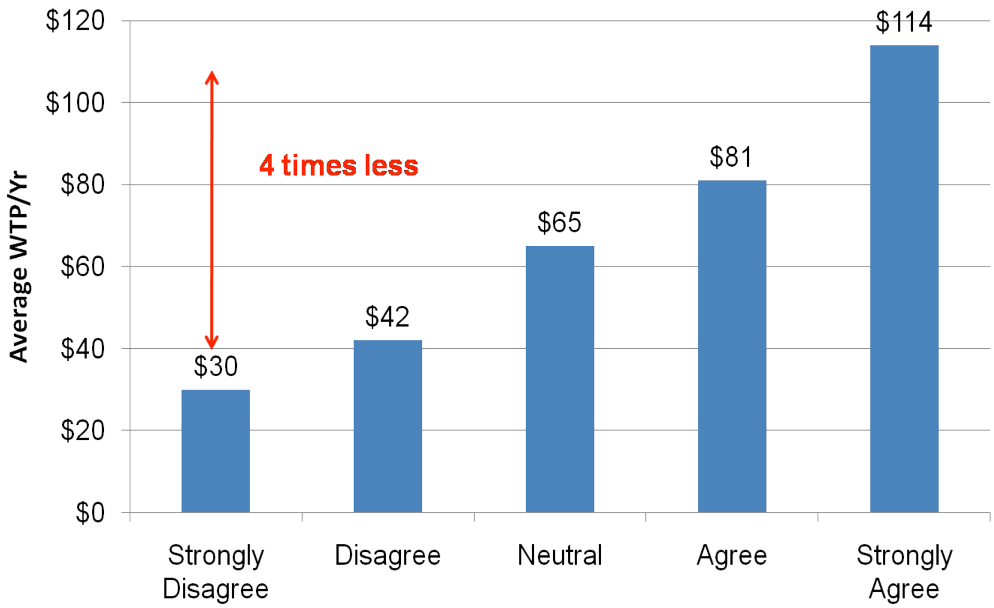


Figure 4.6.4 – Illustration of willingness to pay versus global warming belief

The above graph illustrated in Figure 4.6.4 compares the respondents' beliefs in the severity of global warming and their average willingness to pay for additional costs associated with "green energy." This graph demonstrates that, the more strongly respondents agreed that global warming will cause irreversible harmful effects, the more they were willing to pay to increase "green energy" purchases.

Individuals that strongly agreed that global warming will have significant harmful effects were willing to pay on average $114 per year, while individuals that strongly disagreed were only willing to pay $30 annually, almost four times less. However, even though respondents strongly disagreed that global warming would have severe environmental consequences, they were still willing to pay an average of $30 to increase Carnegie Mellon's "green energy" purchases.

4.6.1.3. Environmental Courses

At Carnegie Mellon, like many other universities, students are provided with environmental classes which they can take. It is hoped that these classes help inform the students about what is going on worldwide, nationally, and at their school.

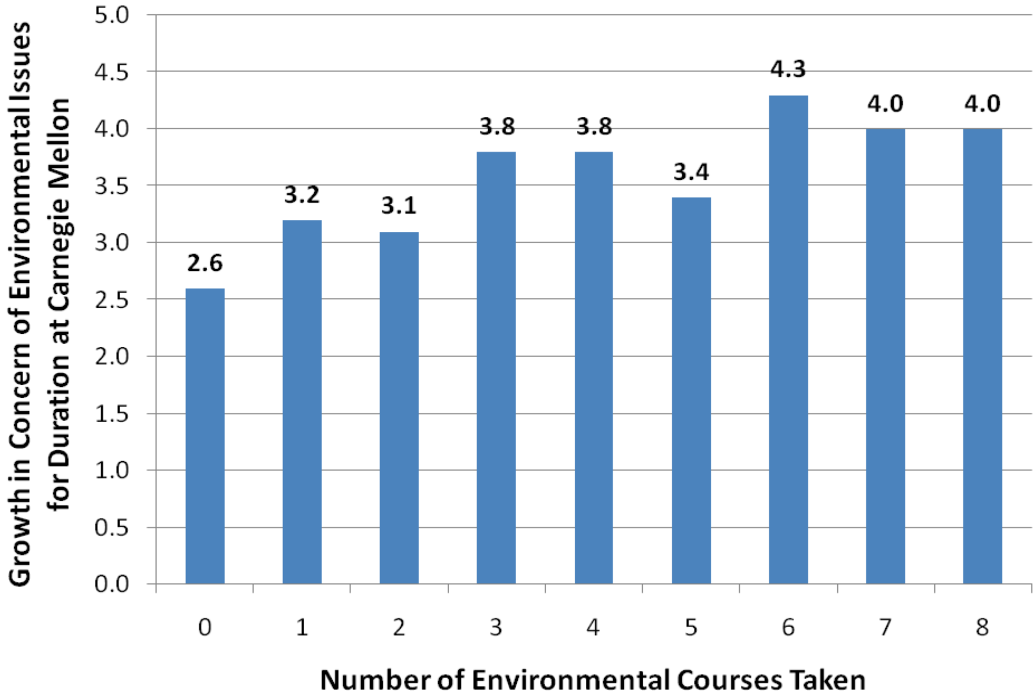


Figure 4.6.5 – Illustration of growth in concern about the environment with relation to number of environmental courses taken

Figure 4.6.5 demonstrates that more environmental related courses taken results in a growth in concern for environmental issues due to Carnegie Mellon efforts. Furthermore, it is interesting to see that students who have taken six or more classes have the greatest concern for environmental issues and that this number represents the edge of a plateau. After having taken six environmental courses, the level of concern plateaus or no longer increases. Overall, Figure 4.6.5 demonstrates that taking more environmental courses will result in an increase in the level of concern for environmental issues due to Carnegie Mellon efforts.

4.7. Conclusions and Recommendations

The survey was conducted mainly to determine the opinions, knowledge, and behaviors of the Carnegie Mellon community and to help the university administration develop effective sustainability policies. The survey was distributed using SurveyMonkey.com on April 11, 2008 and was extremely successful, with over 3,000 total responses and nearly 2,000 completed responses within the first three hours of activation. The high response rate suggests that the Carnegie Mellon community is exceptionally interested in campus environmental issues and is motivated to make the campus more sustainable.

4.7.1 Lessons from Survey Process

Researching previously administered surveys and organizing previous survey questions into a template were very helpful tools and made the Carnegie Mellon Campus Environmental Survey more unique and original. Additionally, various combinations of survey questions were useful in estimating the Carnegie Mellon community's overall understanding and exposure to environmental issues. Although the survey development process was very lengthy, it reduced possible sources of errors and biases. Moreover, submitting the survey to different test groups for improvement of wording and ordering of the questions helped reduce possible systematic and random error. Finally, sending the entire Carnegie Mellon population an e-mail with the link to the survey was a successful method for generating a high response rate. Addressing the importance of the survey and giving prize as a compensation incentive helped increase the response rate as well.

4.7.2. Findings

The response rate was phenomenal and shows that Carnegie Mellon community is highly interested and motivated about environmental issues. The average amount a respondent was willing to pay for increasing Carnegie Mellon's "green energy" purchase is $84 per year. Overall, faculty was willing to pay the most for environmental costs, followed by graduate students, undergraduates, and staff. The survey found that individuals in the Heinz School were willing to pay the most, while people in the School of Computer Science were willing to pay the least. In addition, a stronger belief in global warming resulted in a higher willingness to pay. Those who are in favor of solar energy are willing to pay more than those not in favor. Also, people in any kind of environmental groups were only 10.5 percent of the respondents, and their average willingness to pay for environmental cost was $40 greater than people who are not in the group. This stronger belief or people's stronger concern toward environmental issues increases as people take more environmental courses. At the same time, the more environmental courses students took, the less they disagreed that global warming is harmful. It was also interesting that the Carnegie Mellon community feels that they are much less informed than they should be. Also, the survey respondents believed that Carnegie Mellon should be responsible for additional cost associated with purchasing more "green energy" instead of the students being solely responsible for the cost. Surprisingly, a big portion of the respondents felt that the Federal government should also be responsible for this additional cost. Other findings were that most individuals prefer behavioral changes and demand for an increase in "green energy" usage at Carnegie Mellon to 58 percent.

The number of environmental courses is not relevant to people's knowledge of green energy source. Also, self-assessment of understanding of "sustainability" was not consistent with knowledge of "green" energy sources.

4.7.3. Overall Recommendations

A survey is a great way to communicate with the Carnegie Mellon community. At the same time, understanding of the overall consensus on different environmental issues on campus can be found. Based on the results from the Carnegie Mellon Campus Environmental survey, the following recommendations were created to guide future endeavors to improve Carnegie Mellon campus sustainable practices.

First, it is important to conduct similar surveys every semester in order to calculate progress or lack thereof for further improvements. From this particular survey, researching previously administered survey should be shortened so that more time can be spent on analyzing the survey results. Identifying correlations, regressions, and t-tests generate more interesting findings. Also, the collected data's validity and reliability should be unbiased and free of random error by construct of disinterest.

Secondly, when looking at the comparison between number of environmental courses taken and one's growth of environmental concern since beginning at Carnegie Mellon, it can be inferred that providing environmental education helps to increase an individual's environmental concern. It was surprising to find out from the survey that 76 percent of the students never took any environmental courses. Thus, it is imperative that Carnegie Mellon take initiative by investing in more courses, seminars, and programs for the university community and possibly have an environmental course be a requirement during a student's freshman year. It is hoped that this requirement would increase the knowledge and concern of the community regarding environmental issues.

Finally, Carnegie Mellon needs to emphasize the severity of global warming in environmental courses, since the more an individual is aware of the harmful effects of global warming, the more they are willing to pay annually.

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5. Reductions and Mitigation

5.1. Introduction

The purpose of this chapter is to describe a general method of assessing greenhouse mitigation pathways for universities and also to formulate a list of technologies, programs, and policy strategies specific to the Carnegie Mellon campus.

Collected data since 1970 have shown that it is likely that anthropogenic warming has already had sizeable impacts on many physical and biological systems (IPCC 2007b). These visible problems suggest that it is too late for preventative measures to avoid the influence of climate change completely. Furthermore, due to the unavoidable effects of past emissions, adaptation will be necessary on a number of fronts. However, adaptation alone will not be enough, as human and ecosystem vulnerability to climate change will be magnified as a result of other stresses and can only be lessened through alternate development pathways (IPCC 2007b). As a result of the uncertainties about the extent of future warming effects and possible climate thresholds (Maslin 2004), mitigation strategies play a central role in dealing with climate change, both on a global and on a university-wide basis.

The choice for universities and other institutions to develop and implement plans for greenhouse gas mitigation is motivated by both philosophical and practical concerns. Since universities help to shape the intellectual climate of society, taking the proactive first steps toward sustainable development and environmental responsibility can make universities the pioneers and leaders of this paradigm shift. In addition to promoting sustainable practices, the decision to mitigate also signals university leadership on acknowledging related social issues as well. Externality concerns (like poorer countries being mostly adversely affected by climate change though having only small contributions to the problem) are important motivators to mitigate for institutions with the capacity to do so. Furthermore, a university's proactive stance toward mitigation is indicative of the broader policy to acknowledge or account for all pertinent long-term economic, environmental, and social factors in the decision-making process. This guiding philosophy aligns with precautionary principle to the extent that, owing to the uncertainties and potentially irreversible effects over large timescales that are inherent to climate change, society may require action before the uncertainties can be completely resolved.

While this idea is partially guided by fundamental philosophical moorings, it is firmly entrenched in practical concerns as well. The costs of preventative action now may be less costly than the costs of doing nothing. The Working Group III report from the IPCC (IPCC 2007c) indicates that many emissions reducing strategies can lower energy use and consequently can save money for individuals and companies. Other studies have suggested that mitigation strategies that incorporate emissions trading are more beneficial to the economy than the business-as-usual scenario without trading (Weyant 1999). If carbon pricing is established either at a national or global level, there would be an additional economic impetus to mitigate. Beginning reductions early would reduce costs to mitigate by preparing institutions to lower their emissions gradually rather than to develop a sudden and hastily implemented strategy.

In addition to providing a broad list of existing reduction options (both technology-based and behavioral-based), this work aims to assess the effectiveness of these techniques by calculating probable emissions reductions over time. An analysis of these benefits is complemented by a detailed cost analysis to determine which options should be implemented immediately and which ones require more strategic investments or technological learning before they are employed (if they are implemented at all). Since the implementation of many of these options have additional impacts and synergistic effects, environmental tradeoffs and cross cutting effects of these options are qualitative examined along of the other numerical analyses. Additionally, this chapter establishes the groundwork for an implementation strategy by illustrating how primary decision-makers and stakeholders can be mobilized to begin a sound emissions reductions plan with Carnegie Mellon as an example. To this end, this work provides a number of general decision analysis tools that allow a range of users to evaluate how strategies can change depending on key input variable values.

Building on the analysis in Chapter 2 that assessed the carbon footprint of the Carnegie Mellon campus, this chapter focuses on strategies to decrease emissions from areas like electricity generation, steam/chilled water production, and air travel that were detailed earlier in the report. The classification of these mitigation options aligns with the structure of the Carnegie Mellon energy system. As shown in Figure 5.1.1, there are three primary areas in which mitigation strategies can alter the greenhouse gas output of the energy system: supply-side solutions, on-campus technological solutions, and on-campus behavioral change solutions. Supply-side solutions consist of purchased utility supply options, including power generation, methane recovery from waste, and purchasing carbon offsets. The on-campus technology options include both energy supply solutions (e.g., cogeneration or the installation of solar panels), energy efficiency measures (e.g., lighting replacements or the installation of occupancy sensors), and transportation measures (e.g., using biofuels in the campus fleet). The final reductions category of behavioral change options includes campus-sponsored initiatives like recycling programs and also individual choices like consuming less beef.

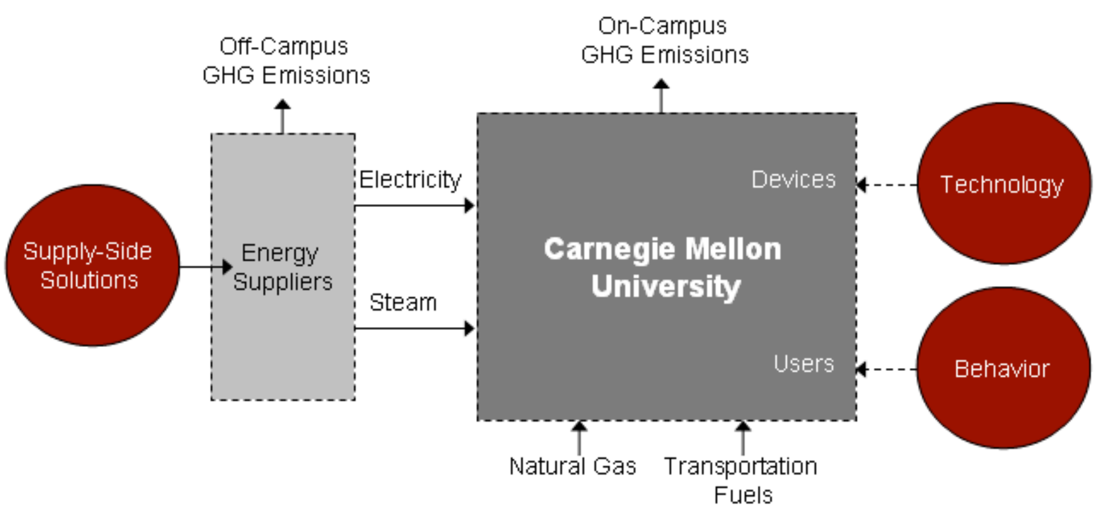


Figure 5.1.1 – Schematic of Carnegie Mellon University's energy system

5.1.1. Motivation

With ever-larger scientific agreement that anthropogenic emissions of greenhouses gases are contributing to a net warming effect (IPCC 2007a), the exigency of providing scientifically and economically sound mitigation strategies has become more pressing. Avoiding the most catastrophic effects of climate change would require emissions to stabilize over the next decade, with reductions between sixty and eighty percent by 2050. Delays of a decade may necessitate a doubling in these reductions (Specter 2008). Since warming would continue for at least a half-century even if emissions stopped immediately, this assemblage of overwhelming evidence transforms greenhouse gases like carbon dioxide into a new form of currency that is both complex to assess yet impossible to disregard.

In addition to greenhouse gas emissions reductions, these mitigation strategies also advance the general goal of campus sustainability in other areas as well. Chapter 3 suggests that the overall environmental impact of campus activities is linked to factors like emissions of criteria air pollutants, material consumption, and toxic emissions. Many of the mitigation options outlined in this chapter also contribute to the amelioration of other ecological indicators as well. For instance, options that reduce electricity use like occupancy sensors and powering down computers avoid electricity generation and its associated emissions (provided that it is a fossil fuel based power plant) not only of carbon dioxide but also of pollutants like sulfur dioxide, nitrogen oxide, and particulate matter.

Developing an effective and economical plan to reduce greenhouse gas emissions is useful not only to the Carnegie Mellon campus but to universities in general. Although some analyses in this project use assumptions that are specific to Carnegie Mellon, the thorough documentation of the general analysis methods and the transparency of the calculations make the work presented here amenable to application for most institutions.

5.1.2. Context

The approach of this analysis to presenting a list of sound and cost-effective mitigation options for campuses begins with existing studies of large-scale reductions. One of the first studies to examine global mitigation strategies was the Princeton "wedge" analysis of 2004 (Pacala 2004), as shown in Figure 5.1.2. With time on the horizontal axis and yearly emissions on the vertical axis, the "stabilization triangle" represents reductions below the business as usual scenario with the goal of decreasing emissions to avoid doubling or tripling of atmospheric greenhouse gas concentrations. To achieve these reductions, several mitigation options or "wedges" break down this complex problem into manageable pieces that can be dealt with by scaling up existing technologies or practices.

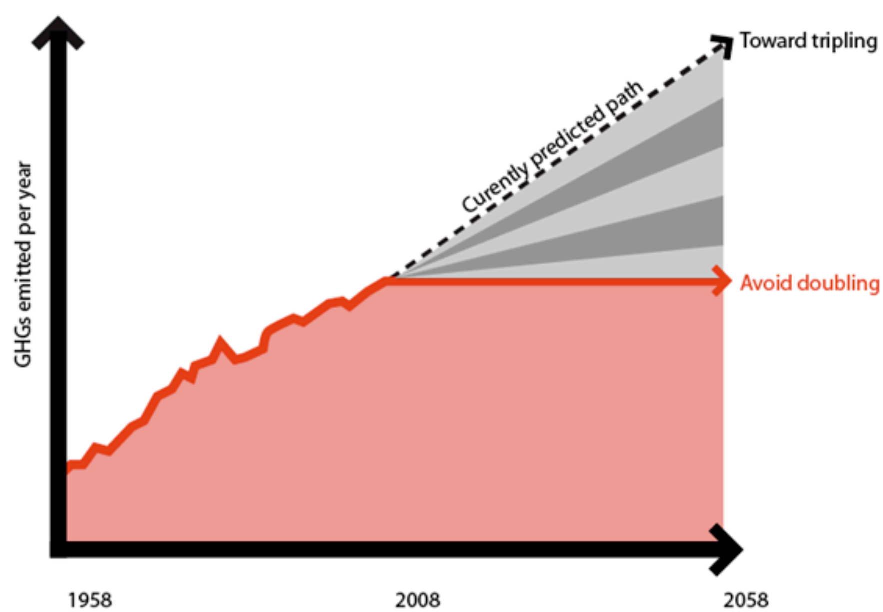


Figure 5.1.2 – Diagram of potential greenhouse gas reductions below the business-as-usual level (Redrawn from Pacala 2007)

However, the costs of putting these wedges into practice vary greatly. Some options require a price trajectory while others have associated cost benefits. Thus, this work aims to identify mitigation strategies for campuses that have the greatest impact for the smallest cost while also providing pathways for implementing effective but more cost-intensive measures by using early monetary gains from readily deployable technologies and practices, as discussed in Section 5.6. Figure 5.1.3 shows how the wedge analysis at a university level can differ from the global context, as implementation of mitigation options is staggered to leverage early cost savings to finance costlier technologies over time.

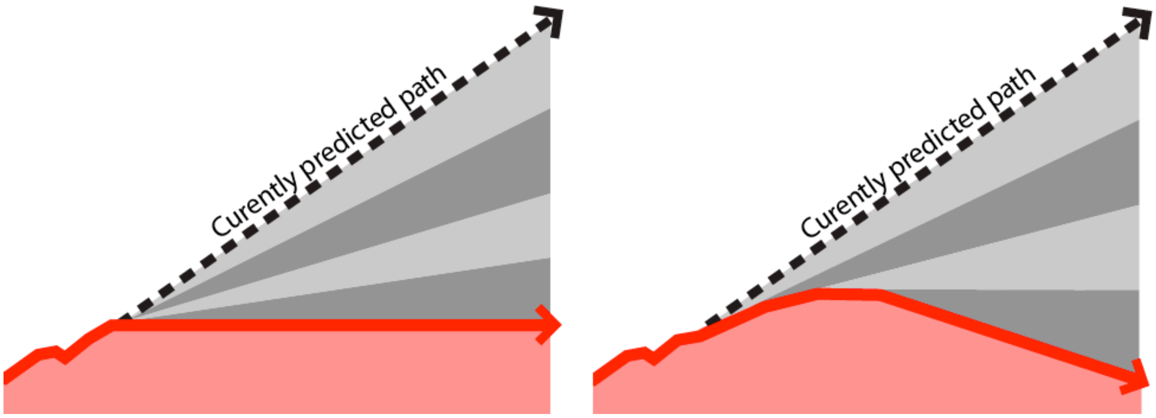


Figure 5.1.3 – Global (left) and university (right) contexts for abatement pathways

Another global greenhouse gas reduction study from the McKinsey management consulting firm provides a valuable way of visualizing not only the abatement potential of individual options but also the cost of the mitigation (expressed in cost per ton of greenhouse gas avoided). Although McKinsey constructed the first global marginal abatement cost curve, this analysis is rooted in the same methodology as studies from the 1980s that assessed conservation potential by using energy supply curves (Meier, Wright, and Rosenfeld 1983). Figure 5.1.4 shows the corresponding summary graph from the McKinsey analysis with mitigation potential beyond the business-as-usual scenario on the horizontal axis and cost-effectiveness of the option on the vertical axis. This analysis served as a model for presenting not only the effectiveness of each mitigation option but also its associated costs, as such considerations are indispensable in making informed planning decisions.

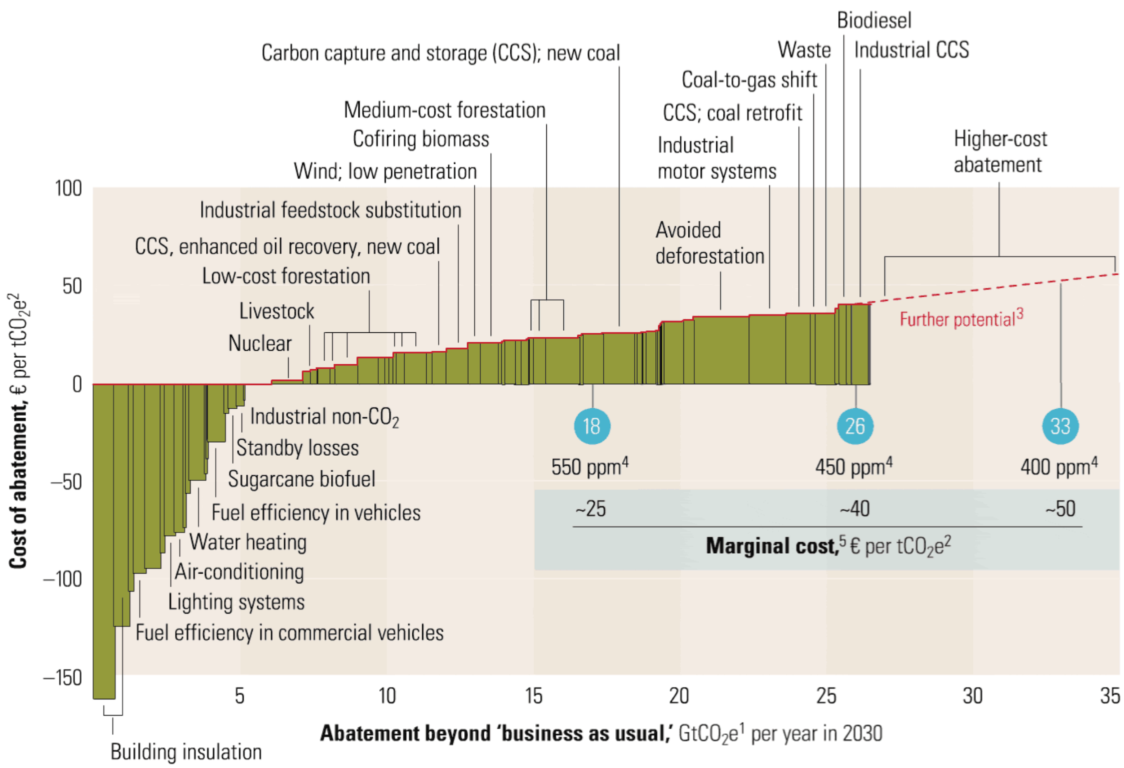


Figure 5.1.4 – Summary diagram of McKinsey analysis (McKinsey/Vattenfall 2007)

5.2. On-Campus Energy Supply Options

5.2.1. CO_2 Capture and Storage

Given the significance of greenhouse gas emissions from the power generation sector, large-scale development and deployment of a new generation of lower emitting and more efficient coal-fired power plants will become increasingly important in the next 50 years. The environmental and economic climates of a carbon-constrained world have led many experts to project that CO_2 capture and storage (CCS) will play a major role in less carbon-intensive technological pathways (James 2007; Pacala 2004). As suggested in other sections of this chapter, although there is significant room to achieve emissions reductions through conservation measures, increased demand for electricity and steam will require a fundamentally new set of technologies to keep emissions low through periods of growth (Revkin 2008).

Since CCS technologies can prevent approximately 90 percent of a plant's CO_2 emissions from reaching the atmosphere, these systems may offer the greatest potential for reductions in the U.S. electric power sector. CCS systems can feasibly be incorporated into most coal-fired plant designs, which include pulverized coal (PC) plants, integrated gasification combined cycle (IGCC) plants, and oxy-fuel combustion plants (James 2007). For universities and other institutions with on-campus power generation facilities, adding CCS capabilities would reduce a considerable amount of the carbon footprint associated with electricity (which represents approximately 30 percent of Carnegie Mellon's footprint, according to Chapter 2).

Despite the importance and potential for reductions from CCS technologies, cost, policy, and technological barriers will likely prevent widespread deployment in the near future. These limitations are particularly true for institutions like universities, which likely do not have enough financial incentive to invest in these more costly technologies absent carbon pricing. Currently, the addition of pre-combustion CO_2 separation processes (like capture, drying, compression, transportation, and storage) to IGCC plant designs would increase wholesale electricity prices by 40 to 50 percent (James 2007). In comparison, the addition of post-combustion CO_2 capture to PC plants is likely to raise the electricity cost by 65 percent while decreasing the net plant output by 29 percent (James 2007).

Total plant costs and fuel costs will determine the cost-effectiveness of implementing CCS systems in the future. Currently, average capital costs for new plants are as follows: NGCC, \$554 per kW; PC, \$1,562 per kW; and IGCC, \$1,841 per kW. In comparison, the capital costs for the same plants with capture capabilities are: NGCC, \$1,172 per kW; PC, \$2,883 per kW; and IGCC, \$2,496 per kW, which means that capital costs will be approximately twice as much for plants equipped with CO_2 capture (Klara 2007). Once CCS technologies are integrated into new plants, the 20-year levelized cost for electricity is projected to increase anywhere from 36 percent for IGCC plants to over 80 percent for PC plants (Klara 2007). Furthermore, the cost of transportation, storage, and monitoring of CO_2 is projected to add ten percent to total CCS costs (Klara 2007).

In addition to cost issues, there many other technological, political, environmental, and economic questions that will require research before CCS can become viable on a large scale. Significant technical and regulatory concerns regarding the injection and storage of captured carbon pose serious challenges. Although the DOE has an active research and development program focusing on carbon sequestration, large-scale injection and storage of CO_2 has not yet been proven (James 2007). Notwithstanding funding issues for these programs, the DOE and EPA also must tackle thorny regulatory issues regarding the responsibility of monitoring injected CO_2 (Ghorbi 2007). Beyond these storage concerns, water needs for CCS technologies at plants may also present economic and ecological challenges. Average PC subcritical plants equipped with CO_2 capture use nearly twice as much water as their conventional counterparts (Klara 2007). This factor can be quite problematic in areas of the country where power plant water needs for cooling purposes have already curtailed plant operations.

Although cost barriers will prevent large-scale penetration of CCS technologies in the immediate future, potential reductions in these costs can be achieved as a result of research and development investments, learning-by-doing, and other factors that have been observed in similar power generation technologies over many decades. For instance, by the time that worldwide capacity IGCC units reaches 100 GW, the cost of electricity is projected to decrease by 18 percent from the onset of technological learning (Rubin 2007). It is projected that capital costs, operation and maintenance costs, and the cost of electricity for a range of plant types will decrease as CCS technologies are increasingly deployed (Rubin 2007).

5.2.2. Fuel Cells

The 2001 EPP/SDS/Heinz project report looked at several types of combined heat and power fuel cells (EPP/SDS/Heinz 2001). The solid oxide fuel cell (SOFC) seemed to be the best fit for Carnegie Mellon and at the time was expected to become commercially viable by 2004. Unlike traditional combined heat and power systems (often referred to as cogeneration), the SOFC is more efficient (45-60 percent) in the generation of electricity alone than a coal or natural gas fired power plant (~35 percent). Thus, utilizing the waste heat from these systems improves the overall fuel efficiency even more (overall efficiency of 80-85 percent for SOFC). According to the National Energy Technology Laboratory (NETL), the current goal for commercialization of these units is to price them at \$400 per kW or less by 2010. In 2006, a handful of small scale, 4-6 kW systems were demonstrated at with estimated costs of \$250-300 per kW (NETL 2008). However, such a small system would not make a dent in the energy consumption of a university like Carnegie Mellon. The 2001 report investigated a unit that would generate 250 kW of electricity, which is an analysis that will be updated here.

A 250 kW system would produce 2.19 million kWh per year or about two percent of the campus total. Using $400 per kW as a conservative estimate, a 250 kW system would cost $100,000 in capital plus the cost of new infrastructure to connect the new fuel cell unit to the campus electricity grid and steam lines near Bellefield Boiler. The 2001 report estimated the infrastructure cost would be $150,000 in 2001 dollars; at 2008 price levels, infrastructure would cost $181,000 (DOL 2008). This would bring the total capital cost of the 250 kW system to $281,000. To simplify the analysis, it is assumed that maintenance costs will not increase as a result of this new system.

Carnegie Mellon currently pays $0.085 per kWh for electricity and $15.52 per Mlb for steam from coal. A 250 kW fuel cell would also produce 3,500 Mlb per year of steam and consume 15,600 MCF per year of natural gas, costing an estimated $12.26 per MCF (EIA 2007). Thus, the fuel cell would save $49,000 per year on the university's utility bill while simultaneously reducing Carnegie Mellon's carbon footprint by 1,200 MTCDE per. This is an emissions cost-effectiveness of one dollar savings per MTCDE reduced if the system lasts only eight years, but seven dollars savings per MTCDE if the system lasts for ten years. The payback period for the first installation would be almost eight years. However, when the unit needs to be replaced, the infrastructure will already be in place, cutting the capital cost by more than half.

The replacement system, using the same $100,000 capital cost estimate, would then have a payback period of just over two years and would save $27 per MTCDE reduced over its eight-year lifetime. The above analysis is given for a single fuel cell unit. However, installing multiple units would have economic benefits similar to the replacement systems. Each 125 kW unit is less than 125 cubic meters in volume, so a 250 kW unit would be expected to be no larger than 250 cubic meters (Siemens 2007b). Thus, it is possible to install multiple fuel cell units. Additional units would only require the capital cost and not the additional $150,000 for new infrastructure required for the first fuel cell installation.

It is important to note that the economics of this fuel system were even more favorable in 2001. When natural gas cost only $5.25 per MCF, the fuel cell would have saved Carnegie Mellon $148,000 per year. However, the system would now come at a net savings of $7,000, whereas the 2001 report estimated a net cost of $19,000-$119,000 for the system. The net cost and savings are also influenced by the change in fuel mix used at Carnegie Mellon, as the university now purchases 18 percent of its electricity from renewable sources, which it did not in 2001. The cost of fuel (especially the currently rising cost of natural gas), fuel switching in electricity and steam generation, and the eventual price of commercial models may change these economics drastically.

Table 5.2.1 summarizes this analysis. Scenarios A and B are the high and low estimates for a first time install, using current industry price goals. Scenarios C and D are high and low estimates for each additional or replacement unit installed, which require nominal infrastructure changes. Scenario E is using a 2001 price estimate and is adjusted for inflation.

Table 5.2.1 – Economic analysis of fuel cells under different scenarios

Scenario	Lifetime (years)	Capital Cost ($)	Infrastructure Cost ($)	Lifetime NPV	Payback Period (years)	Cost-Effectiveness ($/MTCDE)
A	8	$100,000	$181,000	-$7,000	7.7	-$1
B	10	$100,000	$181,000	-$56,500	7.7	-$1
C	8	$100,000	$0	-$188,000	2.3	-$27
D	10	$100,000	$0	-$237,000	2.3	-$29
E	8	$1,387,000	$181,000	$1,280,000	Never	$186

Siemens AG began successful operation of a 250 kW proof-of-concept unit in 2003 (Siemens 2007a). Rolls-Royce plans to begin testing on a megawatt scale SOFC in 2008; the target life of the plant would be twenty years (Rolls-Royce 2007). Many companies including GE and Delphi have tested small-scale SOFC units; however, no large scale units appear to be commercially available (NETL). Given that Siemens has tested SOFC technology at its site in Pittsburgh, a test facility located at Carnegie Mellon might be a fruitful path to pursue.

5.2.3. Cogeneration

A popular mitigation option is the use of cogeneration (cogen) plants which generate both electricity and steam (and sometimes chilled water as well) from a single energy source, such as burning a fossil fuel. The objective of cogen plants is to increase the efficiency of overall energy utility production by capturing the waste energy from electricity production and turning it into useful energy in the form of steam. This application makes sense provided that both electricity and steam comes primarily from carbon-intensive fossil fuels. However, if either or both of these energy services are provided through the use of a low-carbon mix, the change in emissions will be less dramatic or could lead to even higher emissions levels.

It should be noted that carbon reductions and increases in efficiency are not analogous. Large quantities of thermal energy from electricity production are typically dumped into the environment (thermal pollution) after passing through the turbine of the generator. If there is a demand for steam near the power plant, this energy can be recovered and turned into useful steam for heating. There are several obstacles to the economy of the cogen process. First, unlike electricity, steam is inefficient to transport over long distances. Therefore, a cogen plant must be located at or near where the steam will be used. Most electric power plants are not located near sizable populations and thus have no market for their waste energy. Also, demand for steam is not constant year-round. Unlike electricity, the majority of steam requirements come during the winter with little or no demand during the summer. A constant, year-round demand for steam makes a cogen plant much more economical.

Surprisingly, it is possible to find this summer supplement for steam usage in the production of chilled water. This can be accomplished through a chemical reaction system. Such a system would involve a chemical reaction that chills the water through absorption, and the hot steam then is used to regenerate the reactant. Sites where steam is used for purposes other than HVAC, such as universities, are good candidates for cogen as well.

At Carnegie Mellon, a cogen plant that would generate 85 percent of the campus electricity requirement would generate only about 13 percent of the steam requirement and cost $16-25 million. Additionally, installing a cogen plant would *increase* Carnegie Mellon's carbon footprint by 9,000 or 47,000 MTCDE, for a natural gas or coal fired plant, respectively. The reason for this counterintuitive result is that the university's current electricity mix is low carbon, only 41 percent coal. However, a cogen plant would increase the campus fuel mix for electricity to almost entirely fossil fuel while reducing emissions directly from steam generation by only a small amount.

A better option for Carnegie Mellon is switching from coal to natural gas boilers for steam. Natural gas is more expensive than coal. Thus in the long run, it might be beneficial economically to install a cogen facility as well, which is cheaper to operate and would offset the increased cost of the natural gas to fuel the boilers. Combined numbers for a natural gas fired cogen plant and natural gas fired auxiliary boilers are more encouraging. This "best case" scenario would reduce emissions by 6,600 MTCDE per year while saving the university around $930,000 annually. It is important to remember that the carbon savings are coming entirely from switching the boilers from coal to natural gas, not the cogen plant (for the specific case of Carnegie Mellon). However, this result does not suggest any general or categorical conclusions that regarding cogen's capacity to reduce carbon emissions.

This analysis is based on a scale up of the existing cogen facility at nearby Duquesne University, assuming that the proportion of steam generated and money saved to electricity generated will remain roughly the same at higher electricity capacities. Carnegie Mellon uses about twice as much electricity as Duquesne University, not including electricity used for chilled water. However, the steam demand is six times that of Duquesne University. The choice to generate only 85 percent of the university's electricity from cogen was deemed necessary by Duquesne University to maintain a contractual relationship with the regional electricity provider, Duquesne Light Company, so that the when the cogen plant must go offline, the university can draw all of its electricity needs from the grid (Fecik 2008). Thus, 85 percent seemed a reasonable amount of electricity to use in the estimation of a plant for Carnegie Mellon as well. However, this a very rough estimation, but it shows that cogeneration is not a viable carbon mitigation option for Carnegie Mellon and illustrates the importance of taking into account the current energy fuel mix before deciding to invest in a cogen plant.

5.2.4. Solar Power

Solar photovoltaic panels can be added to open spaces on campus in order to generate on-campus renewable electricity. On-campus electricity generation saves money, which could be used to purchase electricity from the utilities. However, it has been found that photovoltaic solar power generation is not cost effective at current market values. In order to generate all campus energy, a system would cost almost a billion dollars. Also, photovoltaic solar cells would exhaust part of the available surface area of campus. Some of this area, such as the roofs of buildings, seems to be prime unused area for solar panels. However, it is important to note that these panels need to be cleaned regularly to maintain conductivity.

Table 5.2.2 – Price and land area of various sized photovoltaic systems

Annual Electricity Produced (kWh)	% Total Electricity (2006)	Square Footage	Capital Cost ($)	% Campus Land Area (%)	Annual Savings ($/year)
1,000	0%	90	$6,800	0.00%	$90
10,000	0%	910	$68,000	0.02%	$900
100,000	0%	9,100	$680,000	0.15%	$8,500
1,000,000	1%	91,000	$6,800,000	1.50%	$85,000
10,000,000	11%	910,000	$68,000,000	15.00%	$850,000
89,547,000	100%	8,200,000	$609,000,000	136.00%	$7,600,000

Table 5.2.2 shows the capital costs, the required land area, and the annual savings of various sized photovoltaic power systems. It was found that in order to generate 100 percent of the total 2006 electricity use, over 100 percent of the total land area is necessary. Of course, at discussed in the metrics section of this paper, this is not possible. 100 percent of the land area of Carnegie Mellon would mean that all campus, roofs, grass, and sidewalks must be covered in solar panels.

Annual maintenance costs were calculated using approximation of the number of effective employee salaries needed per land area of solar panels. From this data, the NPV and cost-effectiveness of an on-campus photovoltaic system were evaluated using methods discussed in Appendix 5.A.

Table 5.2.3 – Cost analyses for on-campus photovoltaic systems of various sizes

Size of System	Maintenance Costs	NPV (Lifetime)	Theoretical Lifetime	Incremental Levelized Annual Cost	Cost-Effectiveness (Electricity)
(kWh/year)	($/year)	($)	(years)	($/year)	($/kWh)
1,000	$0	$5,802	30	$493	$0.49
10,000	$610	$65,197	30	$5,535	$0.55
100,000	$6,096	$651,973	30	$55,348	$0.55
1,000,000	$60,958	$6,519,732	30	$553,479	$0.55
10,000,000	$609,578	$65,197,318	30	$5,534,790	$0.55
89,546,831	$5,458,574	$583,821,323	30	$49,562,292	$0.55

It is clear that the cost-effectiveness per kilowatt hour is above 50¢ per kilowatt hour regardless of the system size. This value is more than five times the cost of power off the grid from Duquesne Light, which is approximately 8.5¢ per kilowatt hour. However, there are many grants available for institutions investing in solar power. Leveraging advanced financing options can dramatically alter the economics of purchasing photovoltaic solar systems. Figure 5.2.1 displays the cost-effectiveness of the solar generation system versus the percent subsidized.

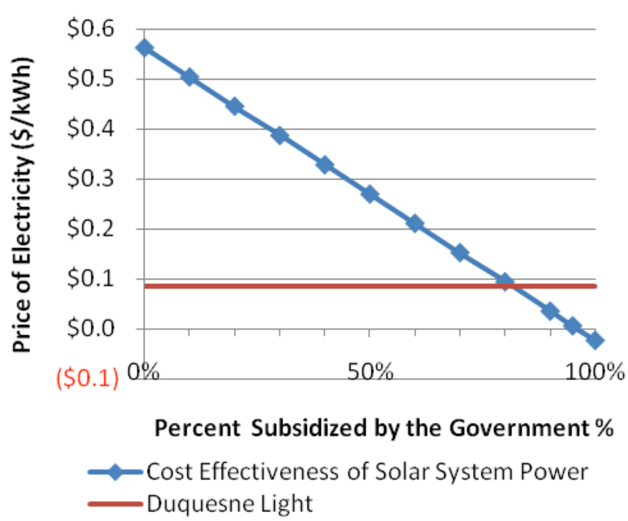


Figure 5.2.1 – Cost-effectiveness of solar generation including subsidies

From Figure 5.2.1, it is clear that the price of electricity from solar power does not become cost effective until at least 80 percent of the capital costs are subsidized by an outside organization.

Just like any shift from carbon sourced energy to a renewable energy, the mitigation effects result from the avoided greenhouse gas emissions of carbon power plants. Using analysis techniques described in

Appendix 5.A, the cost per MTCDE reduced was found to be over $1,000, which is greater than 50 times the cost of an average offset.

5.2.5. Wind Power

In the last few years, a new type of wind turbine made its market debut: the vertical-axis wind turbine. Unlike their three-bladed siblings, these turbines spin around an upright axis which allows efficient performance in cities where wind can suddenly changes direction and absorb high urban wind gusts. These turbines are quiet, elegant (adding to the architecture where they are installed), and can even be imbedded with LEDs to create a wind beacon at night.

The cost-effectiveness of wind turbines depends on the average annual wind speed, as the available power is proportional to the cube of the wind speed. Unfortunately, at Carnegie Mellon's main campus at 5000 Forbes Avenue, measured wind speeds are too low to make wind cost effective. However, data are lacking for new Carnegie Mellon buildings on the Monongahela River. Qualitative observations by going to the river suggest it is much windier at the Entertainment Technology Center building than on the main campus. Particularly as university property expands on the river into Hazelwood, wind may prove to be a viable option after conducting a wind survey.

Outside of Pittsburgh, other areas of the state are characterized as having a "fair" wind potential such as Appalachian ridges and the Erie cost. These are areas where wind is likely cost-effective, especially for utility scale turbines of a gigawatt or more. For an analysis of wind availability outside of Pittsburgh, please refer to the 2001 project report *From Carnegie Mellon to Kyoto: How Far Can We Go?* (EPP/SDS/Heinz 2001).

5.2.5.1. Wind Potential

Pittsburgh's hilly terrain and rivers make the wind potential of any one location different from another. The beta version of the National Renewable Energy Laboratory's (NREL) wind resources map marks all area ZIP codes as having "poor" wind potential, but records of weather stations in Pittsburgh show a wide range of variability. The Pittsburgh average for 45 years is nine miles per hour, which is a measurement from McKees Rocks and the Pittsburgh International Airport. Averages that deviated from nine miles per hour were usually below that mark. However, it was difficult to find any local river front wind data.

Carnegie Mellon's Intelligent Workplace recorded wind data on campus from 2000 to 2004. Unfortunately the data are incomplete; there was no one year with every month represented. The most complete year was 2002, with measurements for 70 percent of the year with errors evenly distributed through the seasons. To estimate the average annual wind speed on campus, the 2002 wind speed average at Pittsburgh International airport (six miles per hour) was compared it to the 45 year average (nine miles per hour). The year 2002 was a third less windy than average. Multiplying the 2002 campus average by 150 percent yields an average wind speed on campus of 8 MPH ± 2.5 MPH.

Technically, a simple average wind-speed is not the correct measure. To find a better measure requires finding the Weibull distribution of wind speeds and then finding the mean value, as gale force winds are fairly rare while gentle "fresh" winds are common (please see the Danish Wind Industry's website for more information). However, average annual wind speed is a sufficient surrogate for universities where even this data is uncommon.

5.2.5.2. Cost

An estimated range for cost for wind power is between $2,000 and $5,000 for every kilowatt of capacity. This estimated cost includes wind towers and installation but does not include battery storage. Larger turbines that are unlikely to fit on campus are less expensive costing between $1,680 and $1,800 (DOE 2007a). Typically, cost per kilowatt capacity decreases as turbines get larger, but there is a high degree of variability for small turbines suited urban sites.

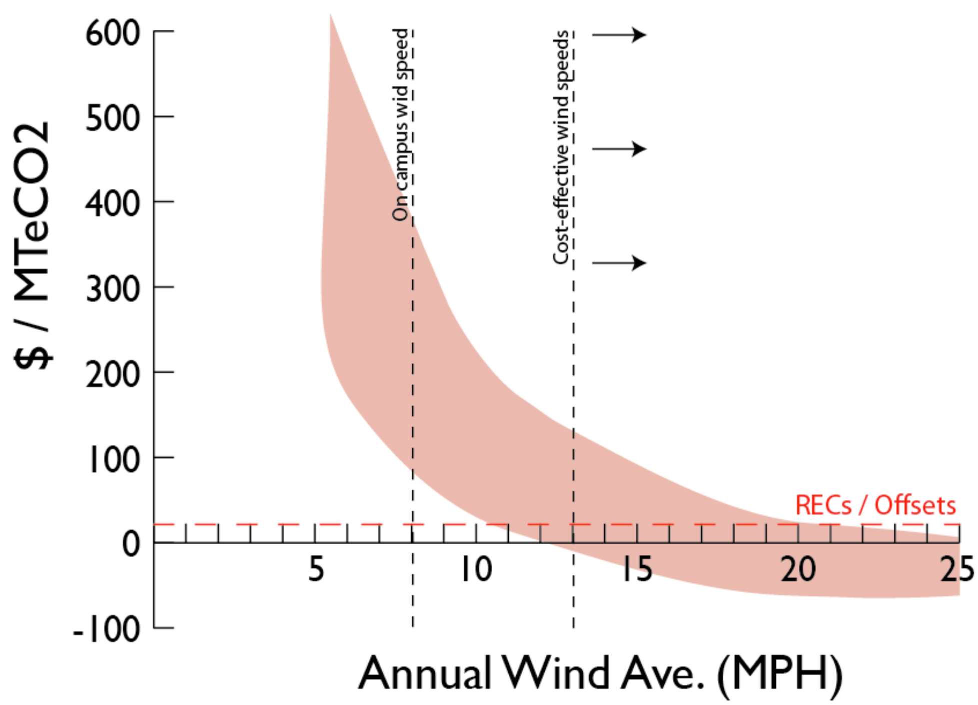


Figure 5.2.2 – Cost-effectiveness of wind generation given average wind speed

The cost-effectiveness of wind power is a function of wind speed. With on-campus average wind speeds of eight miles per hour, wind would cost $90 to $400 per MTCDE, but for a wind speed increase of five miles an hour (13 MPH), the cost-effectiveness range includes values that are below purchasing renewable energy credits or offsets (-$12, $140 per MTCDE).

Wind power at Carnegie Mellon may not make sense if the university paid for these additions by itself. However, there are numerous sources of funding for renewable energy projects. For example, the Pennsylvania Public Utility Commission has four funds available for renewable or “clean energy projects.” To date, the Utility Commission’s Sustainable Energy Board has approved $20 million in loans and $1.8 million in grants. The board has worked with universities before. In 2005, the Board gave St. Francis University in Loretto, Pennsylvania a grant for $143,516 to develop community, farm, and business biased wind projects.

Although wind and solar are not viable options for providing a large portion of Carnegie Mellon’s energy, even a small percent of on-site generation is useful for LEED points. Up to four LEED points are awarded for on-site generation in the following increments:

- 3 percent on-site renewable energy: 1 point
- 6 percent on-site renewable energy: 2 points
- 9 percent on-site renewable energy: 3 points
- 12 percent on-site renewable energy: 4 points

These options are available in combination with the purchase off off-side renewable energy in the form of RECs. That is, one point can be gained from three percent on-site generation, and another point gained from 25 percent off-side generation in the form of RECs (for a total of two points). These two options can be combined for up to four LEED points.

5.2.5.3. Future Research

Cost-effective average wind speeds of 13 miles per hour or more may be present on the shore of Monongahela River where Carnegie Mellon recently opened the Entertainment Technology Center. Carnegie Mellon Field Robotics Center has also suggested interest in expanding its presence on the Hazelwood ALMANO brownfield (formerly LTV steel) to create a "robo-city." Currently, Field Robotics occupies Building 19, a former industrial structure that is longer than the empire state building is tall. It was not feasible to obtain sufficient data on Monongahela wind speeds, although it is suspected that they may be at the low end of the cost-effectiveness range. Since the Intelligent Workplace is no longer collecting wind data for the Carnegie Mellon campus with its anemometer, it would be helpful to collect data on top of the ETC building with such a wind gauge.

5.3. Purchased Utilities Supply Options

5.3.1. Carbon Offsets and Renewable Energy Certificates

Regardless of how committed Carnegie Mellon is to reducing its carbon footprint, it is almost impossible that carbon neutrality can be reached with conservation and new technologies alone. No matter how much energy is conserved on campus, some amount of carbon emissions are inevitable, and many options will prove too expensive to be financially feasible. Thus, if Carnegie Mellon endeavors to become carbon neutral or if it is to even meet any sort of greenhouse gas reduction goals, some carbon reductions must be bought from outside sources.

Purchasable carbon reductions go by many names. Following the convention of the Federal Trade Commission, this study divides them into two categories: carbon offsets and Renewable Energy Certificates (RECs). Both of these reductions are typically sold by third party organizations and both exist in well established markets. Unique to each category, both carbon offsets as well as RECs are often verified or accredited via many different methods by various third party organizations (FTC 2008).

5.3.1.1. Carbon Offsets

Carbon offsets are purchasable reductions sold by third party organizations. Theoretically, they are bought when the cost of reducing greenhouse gasses within an industry is too high. These reductions typically take place in three different sectors: sequestration, reduction of emissions below a baseline, or generation of renewable energy (Greenspan 2008).

Sequestration offsets take place when carbon is either sequestered into newly planted trees or into untilled ground. Reforestation credits can be sold by parks with reforested land or by organizations buying land and planting trees with the purpose of selling the offsets. No tilling sequestration offsets are typically sold to third party organizations by farmers who adjust practices to make extra money from the offset as well as benefit from the extra carbon in the soil.

Carbon offsets can also be sold by businesses reducing below a baseline specific to their product. Due to the fact that greenhouse gases are emitted in a variety of different ways across many industrial sectors, it is natural that the cost of reducing emissions will be cheaper in specific industries. Thus, businesses with difficult to reduce greenhouse gas emissions can purchase reductions from businesses which can reduce cheaply. These types of reductions can even take place abroad where offsets help to fund projects in developing countries. Again, these reductions are typically sold by a third party, which is accredited by another third party.

The final source of reductions in carbon offsets is the generation of renewable energy. This source is simply a translation of RECs into an offset sellable in terms of tons CO_2 reduced.

Accreditation of carbon offsets can be a difficult and painstaking process. In the case of reforestation, it simply translates to proving that trees have been planted or land has not been tilled. However, in the case of business reductions, the process is much more complex. First, an adequate baseline of carbon emission must be produced, then the business must prove that it is emitting below the baseline. Only emissions which have already been reduced can be sold.

Many of the most relied on accreditation agencies used methods set forward by the United Nation's Framework Convention on Climate Change (UNFCCC). The UNFCCC outlines over 70 methods for both large scale and small scale industries establishment on a baseline. The UNFCCC also outlines the methods by which an industry's carbon emissions must be measured as well as establishes conversion factors for finding CO_2 equivalents. Accreditation agencies can be judged by comparing their method to that outlined by the UNFCCC as well as the transparency of their method (UNFCCC 2008).

Using a survey of about ninety carbon offset selling agencies, the price of carbon offsets was found to be between $4 and $45 (excluding one $180 outlier). The average price of these organizations was found to be $19 with a standard deviation of $10.50 (Greenspan 2008; *How Much* 2008). A table of all surveyed companies is included in Appendix 5.B.

5.3.1.2. Renewable Energy Certificates (RECs)

Consumers can purchase Renewable Energy Certificates to offset carbon from their electricity use. RECs result from the additional cost for electricity to be produced renewably. A renewable electricity plant may sell RECs if it is selling electricity at the market rate in its area. Owing to the fact that renewable plant's operation is more expensive than the typical plant's, RECs are used to subsidize the electricity sale, making it profitable.

RECs are typically sold in cents per kilowatt-hour. Thus, a consumer can purchase enough certificates to offset a certain percentage of energy use. Third party organizations often buy RECs and convert them into a value of dollars per ton of CO_2, reduced by comparing them to the local grid mix. In this case, the renewable energy is no longer referred to as a REC but becomes a carbon offset (FTC 2008).

REC accreditation agencies are much simpler than their carbon offset counterparts. RECs must only account for renewable electricity put on the grid additional to that already required by the state. The most important factor for accreditation agencies is making sure that renewable energy is not double counted. That is, they make sure that renewable plants are only selling credits related to the amount of energy they produce. They also make sure that the renewable plant is only selling energy produced over that required by government mandate.

Using a price survey from the U.S. Department of Energy, the cost of a REC was found to be between 0.5¢ and 7.5¢ per kilowatt hour. The average found cost was 2.1¢ with a standard deviation of 1.5¢ (Renewable 2008). A table of all surveyed RECs and their prices is included in Appendix 5.B.

5.3.1.3. Renewable Energy Credits versus Carbon Offsets

Both RECs and Carbon Offsets can be purchased in order to reduce net greenhouse gas emissions. However, RECs account for electricity taken off the grid and carbon offsets account for MTCDE removed from, or not released into, the atmosphere. The two quantities are related by the amount of carbon emitted by a specific gird mix of electricity. For instance, in the Middle Atlantic, about twice as much carbon dioxide equivalent is produced by coal plants than by natural gas plants. Thus, every kilowatt hour of REC bought to offset coal generated electricity is offsetting twice as much greenhouse gas than if it was offsetting natural gas electricity.

Presented in this paper is a Microsoft Excel tool for finding whether the carbon offset or the REC is more cost-effective. A screen shot of the tool is shown in Figure 5.3.1.

Location	Middle Atlantic			
Type	**Slider Bar**	**% REC**	**MTCDE/kWh x10^5**	**Adjusted**
Coal		83.0	94.8	78.6
Petroleum		0.0	84.9	0.0
Gas		0.0	53.4	0.0
Renewables/Nuke		17.0	0.0	0.0
Total				78.6

Carbon Offset Cost (USD / MTCDE)																					
40	6.3	4.3	3.3	2.7	2.2	1.9	1.7	1.5	1.4	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6
38.15	6.0	4.1	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6
36.30	5.7	3.9	3.0	2.4	2.0	1.8	1.5	1.4	1.2	1.1	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
34.45	5.4	3.7	2.9	2.3	1.9	1.7	1.5	1.3	1.2	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5
32.60	5.1	3.5	2.7	2.2	1.8	1.6	1.4	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5
30.75	4.8	3.3	2.5	2.1	1.7	1.5	1.3	1.2	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
28.90	4.5	3.1	2.4	1.9	1.6	1.4	1.2	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5
27.05	4.3	2.9	2.2	1.8	1.5	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4
25.20	4.0	2.7	2.1	1.7	1.4	1.2	1.1	1.0	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
23.35	3.7	2.5	1.9	1.6	1.3	1.1	1.0	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
21.50	3.4	2.3	1.8	1.4	1.2	1.0	0.9	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3
19.65	3.1	2.1	1.6	1.3	1.1	1.0	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
17.80	2.8	1.9	1.5	1.2	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
15.95	2.5	1.7	1.3	1.1	0.9	0.8	0.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
14.10	2.2	1.5	1.2	0.9	0.8	0.7	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
12.25	1.9	1.3	1.0	0.8	0.7	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
10.40	1.6	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8.55	1.3	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
6.70	1.1	0.7	0.6	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
4.85	0.8	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3.00	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
REC Cost (¢/kWh)	0.5	0.7	1.0	1.2	1.4	1.6	1.9	2.1	2.3	2.5	2.8	3.0	3.2	3.4	3.7	3.9	4.1	4.3	4.6	4.8	5.0

Figure 5.3.1 – Tool for figuring cost-effectiveness of a REC over a carbon offset

The user inputs the electric grid mix being offset and the region into the tool. A grid mix reflects percentages of electric power coming from various sources. For instance, Duquesne Light reports that Carnegie Melon receives approximately 50 percent of its electricity from coal plants and 50 percent from nuclear plants.

The tool uses average values for the carbon intensity for different sources of electricity to find overall carbon intensity (Carbon 2000). The overall carbon intensity is multiplied by the cost of the REC to find the effective cost per MTCDE for buying the REC. Each cell's value reflects the effective cost of the corresponding carbon offset divided by the effective cost of the corresponding REC. If the REC is more cost effective, the cell turns green. However, if the offset is more cost-effective, the cell becomes blue. Equation 5.3.1 was used to find the values in the grid.

$$Value = \frac{Adjusted\,Carbon\ Intensity}{Cost\ of\ REC} \times Cost\ of\ off\,se \qquad (5.3.1)$$

Deciding on a grid mix for establishing the carbon intensity of a REC can be difficult. In one argument, the renewable energy is offsetting power used by the purchaser. Thus, the grid mix used by the purchaser should be used. In another argument, the renewable energy being placed on the grid is preventing other electricity from being produced. Thus, the grid mix of non-produced electricity surrounding the renewable energy plant should be used at the offset grid mix. The latter case, although more correct, is extremely difficult to calculate. The approximate grid mix of the purchaser was used in this study. It was found that for Carnegie Mellon's grid mix of 50 percent nuclear and 50 percent coal power, carbon offsets were more cost effective in almost every scenario.

The purchase of RECs counts for up to four LEED points. In order to be awarded LEED points, there must be a proof of contract to purchase RECs for at least two years with a commitment to continue purchases RECs afterward. LEED points are awarded for the following increments of renewable energy:

- 25 percent off-site renewable energy: 1 point
- 50 percent off-site renewable energy: 2 points
- 75 percent off-site renewable energy: 3 points
- 100 percent off-site renewable energy: 4 points

5.3.1.4. Carnegie Mellon as a Carbon Offset Provider

One way for Carnegie Mellon to finance methods for reducing emissions would be to sell its reductions as a carbon offset granting agency. Conceivably, each option could be evaluated by the amount of money brought in via carbon selling carbon offsets. However, in order for this analysis to be done for Carnegie Mellon, an accreditation agency would have to evaluate a baseline for the university, and carbon reductions then could only be sold once the university began emitting below that baseline.

Assuming that the university is currently operating at its baseline and that the previously calculated carbon footprint of about 180,000 MTCDE can be used, the added value to the university via possible carbon reduction would in the range of $900,000 to $5,400,000 per year of revenue to Carnegie Mellon.

5.3.2. Change in Fuel Mix for Steam at Bellefield (Natural Gas)

This following analysis is based on estimates from the 2008 Bellefield Boiler budget provided by Carnegie Mellon's university engineer, Martin Altschul (Altschul 2008). The Bellefield Boiler is the university's sole provider of steam for heating. Currently, a large percentage of the boilers are coal-fired, while the rest run on natural gas. Coal is a much cheaper fuel than natural gas, but burning coal results in significantly higher CO_2 emissions. Using all natural gas will lead to CO_2 reductions but will incur greater costs. The average projected cost for every million pounds (MLb) of steam when using on natural gas is $18.41. This estimate is significantly higher than the current cost of the coal and fuel projected cost of $15.52 per MLb. If Bellefield switches to all natural gas, the annual costs will rise from $5,088,519 to $6,036,059 annually. Therefore, it is clear that switching to all natural cast is a costly solution. From the

2008 estimate, the cost of reduction is close to $55 per MTCDE reduced, more than twice the cost of purchasing an offset.

However costly it may be, using all natural gas will have a large impact on the environment. Natural gas is much cleaner than coal burning, emitting approximately half of the MTCDE as coal (EIA 1993). Carnegie Mellon uses an estimated 330,000 MLbs of steam annually, which leads to emissions of 36,000 MTCDE each year. Of these emissions, 28,000 MTCDE are from burning coal. Given this high demand for steam at Carnegie Mellon, switching to all natural gas would reduce the carbon emissions by 35 percent, an estimated 13,000 MTCDE. Steam use at Carnegie Mellon accounts for approximately 30 percent of the university's carbon footprint. Thus, this reduction in emissions from coal burned at the Bellefield Boiler would reduce the university's footprint by 11 percent, a sizeable percentage. Therefore, even though it is clearly not cost-effective to switch to all natural gas at present, this valuable option should be considered in the future in light of price changes in natural gas. Although it is not feasible to use a 100 percent natural gas option at Bellefield, it would be possible to increase natural gas use by a small percentage. Bellefield's current provider of coal charges $118.50 per ton of coal, but a new provider has been found with a cost of only $95 per ton. The money saved from the cheaper coal could be invested in natural gas. The budget would remain the same, while the CO_2 emissions would decrease.

Switching to natural gas incurs no capital cost and would be a smooth transaction. The Bellefield Boiler is currently equipped and able to run entirely on natural gas with estimates on cost available in the 2008 budget analysis. A portion of Bellefield Boiler is already fueled by natural gas, so there is already a provider as well. Natural gas is currently a widely available resource. However, increased demand might lead to a substantial increase in price, making this option even less practical.

Although there is no capital cost, switching to an all natural gas option will incur a high annual cost. Coal is becoming cheaper, while natural gas prices are still significantly higher. However, cutting out coal completely results in one less provider with which Bellefield will have to do business. The 2008 budget shows that switching to all natural gas would lower the number of full-time employees at Bellefield from 18 to 11. Based on the 2008 budget, this would lower Bellefield's non-fuel costs from $10,434,000 with the current ACP status to $6,336,000. Therefore, the difference in costs between coal and natural gas is not merely contingent on the price of the fuel. Coal firing requires seven more full-time workers who require increasing wages. Switching to natural gas would lead to a decrease in spending, as there will be seven fewer full-time workers. Worker wage must then also be considered along with the price of fuel.

The environmental benefit of fueling Bellefield solely with natural gas can be combined with the economic benefit of converting Bellefield into a cogeneration plant. Cogeneration (discussed in Section 5.2.3 of this report) provides a certain amount of monetary benefit. However, with Bellefield's current boilers, the use of coal as a fuel makes cogeneration impossible. In order for cogeneration to be an option with coal, the boilers must either be replaced or upgraded, which is a very expensive capital investment. However, if the fuel is changed to all natural gas, then it is possible to implement cogeneration without changing any of the boilers. Although it is an expensive choice to switch to all natural gas, there are additional benefits if the Bellefield Boiler is also used as a cogen plant rather than just a steam plant.

Due to Carnegie Mellon's large demand for steam, changing the fuel mix would lead to a significant reduction in carbon emissions and would reduce a sizeable portion of Carnegie Mellon's carbon footprint. Natural gas has much lower CO_2 emissions, but owing to high prices, it is not a cost-effective option for mitigation. However, it is important to explore other fuel options that would reduce MTCDE due to the large CO_2 output from Bellefield.

5.3.3. Change in Fuel Mix (Urban Wood/Coal Co-Firing)

Wood/Coal Co-Firing in the Bellefield Boiler Plant offers a cost-effective option that also reduces Carnegie Mellon's total greenhouse gas emissions. This option has little to no capital cost, and the fuel costs are less than the current coal fuel prices at Bellefield. However, since this new fuel mix is still in an experimental stage, it is not widely available or convenient. As a leader among universities and other institutions, Carnegie Mellon could set an example by investing the resources necessary to implement this new fuel mix.

In 2000, a series of tests were administered in the Bellefield Boiler using varying mixtures of waste wood and coal to determine the effectiveness of a wood and coal mixture. During the experiment, varying levels of wood and coal mixtures were tested for the quality of performance and the effect on the boilers. The co-firing used a mixture of tub-ground pallet wood and coal measured by volume, mixing in wood at five percent increments between 10-30 percent. It was determined that a mixture of 20-30 percent of wood chips by volume resulted in the same heating performance as using all coal as fuel while reducing ten percent of the CO_2 emissions from coal (Cobb 2000a).

The current price of wood from the company that provided the wood in this experiment is around $18 per cubic yard, which is notably cheaper than the same volume of coal. Using a coal wood mixture, the fuel cost is estimated to be $13.50 per MLb, while the estimated cost of the current fuel use is $15.52 per MLb. Carnegie Mellon currently spends $5.1 million each year on steam from Bellefield. By switching to a fuel mix of 30 percent waste wood and 70 percent coal, the cost will be reduced to $4.4 million annually, resulting in a 12 percent decrease in annual costs. There are a number of extra costs that are not calculated here including shipping the wood and mixing the wood and coal together. However, the high amount of annual savings makes switching to a wood/coal mixture an attractive mitigation option.

Wood has a much lower carbon output than coal. For this experiment, it was estimated that a mixture of 30 percent wood by volume resulted in a ten percent reduction of CO_2 emissions. Assuming that the total steam requirement of Carnegie Mellon is 321,000 MLbs, the amount of CO_2 reduced over one year would be approximately 2,000 MTCDE.

Unfortunately, the implementation of a wood/coal mixture on the full scale is not a simple one. The following analysis summarizes the procedure methodology of the 2000 Bellefield Wood/Coal Co-Firing experiment, as detailed in the 2000 technical report (Cobb 2000a). The experiment lasted only a few days and took a good deal of special preparation to execute. In the 2000 report, Cobb details the required process for setting up wood/coal co-firing in Bellefield. For the experiment, it was necessary to obtain both an air permit from the Allegheny County Health Department (ACHD) and a solid waste permit from the Southwest Regional Office of the Pennsylvania Department of Environmental Protection (PADEP). Beyond the need for proper permits, the availability of the wood is also in question. The size of the experiment meant that a small quantity of wood was required, and the wood itself was specially prepared by the James A. Rutter Company, a supplier of wood predominantly used in landscaping. JARC used a different method of grinding wood to be mixed with the coal that produced larger pieces that were less frayed. The availability of this option for a large-scale, long-term project is unknown and should be explored in greater depth. The wood and coal were blended by the Mon Valley Transportation Company. Again, it is not known whether this company would provide similar services for a full-scale project such as this one. In order to implement this option, it is necessary to contact these companies or to find new ones willing to do the same work. Owing to the fact that this work was unusual for all parties involved, it would take some work to set up a similar situation for a large-scale, long-term basis. It may be necessary to hire another full-time worker at Bellefield to be in charge of tasks like mixing the coal and wood together or organizing the shipments. From the current 2008 budget, the wage of a full-time employee can be estimated to be $585,420 annually. If Bellefield were to hire one person to work full-time on monitoring the wood/coal mix at this salary, this option would still save $31 for every MTCDE reduced. However, the addition of any more full-time workers would raise the cost of CO_2 reduction over the $20 line of a REC or offset. The final uncertainty is in the availability of the wood itself. While only a small amount of wood was used for the experiment, switching to a wood coal mixture will require a steady and reliable source of waste wood. While waste wood pallets are readily available for the current market demand, an influx in demand for a project as large as powering Bellefield might cause a shortage.

The largest uncertainty is the carbon output of the wood itself. The type of wood plays a large part in the amount of CO_2 that will be reduced. Some wood can be considered carbon neutral, while the burning of other types of wood or wood mixes only reduces carbon output by a small percentage. The type of waste wood used in the Cobb experiment emitted approximately two thirds of the coal's carbon emissions. No matter the amount of carbon mitigated, wood consistently burns cleaner than coal. However, the implementation of this option would conflict with other proposed fuel options at Bellefield. It would be impossible to implement both this option and switch to an all natural gas, and the natural gas option is necessary for converting Bellefield into a cogeneration plant.

Due to the fact that the wood/coal mixture is still an experimental project, implementation of such a system could be considered for LEED points in innovation and design. The LEED system awards up to four points for innovation and design. This system has not been tried on a large scale before, and Carnegie Mellon's leadership in implementing a cost-effective fuel mix that also mitigates carbon would be considered an innovation and an example for other facilities to follow.

Wood/coal co-firing is a cost effective mitigation technique, saving $237 for every MTCDE reduced. More analysis is necessary before this can be implemented on a large scale, but it is highly recommended that this option be explored as it reduces Carnegie Mellon's footprint by nearly 2,000 MTCDE annually while saving up to $674,000 each year. If advances are made in this area, Carnegie Mellon will be credited with taking another step forward in environmental preservation.

5.4. On-Campus Technology Options

5.4.1. Energy Consumption, Conservation, and Efficiency

On-campus energy consumption can be broken down into many areas, as suggested in the carbon calculator analysis in Chapter 2. As one of the largest consumers of electricity, artificial lighting is employed throughout campus both inside and outside of buildings. Although incandescent bulbs are used in some locations on campus, most lighting at Carnegie Mellon is some type of fluorescent technology.

Heating and cooling are two other on-campus energy sources that contribute a significant amount of the university's total carbon footprint. Although many dormitory and office spaces use window-mounting air conditioning units, Physical Plant and other outside contractors have been replacing such units with central HVAC systems over the past thirty years. Recent decades have shown significant increases in the efficiency of these systems, which has lessened the carbon intensity of each unit (EPP/SDS/Heinz 2001). Hot water heating systems in older buildings largely have not been updated since their installation in the early part of the 20^{th} century. However, new facilities are designed to draw water from older hot water sources from the Bellefield Boiler. Furthermore, ongoing efforts aim to maintain, insulate, and upgrade the steam tunnels that support the university's hot water system on a continual basis.

Other on-campus technologies require electricity and contribute to the overall consumption of Carnegie Mellon. Machines including computers, laboratory equipment, and refrigerators all draw power and are used throughout campus buildings. Computer use is particularly high on campus, especially with university owned and maintained computing clusters around the university.

In order to assess potential mitigation pathways from the four primary areas of energy consumption listed above (lighting, heating, cooling, and computer use), this portion of the report will examine the cost and emissions reductions that can be achieved through technological changes that impact on-campus energy consumption. As such, the following mitigation options will be examined in detail: electric equipment and computer use, green roofs, HVAC systems, lighting, occupancy sensors, and window replacements.

5.4.1.1. Electronic Equipment and Computer Use

Powering down computers is an easy way to reduce carbon emissions and to save money. Changing the power settings on computers requires no capital or maintenance costs and reduces the amount of electricity consumed. If all of Carnegie Mellon's 383 public cluster computers were allowed to enter sleep mode for six hours per day and were turned off for eight hours per night, the campus would prevent 3,000 MTCDE per year from being emitted to the atmosphere and save $350,000 annually. The savings comes from an estimated 4.1 million kWh per year reduction in electricity consumption, which is 4.6 percent of the current campus total. Though this represents only a small portion of the campus' total emissions, it requires no capital investment, and thus the payoff starts immediately. This savings can be substantially greater if applied to department run clusters and the thousands of personally-owned computers and private office computers of the students, faculty, and staff.

Implementation of a power reduction strategy for university-owned computers would be accomplished through software changes administered by computing services or departmental information technology personnel. This would only require setting up the "Group Policy" feature, which already controls many of the settings on university owned computers, stopping the use of screen-savers, making computers go into standby or sleep mode after ten minuets of idling, or making them hibernate to shut off the main power after thirty minutes to an hour of not being used. Some fine tuning might be necessary to find the best setting so that computers shutoff at night but not during the day when students are more likely to use them. Implementation is more difficult on the personally-owned computers of the approximately 10,000 students. This will require a public awareness campaign to educate the student body about the benefits of utilizing sleep mode and/or turning their computers off when not in use.

The amount of carbon emissions actually avoided will depend on the fuel mix being used, but the electricity usage will drop regardless of the generation portfolio. If the university switches to a less carbon intense fuel, the carbon reductions from the lower power consumption will be smaller. However, if the university seeks to purchase all of its electricity from renewable sources, the lower power consumption from computers will provide a larger decrease in the electricity bill.

The largest area of uncertainty is how much power any given computer uses. Only four computers were tested to estimate power consumption. These computers were as follows: iMac G5 in Cyert Hall, Mac in Morewood Gardens, Dell Windows XP in Cyert Hall, and Dell Linux in Morewood Gardens.

Table 5.4.1 – Survey of public computer cluster power usage

	Number of Similar Computers	Active Power (W)	Idle Power (W)	Sleep Power (W)	Off Power (W)
iMac G5	69	80	61.9	10.7	1.5
other Mac	42	290	168	140	2.8
MS	209	141.05	95.05	0.75	1.75
Linux	63	127.55	89.05	0.75*	0.1

* Linux sleep mode power consumption could not be determined on the unit tested and was assumed to be the same as a similar PC running windows

Table 5.4.2 – Computer cluster locations and computer details

Location	Quantity	Description	Details
Baker 140E	31	Dell Optiplex GX520 3.2GHz	WinXP; 1GB RAM; 160GB Disk
Baker 140F	31	Dell Optiplex GX520 3.2GHz	WinXP; 1GB RAM; 160GB Disk
CFA 317	21	Dell Precision 380 3.4GHz	WinXP; 2GB RAM; 80GB Disk
CFA 318	24	Mac Pro 2 Dual 2.66 GHz	MacOSX; 4GB RAM; 500GB Disk; 20" Apple Cinema screen
CFA 321/323	11	Mac Pro 2 Dual 2.66 GHz	MacOSX; 8GB RAM; 500GB Disk; 20" Apple Cinema screen
Cyert 100A Mac	21	iMac G5 1.9GHz	MacOSX; 1.5GB RAM; 160GB Disk
Cyert 100A Windows	31	Dell Optiplex GX520 3.2GHz	WinXP; 2GB RAM; 160GB Disk
Hunt Lower Level - Near & Far	44	Dell Intel Core 2 Duo Processor E6600 2.4GHz	Windows; 4.0GB RAM; 160GB Disk; 17" Flat Panel Monitor
Hunt Lower Level - Linux	12	Dell Optiplex GX270 2.8GHz	Linux; 1.5GB RAM; 120GB Disk
Morewood Cluster	7	iMac G4 700MHz	MacOSX; 1GB RAM; 40GB Disk
	7	Dell Optiplex GX270 2.8GHz	WinXP; 1.5GB RAM; 120GB Disk
Wean 5201/5203	45	iMac G5 1.9GHz	MacOSX; 1.5GB RAM; 60GB Disk
Wean 5202/5204	23	Dell Optiplex GX270 2.8GHz	WinXP; 1.5GB RAM; 120GB Disk
	18	Dell Optiplex GX270 2.8GHz	WinXP; 1.5GB RAM; 120GB Disk
Wean 5205/5207	10	Dell Optiplex GX270 2.8GHz	Linux; 1.5GB RAM; 120GB Disk
	21	Dell Precision 350 P4/2.66GHz	Linux; 1.5GB RAM; 120GB Disk
West Wing Collaborative Cluster	3	iMac G5 1.9GHz	MacOSX; 1.5GB RAM; 160GB Disk
	3		WinXP
	20	IBM NetVista M42 2.4GHz	Linux; 1GB RAM; 80GB Disk

Additionally, the hours that computers could be powered down are estimates based on observations of computer cluster usage. The count of computers in public clusters comes from the computing services website. Including all computers on campus will increase savings significantly; however, other computers are much more difficult to count and estimate electricity use.

Up to 15 LEED points are awarded for a building's energy efficiency. There are different ways to measure energy efficiency. First, the building can receive an ENERGY STAR rating that is equivalent to a number of LEED points. For a building that is not eligible to receive and ENERGY STAR rating, energy efficiency can be demonstrated by comparing the building's energy efficiency to the national average of similar buildings. Installation of CFLs in the dorms will help in increasing the building's energy efficiency, and CFLs are part of a suite of ENERGY STAR approved products. By powering down computers and installing occupancy sensors, the amount of energy used by campus buildings has a noticeable decrease. Both of these options will help to gain a rating of LEED points in energy efficiency. LEED points are distributed according to the following scheme:

- ENERGY STAR Rating
    - 67: 1 point
    - 69: 2 points
    - 71: 3 points

      …
    - 93: 14 points
    - 95+: 15 points
- Percent level of efficiency above the national average
    - 17 percent: 1 point
    - 19 percent: 2 points
    - 21 percent: 3 points

      …
    - 43 percent: 14 points
    - 45 percent: 15 points

Neither of these options will be enough to gain the LEED points listed above, but they are both major contributors so that, when combined with other energy saving options, they can be put toward obtaining a higher rating.

5.4.1.2. Green Roofs

Green roofing is a low-cost, low-maintenance option that provides multiple benefits. A green roof is a roof cover of vegetation and soil over a waterproof membrane on a horizontal roof. Green roofs are either extensive or intensive in nature. An extensive green roof is typically made of low-maintenance plants that are tolerant against drought, wind, and extreme temperatures and well-suited for the environment. Once the roof is established, it is the equivalent of local undeveloped terrain and thus is self-sustaining except for extreme cases such as prolonged drought. Intensive green roofs are populated with plants that require more regular care and are often cultivated for aesthetic or recreational purposes in addition their other benefits. The most cost-effective solution then is the implementation of an extensive green roof. The price of an extensive green roof is anywhere from $9 to $25 per square foot with most green roofs averaging around $15 per square foot.

Green roofs reduce CO_2 in multiple ways. First, they act as insulation, reducing heating and cooling costs. Not only does the thicker roof act as insulation, but the soil also absorbs heat, which keeps a building cool in summer and warm in winter. On average, a green roof reduces the heating and cooling costs of the floor directly below it by 25 to 50 percent. This leads to a reduction in steam and chilled water usage and thus a reduction in CO_2 emissions. Such insulation is more effective on buildings with cooling and heating climate control. Chilled water savings for a building that does not implement cooling will be much lower, as the amount of insulation will not change the chilled water or air conditioning requirement. However, there is still the benefit of a cooler building in summer. In addition, the plant life on the green roof also reduces the amount of CO_2 in the air. Every 16.2 square feet of green roof is enough plant life to provide a year's worth of oxygen for one human being. A green roof with an area of 3,000 square feet will be able to provide enough oxygen for approximately 185 people over a year's time.

Green roofing is a widely available and extremely flexible option. The weather conditions and climate will determine the types of plants that will be used on the roof. Typically, the plants used are local so as not to do any harm to the surrounding environment. The stability of the roof is also an important part of the type of green roof to be used. Thickness of the soil and plants is contingent on the strength of the roof. A layer of green roof that is too heavy could lead to a collapse, especially in the case of heavy rains where the green roof absorbs a large percent of the water. Any roof strong enough to support humans is strong enough to support a green roof, and there are many options for green roofs only a few inches thick that use plants with roots that do not need deep soil. Carnegie Mellon has already implemented a successful green roof on Hammerschlag Hall as part of a student project. Therefore, it is not unfeasible to support more green roofs on campus.

While a green roof only provides very small reductions in CO_2 emissions, there are very few tradeoffs involved. One of the major benefits of a green roof is that it utilizes space that is not commonly used on an average building. However, green roofs also prevent other beneficial uses of roofing such as solar panels or installing a wind turbine. Additionally, a green roof would get in the way of other, cheaper options such as skylights or changing the roof's tiles to a color or material that is more heat-absorbent.

Green roofing is an unpredictable option that relies on the climate and the plants chosen to have an impact on the surrounding environment. Heavy storms during the first year might be enough to damage much of the plant life. Meanwhile, the amount of CO_2 reduced by a single plant is not a fixed value, and the health of the plant is important for continued CO_2 mitigation. Quantitative analyses of the value of a green roof are dependent on climate, building, and the type of roof in question. Additionally, the area of the green roof is important, as the insulation value of smaller green roofs is generally less effective per square foot.

Green roofs have many advantages including the environmental benefits of water management and CO_2 reductions through conversion and reduced energy usage, economic benefits from reduced energy usage and a longer-lasting roof, and social benefits of aesthetics and improved morale of those using the building. The vegetation and soil in green roofs have excellent storm water management capacities. Runoff water from rain has a detrimental effect on the land, washing away sediment and eroding the area. This problem is accented during storms when the sewer systems are unable to handle the large amounts of water. During heavy rainfall, flooding is also common. These floods wash away soil and present a heavy burden on the overworked sewer systems. Storm water retention is a logical solution, but it can be expensive and requires constant maintenance. The vegetation on green roofs collects rainwater and serves as excellent storm water and runoff control. Depending on the depth of the soil and the amount of rain, a green roof can absorb anywhere from 15 percent to 90 percent of runoff water. Not only does a green roof absorb water, but the soil and plants remove many of the impurities, meaning that cleaner water is being put back into the surrounding environment. The plants absorb many of the impurities in the water, and the soil acts as a natural filter. A green roof also acts as a protective barrier for the roof underneath, protecting it from weather erosion and UV rays. On average, this doubles the lifetime of the roof underneath.

Due to their multiple benefits, green roofs are good for a very high amount of LEED points. Some points come from the green roof itself while others are based on the integration of the green roof with the rest of the building. Most options are worth a certain number of points based on how efficient they are. Green roofs can be qualified for LEED points in the following areas:

- Storm Water Design (Quantity Control): 1-2 points
  - A green roof absorbs rain and storm water runoff. The amount of points awarded is contingent on the amount of water retained by the green roof.
- Heat Island Effect (Roof): 1-2 points
  - Green roofs reduce the amount of extra building heat by insulting the roof and absorbing extra heat. The water content in the soil and plants keeps the surrounding area cool. The amount of points awarded is contingent on the heat reduction of the roof.
- Water Efficient Landscaping: 1-2 points
  - Extra points are awarded for efficient watering techniques that do not use energy and make use of waste or runoff water. Things such as gravity-powered watering, drip irrigation, and graywater would fall into this category.
- Optimized Energy Performance: 1-8 points
  - This option is based on the amount of energy reduction provided by a green roof based largely on the heating and cooling of a building. Due to the fact that Carnegie Mellon's heating and cooling comes from steam and chilled water, this section is not applicable for existing Carnegie Mellon buildings.
- Recycled Content: 1-2 points
  - Points are awarded for using recycled content to construct the green roof. The amount of points awarded is contingent on the amount and percent of recycled goods used.
- Regional Materials and Resources:1-2 points
  - Points are awarded for using local materials from the surrounding region to construct the green roof. The amount of points awarded is contingent on the amount and percent of local materials used.
- Innovation and Design: 1-2 point
  - Points are awarded for new mitigation options integrated into a green roof.
- Protect or Restore Habitat: 1-2 points
  - Points are awarded for the green roof's contribution to the local habitat. By mimicking the surrounding local fauna, a green roof provides extra habitat that was once space not available to plants or animals.

This report provides only a qualitative analysis of green roofs, as actual savings are based on the climate and physical makeup of the building, the intended area of the green roof, and the choice of plant life. However, the actual mitigation will be very low relative to the other options considered in this chapter. A green roof of three thousand square feet will only mitigate approximately 60 MTCDE. While green roofs offer many benefits, they are best suited for publicity and garnering large amounts of LEED points. It is recommended that a student group be delegated to investigate the feasibility of green roofs on various campus buildings. Installation of a green roof would provide more positive awareness of Carnegie Mellon's participation in environmental advances as well as a large amount of LEED points.

5.4.1.3. Heating, Ventilating, and Air Conditioning

In order to determine the effectiveness of upgrading heating, ventilating, and air conditioning (HVAC) systems in campus buildings, data from the Commercial Buildings Energy Consumption Survey (CBECS) database were used. CBECS is a sample survey that assembles information regarding the stock of commercial buildings in the U.S., their energy-related characteristics, and their energy expenditures and consumption (CBECS 2006). For more information about CBECS and its detailed use in this report, please refer to Chapter 7. In the time period of this study, no significant quantitative findings came out of the analysis; however, the qualitative results are reported here.

It was found that buildings with HVAC upgrades averaged significantly higher energy use per square foot (i.e., energy intensity) than buildings without upgrades. Even after the data were separated by climate zone and building use code, this result persisted. The CBECS data seemed to show that energy intensity in buildings increased with HVAC upgrades. This result is counterintuitive when considering that HVAC upgrades should increase the efficiency of each system. Following these results, it was considered that HVAC upgrades may include installation of air cooling systems, which would certainly raise the amount of energy used per square foot even if the HVAC system of distribution was more efficient.

Data for buildings using energy for air cooling was excluded, and a decrease in average energy intensity of was found in buildings with HVAC upgrades. However, only 41 buildings were contained in the sample of buildings with HVAC upgrades and without energy used for cooling. These buildings were representative of all climate zones and all buildings types and consequently were not a representative sample for buildings at Carnegie Mellon. Thus, the data from this analysis were not applied to this analysis for Carnegie Mellon or other campuses.

5.4.1.4. Lighting

Though about half of the lighting fixtures in non-residential buildings have been outfitted to use newer, more energy efficient bulbs (such as changing T-12 tube lights to smaller T-8 bulbs), the dorm rooms still the use less efficient incandescent bulbs in the desk lamps (Altschul 2008). Unlike the upgrade of tube lighting which requires replacing the existing socket with a smaller one, switching from incandescent bulbs to compact fluorescent lights (CFLs) in desk lamps requires no change to the light fixture.

The price of a CFL is $3 more than an incandescent; however, this investment pays for itself with energy savings in only a few months (0.28 years). CFLs last about ten times as long as incandescent bulbs and thus incur less cost from replacement. Assuming that lights are on for approximately eight hours each day, CFLs will last about three years as opposed to three months for incandescent. Given that every student in on-campus housing has a desk lamp and assuming that all of these desk lamps currently have incandescent bulbs except those in New House, there are 3,500 incandescent light bulbs currently in use in housing. This would provide a maintenance saving of $36,000 per year and $53,000 per year from reduced electricity consumption. The electricity reduction from switching to CFLs would be 465,000 kWh per year, reducing the campus carbon footprint by 181 MTCDE. While this is only 0.5 percent of the total campus footprint, it provides a net savings with a very short payback period. Switching to CFLs is also one of the easiest options to accomplish, requiring only that the university switch from buying incandescent bulbs to CFL, and installing the CFLs when incandescent ones burn out and require replacement. Installing CFLs in dorm rooms is also a good way to expose students the idea of sustainability and energy efficiency.

There are some concerns with disposing of the CFLs, because they contain a small amount of mercury. However, this is less of an issue for the university than it is for individuals, as most of the bulbs will be replaced by maintenance workers instead of individuals. The university already has a policy in place governing the disposal of CFLs (Kviz 2008).

5.4.1.5. Occupancy Sensors

Another promising lighting-related option to reduce energy consumption and its associated greenhouse gas emissions is the installation of occupancy sensors. Although these sensors have already been installed in a few offices around campus, vending machines, and the Intelligent Workplace, large-scale installation in classrooms, hallways, and restrooms has yet to be successfully implemented. The installation of these sensors not only reduces energy demand and its associated operating costs but also earns LEED points for the building. In fact, the high LEED score of the new Gates Center for Computer Science will be aided by its occupancy sensor control of lights (Horgan 2006).

Occupancy sensors can detect combinations of heat energy (passive infrared sensors) and motion (ultrasonic and microsonic) to determine the presence of occupants in a space. When a space is unoccupied, the sensor system will turn the lights off and also may adjust the temperature and ventilation through a central control system. The lights are then turned on when the sensor detects someone entering the area. Although the effectiveness of these sensors is dependent on the installation location, location and height of objects in the space, and the sensitivity setting, most occupancy sensors save money and energy (and its related CO_2 emissions). Table 5.4.1 shows the potential benefits from the use of occupancy sensors.

Table 5.4.1 – Estimated energy savings in various lighting applications with occupancy sensors (NEMA 2001)

Application	Energy Waste (%)	Energy Savings Using 5-Minute Delay (%)	Energy Savings Using 10-Minute Delay (%)
Break Room	39%	29%	17%
Classroom	63%	58%	52%
Conference Room	57%	50%	39%
Private Office	45%	38%	28%
Restroom	68%	60%	47%

In order to determine the potential reductions from the installation of occupancy sensors on the Carnegie Mellon campus, two methods of analysis were used. The first model used CBECS building data to estimate the electricity savings benefits from spaces with auto controls or sensors on lighting. The campus was modeled as a combination of education, lodging, laboratory, and office space categories, as defined by the CBECS survey (please refer to the detailed data in Appendix 5.C). The electricity use per square foot with and without the sensors was compared and multiplied by the appropriate floor space figures determined in Chapter 7. This analysis assumes that 50 percent of the total usable space on campus will be monitored by occupancy sensors. Although this is a rough approximation, it provides a useful estimate for the potential benefits of sensor installation.

When installation costs and the option's ten-year lifetime are taken into account, occupancy sensors appear to be an extremely attractive mitigation strategy according to this first method of analysis. As shown in Table 5.4.2, the payback period would be less than a year and would save approximately 18,000 tons of CO_2 emissions each year. However, since the data set for buildings with lighting controls in the CBECS database is limited for some of the types of space listed above, the results using this method likely represent extreme upper bounds on the cost-effectiveness and CO_2 savings of installing occupancy sensors. Even though data regarding end-use energy consumption for lighting is not explicitly available, the model's prediction of 24 million kWh of electricity saved for lighting technologies is likely a significant overestimate both of probable reductions and also the total percentage electricity share that lighting occupies. Considering that the annual electricity use at Carnegie Mellon totals 90 million kWh, these reductions alone would account for 27 percent of yearly electricity use. These results indicate that the CBECS data are an unreliable indicator of probable electricity reduction benefits from the installation of occupancy sensors.

The second method of analysis used campus building data to determine potential reductions for Carnegie Mellon. Data were found on the average savings percentages for different types of spaces through the installation of occupancy sensors. When coupled with estimates on average electricity consumption for lighting on all spaces on campus, these data allowed for cost and reductions estimates to be performed. The total annual electricity required for lighting is estimated to be 7.8 million kWh with this model. Using occupancy sensors, approximately 3.7 million kWh of electricity would be reduced each year. The results are shown in Table 5.4.2 alongside of the outputs from the first model.

Table 5.4.2 – Estimated cost and emissions savings from occupancy sensor installation on the Carnegie Mellon campus

	CBECS Data	Carnegie Mellon Building Data
Annual Electricity Savings (kWh/year)	24 million	4 million
Percentage of Campus Electricity Saved (%)	27%	4%
Incremental Levelized Annual Cost ($ saved/year)	$2.0 million	$0.2 million
Internal Rate of Return (%)	356%	53%
Carbon Savings (tons CO_2/year)	18,000	3,000
Cost-Effectiveness ($ saved/ton CO_2 reduced)	$110	$85

5.4.1.6. Window Replacement

One way to make significant reductions in energy consumption and in the resulting greenhouse gas emissions on campus is to replace aging windows with newer and more efficient ones. New windows reduce heat transfer between the inside of a building and its surrounding environment. This insulation provides both energy and money savings due to reductions in the energy needed for heating, cooling, and lighting the buildings.

There are several important parameters that determine the magnitudes of cost and energy savings that result from window replacements. Age is a significant factor, since older windows are more likely to be inefficient than newer ones. Current ENERGY STAR labeled windows are twice as efficient as those produced ten years ago (DOE 2005). Second, climate control characteristics of buildings play a large role in determining how effective window replacements can be. On the Carnegie Mellon campus, all buildings have some form of heating for the winter, though not all buildings are equipped with air conditioning for the summer months. The energy intensity of air conditioned buildings suggests that locations with both heating and cooling will produce larger cost and emissions savings. Additionally, buildings with large exterior window surface areas have a greater capacity for heat loss to the external environment. Thus, older buildings with many sizeable windows and larger demands for steam and chilled water are the best candidates for window replacements.

In addition to building characteristics, the cost to replace windows greatly influences whether replacements are an economically effective way of reducing energy use. The lower the capital and installation costs for new windows, the more likely it will be for project sponsors to have shorter payback periods and greater total profit from their investment.

In order to provide an illustration of how to assess the cost-effectiveness of replacing windows for campus buildings, two case studies were developed. Although these case studies are specific to the Carnegie Mellon campus, the basic research method used in this analysis is applicable to buildings from any institution in all climate zones.

These case studies estimate the impact of replacing the older windows in the College of Fine Arts building and the Morewood Gardens E-Tower with newer, more efficient windows. These two particular locations were chosen due to their different use and building characteristics. The College of Fine Arts building was completed in 1916. The space inside of the building is used for a range of purposes including small performance and recital halls, classrooms, practice rooms, studios, and offices for faculty and staff in the College of Fine Arts. Constructed with a significant amount of terra cotta, granite, and brick, the CFA building is equipped with both heating and air conditioning. These characteristics mean that the building has extensive steam and chilled water requirements. In contrast, the Morewood Gardens E-Tower is a student dormitory that was constructed in 1961. This mostly brick building is not equipped with a central air conditioning system and instead uses just a few window-mounted units, which means that the building uses no chilled water.

This analysis assumes that the existing windows in these buildings are ordinary, single-paned windows. Used as a coefficient to describe heat transfer characteristics of the window, the U-value for older windows is assumed to be 1.1. Such windows are assumed to be replaced with newer, double-paned windows with an inert gas fill, which commonly have U-values between 0.25 and 0.33. A U-value of 0.29 was assumed for these case studies. Additionally, the calculations assume that the cost per square foot of new window is approximately $80. This value was determined by using the 2001 cost of a three-by-five foot window (EPP/SDS/Heinz 2001) and adjusting for price changes and inflation since this time (DOL 2008).

As suggested above, the energy savings from window replacements is principally derived from the heat transfer reduction from lower U-values. The reduction in heat transfer can be found through the equation:

$$q = UA(T_1 - T_2) \tag{5.4.1}$$

where q is the heat transfer, U is the U-value of the windows, A is the window area, and T_1 and T_2 are the inside and outside temperatures. Since all other quantities on the right-hand side of Equation 1 remain fixed, decreasing the U-value is the only way to achieve reductions in the heat transfer between the building and its surroundings. Using the U-values listed above, the heat transfer through the windows is reduced by 74 percent through the installation of new windows.

The window analysis also assumes the following:

- New windows have a lifetime of 28 years.
- 60 percent of heat transfer occurs through windows.
- All steam in the buildings is used for heating.
- All chilled water in CFA is used for cooling.
- CFA has 21,600 square feet of window space, while E-Tower has 10,500 square feet.

The results for the case study for the College of Fine Arts building suggests that energy savings can come both through the reduction in steam and chilled water use. These associated savings have associated cost and CO_2 reductions as well. Annual values for these savings are shown in Table 5.4.3.

Table 5.4.3 – Estimated annual energy, cost, and CO_2 reductions for window replacements in CFA

	Heating (MLbs of steam/year)	**Chilled Water (MMBTU/year)**	**Total**
Baseline	10,700	3,500	-
Energy Reduction	4,700	1,600	-
Energy Savings (USD/year)	$63,500	$10,900	$74,400
CO_2 Reduction (tons/year)	500	350	850

While the cost savings in Table 5.4.3 represent annual values for energy, there are other associated costs with window replacements that make this option less cost effective. The estimated capital costs associated with purchasing and installing the windows in CFA is approximately $1.7 million. While the maintenance costs for new windows are negligible, the incremental levelized annual cost of the option is $67,000 during the 28-year lifetime of the option. This indicates that the payback period for window replacements in CFA would be greater than the lifetime of the option. Thus, the cost-effectiveness of replacing the windows in CFA is approximately $81 per ton of CO_2.

In the case of the Morewood Gardens E-Tower, the analysis indicates that annual cost and emissions savings would not be as large as for CFA, as shown in Table 5.4.4. Although the capital costs of replacing windows in E-Tower are less than half of that for CFA, the cost-effectiveness is lower (about $201 per ton of CO_2). This effect is caused by the fact that E-Tower does not have any installed air conditioning, which reinforces the fact that buildings with both steam and chilled water needs are the best candidates for window replacements.

Table 5.4.4 – Estimated annual energy, cost, and CO_2 reductions for window replacements in Morewood Gardens E-Tower

	Heating (MLbs of steam/year)	Chilled Water (MMBTU/year)	Total
Baseline	4,600	0	-
Energy Reduction	2,000	0	-
Energy Savings (USD/year)	$27,000	0	$27,000
CO_2 Reduction (tons/year)	210	0	210

Again, it is important to bear in mind that all of these values are estimations. Approximations regarding the important variables discussed in this section meant that values such as the capital cost of windows and the percentage of energy savings (which is a function of the U-values of the windows) may not correspond to the actual windows in CFA. In order to investigate the impact that alterations in these values can have on the analysis, these two values were varied in a sensitivity analysis to account for the uncertainty associated with the representative window values. Figure 5.4.1 illustrates how the incremental levelized annual cost of window replacements in CFA decrease as capital costs decrease and the percentage of energy reduction increases. As with the analysis above, steam and chilled water costs are assumed to be constant.

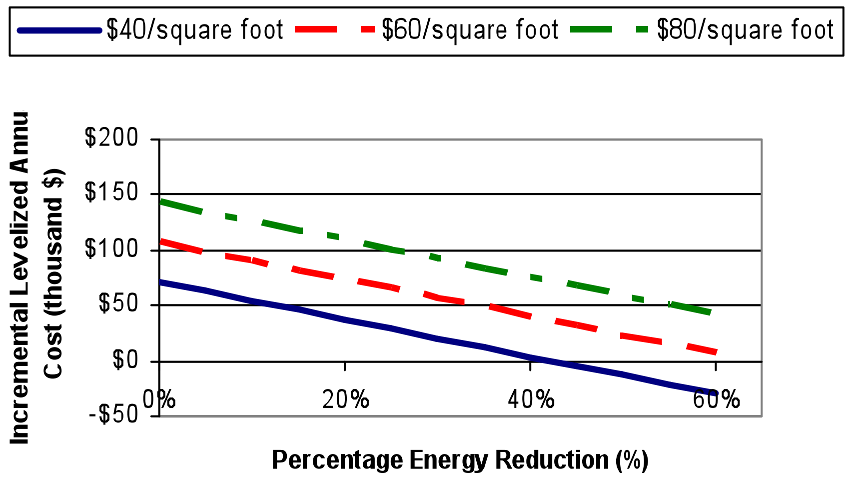


Figure 5.4.1 – Sensitivity analysis for CFA window replacement costs

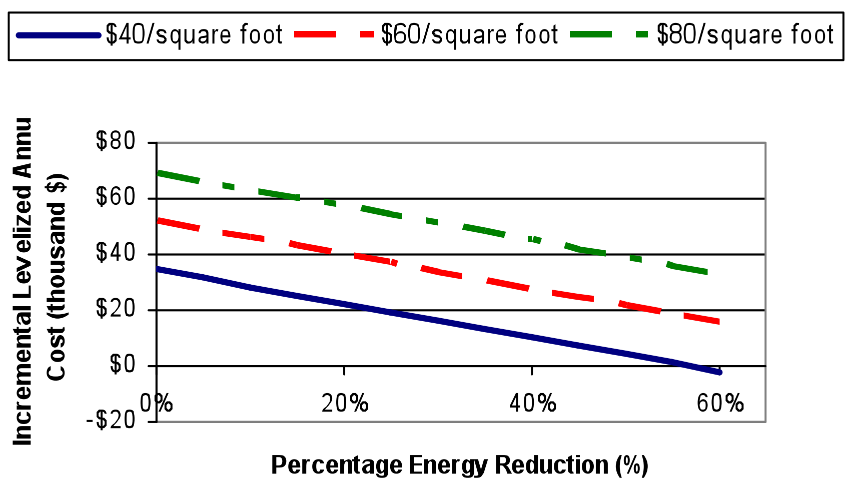


Figure 5.4.2 – Sensitivity analysis for E-Tower window replacement costs

The cost sensitivity analysis for both buildings indicates that the parameters of energy reduction percentage and capital costs of windows affect how cost effective replacing windows can be. Since the current estimated percentage energy reduction for new windows is approximately 45 percent, the analysis suggests that the option would save money and pay for itself during its lifetime if the upfront window costs are approximately $40 per square foot for CFA and $35 for E-Tower. Thus, the capital and installation costs for windows are an important variable for which a more detailed investigation should assess before deciding whether to implement this option. The decision tools provided in this section could then be applied easily to determine the cost-effectiveness of window replacements.

In order to get a rough, first-order approximation of the mitigation potential and projected costs of replacing all older windows on campus, the analysis above was repeated for the entire Carnegie Mellon campus. All assumptions listed in the section above were also used for this calculation. Since many of the windows across campus are much newer than the ones in CFA or E-Tower, the efficiency of these windows is likely much higher. Thus, this aspect of the analysis represents an upper bound on the potential CO_2 reductions and cost associated with window replacements.

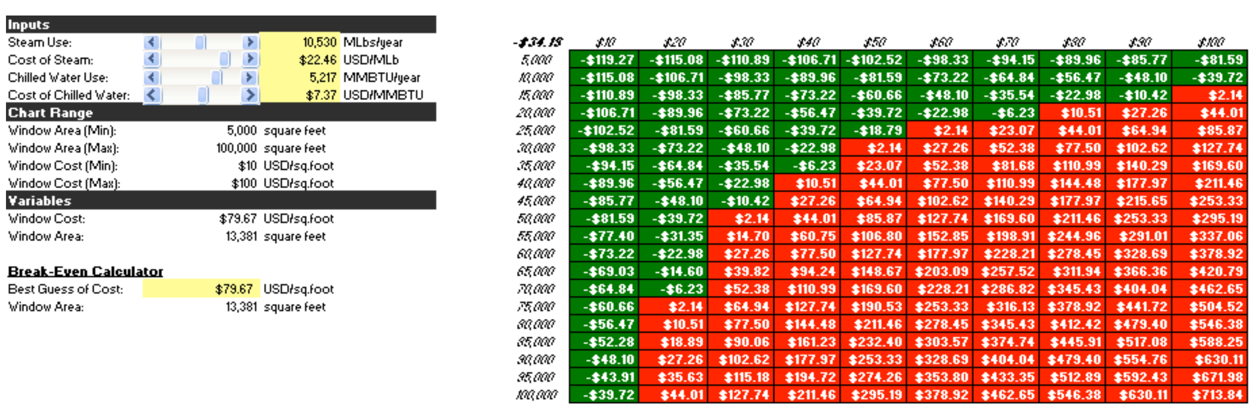
Table 5.4.5 – Estimated annual energy, cost, and CO_2 reductions for window replacements across the entire Carnegie Mellon campus

	Heating (MLbs of steam/year)	Chilled Water (MMBTU/year)	Total
Baseline	332,000	190,000	-
Energy Reduction	150,000	84,000	-
Energy Savings (USD/year)	\$2 million	\$0.6 million	\$2.6 million
CO_2 Reduction (tons/year)	15,000	18,000	33,000

Once again, the costs associated with the implementation of this option are extremely large. Replacing all of the windows across campus would have an upfront cost of nearly \$74 million. While the annual carbon saving is large, the cost-effectiveness of these reductions (\$106 per ton of CO_2) is still higher than purchasing carbon offsets or RECs.

The analyses in the previous sections suggest that variables like window cost and energy use characteristics in buildings greatly impact whether it would be cost effective to install new windows in a building. Furthermore, these characteristics also affect potential CO_2 reductions for these buildings. Since there is a modest degree of uncertainty in these values, it is important to be able to know how fluctuations in these numbers interact with other key variables to change the results of decision-making.

In order to show how these values change whether window replacements are cost effective, an interactive decision tool was developed. This spreadsheet allows users to update values for steam use, cost of steam, chilled water use, and cost of chilled water and to decide the viability of window replacements based on both window cost and area. Such a tool would be well-suited for a web-based applet that could allow users to input these values and to easily see how results change under different scenarios. A screenshot of this application is shown in Figure 5.4.3.



Inputs		
Steam Use:	10,530	MLbs/year
Cost of Steam:	$22.46	USD/MLb
Chilled Water Use:	5,217	MMBTU/year
Cost of Chilled Water:	$7.37	USD/MMBTU
Chart Range		
Window Area (Min):	5,000	square feet
Window Area (Max):	100,000	square feet
Window Cost (Min):	$10	USD/sq.foot
Window Cost (Max):	$100	USD/sq.foot
Variables		
Window Cost:	$79.67	USD/sq.foot
Window Area:	13,381	square feet
Break-Even Calculator		
Best Guess of Cost:	$79.67	USD/sq.foot
Window Area:	13,381	square feet

-$34.18	$10	$20	$30	$40	$50	$60	$70	$80	$90	$100
5,000	-$119.27	-$115.08	-$110.89	-$106.71	-$102.52	-$98.33	-$94.15	-$89.96	-$85.77	-$81.59
10,000	-$115.08	-$106.71	-$98.33	-$89.96	-$81.59	-$73.22	-$64.84	-$56.47	-$48.10	-$39.72
15,000	-$110.89	-$98.33	-$85.77	-$73.22	-$60.66	-$48.10	-$35.54	-$22.98	-$10.42	$2.14
20,000	-$106.71	-$89.96	-$73.22	-$56.47	-$39.72	-$22.98	-$6.23	$10.51	$27.26	$44.01
25,000	-$102.52	-$81.59	-$60.66	-$39.72	-$18.79	$2.14	$23.07	$44.01	$64.94	$85.87
30,000	-$98.33	-$73.22	-$48.10	-$22.98	$2.14	$27.26	$52.38	$77.50	$102.62	$127.74
35,000	-$94.15	-$64.84	-$35.54	-$6.23	$23.07	$52.38	$81.68	$110.99	$140.29	$169.60
40,000	-$89.96	-$56.47	-$22.98	$10.51	$44.01	$77.50	$110.99	$144.48	$177.97	$211.46
45,000	-$85.77	-$48.10	-$10.42	$27.26	$64.94	$102.62	$140.29	$177.97	$215.65	$253.33
50,000	-$81.59	-$39.72	$2.14	$44.01	$85.87	$127.74	$169.60	$211.46	$253.33	$295.19
55,000	-$77.40	-$31.35	$14.70	$60.75	$106.80	$152.85	$198.91	$244.96	$291.01	$337.06
60,000	-$73.22	-$22.98	$27.26	$77.50	$127.74	$177.97	$228.21	$278.45	$328.69	$378.92
65,000	-$69.03	-$14.60	$39.82	$94.24	$148.67	$203.09	$257.52	$311.94	$366.36	$420.79
70,000	-$64.84	-$6.23	$52.38	$110.99	$169.60	$228.21	$286.82	$345.43	$404.04	$462.65
75,000	-$60.66	$2.14	$64.94	$127.74	$190.53	$253.33	$316.13	$378.92	$441.72	$504.52
80,000	-$56.47	$10.51	$77.50	$144.48	$211.46	$278.45	$345.43	$412.42	$479.40	$546.38
85,000	-$52.28	$18.89	$90.06	$161.23	$232.40	$303.57	$374.74	$445.91	$517.08	$588.25
90,000	-$48.10	$27.26	$102.62	$177.97	$253.33	$328.69	$404.04	$479.40	$554.76	$630.11
95,000	-$43.91	$35.63	$115.18	$194.72	$274.26	$353.80	$433.35	$512.89	$592.43	$671.98
100,000	-$39.72	$44.01	$127.74	$211.46	$295.19	$378.92	$462.65	$546.38	$630.11	$713.84

Figure 5.4.3 – Screenshot of window replacement analysis tool

Although the analyses in the previous sections are specific to the Carnegie Mellon campus, the general method of analysis and this decision tool can be applied to any type of building anywhere in the world. The inputs of the application are designed to facilitate use by a wide range of individuals, including facilities management engineers, home owners, and members of school administration. It does not assume any specialized knowledge, allows users to input values in commonly used units, has optional customization, and provides numerical and visual feedback.

5.4.2. Biofuels

Over the past year biofuels have been getting a lot of bad publicity. Less than half of Carnegie Melon students surveyed consider biofuels to be a "green energy source." In two papers published in the March 2008 issue of the journal *Science* (Fargione 2008; Searchinger 2008), new economic models of biofuels' pressures on global agricultural demand showed that ethanol would create a net increase of greenhouse gas emissions compared to gasoline. The model predicted destruction of forests and grasslands that would release more greenhouse gasses than the plants replacing them would sequester. Last year "tortilla riots" in Mexico were blamed in part on ethanol production in the U.S. Responding to the food crisis in April, the United Nations World Food Program asked for a five-year moratorium on all biofuels.

The Carnegie Mellon community is right to be skeptical of biofuels. Clearly not all biofuels are created equal. Every batch of a given biofuel is the product of a different amount of ecological benefit or harm. Fortunately, most biofuels in Pittsburgh do in fact decrease greenhouse gas emissions when compared to petroleum and come from different feedstocks about which researchers are worried.

5.4.2.1. Pittsburgh Biofuel Suppliers

There are at least two suppliers of biofuels operating in the Pittsburgh area now and two more to come on-line in the near future. Currently, the GetGo gas station on Baum Boulevard in Shadyside offers a 20 percent biodiesel 80 percent diesel mix (B20). The biodiesel is supplied by United Oil located on the North Side. United Oil will also be supplying the Steel City Biofuels' pump in the East End with 100 percent biodiesel (B100) in the summer and mixtures with less biodiesel during colder months. Steel City Biofuels is a nonprofit and their business plan calls for pegging the price of their biodiesel at 15¢ less than the regional price for diesel. Fossil Free Fuel in Braddock, Pennsylvania plans to offer Straight Vegetable Oil (SVO) for a flat rate of $2.20. Vegetable oil can be used in diesel engines with modifications from Fossil Free Fuel that cost between $1,500 and $2,500.

Table 5.4.6 – Pittsburgh liquid transportation fuel supplier comparison

Supplier	Fuel	Price*	Energy Equivalent Price	Future Price Change	Operation Date	Location
		($/gal.)	**($/gal. gas eq.)**	**(Expected)**	**(Expected)**	**(Neighborhood or City)**
GetGo	Gasoline	$3.29	$3.29	Increase	Operational	Shadyside
GetGo	Diesel	$4.20	$3.48	Increase	Operational	Carnegie
GetGo	B20	$4.19	$3.52	Increase	Operational	Shadyside
Steel City Biofuels	B100	$4.04	$3.61	15¢ less diesel peg	Summer 2008	East End
Fossil Free Fuel	SVO	$2.20	$2.05	No change	Summer 2008	Braddock
Sheetz, Inc.	E85	$2.99	$4.23	Increase	Operational	Monroeville

* All prices quoted from March 23, 2008

5.4.2.2. Carbon Intensity of Pittsburgh Biofuels

Emissions for fuels can be measured in two ways. The most common way is only to measure the emissions that come out of the tailpipe of a vehicle due to fuel combustion. A more comprehensive measure is to estimate all of the emissions associated with the life cycle production of the fuel up to and including emissions from combustion. It is essential that one uses an estimate for life cycle emissions when comparing biofuels, because the ecological cost or benefit will be found in the life cycle and not during combustion alone. When proponents of biofuels claim that biofuels are carbon-neutral, they are indicating that, in the life cycle of biofuels, the plants that are grown to make the fuels sequester at least as much carbon as is combusted. Similarly, when opponents of biofuels said in *Science* that biofuels increase emissions when compared to gasoline, they are claiming that the direct or indirect clearing of land for biofuels creates a net life cycle increase of carbon emissions compared to gasoline.

This analysis assumes that emissions per unit of energy are the same in petroleum and biofuels. The assumption may be erroneous. The emissions factors are likely a little bit better for biodiesel, vegetable oil and ethanol than for gasoline and diesel. However, there is not enough reputable available research on tailpipe emissions for these fuels.

An additional three kilograms carbon-dioxide equivalent (kgCDE) for gasoline and diesel come from extraction, transportation, refining and combustion. These values were found using the national average fuel mix in the GREET 1.8b model from the Department of Energy's Argonne National Laboratory. A slightly higher estimate of about 4 kgCDE was found using the Economic Input-Output Life Cycle Assessment model developed at the Carnegie Mellon Green Design Institute.

Table 5.4.7 – Pittsburgh liquid transpiration fuels life cycle emissions

	Energy content (1,000 BTU/gal)	Tailpipe emissions* (kgCDE/gal gas eq.)	Life cycle Emissions (kgCDE/gal gas eq.)
Gasoline	116	8	11
Diesel	140	8	11
Biodiesel (B100)	130	8	9
Vegetable Oil	130	8	8
E85	82	8	10-16

* Assumes equal emissions per BTU

United Oil on the North Side supplies GetGo and will supply Steel City Biofuels with biodiesel. The fuel feedstock changes from batch to batch, but it mostly comes from waste animal fats from regional slaughterhouses, and the remainder is composed of regional vegetable oils (mostly soybeans). Steel City Biofuels, in partnership with United Oil, is in the process of securing contracts for waste vegetable oil with as many area restaurants as possible. With the future of the fuel mix in mind, it was assumed the fuel mix was composed of waste animal fasts or waste vegetable oil. Neither of these feedstocks received a carbon credit for carbon sequestered nor land use change or agricultural emissions as virgin vegetable oil would. The feedstocks could receive a carbon credit if their use by biofuels producers can be shown to be diverted from an activity with greater carbon emissions like going into a land fill without methane capture. No data specific to United Oil was obtained for emissions from processing, so the GREET national average for biofuel processing was used instead.

The straight vegetable oil (SVO) distributed by Fossil Free Fuel will also be collected from restaurant waste vegetable oil. Again, no carbon reduction or increase was associated with the waste oil. Many including will argue that the waste oil has an associated carbon credit because the plants grown to make the virgin oil absorbed carbon-dioxide from the atmosphere. This is a difficult issue of carbon counting that has not been resolved in biofuels research. Owing to the fact that the virgin oil was purchased for cooking, the life cycle of the virgin oil was not counted, which resulted in a conservative estimate.

This research was unable to obtain the specific feedstock mix for ethanol (E85) at Sheetz, Inc. in Monroeville. However, it is reasonable to assume that the primary feedstock is corn. The emissions range therefore was found using the GREET model with and without land use change emissions proposed by Searchinger (Searchinger 2008). The range includes increased emissions compared to gasoline and therefore it is uncertain if the ethanol at Sheetz decreases life cycle emissions compared to gasoline.

Biofuels in the next five years may have significantly improved life cycle emissions as more sustainable feedstocks enter the mix. GTECH Strategies, a local non-profit, is in the experimental phase of a plan for brownfield and vacant lots in Pittsburgh involving phytoremediation followed by biofuel crop production. Growing brassicas like canola and sunflower, GTECH hopes to first remove toxins from the soil and subsequent seasons use the crops to build the soil and produce oil for biofuels. The next generation of ethanol production brings enzymatic digestion so that any thing containing cellulose can be used to make ethanol. Switchgrass, a native soil building perennial also grown by GTECH, along with anything from to paper pulp sewage could be a feedstock. These feedstocks would neither displace food-crops nor require large energy inputs as corn does.

5.4.2.3. Biofuels at Carnegie Mellon

According to the "Environmental Indicators for Carnegie Mellon University: 2004 Baseline Assessment" (Tipton and Dzombak 2004), Carnegie Mellon has 50 gasoline powered vehicles with an average fuel economy of 21 miles per gallon driving an average of 75,000 miles a year. Using the fuel prices and mitigation potentials above, the annual cost and cost-effectiveness were calculated. Shown in Table 5.4.8 are the expected annual emissions and cost-effectiveness for each fuel for a fleet of 50 driving at the same rate as above. For diesel, biodiesel, and vegetable oil, this would require buying diesel vehicles or instituting a purchasing policy such that as gasoline vehicles are retired they are replaced with diesel vehicles. It was further assumed that similar vehicles could be purchased with diesel engines at a similar cost to gasoline vehicles.

The cost-effectiveness was calculated using a five-year life of the vehicle. This assumption was only relevant for vegetable oil, because vegetable oil is the only fuel that requires vehicle modification. Vegetable oil vehicles also require fuel filters to be replaced more frequently than for diesel or gasoline vehicles. Biodiesel vehicles also need to have their fuel filters replaced more frequently; however, the improved lubricity of the fuel decreases drive train wear and offsets the cost of additional fuel filters.

One component of the carbon savings from diesel, biodiesel, and vegetable oil is the efficiency of diesel engines. The analysis used a 50 percent efficiency increase from gasoline vehicles. This was obtained by comparing the EPA fuel economy rating of current model year vehicles available with both gasoline and diesel engines.

Table 5.4.8 – Pittsburgh transportation fuels for Carnegie Mellon fleet of 50

	Predicted Fuel Use	Annual Cost	Expected Annual Emissions	Cost-Effectiveness*
	(1,000 gal/year)	(1,000$/year)	(MTCDE/year)	($/MTCDE)
Gasoline	180	$590	2000	-
Diesel	120	$500	1500	-$180
*B100 Mix***	130	$430	800	-$120
B20	138	$430	1100	-$180
Vegetable Oil	130	$360	1000	-$300
Ethanol	250	$760	1800 - 2200	Emissions range includes increase

* Negative values indicate savings
** Using B100 in warm months, B50 below 40°F, and B20 below 20°F

5.4.2.4. Recommendations for Biofuels

- ***Use Biodiesel***

Biodiesel could reduce the most MTCDE of any option and has advantages over the others. While the efficiency of switching to diesel vehicles would make using diesel fuel more cost effective than biodiesel, diesel has greater non-carbon emissions, including a higher sulfur content and other noxious fumes. Biodiesel, because of its natural lubricity, performs better than diesel. Vegetable oil is the most cost effective option, but there are few studies on its effect on vehicles over many miles. The vehicle modifications made by Fossil Free Fuel are only to heat the oil so that it dose not gel. The company does not change the burn rate of engines to account for the chemical difference of vegetable oil. An expert elicitation confirmed that this may contribute to shorter engine life.

5.5. Behavioral Change Options

5.5.1. Campus-Wide Policy Options

5.5.1.1. Reducing Air Travel

Accounting for about 40 percent of Carnegie Mellon's carbon footprint (as discussed in Chapter 2), air travel appears to many on campus to be the least flexible carbon contributor. "I cannot just forgo field research trips," said a professor, which illustrates how necessary air travel is. However, after basic preliminary analysis, it is clear that there are ways to make inroads into one of the largest contributors to the carbon footprint and save money while doing so.

- ***Don't fly; webcast***

With the proper incentives and streamlined availability, faculty may choose to appear at conferences or conduct meetings via webcast. To incentivize adoption, faculty could be paid a quarter of the typical value of the plane ticket that they would have otherwise purchased to avoid flying. Money saved from reduced flights could be invested in webcasting technology, which has obvious spillover benefits. If only five percent of flights were grounded, Carnegie Mellon's total carbon footprint would drop by more than 1.5 percent.

- ***Carnegie Mellon service to D.C.***

The most frequent destination for Carnegie Mellon faculty flights is Washington, D.C. The 2,300 flights to D.C. cost the university $522,000 in 2007. The university could instead charter a luxury bus making regular stops three times a week during the school year, cutting D.C. air emissions by three quarters and saving $385,000. Single occupant car trips with low fuel economy (21 miles per gallon) increase emissions compared to flying. However, car trips with two or more decrease emissions even with low fuel economy. Taking a train is better than driving by oneself but has similar emissions to flying.

Table 5.5.1 – Pittsburgh to Washington, D.C.: alternatives to air travel

	Air	Car	Carpool	Train	Bus
Miles per Equivalent Gallon per Passenger	N/A	21	21	N/A	148
Cost per Passenger	$190	$40	$20	$50	$50
Total Cost ($1,000/year)	$500	$90	$45	$115	$115
Total Emissions (MTCDE/year)	200	310	155	220	45

- ***Incentivize fight restraint***

Carnegie Mellon spent more than $7 million last year for faculty air travel. One way to reduce carbon emissions would be to pay faculty not to fly. If the university gave faculty a quarter of the expected savings from not flying, it would save money and increase faculty earnings modestly. If flights were reduced by five percent in this way, it would reduce the total campus footprint by two percent and save the university $250,000. However, if the university chooses to reduce its carbon footprint by purchasing carbon offers or renewable energy credits, Carnegie Mellon should be willing to give the same amount (about $20) for every MTCDE reduced plus the expected savings from not flying to faculty members.

- ***Air awareness***

Perhaps the most effective measure for reducing the campus footprint from air travel will be to raise awareness of the proportionally large emissions associated with flying. The survey showed that faculty members are willing to pay the most to reduce Carnegie Mellon's carbon footprint. This high willingness to pay may translate into voluntarily not flying if the campus community is made aware of the high proportion of the carbon footprint that comes from flying.

5.5.1.2. Engaging Courses for Reductions

There are many environmental courses that can be engaged to assist the campus emission reductions effort. Here are but two examples:

- ***Turn off the lights!***

Design for Social Change (51-274), a course offered to all sophomore students in the Design Department could be charged with designing and placing "turn off the lights" signs above light-switches throughout campus every one or two years. Replacing old signs with new ones could become a campus wide event that raises awareness about saving energy and climate change.

- ***Programming for carpooling***

Project-based database classes are uniquely poised to assist the campus community adopt low-carbon behavior. One course could create an applet to allow campus commuters to find commuters near them to carpool. It is estimated that faculty and staff that live more than eight miles away make up less than 30 percent of faculty and staff commuters and account for more than half of that groups carbon emissions from commuting and save drivers money. A successful carpooling program could reduce the campus carbon footprint by about one percent and generate up to four LEED points.

Table 5.5.2 – Faculty carpooling data

	> 4 miles	> 8 miles	Total
Average Annual GHGs per Person (MTCDE)	1.5	2	1
Percent of All Commuters GHGs (MTCDE)	78%	54%	100%
Percent Drivers (%)	56%	28%	100%
Number of People Living Area Code with n > 1	2,870	1,430	5,100
Reduction Potential (MTCDE)	2,108	1,450	-
Potential Savings (100,000 $)	9	4.5	-

Up to four LEED points are awarded for reductions in car travel from carpooling, public transportation, or any form of alternative transportation. This reduction is measured by the percent of conventional commuting trips. A vehicle going to and from the place of work is considered one conventional commuting trip. The ability to demonstrate an actual reduction requires a certain amount of record-keeping. It is possible to measure this reduction through surveys or the count of parking and parking permit information. By encouraging carpooling, the number of vehicles on a conventional commuting trip will be reduced. LEED points are awarded in the following increments:

- Demonstrate a 10 percent reduction in conventional commuting trips – 1 point
- Demonstrate a 25 percent reduction in conventional commuting trips – 2 points
- Demonstrate a 50 percent reduction in conventional commuting trips – 3 points
- Demonstrate a 75 percent reduction in conventional commuting trips – 4 points

5.5.2. Individual Behavioral Options

Most published carbon mitigation strategies have focused on the role of governments, industries, and other institutions to develop low-carbon pathways and to reduce global emissions (James 2007; Pacala 2004). Bearing in mind the success of the legal and economic framework that helped to reduce acid rain through the 1990 Clean Air Act in the U.S., some analysts view methods like cap-and-trade schemes as ideal solutions for fixing problems associated with the management of collective goods (i.e., to prevent the so-called "Tragedy of the Commons") while also creating value for investors (Specter 2008).

However, despite the importance and need for supportive governmental policies and the financial backing of large institutions, there is a great capacity for individuals to make efforts to lessen the carbon intensity of their own lives. Since climate change is fundamentally a problem of lifestyle, finding a resolution to the challenges posed by it will require profound changes in the way that individuals live from day to day. To wait until institutional lag has been overcome or until new mitigation technologies have been deployed would suggest that individuals are not yet serious about changing. Thus, beginning mitigation efforts at the individual level sets an example for others to follow. If enough people emulate each other in a behavior change chain reaction, avenues for environmentally benign product and services may expand, while increased awareness is fostered and new mores are established within a culture.

Another impetus for encouraging individual efforts to assuage their personal carbon intensity is the large magnitude of the carbon footprint of average Americans per capita. At present, the average U.S. footprint is twice as large its British counterparts and nearly twenty times larger than the global average (Specter 2008). Although institutional and governmental policies to an extent affect choices that contribute to individual emissions, the large magnitude of the average U.S. personal footprint points toward the larger need for a certain amount of accountability at the individual level to make lifestyle changes that lower their greenhouse gas output to the extent to which such actions are possible.

Finally, in addition to reducing emissions, many of these individual mitigation options also save money. Energy saving through adjusting thermostat settings and tuning up vehicles translates into lower utility and fuel costs, which is another motivation for individuals to adopt practices to reduce the carbon intensity of their daily lives.

The following list is intended to provide a pragmatic array of options that individuals can employ in their daily lives without expending a great deal of time, effort, or money. In fact, many of these suggestions not only reduce emissions but also save money and improve one's quality of life. The emissions associated with each option represent the best available estimate of greenhouse gas abatement potential from the option if deployed on the entire Carnegie Mellon campus.

- ***Reduce meat consumption*** [4,700 MTCDE per year]

The ecological footprint of meat consumption is substantial. In addition to global livestock grazing and feed production using 30 percent of the planet's land surface, livestock are responsible for 18 percent of global warming effect (New York Times 2006). It takes approximately one gallon of fossil fuel and 2,500 gallons of water to produce one pound of grain-fed beef. Furthermore, enteric fermentation from a single cow per day can produce 130 gallons of methane, which is 20 times more potent of a greenhouse gas than carbon dioxide (Slater 2008). Taking into account average beef consumption (DOA 2006) and the average amount of carbon dioxide equivalent emitted for every pound of beef produced (Ogino 2007), Carnegie Mellon could prevent 3,900 MTCDE per year from being emitted if half of the campus decreased its beef consumption by 50 percent. If a quarter of the student body decreased its consumption of pork, goat/sheep meat, and chicken by 50 percent, 780 MTCDE more could be saved each year.

- ***Adjust thermostat settings*** [2,700 MTCDE per year]

Since half of the energy used in homes is used for heating and cooling, a typical U.S. household can save approximately one MTCDE per year by moving thermostat down 2° in winter and up 2° in summer. Furthermore, technologies like programmable thermostats can reduce energy consumption while saving $100 per year on the energy bill (Climatecrisis.net 2006). If half of all Carnegie Mellon students living off-campus adjusted their thermostats by ±2° as was mentioned above, approximately 2,700 MTCDE per year would be saved.

- ***Avoid heavily packaged products*** [1,400 MTCDE per year]

Cutting down garbage by ten percent can save approximately 1,200 pounds of carbon dioxide equivalent per year. If a quarter of Carnegie Mellon students decreased their waste by ten percent, 1,400 MTCDE would be avoided each year. However, it is important to note that not all packaging is bad for the environment. In addition to some packaging being vital to ensuring the freshness of produce, food packaging is not nearly as large of a problem as wasted food that rots and releases methane in landfills (Goodall 2007).

- ***Recycle*** [1,400 MTCDE per year]

If households recycled half of their domestic waste, 2,400 pounds of CO_2 emissions can be saved yearly (Climatecrisis.net). Recycling is particularly important for products like those made from aluminum, which helps to save a considerable amount of energy. Assuming that one-fourth of the Carnegie Mellon student body can recycle one-fourth of their waste, 1,400 MTCDE are prevented each year.

- ***Buy organic foods*** [1,100 MTCDE per year]

Most organic foods avoid the use of conventional pesticides and fertilizers during their growth. In addition to the other ecological benefits of organic farms (sustaining diverse ecosystems, avoiding harmful effects to local environments, and reducing waste), organic farms have lower carbon footprints than conventional farming techniques due to increased energy efficiency and by avoiding the use of chemical-rich fertilizers that contribute to climate change. If one-fourth of the student body at Carnegie Mellon choose to eat organic foods 50 percent of the time, 1,100 MTCDE are avoided each year.

- ***Conserve water*** [900 MTCDE per year]

Conserving water by installing a low-flow showerhead can save an individual $100 annually on utility bills while reducing carbon dioxide emissions by 580 pounds per year (Jones 2007). If ten percent of all Carnegie Mellon students installed low-flow showerheads, approximately 260 MTCDE would be saved each year. Another effective way to lower energy bills and to reduce greenhouse gas emissions is to wash clothes in warm or cold water. Assuming that 25 percent of Carnegie Mellon students could make this switch, 570 MTCDE can be prevented from entering the atmosphere. Furthermore, using the energy-saving mode on the dishwasher and only operating it when full can save 100 pounds of CO_2 each year (Climatecrisis.net 2006). If 25 percent of students living in off-campus housing would perform this action, 70 MTCDE could be saved each year.

- ***Replace light bulbs*** [820 MTCDE per year]

Since home lighting consumes approximately 25 percent of total domestic energy use (Jones 2007), it is important to replace older, incandescent bulbs with less energy intensive lighting like CFLs, as suggested in Section 7.5.1.4. CFLs use 75 percent less energy and last 10 times as long as incandescents (New York Times 2007b). According to the U.S. Environmental Protection Agency, if every U.S. household replaced their five most frequently used conventional bulbs with ENERGY STAR bulbs, it would prevent the greenhouse gas equivalent of nearly ten million cars. Since switching to a CFL saves about 300 pounds of carbon dioxide from being emitted each year, if all Carnegie Mellon students living in off-campus housing (~6,000) changed just one light bulb, it would save 820 MTCDE each year.

- ***Keep car tuned up*** [680 MTCDE per year]

Small, preventative maintenance to one's vehicle can lead to increased savings and better performance. For instance, properly inflating one's tires can improve the vehicle's gas mileage by at least three percent. Nearly one billion pounds of CO_2 are saved if one percent of automobile owners keep their vehicles properly maintained. If a car can get only three miles per gallon more, 3,000 pounds of CO_2 annually can be kept from entering the atmosphere from that car alone (Climatecrisis.net 2006). For the Carnegie Mellon campus, assuming that five percent of students perform maintenance that leads to fuel efficiency increases of three miles per gallon more, the campus would save 680 MTCDE each year.

- ***Wrap water heater in insulation blanket*** [420 MTCDE per year]

Wrapping a water heater in an insulation blanket can save up to half a MTCDE of emissions per year (Climatecrisis.net 2006). Furthermore, annual savings are about 550 pounds of CO_2 per year for setting the water heater thermostat on no higher than 120° F. If ten percent of off-campus students performed both of these small actions, 420 MTCDE can be mitigated annually.

- ***Walk, bike, carpool, or take mass transit*** [340 MTCDE per year]

Approximately 500 pounds of CO_2 emissions are saved annually by avoiding ten miles of driving each week. If 15 percent of Carnegie Mellon students would perform this action, 340 MTCDE are saved on a yearly basis. Additionally, carpooling just two days each week can save up to 1,590 pounds of CO_2 each year (Climatecrisis.net 2006).

- ***Clean/replace filters on furnace and air conditioner*** [95 MTCDE per year]

Cleaning a dirty air filter can save 350 pounds of CO_2 emissions annually (Climatecrisis.net 2006). Assuming that ten percent of student living in off-campus housing (approximately 600 people) would perform this action, 95 MTCDE per year would be prevented from being released into the atmosphere.

- ***Skip bottled water*** [9 MTCDE per year]

16.5 MTCDE are emitted for every one million bottles of water that are manufactured and transported to consumers (New York Times 2007b). If one were to drink his or her recommended eight glasses a day through bottled water sources, it could cost up to $1,400 each year. However, this same volume of water from the tap would only cost about 49¢. Considering that America's tap water is one of the best water supplies in the world, drinking tap water is a safe and cost-effective way to reduce one's carbon footprint (New York Times 2007a). If half of the student body at Carnegie Mellon decreased their bottled water consumption by 50 percent, nine MTCDE would be saved each year.

- ***Reduce junk mail*** [2 MTCDE per year]

U.S. households receive 19 billion catalogs each year through the mail, which requires 53 million trees and emits 4.7 million MTCDE (Stryker 2008). Americans can reduce the amount of unsolicited mail that they receive by signing up for the Direct Marketing Association's mail-preference service, which is modeled after the national do-not-call registry. If five percent of Carnegie Mellon students placed themselves on this list and received a quarter of the magazines as before, this small action would save two MTCDE each year.

The following options were not incorporated into the low-carbon behavior reductions analysis for the Carnegie Mellon campus and consequently do not have emissions reduction potential estimates associated with them. These options were not included due to the difficulty in providing accurate quantitative estimates for possible reductions on campus due to these changes. Nevertheless, each of these actions can have significant impacts and should not be overlooked by carbon-conscious individuals.

- ***Avoid unnecessary food miles***

Since what individuals eat accounts for about one-fifth of their personal carbon footprints (Pollan 2008), becoming more conscious of the life cycle emissions associated with one's diet is a significant step toward sustainable living. The fact that the average U.S. meal travels 1,200 miles from farm to plate means that buying local can, in certain instances, reduce one's carbon footprint. While local farmers markets reduce amount of energy required to grow and transport food by one-fifth (Climatecrisis.net 2006), buying local may not be enough. What one eats is ultimately more important than where the food is grown (Weber 2008; Goodall 2007).

- ***Buy a low-emission, fuel efficient car***

The three most important greenhouse gas emissions related factors when purchasing a new vehicle are fuel efficiency, tailpipe emissions, and reliability (Jones 2007).

- ***Downsize car***

Every extra 100 pounds of weight in an average car requires two percent more fuel to move (New York Times 2007b).

- ***Fly direct***

During a typical flight, most fuel is burned during takeoffs and landings. Takeoffs account for nearly 25 percent of total fuel use for shorter flights (New York Times 2007b).

- ***Plant a tree***

An average tree will absorb approximately one ton of CO_2 during its lifetime of about 55 years. Furthermore, shade from a tree nearby one's place of residence can reduce air conditioning costs by 10-15 percent (Climatecrisis.net 2006).

- ***Pull the plug on appliances and electronics***

Appliances like televisions and DVD players still consume energy even when they are turned off. The energy used to power display clocks and to keep memory chips working consumes approximately five percent of domestic energy consumption in the U.S. and emits 15 million MTCDE each year. Turning off electronic devices like computers, televisions, and DVD players can save thousands of pounds of CO_2 emissions each year (Climatecrisis.net 2006).

- ***Purchase efficient appliances***

As suggested in Section 5.4.1, using energy more efficiently at one's place of residence can reduce energy costs and emissions by more than 30 percent (Climatecrisis.net 2006). It is estimated that, if all U.S. households replaced their conventional appliances with the most efficient current models (like those certified by the ENERGY STAR program), 160 million MTCDE each year would be eliminated.

- ***Vote***

Perhaps the most important way to make a positive environmental impact is to vote (Friedman 2007). Since politicians write the policy that drives the behavior of the entire market, even small changes in standards or tax incentives can lead to dramatic reductions. This aspect of scale makes choosing the right leaders an absolutely vital component of any individual's personal mitigation portfolio.

If all of the mitigation potentials of the bulleted options are totaled, 15,000 MTCDE would be saved annually by Carnegie Mellon students. For the mitigation analysis, the reductions that result from taking the actions above can be treated like offsets. As such, these emission cuts can be considered reductions over the baseline emissions scenario, even though these emissions are not account for in the total Carnegie Mellon carbon footprint (as described in Chapter 2). All of the aforementioned activities are similar to purchased offsets (see Section 5.3.1.1) in that they reduce the total amount of greenhouse gas emissions emitted globally. The primary difference is that these reductions are not publicly available commodities and accordingly would not represent costs to the university.

As discussed in Chapter 2, the total carbon footprint of Carnegie Mellon University is roughly 179,000 MTCDE per year. If the individual mitigation options are considered to be offsets, eight percent of the university's total yearly emissions can be mitigated simply through the aforementioned low-carbon behavior efforts.

Although the reductions values discussed above largely center on the capacity for individual efforts to reduce the total Carnegie Mellon footprint, another way of framing the problem is to consider how small efforts can decrease an individual's personal carbon footprint. The average Carnegie Mellon student's emissions footprint is 16 MTCDE, as discussed in Chapter 2. Figure 5.5.1 shows how implementing all of the behavior changes above can mitigate nearly 40 percent of a student's personal carbon footprint. Although it may seem optimistic to assume that students would be willing or capable of putting all of these actions into practice, this analysis demonstrates the large capacity for concerned students to reduce significantly the emissions associated with their daily activities. These large reductions on an individual basis can translate into large-scale aggregate reductions, as increasingly more people become interested in participating in sustainable initiatives. In this sense, these small first steps can be an empowering way to begin mitigation strategies from the ground up.

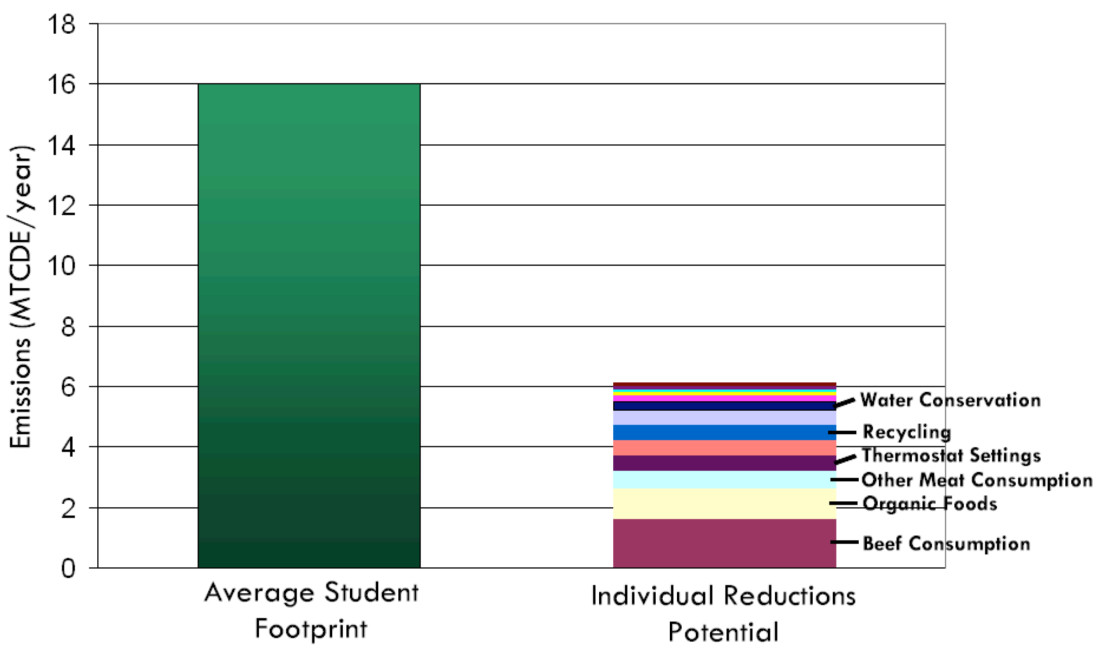


Figure 5.5.1 – Comparison of average Carnegie Mellon student footprint and individual mitigation potential

5.6. Pathways for Implementing Mitigation Options

5.6.1. Considerations

When making a reductions plan, there is more than one metric to consider. If getting the most reductions for the money is important, then it is not always wise to go after the largest reductions first or ever.

- ***Cost-effectiveness of each option***

The cost-effectiveness (expressed in terms of U.S. dollars per MTCDE avoided) informs decision makers of how the cost and savings of options compare over their expected lifetime. Options with net savings could be used to save capital for other reduction projects or reduce a campus' footprint immediately by purchasing RECs and offsets with the money.

- ***Capital cost of each option***

Reductions options can have wildly varying capital costs and with limited capital to spend. Universities should be strategic about implementing projects with high capital costs so that they are able to continue their efforts.

- ***Amount of potential reductions for each option***

Cost-effective and low capital cost options may have small reductions potential. With limited human resources for implementing projects, savings and impact need to be balanced. If a university has a reductions target for which they are willing to buy RECs or offsets to make up the difference, then reducing the footprint on campus means that the university will need to buy fewer RECs or offsets. At about $20 per metric ton of CO_2, these savings should be considered as well.

- ***Visibility, publicity, and LEED points from each option***

A university may want to implement options that are not cost effective or have low emissions reductions but clearly send a public message that, "This is a university that is serious about reducing climate change." Many cost effective options may not be visible at all to the public. Small projects like installing a vertical wind turbine or several visible photovoltaic solar panels can serve as a permanent ecological billboard for a university and an important symbol to help focus attention.

- ***Time and available resources***

All of these considerations will be weighted by the reductions time target that the university sets and the available resources for bringing options on-line.

- ***Lifetime of each option***

Options with longer lifetimes may save costs associated with replacement and may require less maintenance. For instance, CFLs not only consume less energy than standard incandescent bulbs but also last much longer, which reduces the need for constant maintenance (see Section 5.4.1.4).

- ***Other ecological considerations***

When selecting an abatement strategy, the university may be more interested in broader sustainability concerns and the mitigation of other environmental impacts beyond climate change.

5.6.2. Exploratory Analysis for Carnegie Mellon

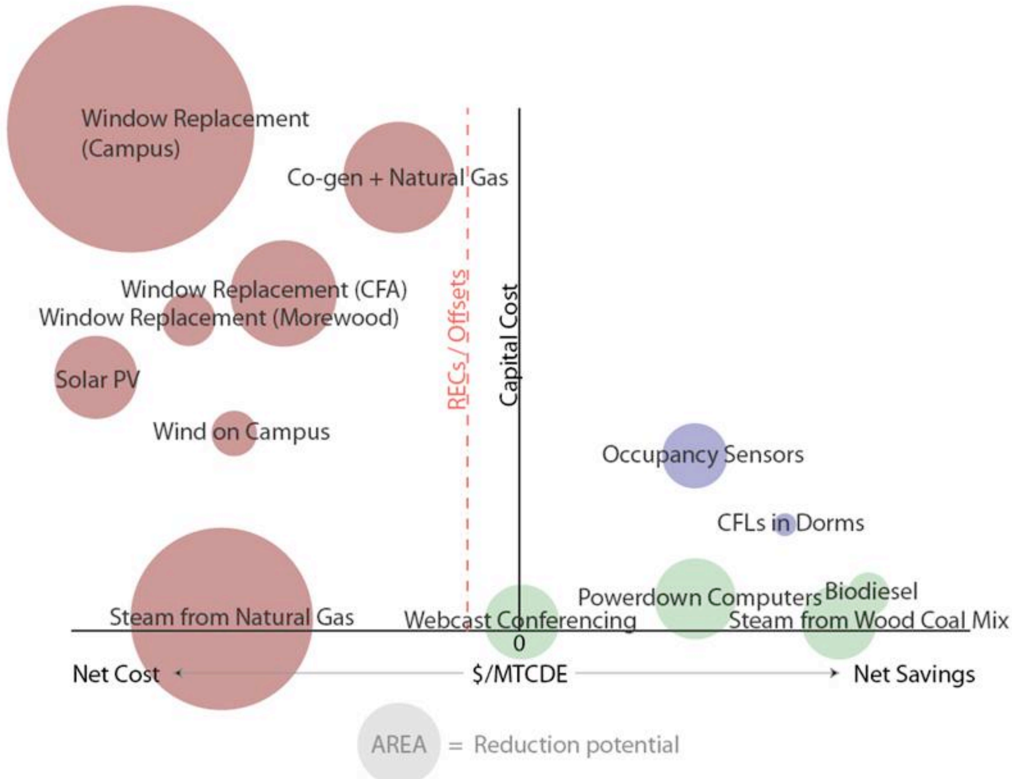


Figure 5.6.1 – Three category's of options at Carnegie Mellon

Conducting an exploratory analysis, the reductions options were placed on a chart according to their cost-effectiveness (horizontal axis) and their capital cost (vertical axis). The area of the dot placed for each option shows the reductions potential. The options explored in this report fell into three categories. These categories can help place the options into a strategic plan.

- ***Category One (Green): Negligible Capital Cost***

In the first category are options that have negligible capital cost and net savings. These are: webcast conferencing as an alternative to five percent of faculty air travel, turning off cluster computers at night and asleep when not in use, using a wood coal mix in the Bellefield Boiler, and switching to biodiesel for the Carnegie Mellon fleet.

- ***Category Two (Blue): Some Capital Cost***

In the second category are two options: installing occupancy sensors across campus and replacing incandescent desk lamp bulbs with compact florescent bulbs (CFLs). These options have low capital costs and would pay for themselves in less than about a year.

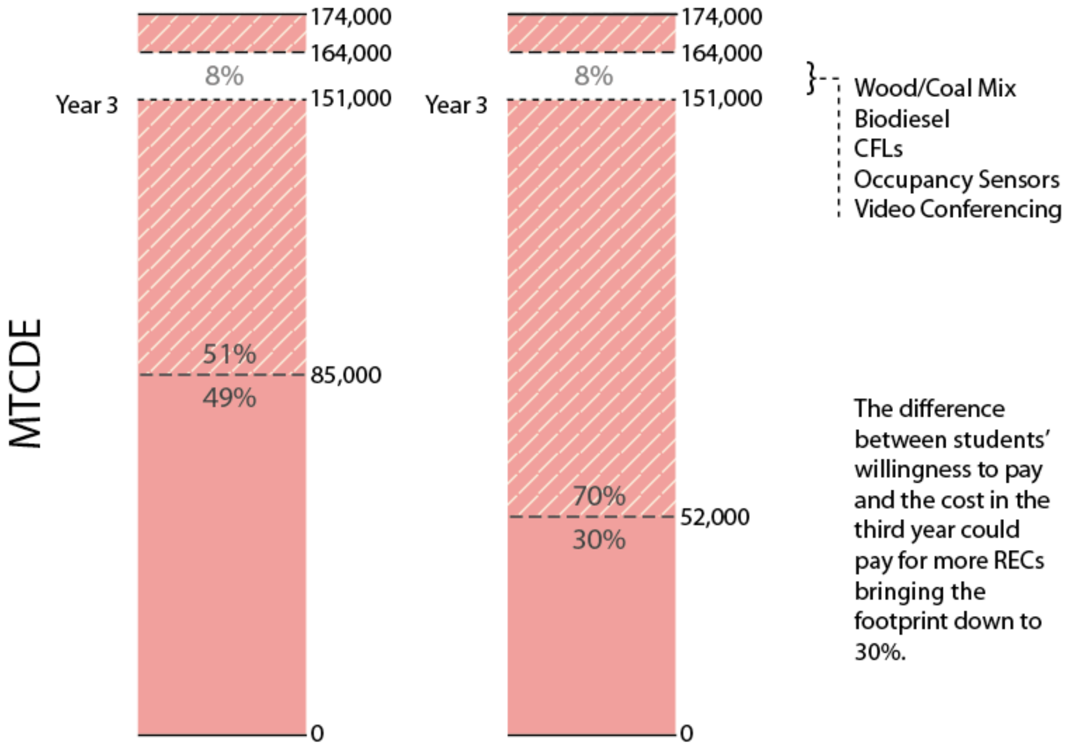
- ***Category Three (Red): Not Cost Effective***

Mitigation options that are not cost effective are shown in red. These options cost more per MTCDE reduced than purchasing RECs or offsets and therefore need some other form of justification like visibility to merit implementation.

5.6.3. Example Plan for Carnegie Mellon

Using 51 percent as a reductions target for an example plan was drafted to show how much such a target would cost Carnegie Mellon. For this mitigation plan, every option that had little or no capital cost is deployed over three years with the exception of wood/coal mix at Bellefield which is fully implemented in the first year.

The carbon footprint for Carnegie Mellon estimated using the Clean Air Cool Planet calculator was at 164,000 MTCDE, as discussed in Chapter 2. However, the university is already purchasing RECs from an area wind farm for about 18 percent of its electricity. Without these RECs, the footprint would be 174,000 MTCDE. Subtracting 51 percent of this footprint would bring the University's footprint down to 85,000 MTCDE.



Year	Total Cost / Yr. RECs only	Mix	Energy savings
0	$1,580,000	$1,580,000	$0
1	$1,580,000	$950,000	$523,000
2	$1,580,000	$600,000	$804,000
3	$1,580,000	$200,000	$1,085,000

Year	Cost per student/ Yr. RECs only	Mix
0	$158	$158
1	$158	$93
2	$158	$57
3	$158	$22 ←

Figure 5.6.2 – Costs to Carnegie Mellon to reduce its footprint

If Carnegie Mellon decreased its footprint to 85,000 MTCDE by purchasing only RECS or offsets, it would cost $1.6 million per year or about $158 annually for every student, as shown in Figure 5.6.2. However, if the university implemented all low and no cost options over three years, hitting the rest of the 51 percent target with RECs or offsets would cost per student: $93 in the first year, $57 in the second, and only $22 in the third year. Recall that the survey found students are willing to pay about $86 per year. The difference between students' willingness to pay and the cost per student in the third year could pay for more RECs or offsets and bring the university's footprint down to 30 percent of the baseline.

5.6.4. LEED Certification

The Leadership in Energy and Environmental Design (LEED) Green Building Rating system is already a Carnegie Mellon standard for all new buildings. However, LEED for Existing Buildings allows any existing building to be given an initial or an updated LEED rating. Many of the mitigation strategies summarized in this report are worth unclaimed LEED points. Implementation of these building upgrades and other mitigations options can result in a higher LEED ranking. Since Carnegie Mellon has already established itself as a leader in the construction of green buildings (New House was the first residence hall to receive LEED certification), factoring LEED points into the project planning process may help to make the mitigation initiatives detailed above to become more favorable for implementation.

Table 5.6.1 – LEED point requirements, values, and mitigation options that contribute to those requirements

Option	Requirement	Point Value
RECs	25-100% off-site renewable energy	1-4
Solar Power	3-15% on-site renewable energy	1-4
Wind Power	3-15% on-site renewable energy	1-4
CFLs	67+ ENERGY STAR rating Or 17-45% efficiency above national average	1-15
Cluster Power Down	67+ ENERGY STAR rating Or 17-45% efficiency above national average	1-15
Occupancy Sensors	67+ ENERGY STAR rating Or 17-45% efficiency above national average	1-15
Green Roofs	Storm water capture, water efficient landscaping	1-4
Green Roofs	Heat island reduction	1-2
Green Roofs	Materials and innovation	1-8
Carpooling	10-17% reduction in conventional commuting trips	1-4

5.7. Conclusions and Recommendations

5.7.1. Summary

As global warming comes to the forefront of public attention, colleges and universities are uniquely positioned to lead the charge for carbon mitigation. Universities are already centers for climate change and energy research, but more importantly, they have the opportunity to influence the knowledge of young adults beyond simple academics. Carbon mitigation steps taken by universities do not only reduce the carbon footprint of the individual university but have the added advantage of influencing the thoughts and habits of its students to become more environmentally contentious citizens when they graduate.

There is a wide array of options available to help universities mitigate carbon dioxide emissions, and no one option is enough. These options vary in cost-effectiveness from net savings to hundreds and even thousands of dollars per ton reduced and in the capital cost from free to millions of dollars, as shown in the cost abatement curve in Figure 5.7.1. New options are continually be explored and entering the market, and many of the more established options are becoming cheaper. For these reasons, universities must continually review the available options. The specifics of the university must be taken into account when determining the effectiveness of a carbon mitigation option in addition to the monetary price. As technologies like cogeneration illustrate (see Section 5.2.3), carbon mitigation options are not always effective in every situation. The three main culprits in university carbon emissions are electricity generation, steam generation, and air travel. Thus, options that address the amount and carbon intensity of these three areas will be the most effective for the majority of universities.

Universities have the most control over energy utilities generated on-campus. For institutions that already generate their own electricity, these locations should investigate installing a cogeneration facility, while combined heat and power fuel cells and carbon capture and storage may be viable options in the near future. Solar and wind power may also be effective on-campus options depending on the location of the university, but they can also be purchased in the form of renewable energy credits. Additionally, institutions should consider switching steam boilers to natural gas or a mixture of coal and wood as a less expensive option for universities with coal fired steam plants.

There are many options to consider for reducing the campus demand for electricity and steam. Some are institutional policies such as setting university owned computers to go into a lower power state when not in use, installing motion sensors to control lighting, replacing inefficient windows, adjusting HVAC settings, and purchasing ENERGY STAR approved appliances. Universities can also encourage students to reduce their own carbon footprint by turning off lights and computers when they are not needed, eating less beef, adjusting the thermostat, and walking, biking, or taking public transit.

Reducing air travel may prove more difficult. Universities with large populations of international students will also have large emissions from student air travel. Most universities recognize that having a campus population from all over the country and around the world adds to the diversity and culture of their schools. However, student travel, though related to the university, does not fall under the scope of the university's control. Faculty air travel is a large contributor to the university carbon footprint and is sometimes discretionary. Travel to conferences and to visit locations for research will likely not change. However, video conferencing should be encouraged over face-to-face meetings when possible.

It is important for universities to keep in mind that there is no "silver bullet" solution for carbon mitigation. Every university must evaluate where its own carbon gremlins lie and what options are best suited for that campus.

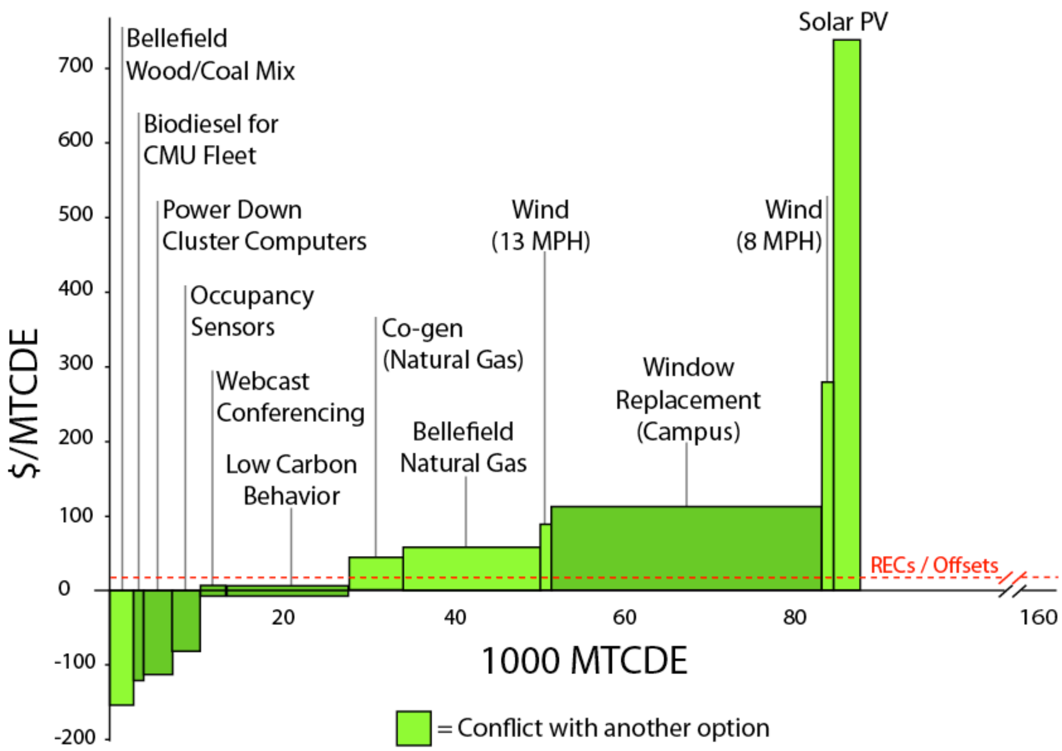


Figure 5.7.1 – Marginal abatement cost curve for Carnegie Mellon

5.7.2. Recommendations

In order to reduce Carnegie Mellon's yearly carbon footprint, continual ideological and financial commitments must be made on the part of the university. Beginning a mitigation strategy as soon as possible can take advantage of the cost reductions that result from abatement options with short payback periods like installing occupancy sensors or replacing older light fixtures with CFLs. The low or no cost options can reduce the university's greenhouse gas emissions immediately while providing a means to finance more costly mitigation options or the purchase of RECs.

As the Bellefield Boiler provides a signification portion of Carnegie Mellon's CO_2 footprint, it should be one of the areas first considered as the university seeks to reduce CO_2 emissions. While it is not practical to consider an all natural gas option, increasing the percent of natural gas used would be a simple and effective mitigation option. Switching to a wood/coal mix would result in both a lower CO_2 output and lower annual costs.

In terms of energy end-use applications, setting group policies to make university owned computers go into low power modes when not being used and encouraging students, faculty, and staff to do the same with personal computers are easy ways to save both greenhouse gas emissions and money.

Although it is important to pick the low hanging fruit first (i.e., the most cost-effective options), there are other considerations like visibility that must be accounted for in developing a mitigation pathway for institutions. For instance, placing a vertical wind turbine on the ETC building may cost the university money, but the high visibility of this option would be a positive indicator to the broader community of Carnegie Mellon's commitment to sustainability and other environmental initiatives.

In addition to reductions made on an institutional level, individuals have a large capacity for taking actions to reduce the overall carbon intensity of campus. Faculty, staff, and students can take actions including webcasting, reducing beef consumption, adjusting thermostat settings, and simply turning off lights and electronic equipment to reduce their associated greenhouse gas emissions. Many of these low-carbon behavior options have other ecological benefits as well. For instance, installing low-flow shower heads not only saves energy but also helps to conserve water.

Future research should examine how to encourage low-carbon behavior. Although this report gives many suggestions for how individuals can reduce their personal carbon footprint, finding mechanisms to encourage community members to adopt these practices will require more knowledge of effective education and incentive structures.

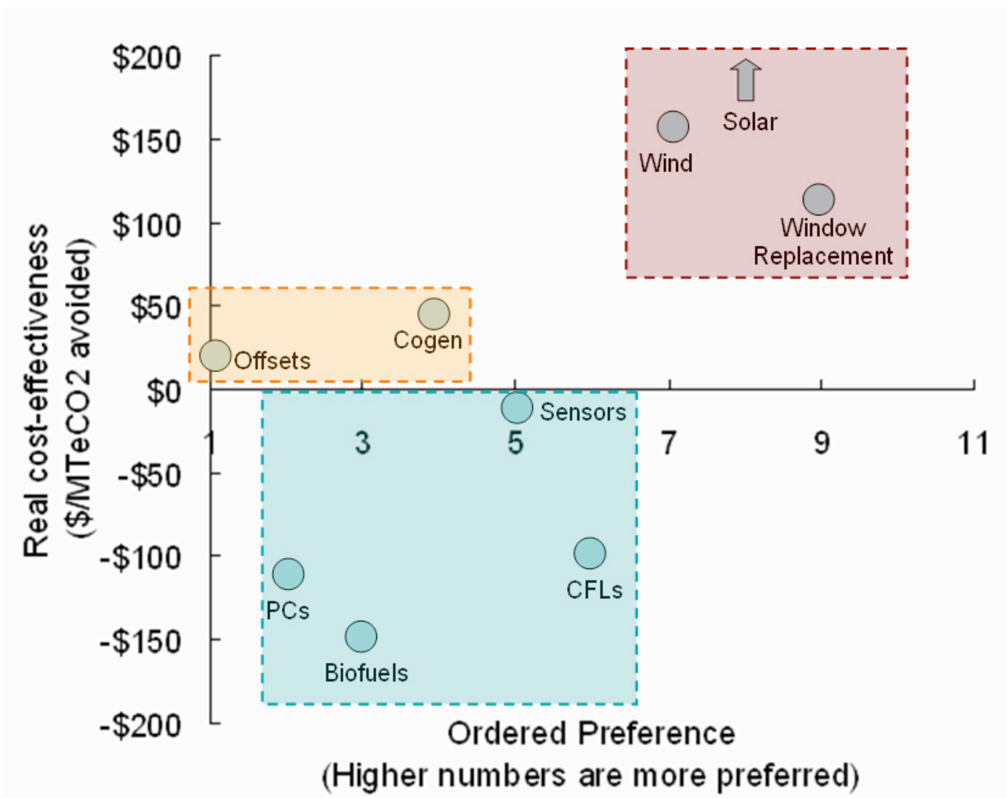


Figure 5.7.2 – Comparison of perceived versus actual cost-effectiveness of mitigation options

Based on data from the survey results (please refer to Chapter 4), Figure 5.7.2 shows that student preferences have a negative correlation with cost-effectiveness. Although money-saving options such as occupancy sensors and CFLs are more popular than some costly options like purchasing offsets or cogeneration, they are still less popular than the most expensive options like wind and solar power. This result reveals an urgent need for increased and mandatory environmental education for students. In order to maintain its role as a leader in environmental initiatives, Carnegie Mellon must ensure that its students are well-educated on important sustainability issues. Such education would be best implemented as portion of freshman orientation or as a required course similar to the mandatory first-year class Computing@Carnegie Mellon (99-101).

Thus, in order to facilitate reduction measures on an institutional level, individuals must be made more aware of the broad environmental ramifications that accompany their personal choices. Since the results above suggest a large gap between student perceptions of mitigation options and their technical and economic realities, education must reflect the interconnections between behavior and its associated effects. For instance, the Carnegie Mellon printing quota, which limits total printing at on-campus locations each semester, was instituted in 2005 to eliminate paper waste and to encourage users to be more conservative about their printing habits. Likewise, one can imagine that a greater deal of attention would be paid to computer use and lighting habits if students were directly accountable for the monthly electric bill at their dormitory or were required to pay fines for excessive use of utilities. One practical way to bridge disparities in student awareness (while also saving money) is to institute a dormitory energy and water conservation competition, as recently done by schools like Indiana University and Harvard. These competitions serve not only to make reductions in a school's carbon and ecological footprints but more importantly help to foster a spirit of community involvement while promoting greater environmental sustainability.

Chapter 5 References

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6. Campus Initiatives Comparison

6.1 Introduction

6.1.1. Background

The issue of sustainability on university campuses goes beyond the task of creating an inventory or footprint assessment. It also encompasses what a campus is doing to improve energy efficiency, reduce waste, reduce emissions, and other similar initiatives. The actions taken on behalf of an institution to reach these goals make up the set of sustainability initiatives that are taken on nationwide. The diversity of sustainability initiatives that have been implemented in the United States shows a wide range of associated costs as well as varying levels of efficacy. For instance, installation of photovoltaic solar panels would be less useful in a geographic region that gets very little sunshine.

As sustainability initiatives become more common and as universities receive greater pressure to take a leadership role in implementing these initiatives, the task of assessing which initiatives may be right for a campus has become larger. One important step in this decision-making process is to know what other campuses have done and what has worked. This presents a fundamental challenge of not only assessing a university's sustainability initiatives but also establishing a basis for fair comparison between institutions. The difficulty in making such a comparison has been recognized by many sustainability coordinators and business officers at universities around the country. The 2008 Smart and Sustainable Campuses Conference at the University of Maryland placed a strong emphasis on the process of benchmarking and reporting in order to aid the comparison process (Powers 2008). Additionally, the desire is high on the part of schools for a tool that is able to perform this assessment. As Julian Dautremont-Smith of the Association for Advancement of Sustainability in Higher Education (AASHE) indicates, "An emerging area of interest is in comparing information" (Powers 2008).

6.1.2. Motivation

The primary goal of this portion of the project is to provide a means for fair comparison of sustainability initiatives between universities. Preliminary research found several sustainability assessment tools. The research in this report aims to provide a framework that differs from these previous tools by improving on the ability to make comparisons between schools. The Community Sustainability Assessment (CSA) of the Global Ecovillage Network provides a detailed but user-friendly checklist that allows a community to assess its sustainability. However, the tool was not tailored for colleges nor does it provide for comparisons between different organizations and institutions that have completed the assessment. The Sustainability Tracking, Assessment, and Rating System (STARS) from AASHE is a new tool that has been specifically designed for colleges and universities and hopes to be able to make comparisons between universities. Nonetheless, the STARS program, while detailed and comprehensive, is still based on voluntary reporting to build the database of information that schools will be able to use for comparisons. Neither assessment makes an attempt of suggesting a peer comparison list for a particular institution, leaving the idea of a sustainability peer group untouched.

The ability to compare schools actively against peers is important in the context of announcements of new college "green" rankings (Carlson 2008). While rankings may be beneficial in bringing awareness to the issue of sustainability and in highlighting which schools are doing significant things, they present problems if not done in a transparent or fair way. Being able to define a sustainability peer group is beneficial for schools, as they can compare themselves to a small subset of schools in the ranking system rather than all schools which may or may not be similar from a sustainability perspective. It also allows schools to track progress in an ongoing and internal way that does not rely on external reporting to guide their sustainability initiatives.

This work proposes a method of assessment where schools can compare their efforts in sustainability initiatives against other peer institutions regardless of whether the peer institutions have conducted their own sustainability assessment. This process makes use of a sustainability peer group and publicly available data on university sustainability initiatives. This tool was used for Carnegie Mellon but was created and documented in such a way that any school would be able to conduct a similar assessment. This thoroughness and transparency is intended to help other institutions to determine a list of peers to which they should be comparing themselves. As suggested in Chapter 2, the Carnegie Mellon carbon footprint indicates that a great deal of the university's emissions comes from the energy required to generate steam to heat the built environment. Comparing Carnegie Mellon to a school in a much warmer part of the country would not make sense, as the issues of heating and cooling do not put the universities on equal footing. The second distinguishing feature of this assessment is that it can be conducted whether or not a school has done its own assessment. Publicly available sustainability assessments are rare, and the ability to conduct one on another university is a great benefit to an institution using this tool.

6.2. Methods for Comparing Green Initiatives at AASHE Schools

This study examined data from the Association for the Advancement of Sustainability in Higher Education (AASHE) website. AASHE is a member organization of colleges and universities in the U.S. and Canada working toward sustainability. It has 424 member schools, including four-year and graduate institutions, two-year institutions, and community colleges.

The focus of this research was on the initiatives of the 44 schools listed under Campus Sustainability Profiles, which was one of the resources available on AASHE website. Campus Sustainability Profiles displayed applications of the schools competing for Sustainability Leadership Awards each year. Information on the applicant schools' sustainability initiatives in the categories of "Governance and Administration," "Operations," "Curriculum and Research," "Campus Culture," and "Community Service and Outreach" was available on the Campus Sustainability Profile. All schools under the Campus Sustainability Profiles were colleges and universities in the U.S. An Excel spreadsheet was created for sustainability initiatives of the 44 applicant schools. The categories provided in the application were further divided into more specific subcategories to examine specific programs adopted by the schools. Initiatives data were then collected based on what the applicant schools listed under their applications. Individual websites of institutions were searched for clarification when information was not obvious from the AASHE applications.

6.2.1. Initiatives

- ***Governance and Administration***

The Presidents Climate Commitment referred to colleges and universities that had signed American College and University Presidents Climate Commitment. In the context of setting up office space dedicated to sustainability issues, the term "office" was not merely a physical space, but schools were considered to have a sustainability office if they had new policies or master plans for environmentally-oriented initiatives. Inventory updates and internal audits were not limited to a greenhouse gas emissions inventory. This category included any kind of comprehensive report on the sustainability initiatives and data regarding their emissions.

- ***Transportation Improvements***

An example of having cleaner fuels would be having the fleet run by biodiesel. Initiatives to reduce single occupancy vehicle trips included existence of preferential treatment for carpools. Subsidized public transportation referred to subsidizing bus fares and other similar initiatives.

- ***Infrastructure Improvements***

The adoption of a recognized environmental standard referred to implementing LEED standards for buildings and installing ENERGY STAR products. The water conservation projects consisted of installation of water conservation devices, such as low-flush toilets and low-flow showerheads. The energy conservation projects indicated installation of motion sensors, ENERGY STAR appliances, or more efficient lighting. Electricity generation capabilities referred to the existence of electricity generating utilities on the campus. The renewable energy indicated energy generated by solar, wind, geothermal, and other natural resources.

- ***Curriculum and Research***

Concepts of environmental sustainability in the curriculum included having sustainability courses available. Research of feasibility studies referred to studies being done to promote sustainability practices.

- ***Campus Culture***

Availability of environmental student groups and awareness programs to emphasize importance of sustainability was examined. Recycling programs and purchasing of locally grown and organic food were also considered. The availability of environmental housing option was another subcategory. This referred to the housing that was occupied by group of students that are promoting sustainability by committing themselves to the environmentally friendly lifestyle.

- ***Service and Outreach***

Engagement in outreach programs to promote sustainability in the community was also considered.

6.2.2. Sensitivity Analysis

After compiling the spreadsheet for the categories detailed in Section 6.2.1, various sensitivity analyses were conducted to grasp the overall progress of the schools that were competing for Sustainability Leadership Awards. Popular initiative analyses were conducted by compiling the initiatives taken by the 44 schools. A graph showing the percentage of the AASHE schools that adopted each sustainability initiative was created (see Figure 6.3.1).

Regional comparisons were also conducted to see if regional differences affected the type of the programs adopted or the range of the sustainability programs adopted by the schools (see Section 6.3.2). To conduct a regional analysis, the U.S. was divided into four regions: the West, the Midwest, the Northeast, and the South, as shown in Figure 6.2.1. The West had total of 13 schools that were from four states. 11 schools were from the six states in the Midwest region. 11 schools were from the seven states in the Northeast region. Nine schools were from the seven states in the South. The West represented the most schools from AASHE profile.

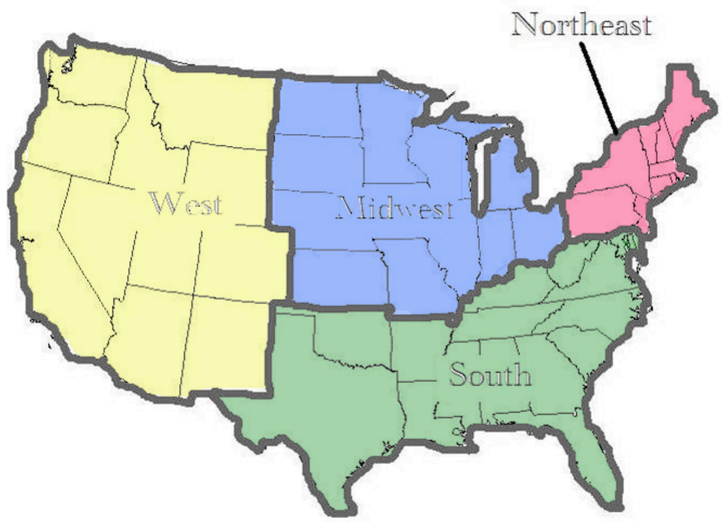

Figure 6.2.1 – U.S. regional divisions for the sustainability initiative comparison

Comparisons between American College and University Presidents Climate Commitment signatory and non-signatory schools were conducted to test the effectiveness of the agreement (see Section 6.3.3). If the signatory schools adopted more programs than the non-signatory schools, there would be a correlation between signing the commitment and how active the schools are in adopting sustainability programs.

6.3. Results

6.3.1. Popular Initiatives

The most popular initiatives at the AASHE schools were recycling and energy conservation programs, which all 44 schools had. Although most schools were actively pursuing programs like recycling, energy conservation, curriculum integration, setting environmental standards, setting offices toward sustainability initiatives, and using renewable energy, less than half of the schools had carpooling, and very few schools had subsidized public transportation or some type of inventory or internal audit. Barely half of the schools signed American College and University Presidents Climate Commitment, which was surprising given that these were schools that claimed themselves to be leaders of sustainability programs. Figure 6.3.1 displays 12 initiatives implemented by 44 schools from the least popular to the most popular.

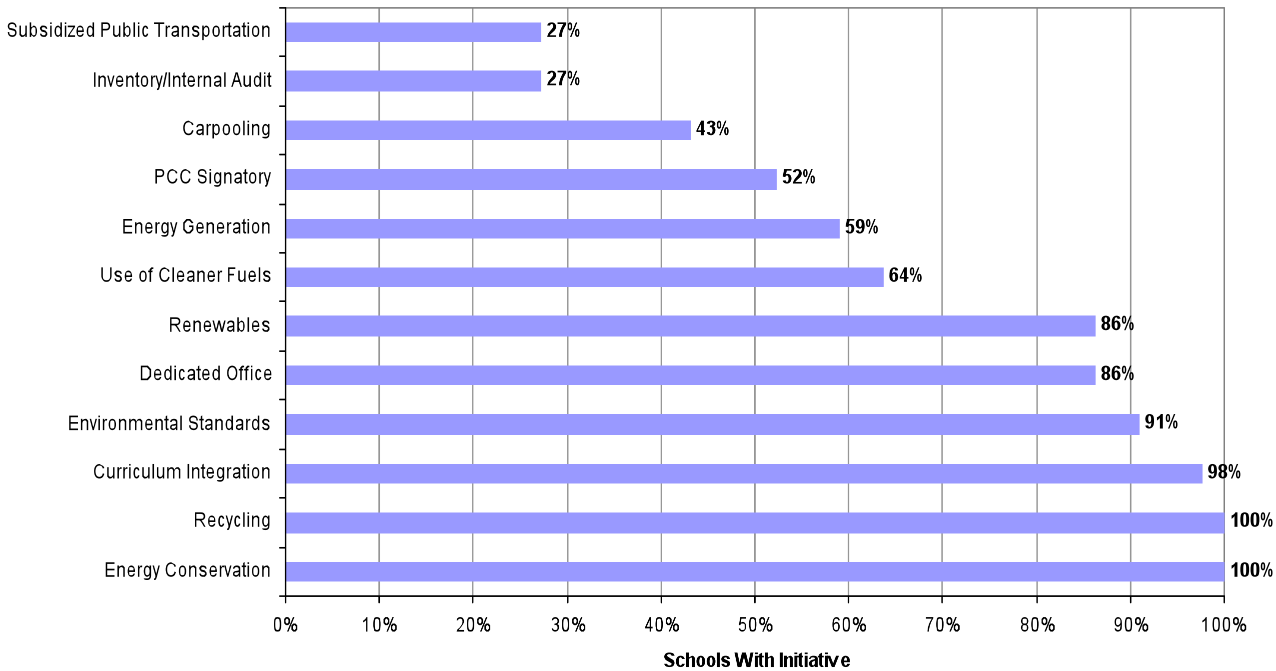

Figure 6.3.1 – Sustainability initiatives and percentage of AASHE 44 schools that have undertaken them

6.3.2. Regional Analysis

Of the 11 schools representing the Northeast, only four were signatories to American College and University Presidents Climate Commitment. Of the nine schools represented in the South region, only two have signed it. Out of 11 schools in the Midwest region, two have signed the PCC, and 4 of 13 schools in the West have signed it. 64 percent of Northeast region institutions, 56 percent of the institutions in the South, 18 percent of the institutions in the Midwest, and 69 percent of the institutions in the West signed the American College and University Presidents Climate Commitment.

The distribution of initiatives across the four regions is shown in figure 6.3.2. When comparing inventory/internal audit, carpooling, energy generation, and renewable energy initiatives by region, Northeast schools performed the best in inventory or internal audit and energy generation categories. The schools in the West did the best in carpooling category. The Midwest had the highest participation in the Renewable category but did relatively poorly in inventory or internal audit and carpooling categories. The West did relatively poorly in energy generation and renewable category. There was not a single region that had most schools across all categories. Thus, there was no apparent correlation between region and having most initiatives.

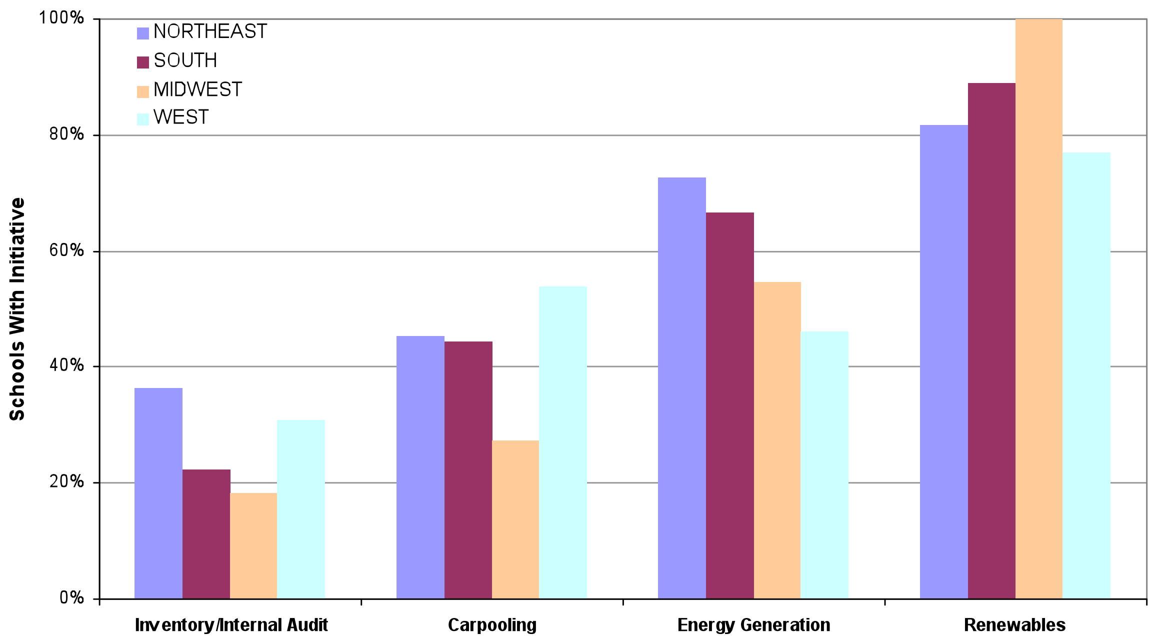

Figure 6.3.2 – AASHE 44 initiatives by region

6.3.3. Signatory and Non-Signatory Institution Comparison

The initiatives between the signatories and the non-signatories to the American College and University Presidents Climate Commitment were compared, as shown in Figure 6.3.3. In most cases, more signatory schools adopted sustainability programs than the non-signatory schools. The discrepancy between the non-signatories and signatories were most apparent in subsidized public transportation, inventory or internal audit, and carpooling. Ten percent of non-signatory schools had subsidized public transportation, while 43 percent of the signatory schools had subsidized public transportation. Only ten percent of the non-signatory schools had inventory or internal audit, while 43 percent of the signatory schools had it. Although considerably more signatory schools had subsidized public transportation and internal audit compared to non-signatory schools, 43 percent did not seem like a large number, considering that the signatory schools consider themselves to be leaders in promoting sustainability. Carpooling was done by 24 percent of the non-signatory schools and 61 percent of the signatory schools.

In the energy generation, cleaner fuels, water conservation projects, environment standards, and recycling, the gap was less pronounced, but signatories nevertheless were more active. However, non-signatories did better than signatories in use of renewable energy and setting a dedicated office for sustainability. 90 percent of the non-signatories had renewable energy, while 83 percent of the signatory schools had it. Similarly, 90 percent of the non-signatory schools had dedicated office for sustainability initiatives as compared with 83 percent of the signatory schools.

Although the signatory schools were more likely to have the initiatives than the non-signatory schools in most cases, it cannot be concluded that there is a correlation, because there were exceptional cases where the non-signatory schools had done better. Overall, even when the signatory schools were ahead, the gaps between the signatory and non-signatory schools were not pronounced. Moreover, the results merely show that the initiatives are available and not the impact of the initiatives.

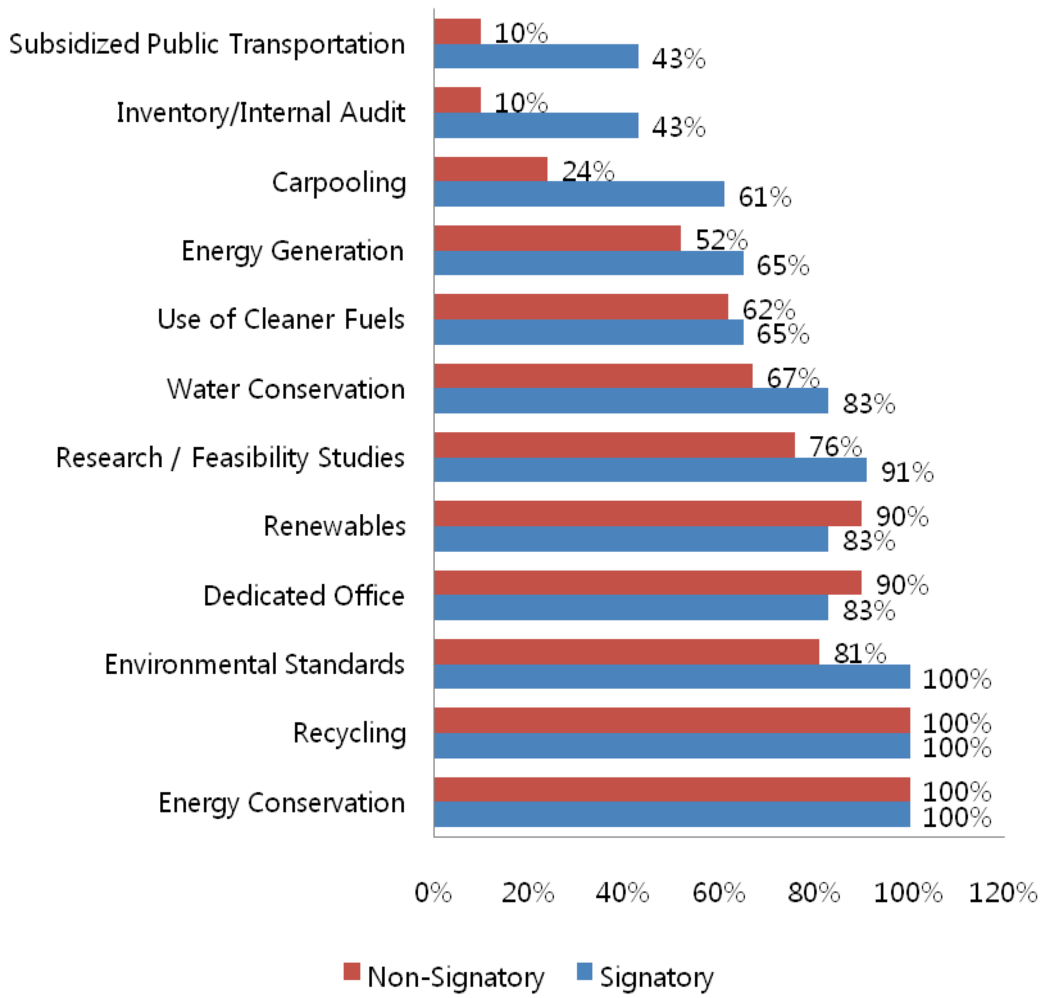

Figure 6.3.3 – Comparison of initiatives at signatory and non-signatory institutions

The programs that the schools are undertaking should not be generalized to the entire population. These 44 schools are not representative of all colleges and universities in the U.S., since these are the schools competing as leaders of the sustainability initiatives. Their self-selection for the award suggests that they are likely to have more programs than average institutions in the U.S.

6.4. Defining Peer Groups

Colleges and universities create peer groups of schools for comparison over a wide range of characteristics. Based on the goals of different departments in the school, the characteristics they are interested in vary. The admissions office, for example, is concerned with a different set of characteristics and facts than the athletics department. Similarly, to examine Carnegie Mellon's status in pursuit of sustainability initiatives, it was irrational to compare Carnegie Mellon to just any university. It was important to consider a few key characteristics about Carnegie Mellon that have a significant effect on the natural environment and energy usage and to find schools that match those characteristics.

A database of statistics from over 6,000 colleges and universities was created from the available data on the U.S. Department of Education's College Navigator website. The database had general information, information on enrollment, student expenses, financial aid, admissions, programs/majors, accreditation, and athletics. Added to the database was information from the MelissaData's Climate Average Lookup on the number of heating and cooling degree days for each school by its ZIP code, which is explained in more detail in the following section (MelissaData 2008). The data were used to filter the schools into peer groups with similar characteristics. Having this sustainability peer group would allow Carnegie Mellon to consider adopting popular initiatives among its peer group and to evaluate its relative position.

6.4.1. Description of Filters Applied for Peer Group Generation

In order to narrow down the list of over 6,000 schools into a realistic Carnegie Mellon sustainability peer group, filters were applied to remove the schools that do not model Carnegie Mellon very well from a sustainability viewpoint. The filters that were used are detailed in Section 6.4.1.1 through 6.4.1.8.

6.4.1.1. Two-Year versus Four-Year

As a four-year university, Carnegie Mellon and its sustainability peer group will only include schools that are four-year colleges or universities. Many of the two-year institutions that were in the initial list of schools were vocational schools or community colleges. These institutions appeal to a different group of students than Carnegie Mellon and also have a different set of challenges when it comes to sustainability. This was the first filter applied, and it narrowed down the peer group from over 6,000 schools to roughly 2,700 institutions.

6.4.1.2. Campus Housing versus None

Residence halls present some unique challenges when it comes to sustainability. Residential buildings make up a significant fraction of a campus, which in turn means that they will be responsible for a significant portion of a university's energy consumption. Dormitories also have a number of properties that make their energy consumption unique. Additionally, residence halls are the site of many different sustainability initiatives, such as the installation of toilets and showers that use less water or occupancy sensors for hallway lighting. Only universities with campus housing were included in Carnegie Mellon's peer group. This shrunk the list of schools from a number of about 2,700 to around 1,800 schools.

6.4.1.3. Urban versus Rural Campuses

The Carnegie Mellon peer group included only schools that are located in cities. While urban and rural campuses are both interested in certain sustainability challenges like reducing waste and increasing energy efficiency, the setting of a campus may impact a college's response to a particular problem. As an example, some schools have on-campus farms that both present unique challenges and act as sustainability test platform for the campus. Carnegie Mellon is a very land-locked university and would be neither able nor motivated to have an on-campus farm. Also, schools in largely populated areas may have a different relationship with the community than schools in more sparsely populated areas. By applying this filter, the peer group went from approximately 1,800 schools to just about 860 schools.

6.4.1.4. For-Profit versus Not-for-Profit

For-profit schools also are often vocational and offer very different academic programs than many not-for-profit schools. The differences between these schools and Carnegie Mellon make it inappropriate to compare them. As such, only not-for-profit universities are included in the peer group.

6.4.1.5. Private versus Public Schools

One of the main differences between private and public universities is the way they secure funding. Most public universities in the United States are state universities and are operated by state entities. They are predominantly funded by public means through national or subnational government. On the other hand, private universities are primarily funded by means of tuition, alumni contributions, donations, and private grants. Different funding sources imply different funding considerations for the university. This naturally has an impact on the administration's priorities. Funding constraints for a typical private university will influence the types of programs that the university will be able to embark on and sustain. On the contrary, the relative ease in obtaining public funds provides a public university's administration greater liberty and flexibility in the types of program it chooses to initiate, for instance, sustainability programs. The combination of this filter and the for-profit versus not-for-profit filter brought the peer group down from 860 to a size of 620 schools.

6.4.1.6. Population

The student population of a school makes an impact on the sustainability initiatives in place at that school. On one end of the spectrum, a small college or university may be able to switch to entirely renewable energy or offset all of their carbon, because the smaller energy usage makes the cost relatively small to do so. On the other end of the spectrum, a larger institution may have the ability to finance major construction projects such as a cogeneration plant or a complete retrofit of all campus utilities. Carnegie Mellon has roughly 5,500 undergraduates and roughly 4,500 graduate students for a total student body population of about 10,000. For the purpose of conducting an examination of Carnegie Mellon peer institutions, only institutions with total student populations of above 5,000 were considered. This narrowed the peer group of 620 schools down to 230 institutions.

Just as a peer group can be defined in many ways, there are many ways of placing a boundary on student populations to ensure an appropriate peer group. To conduct the examination of peer institutions, a fairly loose filter was applied as seen above. However, a tighter bound could be placed on the population filter, where both undergraduate and graduate populations should be within a certain range of Carnegie Mellon's enrollment. When the ranges of 3,000 to 8,000 undergraduates (± 45 percent) and 3,000 to 6,000 graduate students (± 33 percent) were applied to the data set, the peer group was just eight schools. The method by which the peer group was generated in Excel pivot tables made this change very easy. However, for the analysis reported below, the filter resulting in 230 schools was used.

6.4.1.7. Number of PhDs Awarded

PhD's indicate that research is taking place at a university. As a research university, Carnegie Mellon should be comparing itself to other research universities. Research buildings also are different from other buildings on a college campus and thus have different energy use characteristics. Only institutions that award PhDs were considered in the peer group. However, it is more than just the fact that a school awards PhDs that matters. A quick examination of schools that simply award PhDs showed a number of schools that did not seem to be appropriate peer group schools for Carnegie Mellon. Almost always, the institutions that did not seem to fit into a Carnegie Mellon peer group had very few PhDs awarded per year. As a result, the schools were filtered on the number of PhDs awarded per year. This particular filter is a point of departure from the other filters due to the availability of data. The large initial dataset of over 6,000 schools does not provide the number of PhDs awarded per year. Therefore, the filter was applied using data that was manually collected on each of the schools individually. To simplify the task, schools that did not award PhDs were removed first, which brought the list of 230 peer schools down to 85 schools. Then, by checking each of the 85 schools, the peer group was narrowed down to only 49 universities that awarded more than 50 PhDs per year.

6.4.1.8. Climate Zone

Sustainability challenges are highly dependent on climate, so comparing schools that are of a similar climate makes for a better comparison. In Figure 6.3.2, it was seen that schools from different regions in the U.S. undertake sustainability initiatives in different ways. One way of accounting for the differences in climate is through use of a climate zone filter. The climate zone filter is one thing that makes the sustainability peer group very different than many other peer groups that the university may use to assess itself. Climate zones were assessed by placing schools into one of five "bins" according to heating and cooling degree day information for a school. Heating and cooling degree days are units of measurement for temperature variations from a norm of 65° F over the course of one year. Climate zone data in annual heating degree days and cooling degree days was acquired for a majority of ZIP codes in the U.S. from MelissaData (MelissaData 2008). Schools were matched up to heating/cooling degree day data based on ZIP codes. Finally, thresholds were applied to the heating/cooling degree day data to establish climate zones according to the thresholds found from the Energy Information Administration (EIA 2008).

Carnegie Mellon has on average about 700 cooling degree days and over 5,700 heating degree days and is thus placed in Climate Zone 2. For a comparison, Stanford University has roughly 65 percent of the number of cooling degree days as Carnegie Mellon and 45 percent of the number of heating degree days, which makes Stanford in Climate Zone 4, suggesting it uses substantially less heating and cooling energy than Carnegie Mellon. As a result, Stanford most likely consumes less energy than Carnegie Mellon for heating and cooling. While Stanford and Carnegie Mellon may appear to be appropriate peer institutions for academic purposes, the connection is weaker from a sustainability standpoint. Therefore, when it comes to a sustainability peer group, it makes sense to compare institutions in the same climate zone. The climate zone filter removed a number of schools from the peer group, taking its size from 49 institutions to just 24. These 24 schools became the peer group that was used as a basis for analysis.

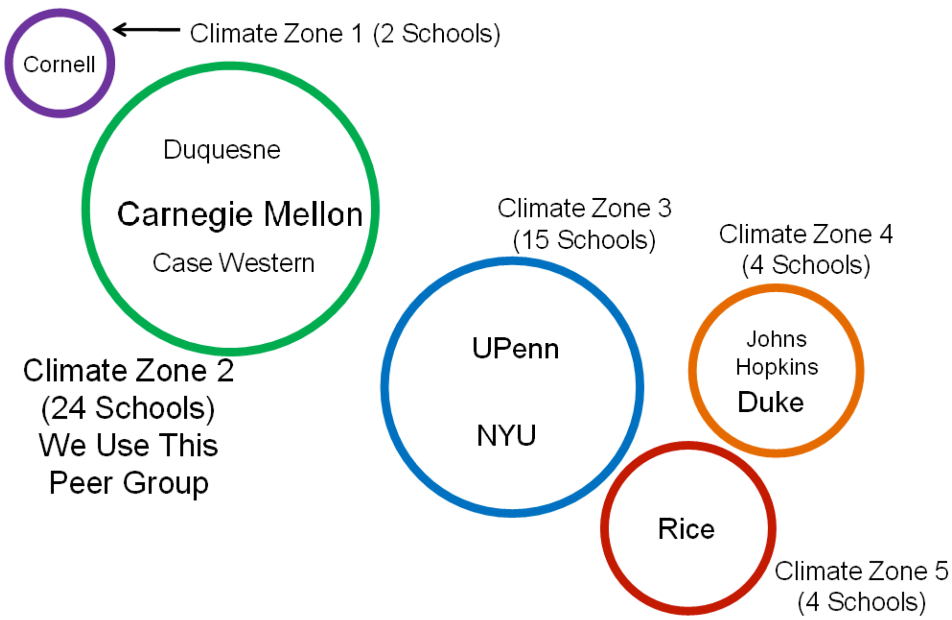

Figure 6.4.1 – Breakdown of 49 institutions by climate zone with examples

Another way of showing how the climate zone filter was able to reduce the number of schools in the peer group is to show geographically where schools were located before and after the filter was applied. Figures 6.4.2 and 6.4.3 show maps of the United States with climate zones drawn onto it. This map shows approximately where the climate zone boundaries are, but there are several climate zone "pockets" around the country where a relatively small area may not fall into the same climate zone as much of its surroundings due to certain geographic features. Some of the peer group schools are located in some of these pockets. Figure 6.4.2 shows the number of schools in the peer group located in different states before the application of the climate zone filter. Figure 6.4.3 shows the schools' home states after the filter was applied. The schools in Figure 6.4.3 are the universities that make up the Carnegie Mellon sustainability peer group.

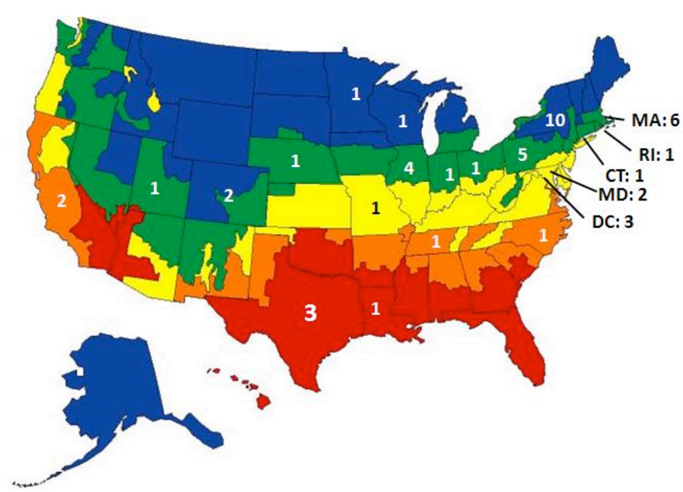

Figure 6.4.2 – Geographic location of peer group schools before climate zone filter (EIA 2008)

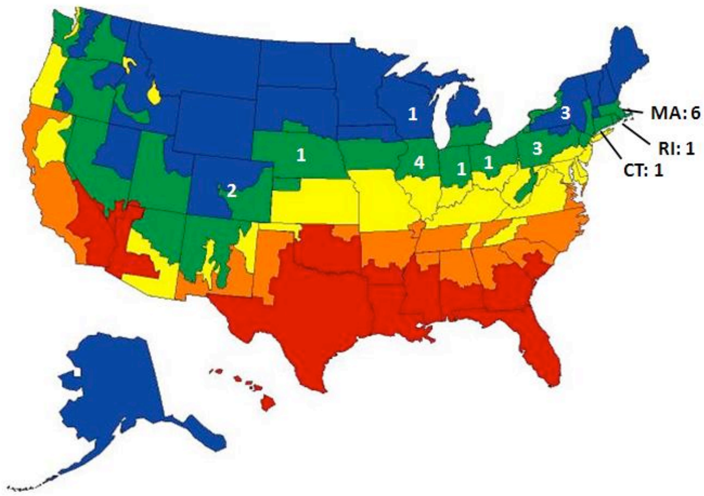

Figure 6.4.3: Geographic location of peer group schools after climate zone filter (EIA 2008)

6.4.1.9. Carnegie Mellon Sustainability Peer Group

After the application of each filter, there were 24 remaining schools in the Carnegie Mellon sustainability peer group. These schools are:

- Boston College
- Boston University
- Brandeis University
- Brown University
- Carnegie Mellon University
- Case Western Reserve University
- Creighton University
- Duquesne University
- Harvard University
- Illinois Institute of Technology
- Lehigh University
- Loyola University Chicago
- Marquette University
- Massachusetts Institute of Technology
- Northeastern University
- Northwestern University
- Regis University
- Rensselaer Polytechnic University
- Syracuse University
- University of Chicago
- University of Denver
- University of Notre Dame
- University of Rochester
- Yale University

6.4.1.10. Automatic Peer Group Generation

The primary reason for generating the Carnegie Mellon sustainability peer group in this way was to ensure that any school in the nation would be able to do much the same thing and create their own group of peer institutions for the purpose of sustainability benchmarking. As such, the generation of a school's peer group can be automatic given that a particular institution is using the same family of filters that Carnegie Mellon is using to find a peer group (even though the filter assumptions could be different). This process is not only easy to undertake but can very simply be implemented via website and made available to all U.S. colleges and universities. This can be shown by creating a sustainability peer group for the University of Pittsburgh. While Carnegie Mellon and the University of Pittsburgh are very similar (both four-year, not-for-profit, in an urban setting, greater than 5,000 students, have campus housing, award PhDs, and are in Climate Zone 2), University of Pittsburgh is a public school and thus falls into a different peer group. The sustainability peer group for University of Pittsburgh was created in a matter of seconds and contains the following 32 schools:

- Ball State University
- Boise State University
- Chicago State University
- Cleveland State University
- Colorado State University
- Illinois State University
- Indiana University-Purdue University-Indianapolis
- Iowa State University
- Northern Arizona University
- Pennsylvania State University-Main Campus
- Rhode Island College
- Southern Connecticut State University
- SUNY at Albany
- SUNY at Buffalo
- University of Akron Main Campus
- University of Colorado at Boulder
- University of Colorado at Colorado Springs
- University of Colorado Denver
- University of Illinois at Chicago
- University of Illinois at Urbana-Champaign
- University of Iowa
- University of Michigan-Ann Arbor
- University of Nebraska at Omaha
- University of Nebraska-Lincoln
- University of Northern Colorado
- University of Pittsburgh-Pittsburgh Campus
- University of Wisconsin-Milwaukee
- Virginia Polytechnic Institute and State University
- Wayne State University
- Western Connecticut State University
- Western Michigan University
- Youngstown State University

If this peer group was considered not to be accurate or to be too large, it could easily be adjusted by manipulating some of the filter criteria on population, since the University of Pittsburgh is a much larger school than Carnegie Mellon or by adjusting some of the filters such as the number of PhDs, as was done in the Carnegie Mellon case.

6.5. Other Peer Groups

The importance of generating a sustainability peer group can bee seen by looking at other Carnegie Mellon peer groups. The sustainability peer group was founded on different criteria. Consequently, many schools that are typically considered part of the school's peer group are not in the sustainability peer group, while schools that may not be considered peer institutions have been included in the sustainability group. The following are some popular peer groups for Carnegie Mellon and how they compare to the 24 schools in the sustainability peer group.

6.5.1. Carnegie Mellon Self-Reported List of Peer Institutions

The Carnegie Mellon 2007-2008 Factbook publishes a list of fourteen peer institutions for the purposes of benchmarking. Of the 14 schools, only four of them are in the sustainability peer group. Each of the ten schools in the administration's peer group list that were not included in the sustainability peer group was located in a different climate zone. However, for several of the schools, there were other criteria that were responsible for filtering them out. Table 6.5.1 lists the fourteen schools and lists the reason(s) for not being included.

Table 6.5.1 – Carnegie Mellon administrative peer group

Peer Institution	Reason(s) for Not Being in Sustainability Peer Group
California Institute of Technology	Climate zone (4), population (2,086 total students)
Carnegie Mellon University	Included
Cornell University	Climate zone (1)
Duke University	Climate zone (4)
Emory University	Climate zone (4), campus setting (suburban)
Georgia Institute of Technology	Climate zone (4), institution type (public)
Massachusetts Institute of Technology	Included
Northwestern University	Included
University of Pennsylvania	Climate zone (3)
Princeton University	Climate zone (3)
Rensselaer Polytechnic Institute	Included
Rice University	Climate zone (5)
Stanford University	Climate zone (4), campus setting (suburban)
Washington University in St. Louis	Climate zone (3), campus setting (suburban)

6.5.2. U.S. News & World Report Top 50 Universities

The U.S. News & World Report college rankings are a very popular way of comparing colleges and universities. Each of the 14 schools that are in Carnegie Mellon's administrative peer group is in the top 50 list. The sustainability peer group of 24 schools contains fifteen of the top 50 universities. These fifteen schools are:

- Boston College
- Brandeis University
- Brown University
- Carnegie Mellon University
- Case Western Reserve University
- Harvard University
- Lehigh University
- Massachusetts Institute of Technology
- Northwestern University
- Rensselaer Polytechnic University
- Syracuse University
- University of Chicago
- University of Notre Dame
- University of Rochester
- Yale University

As in the case of the administrative peer group, most of the schools in the top 50 list were not included in the sustainability peer group due to the climate zone classification. To reemphasize the importance of the climate zone filter in reducing the number of schools in the peer group, there are only four Climate Zone 2 schools that are in the U.S. News & World Report Top 50 but not in the Carnegie Mellon sustainability peer group. The name of the institution and the reasons they were not included are shown in Table 6.5.2.

Table 6.5.2 – U.S. News & World Report schools in Climate Zone 2 but not in peer group

Institution	Reason(s) for Not Being in Sustainability Peer Group
Pennsylvania State University, University Park	Institution type (public)
Tufts University	Campus setting (suburban)
University of Illinois, Urbana Champaign	Institution type (public)
University of Michigan, Ann Arbor	Institution type (public)

6.5.3. University Athletic Association (UAA)

Athletic leagues are another way of establishing a peer group for an institution. Carnegie Mellon belongs to the University Athletic Association, a conference of eight schools. Five of these schools are members of the sustainability peer group, where each of the schools not included was filtered out based on climate zone. The list of the schools in the UAA as well as the reasons that schools were filtered out of the peer group is listed in Table 6.5.3 below.

Table 6.5.3 – UAA member institutions

Peer Institution	Reason(s) for Not Being in Sustainability Peer Group
Brandeis University	Included
Case Western Reserve University	Included
Carnegie Mellon University	Included
Emory University	Climate zone (4), campus setting (suburban)
New York University	Climate zone (3)
University of Chicago	Included
University of Rochester	Included
Washington University in St. Louis	Climate zone (3), campus setting (suburban)

6.5.4. AASHE Member Schools

The administrative peer group, the US News & World Report college rankings, and the UAA member schools show that there are multiple ways of determining a school’s peer institutions. This is true even on the issue of sustainability peer groups. Another way of determining a sustainability peer group is to use the Association for the Advancement of Sustainability (AASHE) member schools. AASHE has 424 member institutions, including Carnegie Mellon. However, the list of AASHE member schools presents some problems as a sustainability peer group. First, a peer group of 424 institutions present a very significant analysis challenge when it comes to benchmarking. Secondly, AASHE contains member schools that are two-year community colleges as well as very small rural universities that do not resemble Carnegie Mellon. 15 of the AASHE member schools were included in the sustainability peer group that was generated through the filtering process.

6.6. Non-Carnegie Mellon Peer Groups and Filter Effectiveness

The process of determining a peer group is not just for Carnegie Mellon but could be undertaken by any college or university in the list of over 6,000 schools that served as the starting point. There are many permutations of values for the filters applied to get the Carnegie Mellon sustainability peer group, with only one that does not include Carnegie Mellon as a member. All schools that were not included in the Carnegie Mellon sustainability peer group must fall into one of the many other peer groups that could be established with the same filters. There are six filters (two-year versus four-year, for-profit versus not-for-profit, public versus private, campus housing versus none, and awards PhDs or not) that have two possible values. The campus setting filter, whether a school is located in a city or not, has three possible values due the fact that data were not available for all schools. The three values are located in a city, not located in a city, or data unavailable. The climate zone filter has five possible values. Due to the fact that this was an automatic peer group generation, the filter of whether a school awards any PhDs was used as the filter, rather than filtering on a school awarding more than fifty PhDs per year. The reasoning for this is explained in Section 6.4. In total, this creates 960 different peer groups into which a school could fall. However, not all of these peer groups actually have schools in them. For instance, no two-year institution grants PhDs, so any peer group established with both of these criteria would not have any schools in it. Running an exhaustive search across all possible peer groups, it was determined that only 271 out of the 960 total peer groups had any schools in the group. In addition, 58 of the 271 groups only had one institution in the peer group. On average, there were roughly 23 schools per group.

The largest peer group out of the 960 total peer groups had 455 schools and filtered to institutions that were two-year, private, for-profit, schools that had no campus housing, did not award PhDs, had less than five thousand students, and were located in cities in Climate Zone 5. In fact, the largest four peer groups, with respective school counts of 455, 390, 387, and 319 were all very similar, differing only by the climate zone that they were located in. Removing two-year and for-profit institutions from the list, the average size of a peer group dropped down to about 17 schools.

The exhaustive peer group search also demonstrates which filters are the most effective to apply. Effectiveness was defined on the criteria that a filter will be effective if it narrows down the number of schools in a peer group by being applied. This was measured by looking at adjacent peer groups, which is defined as two peer groups that differ on only one criterion. For example, two peer groups that are identical with the exception that one awards PhDs and one does not are said to be adjacent with respect to the PhD filter. If two adjacent groups both have schools in them, then the filter that they are adjacent with respect to is an effective filter, because by being applied, it narrowed down the number of schools. This was done across all 271 peer groups that had schools in them to get a measure for a filters average effectiveness. Table 6.6.1 shows the effectiveness of each filter. The most effective filter was climate zone, which was effective 97 percent of the time. This was followed by campus housing, which was effective 86 percent of the time. The least effective filter was the public versus private filter, which was only effective 46 percent of the time.

Table 6.6.1 – Filter effectiveness

Filter	Effectiveness (%)
Two-Year versus Four-Year	60%
Public versus Private	46%
For-Profit versus Not-for-Profit	61%
Campus Housing versus None	86%
Campus Setting: City versus Rural	79%
Population: Greater or Less than 5,000	66%
Awards PhDs	52%
Climate Zone	97%

6.7. Methods for Comparing Peer Group Green Initiatives

After determining Carnegie Mellon's sustainable peer group, the next step was to compare different programs implemented at each school. However, this can be a difficult task, since there are an infinite number of ways that these initiatives can be compared. Given that each school presents only a limited amount of information on each initiative and that amount varies between each school, it is nearly impossible to compare the overall effectiveness of each initiative.

Due to time constraints, it was necessary to eliminate all comparisons regarding the effectiveness of an initiative. By doing this, the job of comparing these schools winded down to merely determining whether they had the program or not. To this extent, a school that has the program it is counted, and a school that does not have the program is not counted. Ensuring consistent data collection for each of these initiatives required a list of definitions for each initiative and rules to which each of the initiatives were considered to count as having taken place. Before discussing these definitions and rules for each initiative, it is necessary to talk about which initiatives were chosen to use for school comparisons and justifications for these choices.

6.7.1. Determining and Defining School Initiatives

In total, a list of 31 initiatives to compare was generated. Most of these initiatives were taken from the (AASHE) website as popular initiatives implemented on university campuses. Some initiatives were excluded and a few were added based on their relevance to the analysis of Carnegie Mellon programs. For example, while paper conservation is a very popular initiative on the Carnegie Mellon campus, it was not included in the list of 31 initiatives. Again, this exclusion is due mostly to time constraints and the impact that an initiative has on a campus. Although paper conservation may be beneficial, it is not as significant, for example, as an on-campus cogeneration plant. Therefore, the decision to include or exclude a certain initiative on the list was based upon time constraints and the relative impact the initiative has on the campus. Once the list of initiatives was finalized, each program was given a clear definition of what it incorporated.

6.7.2. List of Initiatives and Definitions

All incentives must already be built, installed, or implemented or in the process of being done so to be counted.

- **Presidents Climate Commitment:** signed PCC
- **Talloires Declaration:** signed Talloires Declaration
- **Other Sustainability Pledge:** signed any type of national or international pledge similar to PCC or Talloires Declaration; excludes individual school pledges
- **Setting Up Offices:** office where environmental groups meet to set up programs on campus; should also be place where students can visit in order to inquire about sustainable programs on campus; excludes private offices of faculty, staff, or students that have irrelevant job titles to sustainability initiatives
- **Environmental Coordinator:** person or group of people with a job title of Environmental Coordinator/Environmental Coordination group or is related to such a title; must spend a significant amount of their job dealing with sustainable programs on campus; should be at least a contact number, a job description, a title, or achievements listed
- **Inventory Update/Internal Audit:** any significant amount of data collected and recorded at a school regarding measures of energy/electrical/waste/toxic inputs or outputs; not considered significant if it is done by surveys or does not have a solid justification source
- **Reduction Plan:** statement written for a school mission, strategic plan, or sustainability website that outlines future reduction plans for energy/electrical/waste/toxic inputs or outputs; must include detailed description of plans, amount of reduction, and date by which it will be done
- **Hybrid/Biodiesel:** any on campus (or campus used) fleet of vehicles (or vehicle) that are hybrid or use biodiesel as fuel
- **Campus Shuttle:** shuttle that is used primarily for the purpose of reducing carbon emissions by carpooling faculty/staff/students to and from campus; shuttle(s) must be associated with green practices to count; does not count if the shuttle is used primarily for other reasons (e.g., safety)
- **Subsidized Public Transportation:** any monetary incentive(s) used by the school to promote public transportation use from the faculty/staff/students
- **Car Sharing:** any incentive, monetary or otherwise, used by school to promote car sharing between faculty/staff/students; Zipcars or other cars used by more than one person on campus count in this section
- **"Tax" or "subsidy:"** any monetary incentive/disincentive given to faculty/staff/students to decrease emissions from traveling to and from campus
- **LEED Certified Buildings:** any LEED Certified Buildings built on campus; future plans for building(s) are excluded
- **Insulated Windows/Roofs:** any noteworthy amount of insulation added to windows/roofs while retrofitting a building; must be specified as a green initiative being done on campus to reduce emissions from heating/cooling a building
- **Centralized Load Shedding System:** system installed in order to control power consumption metering and meter interfacing circuitry; by entering overall power consumption into a central processing unit, this system should be able to increase energy efficiency and should be installed for this purpose
- **Energy Efficient Lighting:** replacing older light bulbs in at least one building with CFLs or LEDs to reduce energy consumption
- **Motion Sensors:** installing motion sensors for lighting or all electricity/energy use in at least one campus building
- **Geothermal Heating/Cooling:** installing geothermal heating/cooling system or ground source heat pump in at least one building to increase energy efficiency

- **Utility:** any larger energy/electricity generator installed on campus to reduce emissions from getting energy/electricity elsewhere; includes Heating/Cooling utility and cogeneration plants
- **Utility Retrofit:** any additions of new technology or features to older systems or utility mentioned above *(Note: the percentage was not calculated by including all schools but only considering the schools that have utilities)*
- **Cogeneration Plant:** has an operating cogeneration plant used to produce energy and heating for the school
- **Renewable Energy:** uses any type of renewable energy technologies such as solar power, wind power, hydroelectricity, or other renewable source for on campus utility; includes small amounts of energy inputs from these technologies
- **Water Conservation:** installing water conservation technologies or devices to reduce the amount of water used; devices may vary widely; must be used in at least one on campus building
- **Green Cleaning:** switched cleaning solutions or techniques that decrease the amount of toxics and waste produced from cleaning on campus buildings
- **Sustainability Courses:** any courses added to school curriculum largely associated with sustainability and green practices
- **Research Programs:** studies involved in sustainability issues
- **Environmental Student Groups:** any number of students that form a group concerning themselves with sustainability on/off campus that are officially recognized by the school
- **Waste Reduction/Recycling Compositing:** program that encourages waste reduction/recycling on a school-wide basis
- **Sustainable Food Purchasing Policy:** purchasing organic, local, or environmentally friendly made food for use on campus
- **Public Awareness Campaigns/Campus Conference:** any type of formal speech or campaign made on campus in order spread knowledge on sustainability
- **Environmental Housing Option:** home for a group of students dedicated to living together with a focus on environmentally-friendly practices

6.7.3. Process of Compiling Data

In order to compile data for this analysis, the first approach was to search for sustainability websites associated with these institutions. When the comprehensive websites were available, it was easy to extract information. However, it was rare to find all information necessary from the sustainability websites alone. In some cases, the websites were not useful at all, which then required keyword searches to locate the needed results. For instance, if the sustainability websites did not have information on initiatives for transportation, the keyword "transportation" was searching. If the transportation website existed, more specific initiatives within the website were examined. If the information was still unavailable, more specific keywords (e.g., "carpool") were searched. When no results were found, it was recorded that such initiative does not exist. It took average of two hours to look for initiatives for a single school. Therefore, compiling the initiatives of the peer group schools took over 50 hours.

6.7.4. Criteria to Create Consistent Data

Once determining the peer group, initiatives, and their definitions, it was also necessary to determine additional criteria for deciding if an initiative is counted as completed. Working under certain time constraints only gave the opportunity to look up these schools and their initiatives online. Therefore, the following three criteria were developed to determine if the initiative was readily documented on the Internet: available, updated, and sufficient.

The availability of the program or initiative was important in building the dataset. The Internet was the only means of determining whether an initiative was in place, and an initiative was not considered to be complete if documentation on the school's website was not available. Even if the school had the initiative, if they did not advertise is on their website and keep information readily available for the public, it was assumed that the initiative was nonexistent at that school.

In addition to the availability of the website, it must have been updated to within ten years of the date that information about the incentive was searched. This filter prevented the analysis from counting initiatives that were completely outdated.

The last criterion was based on whether information regarding the initiative was sufficient enough to define it similarly to the assigned definitions of each program. If the website included minimal information about the initiative as to be unclear about what it was, these initiatives were considered to be not undertaken.

6.7.5. Building the Dataset

After devising a clear set of rules for determining if an initiative was counted as completed, it was possible to begin building the dataset. The dataset was based on a binary system of numbers, where "1" designates an initiative at a school that was completed and "0" indicates that it was not undertaken.

The actual dataset was built in Excel with all 24 schools in the far left column and all 31 initiatives in the second to top row. In the first row, the initiatives were split into five different categories to ease to process of finding each type of initiative online. The five categories were taken from the ASSHE profiles website and are listed in the following order: Governance and Administration, Transportation, Infrastructure, Curriculum and Research, and Campus Culture.

After filling in the dataset for completed initiative, the columns or rows could be added up to see what schools are doing the most and how Carnegie Mellon compares. Additional data were collected for each school that was believed to be useful in the analysis of the campus initiatives. These categories of information were: school endowments, number of PhDs awarded, total estimated student expenses before aid, number of full-time and part-time undergraduates, sustainability websites, and any additional useful information. The next section will describe the analysis of these data.

To compensate for information not captured in the dataset, an additional column for remarks was included. Special notes were taken for the schools that were in the process of implementing sustainability programs but were not yet installed. Sustainability initiatives were also recorded that seemed effective but did not fall into a category included in the dataset, such as green purchasing and green roof installation.

This was a very time consuming process, because unlike AASHE profile, information was not already available and in a single location. In many cases, the information was unavailable, and when it was accessible, it seemed outdated or scattered across different websites. The schools that had sustainability-related websites made this task more manageable. However, even in their sustainability websites, required information was difficult to find and required more extensive searches of the school websites.

6.8. Results of Peer Group Comparison

Based on the AASHE 44 profiles, a green initiative datasheet was developed to capture information on the types of sustainability programs that universities have initiated. The types of programs were broken down into five broad categories: "Governance and Administration," "Transportation," "Infrastructure," "Curriculum and Research," and "Campus Culture."

Figure 6.8.1 shows the initiatives that were assessed for every university in Carnegie Mellon's peer group. The chart illustrates the percentage of universities in the peer group that have embarked on that particular initiative. The bars on the chart are one of two colors to demonstrate whether Carnegie Mellon has done the initiative, revealing Carnegie Mellon has undertaken 23 of the 31 initiatives. In general, the participation in sustainability programs for the Carnegie Mellon peer group was comparable to that of the AASHE 44 group that was analyzed previously. 67 percent of the universities in the peer group have offered subsidized public transportation as opposed to 27 percent for the AASHE 44. However, participation in initiatives under the governance and administration category was less common. For instance, 52 percent of the AASHE 44 schools signed the Presidents Climate Commitment, whereas only 27 percent of schools in the Carnegie Mellon peer group signed the commitment. One explanation for the high level of signatories among the AASHE 44 is that this group has self-selected itself to compete for a sustainability award. The schools are therefore more likely to make more public pledges to validate their commitment. Schools that are not signing the PCC tend not to apply for awards. Even though the majority of schools within the Carnegie Mellon peer group have not signed the PCC, participation in other sustainability initiatives was comparable if not better.

It is important to keep in mind that the information regarding the peer institutions' initiatives was collected by solely relying on what was available through their websites. Thus, there is a possibility that the information given may not be accurate, given whether or not the website was comprehensive, up-to-date, and easily accessible. Ideally, having access to a better and larger database of initiatives would have increased the accuracy of this analysis.

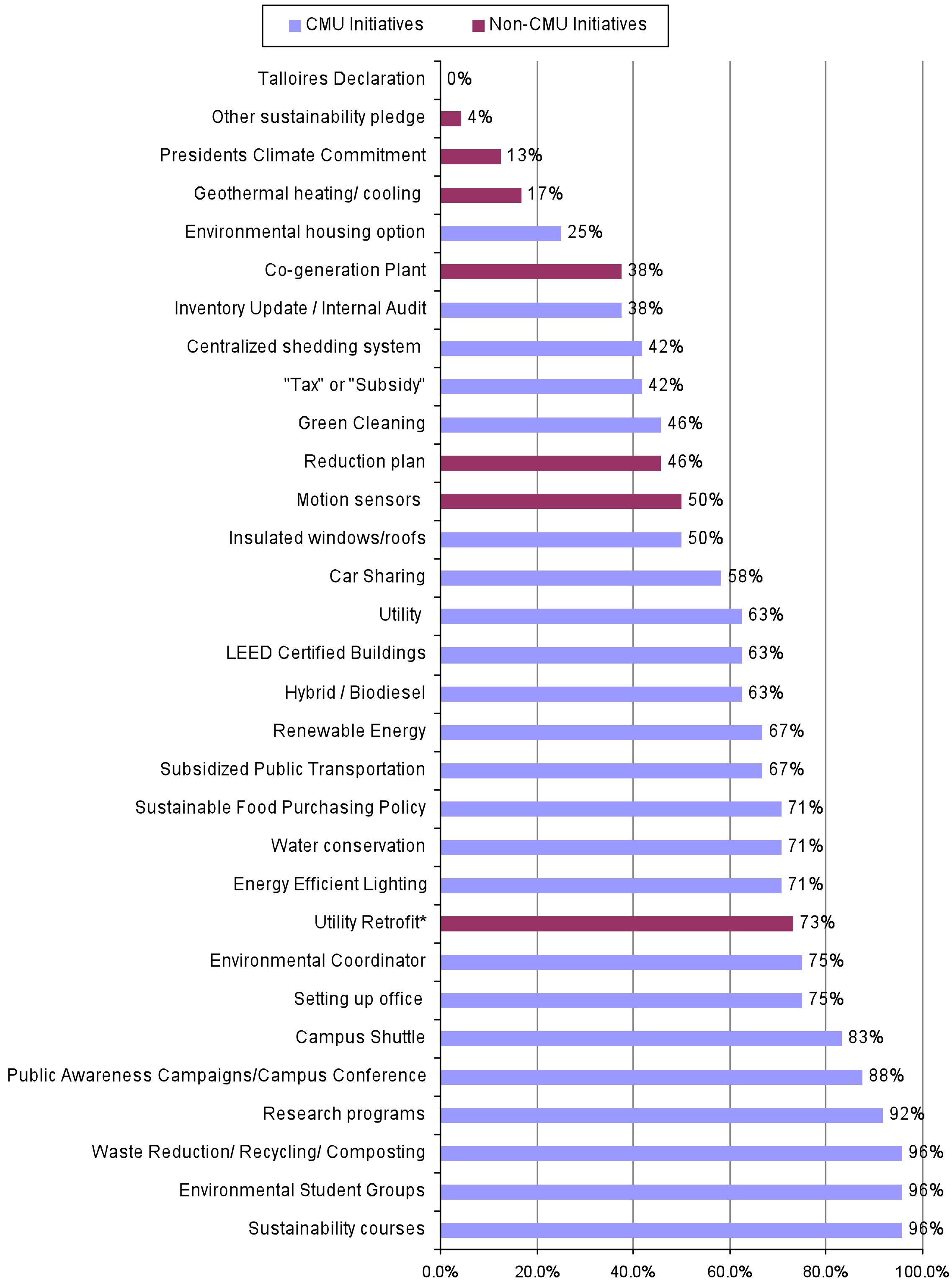

Figure 6.8.1 – Summary chart of initiatives

* Utility retrofit computed as function of schools that have on-campus utilities

From Figure 6.8.1, it appears that Carnegie Mellon fares very well in comparison to its peer institutions, as the majority of the non-Carnegie Mellon adopted initiatives were adopted by less than half of the peer institutions. Two metrics allowing a quantitative comparison of progress for each institution were generated: one that was essentially a quick count of the sustainability initiatives adopted by the university and the other an equation of a sum of scores of individual initiatives, as shown in Figure 6.8.2.

Method one reveals that approximately one-quarter of the universities in the peer group have adopted more initiatives than Carnegie Mellon, as shown in Table 6.8.1. Nevertheless, Carnegie Mellon has adopted total 22 initiatives, which is only marginally lower than institutions that have adopted the most initiatives. For instance, Yale University has adopted 27 initiatives, while Brown University has adopted 24 initiatives. Of these five universities, the average endowment is about $15.18 billion, approximately 13.6 times larger than Carnegie Mellon's endowment. Although this might suggest that endowment has a role to play in the number of initiatives that a university is able to adopt, there is a lack of evidence to substantiate this hypothesis. Several notable exceptions include Syracuse University and Brown University, which both have lower endowments than average. A regression analysis was performed between endowment figures and the number of initiative adopted. This analysis yielded an R^2 value that was about 0.3, indicating that there might be little connection between endowment size and the number of initiatives the university adopts. This analysis shows that a university with a relatively small endowment can still adopt many sustainability initiatives. Thus, endowment size should not be a huge obstacle in becoming more sustainable.

$$\text{score}_n = \begin{cases} 1 - p_n, & \text{if initiative}_n \text{ adopted} \\ -p_n, & \text{if initiative}_n \text{ not adopted} \end{cases} \quad \text{- equation (1)}$$

where p_n is the percentage of schools that have adopted initiative$_n$

$$\text{final score} = \sum_{i=1}^{n} \text{score}_n$$

Figure 6.8.2 – Equation for method two

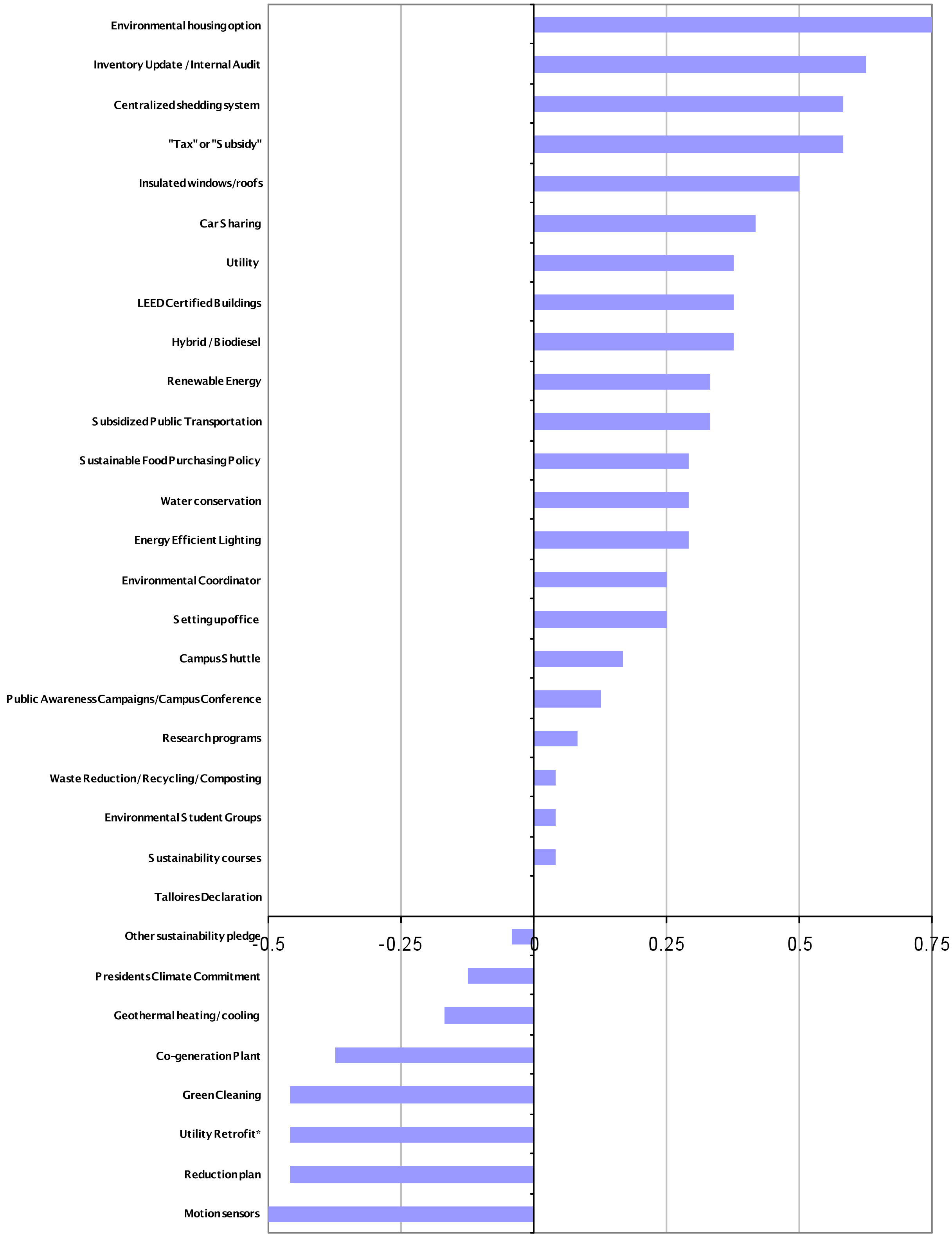

Figure 6.8.3 – Initiative contribution to Carnegie Mellon's final score

Table 6.8.1 – University sustainability score rankings (method one)

Rank	School Name	Number Of Initiatives	Endowments 2007 (in thousands of $)
1	Yale University	27	22,530,200
2	University of Notre Dame	25	5,976,973
2	Harvard University	25	34,634,906
3	Massachusetts Institute of Technology	24	9,980,410
3	Brown University	24	2,780,798
4	University of Rochester	22	1,726,318
4	Syracuse University	22	1,086,143
4	**Carnegie Mellon University**	**22**	**1,115,740**
5	Boston University	19	1,101,386
6	University of Denver	18	277,465
6	Illinois Institute of Technology	18	271,718
6	Boston College	18	1,670,092
7	Rensselaer Polytechnic Institute	17	812,996
7	Case Western Reserve University	17	1,841,234
8	Loyola University Chicago	16	181,530
8	Brandeis University	16	691,370
9	Northwestern University	15	6,503,292
9	Northeastern University	15	679,926
10	University of Chicago	13	6,204,189
11	Marquette University	12	360,250
11	Duquesne University	12	174,670
12	Lehigh University	9	1,085,639
12	Creighton University	9	408,311
13	Regis University	4	39,446

Method two was then used to compute a score for each university. This method yielded a similar rank of universities. Using this method, a university would gain more points for adopting initiatives that only a small proportion of universities have taken up. Conversely, this method would penalize a university with a higher negative score for not adopting initiatives that most of its peers have. Using this metric, an institution that has a score of above zero would be performing above average, while a score below zero would be performing below average. Figure 6.8.3 shows the scores contributed by each initiative for Carnegie Mellon. This figure shows that Carnegie Mellon offers an "Environmental Housing Option," which is undertaken only by a minority of its peer institutions. On the other hand, Carnegie Mellon has been penalized for not developing and making public its reduction plans. This was an initiative that has been adopted by close to half of its peer institutions.

From this analysis, Carnegie Mellon achieved a score of 4.54 and is ranked fourth amongst its 24 peer institutions. This score implies that Carnegie Mellon is doing more and performing better than many of its peer institutions. Additionally, this shows that Carnegie Mellon is within the top third band relative to its peer institutions for sustainability initiatives, even though it resides at the bottom of this band.

Table 6.8.2 – University sustainability score rankings (method two)

Rank	School Name	Score	Endowments 2007 (in thousands of $)
1	Yale University	9.54	22,530,200
2	Harvard University	7.54	34,634,906
2	University of Notre Dame	7.54	5,976,973
3	Brown University	6.54	2,780,798
3	Massachusetts Institute of Technology	6.54	9,980,410
4	University of Rochester	4.54	1,726,318
4	**Carnegie Mellon University**	**4.54**	**1,115,740**
4	Syracuse University	4.54	1,086,143
5	Boston University	1.54	1,101,386
6	Illinois Institute of Technology	0.54	271,718
6	University of Denver	0.54	277,465
6	Boston College	0.54	1,670,092
7	Case Western Reserve University	-0.46	1,841,234
7	Rensselaer Polytechnic Institute	-0.46	812,996
8	Brandeis University	-1.46	691,370
8	Loyola University Chicago	-1.46	181,530
9	Northeastern University	-2.46	679,926
9	Northwestern University	-2.46	6,503,292
10	University of Chicago	-4.46	6,204,189
11	Duquesne University	-5.46	174,670
11	Marquette University	-5.46	360,250
12	Creighton University	-8.46	408,311
12	Lehigh University	-8.46	1,085,639
13	Regis University	-13.46	39,446

Figure 6.8.4 shows the list of initiatives that Carnegie Mellon has not undertaken. Most of these initiatives were adopted by a minority of the universities in Carnegie Mellon's peer group with the exception of utility retrofit. Signing sustainability pledges like the Presidents Climate Commitment and Talloires Declaration seems to be an unpopular initiative to adopt. Among the initiatives that Carnegie Mellon has failed to adopt, the three initiatives of reduction plans, motion sensors, and cogeneration plants have been adopted by close to one-third of Carnegie Mellon's peer institutions. This suggests that these initiatives are practical and that feasibility studies on these initiatives are worth exploring.

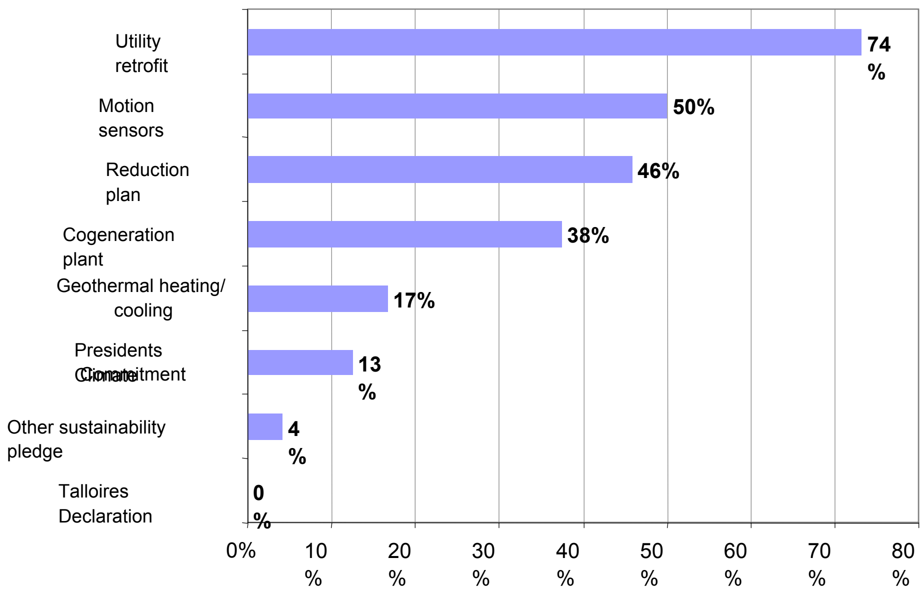

Figure 6.8.4 – Initiatives that Carnegie Mellon has not undertaken

This analysis also looked at the average participation rate of initiatives for each category. The results are shown in Figure 6.8.5. According to the collected data, schools within Carnegie Mellon's peer group are particularly active in the "Curriculum and Research" category but tend to be more passive for "Governance and Administration" initiatives. This mix of initiatives is odd, because good governance and administration are likely to lead to proper management of sustainable initiatives, which is a precursor to a cohesive and progressive effort toward becoming a more sustainable campus. It should be noted that the low statistic for "Governance and Administration" was partly contributed by the lack of interest in signing sustainability pledges like the Presidents Climate Commitment and the Talloires Declaration. If the Presidents Climate Commitment, Talloires Declaration, and other sustainability pledges are omitted for the calculation of the average participation rate for "Governance and Administration," this statistic would increase to 58 percent. These figures indicate that schools within Carnegie Mellon's peer group are relatively active in adopting sustainability initiatives and that Carnegie Mellon will actively have to seek out more ways to achieve a greater level of sustainability to remain at the top of its peer group.

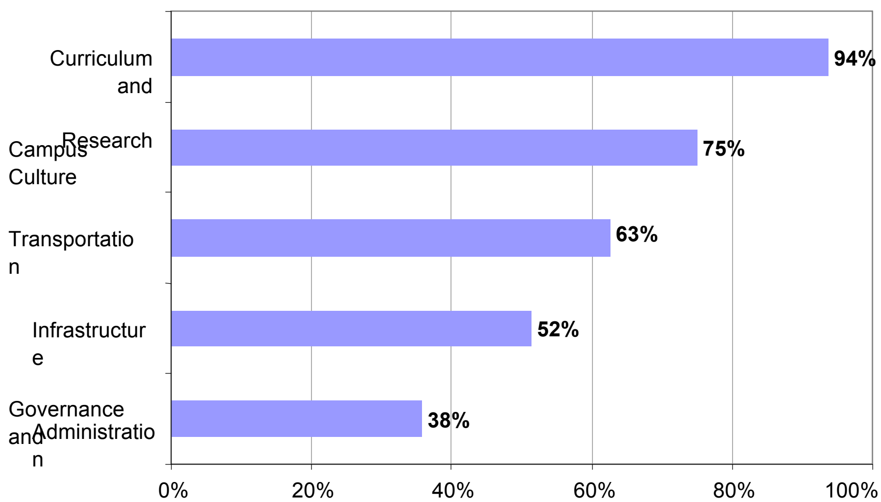

Figure 6.8.5 – Average participation rate by category

6.9. Comparison of Evaluation and AASHE STARS Program

AASHE has developed the Sustainability Tracking, Assessment, and Rating System (STARS) program and has just released Version 0.5 on April 10, 2008. STARS is a voluntary, self-reporting framework for gauging relative progress toward sustainability for colleges and universities.

The STARS framework consists of many initiatives with which a certain number of credits were assigned. These credits reflect the relative importance, difficulty and weight of each initiative. The broad categories were "Education and Research," "Operations Credits," and "Administration and Finance." These categories were then subdivided into many subcategories that make up the individual initiatives.

The STARS framework is superior to this assessment of the schools in several ways. Even though the list of initiatives in STARS is not exhaustive, it is very comprehensive. The results from adopting this framework can be very insightful to an institution, because it will identify the areas that the university has failed to tackle adequately. In addition, the scoring algorithm that has been made public with this framework makes the assessment transparent and establishes an acceptable metric for universities to compare with one another.

However, the framework is not without flaws. STARS is based on a voluntary and self-reporting system, partially because some non-public information may be required to complete its score sheet. This can be a problem, because some universities may not be willing to publish this information in the public domain. This might give rise to a situation where some universities would not be able to find a peer institution that has submitted its STARS worksheet to benchmark against. Thus, it should be evident that the success of the STARS program will be largely dependent on the level of participation and support by higher education institution within the United States. Even though the assessment methodology demonstrated in this chapter is not as comprehensive as STARS, it can be completed using publicly available information. This offers a rather quick alternative for an institution to approximate its progress relative to its peers. However, the downside of this assessment methodology is that accuracy of information is limited; as mentioned before, the assessment method was not done based on a comprehensive database.

Even though STARS is still in its infancy, the program has already shown immense potential in turning it into the definitive “scorecard” for determining a university’s progress toward sustainability.

6.10. Policy Recommendations

Based on these evaluations of schools in Carnegie Mellon’s peer group and schools that applied for the AASHE Leadership Award, signing the Presidents Climate Commitment seems to have relatively little impact on a school’s progress toward sustainability. The notion that the PCC represents an ideal pledge and should be signed is not supported by the number of signatures obtained, as only 13 percent of Carnegie Mellon’s peer schools have signed it. When counting the total number of colleges in the U.S., those in AASHE, or just within Carnegie Mellon’s peer group, only a small number of schools have signed the PCC. Most schools in Carnegie Mellon’s peer group have yet to sign *any* commitments or pledges. There was no evidence to show that schools in Carnegie Mellon’s peer group that have signed the commitment were more engaged than non-signatories of the commitment. In addition, of the 44 schools that applied for the AASHE award, only half signed the PCC. There appears to be marginal differences of the types of initiatives that have been adopted between signatories and non-signatories. The PCC alone does not even offer an effective framework or forum where universities can come together to share experiences and knowledge about moving toward carbon neutrality. Such a framework appears to be offered by AASHE but not the PCC.

The most obvious and perhaps the singular reason why a university should sign the PCC is the commitment that subsequent administrations would recognize achieving carbon neutrality as one of the university’s priorities. However, many PCC signatories do not seem to do much more in comparison to their non-signatory counterparts. Hence, the value of signing the commitment is questionable. Declining to sign the PCC does not imply the reluctance to move toward a more sustainable future. On the contrary, there exist universities that have embarked on a plethora of sustainability initiatives without signing any form of commitment. For instance, Harvard University is arguably more engaged in environmental issues than many PCC signatories. Much information about the many ongoing efforts taking place on its campus is widely publicized on the Harvard’s Green Initiatives website. Actions speak louder than words, and signing the PCC would mean next to nothing if an institution fails to act on its commitment.

Nonetheless, it is recommended that the university sign the commitment if and only if the administration views the targets dictated by the PCC as feasible and achievable. There appears to be little harm for Carnegie Mellon to sign the commitment, since the university has already committed itself to a multitude of initiatives that even some PCC signatories have yet to adopt and put into action. However, one must note that the greatest challenge for the university when it signs the commitment is to come up with a feasible and effective plan to achieve carbon neutrality within the timeframe dictated by the commitment. Hence, the pivotal question that would influence the administration to sign the commitment would be whether the university is ready to commit itself to achieving carbon neutrality.

Universities have a broad role to play in society, and being environmentally friendly and sustainable is merely one of many roles that the university is expected to fulfill. Other responsibilities include equipping its students with the necessary knowledge to become global citizens that are culturally, socially, and politically conscious as well as technology transfers and innovations through research and collaboration to bring about betterment of society. Given the other social responsibilities that a university must fulfill, the decision to move toward carbon neutrality must be dependent on the university's ability to fund the associated programs without neglecting its other responsibilities. It would no doubt be a failure of judgment on the administration's part if it opts to become carbon neutral and subsequently neglects and fails in its other social responsibilities to society. Signing the PCC would enhance the university's image in regard to its environmental commitments. However, there does not seem to be any additional value for the university to become a signatory. Furthermore, becoming a PCC signatory and adopting sustainable practices are not two mutually exclusive entities. In the worst case scenario, the university may lose much of its credibility by pledging itself to a nearly impossible commitment. A delicate balance must be struck, and the best way for Carnegie Mellon to contribute to society does not necessary have to manifest itself in signing the PCC.

An alternative to the PCC might better achieve the objective of sustainability. The fact that so few schools have signed the PCC may be a sign that it does not capture the goals of institutions or is setting objectives that schools do not feel are attainable. With over 80 percent of colleges uncommitted, there is a huge opportunity for more substantive action. A more effective program that includes a more robust framework and enforcement mechanism may attract other schools.

It is also recommended to have information easily accessible and transparent on websites. One of the difficulties faced while compiling data was locating the needed information. It is possible that some initiatives were being conducted by schools but were not considered for this analysis due to an inability to locate the information. Since the difficulty in locating the information could cause significant discrepancies in research results and recommendations, it is advised to hire a designated employee who can update their institution's website on a regular basis and also can compile data of other institutions as well. Outdated data can feed misinformation to the public, which hinders the accuracy of assessments.

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7. Data and Metrics

7.1. Introduction

7.1.1. Motivations

All of the information necessary to calculate Carnegie Mellon's carbon and ecological footprints analyses was already available. However, estimating footprints of every major four-year institution in the United States was essential in defining where Carnegie Mellon stands in relation to its peers. Since there is no such thing as the "average school" against which to make comparisons, this analysis had to have the capability to determine the footprints of as many institutions as possible. It would have been much more accurate and easier if every target institution in this analysis had their footprints publicly available. Unfortunately, only a small portion of the entire university sector has conducted footprint analyses of any sort. Thus, the analysis in this chapter estimates carbon footprints using the information available for as many institutions as possible.

The database and the estimation models can not only help Carnegie Mellon locate where it stands among all U.S. universities and colleges but also helps other institutions do the same. Thus, this analysis will not end up being "another carbon footprint" but a new guideline for every U.S. institution to improve its commitment to sustainability.

7.1.2. Objectives

The main objective of this section is to estimate electricity, energy, and carbon footprints of each four-year institution in the United States. The need for such estimations is crucial for benchmarking and peer comparison purpuses, given that only a limited number of institutions have made their carbon footprints assessments available to the public. In order to estimate these footprints, three steps were taken.

The first step was to establish a database summarizing various data on over 6,000 universities and colleges in the United States that make it possible to sort every institution into peer groups. The second step was to create estimation models that calculate energy and electricity consumption as well as greenhouse gas emissions for over 1,600 four-year institutions with undergraduate enrollment greater than 1,000. Then, using the database and the estimation model results, metrics were selected to establish fair comparisons between the target institutions of this analysis.

Aside from development of the estimation models and metrics, the database was used for two analyses. Various facts from the database were used as filters to sort schools into their respective peer groups. Also, the school-specific data such as location of the campus (e.g., ZIP-Code), and regional information including renewable energy source availabilities sorted by ZIP-Code were combined to assess the effectiveness of each mitigation possibilities for a specific campus.

Establishing a nationwide database and estimation model will not only help Carnegie Mellon locate itself among the entire sector of U.S. four-year institutions but also will provide every institution with the tool to do the same. Thus, data and metrics aspects of this project were essential in making this work a new guideline to be followed by all colleges and universities for improvements to their campus sustainability initiative and for transparently benchmarking themselves against other schools.

7.1.2.1. Significance of the Database

When comparing academic insitutions' energy or electricity consumption, it is essential to consider the broader context of their campuses for a fair comparison. For example, schools in a warmer climate zone are likely to need less energy for heating than schools in colder climate zones. Schools with on-campus housing are likely to require more energy and electricity per student than schools in which every student is a commuter. Thus, a simple list of the energy consumptions of each campus would not be the best way to identify energy intensive schools. Establishing a database and assessment of peer groups would solve this problem by identifying the characteristics of each campus that are related to its energy and electricity consumption profiles.

In addition, the database would also help to identify the most efficient mitigation possibilities. Just as energy and electricity profiles of institutions vary based on their backgrounds, the effectiveness of each mitigation possibility would change from campus to campus based on availability of renewable energy sources and other mitigation strategies. With this database, a baseline estimate can be made about the most effective mitigation possibilities for each institution.

7.1.2.2. Significance of the Energy and Electricity Estimation Models

Although it is nearly impossible to estimate the exact level of energy and electricity consumption at all U.S. colleges and universities, building estimation models and presenting the results of calculations can encourage institutions who have not reported their energy and electricity consumptions to initiate a similar effort. As much as the actual energy consumption data are important, the distributions of expected values computed by the models are equally significant since that is the "ideal" level of the consumption based on the data and information about the institution from the master database.

While the list of actual consumption data would define the biggest consumers among the U.S. institutions, the "ideal" estimates of the models would provide the list of potentials of each institution to become less energy intensive. Comparing these lists would reveal focus areas in which institutions have been making progress in comparison to each other. For instance, if two schools with similar levels of actual energy and electricity consumption have completely different values of estimated consumption according to the models, the school with a higher potential likely would have put more efforts than the school with a lower potential to reduce its energy and electricity demand. While the list of actual consumption may rank them at the same level, incorporating estimates from the models would provide more information about how energy and electricity intensive each school is given their backgrounds.

Finally, comparisons of two different models would reveal the significance of space usage in assessing energy and electricity profiles of institutions. By showing the importance of the necessary data to improve analysis estimations, all U.S. institutions can be encouraged to provide essential information to create more accurate energy and electricity profiles.

7.1.2.3. Analyses Enabled by the Designed Estimation Models

Consistent self reporting of carbon footprints form academic institutions would enable the following achievements through the use of the designed estimation model:

- To benchmark institutions within and across peer groups,

- To estimate impact of mitigation strategies,
- To estimate energy use and greenhouse gas emissions from the entire university sector, and
- To determine which data is necessary to estimate electricity use accurately.

7.2. Process Overview

7.2.1. Creating the Database

An extensive database, consisting primarily of school-specific and regional data was complied. School-specific data include locations of the schools by ZIP code, undergraduate, graduate and faculty headcounts, and the type of institutions. Those school-specific data were used to define peer groups to which each of over 6,000 institutions belong. Since the ZIP code of these schools is publicly available, the regional data sorted by ZIP codes (e.g., heating and cooling degree days or renewable source availabilities) can be assigned to each school. Those items were used to estimate how energy and electricity intensive each school is expected to be and what mitigation possibility would be the best fit for that particular campus.

7.2.2. Energy and Electricity Estimation Models

Two main sources of information were mainly used to estimate campuses' electricity consumption, one school-specific database and one regional database, to establish estimation models for the levels of campus energy and electricity consumption and carbon footprint. One of the databases used to build the model was the square footage data of campus buildings broken down into ten different categories of space use, from the Campus Facility Inventory (CFI) report by the Society for College and University Planning. Another database used for the model was the data on energy and electricity intensity per square foot from the Commercial Buildings Energy Consumption Survey (CBECS) microdata issued by the Energy Information Administration (EIA). To estimate levels of energy and electricity consumptions at each campus, the square footage value of each CFI space usage category in CFI report was multiplied by the electricity and energy intensity per square foot data of the corresponding building type from CBECS.

7.2.2.1. CFI-Based Estimation Model

The CFI Report was only available for approximately 150 four-year institutions. For institutions reporting space usage data, this model treats the reported square footage values as constants and multiplies them by the corresponding distributions of CBECS microdata points. The output of the model would be some distribution that defines the expected energy/electricity consumptions of each campus.

7.2.2.2. Regression-based Estimation Model

Although the CFI-based estimation model can give reasonable estimates, only 150 out of over 1,600 institutions have reported their square footage to the CFI. As a result, the scope of the estimations can be expanded by estimating square footage data for every CFI category for the remaning institutions using linear regression.

For schools that have not reported their space usage information to the CFI Report (classified as non-CFI institutions), analyses were run and estimates of CFI square footage in terms of facts from the master database available about those institutions were defined. Using the results of the regression analyses, distributions that define square footage for each space usage category were assigned and were used as the square footage inputs of this model.

Since the regression-based estimation model has its square footage inputs in the forms of distributions rather than constants, 90 percent confidence intervals of the estimates are wider than that of the CFI-based model results.

7.2.2.3. Carbon Footprint Estimation Model

Once the electricity consumption distribution of a campus is estimated, the carbon footprint can be obtained by multiplying the estimated electricity consumption distribution by the average state carbon dioxide emission factor in “tons of CO_2 per kWh of electricity” from eGRID database from the Environmental Protection Agency (EPA).

7.2.2.4. Estimation Model Verifications

The estimated electricity consumption values can be compared to the self-reported values of electricity consumption. For this analysis, all the estimated self-reported figures fell inside the 90 percent confidence interval of the estimates, and it was concluded that the CFI-based and regression-based models would provide reasonable estimates of electricity and energy consumption.

7.3. Data Aggregation

7.3.1. Summary Datasets

Determining which school information to include in the database is a more difficult task than it initially appears. Due to time constraints, data could not be searched and collected on a school-by-school basis. With over 4,000 four-year schools in the United States, it would not have been feasible to go through the list one school at a time. Instead, focus was placed on finding larger existing datasets and merging them.

The decision of what to include ultimately came down to two factors: availability and utility. There are many sets of information that would have been useful. However, much of this data has not been compiled by any entity into a single accessible location. Due to the large scope of this aspect of the analysis and time constraints for project completion, information from individual schools was not collected. One summary statistic is the number of full-time equivalent faculty employed by the university. This variable was later shown to correlate well with electricity use. Unfortunately, a large database with this information could not be located. The exception to this general rule is the set of schools’ self-reported energy usage. These figures were crucial for initially calibrating the model and checking its accuracy. These numbers were deemed to be important enough to find as many electricity usage numbers as possible, even on a school-by-school basis. The information in each major dataset and its source can be seen in Table 7.3.1. A full description of each source is located in Appendix 7.A. Detailed information about the matching process can be found in Appendix 7.B.

Table 7.3.1 – Table of major dataset information with sources

Information	Source	Approximate Number of Schools
Student enrollment	National Center for Education Statistics	1,600
Location	National Center for Education Statistics	1,600
Number of Doctorates Awarded	National Science Foundation	300
Research Budget	National Science Foundation	300
NCAA Division	NCAA	770
Tuition	Paul Fischbeck	1,070
SAT/ACT 25^{th} and 75^{th} percentiles	Paul Fischbeck	1,090
Space Usage	Society for College and University Planning	150

7.3.2. Local and Regional Datasets

While school-specific descriptive data are important to energy use estimations, this information does not paint a complete picture. Data for the context is indispensable to energy usage estimations. Local and regional datasets can also be used to give a baseline validation to evaluate the cost effectiveness of pursuing renewable resources. A quick overview of the regional data sources that used in the analysis can be seen in Table 7.3.2. A full description of regional data sources can be found in Appendix 7.C.

Table 7.3.2 – Local and regional data sources

Information	Source
Fuel Mix for Electricity Generation	Environmental Protection Agency
Heating and Cooling Degree Days	Department of Energy
Renewable Energy Availability	National Renewable Energy Laboratories
Energy Usage by Building Type	Department of Energy

One of the main electricity sinks within buildings is the climate control system. It takes a large amount of energy to maintain a near constant internal building temperature during the winter and summer months. This energy consumption varies for different schools, since schools in different parts of the country are located in vastly different climates. Fortunately, statistics about heating degree days and cooling degree days are available by ZIP code. Annual total heating and cooling degree days provide a quick way to see how much the daily temperature differs from 65° F, summed for the entire year. The distribution of heating and cooling degree days defines in which climate zone a school is located, as seen in Table 7.3.3.

Table 7.3.3 – Heating and cooling degree day breakdown

Climate Zone	Heating Degree-Days	Cooling Degree-Days
1	7,001 or more	1,999 or fewer
2	5,500-7,000	1,999 or fewer
3	4,000-5,499	1,999 or fewer
4	3,999 or fewer	1,999 or fewer
5	3,999 or fewer	2,000 or more

By linking heating and cooling degree days to each school by ZIP code, this study was able to determine each school's climate zone. The CBECS database has data on average energy usage per square foot by primary use and climate zone. This addition allowed for conversion between square footage and electricity usage. The EPA's eGRID database contains information on electricity carbon intensity by location. This addition enables the conversion between space usage and estimated carbon output due to electricity usage.

7.3.3. Renewable Resource Availability

Local and regional data can be used to give a first-order estimation of renewable energy availability for schools. Weather information is also the key factor here. Records of average solar intensities and wind speeds, compiled by ZIP or area code, are good indicators of how efficient an array of solar cells or a turbine would be at generating renewable energy. A visual distribution of these averages across the United States can be seen in Figure 7.3.1.

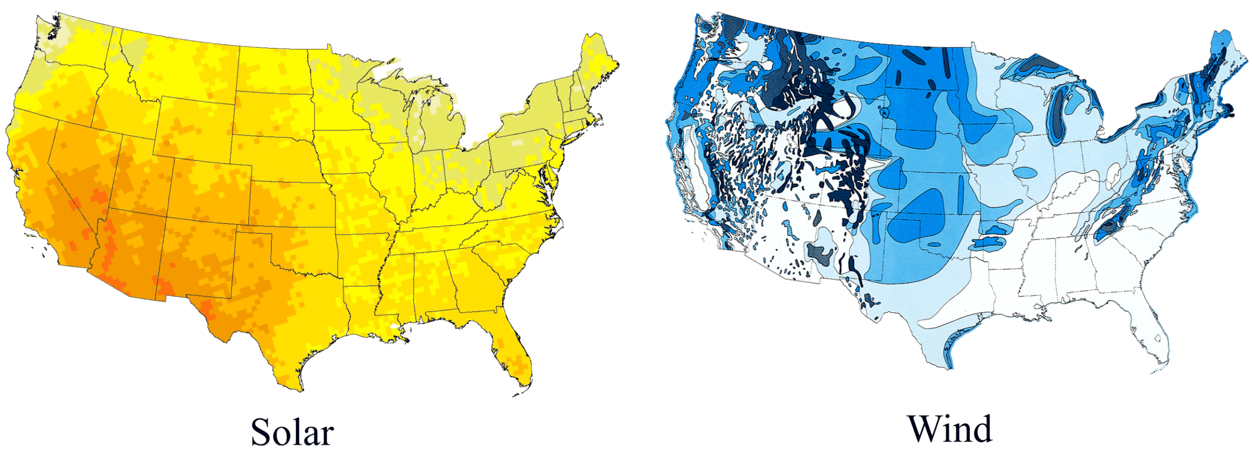

Figure 7.3.1 – Maps of solar and wind availability in the U.S. (NREL)

Merging by ZIP code and the potential for solar and wind availability provides an insight as to which academic institutions would benefit most from solar or wind renewable opportunities. While this is not indicative of schools' carbon footprints, it is an important piece of information to assess possible mitigation strategies, as discussed in Sections 5.2.4 and 5.2.5.

7.3.3.1. Wind

Wind data were provided on a county level, and ZIP codes were similarly mapped to their counties. Wind strength is reported in six power classes, 1 through 6, based on the average wind speed for the year, measured 40 feet from ground level. Conversion of this power class into an actual number for the density of wind power was made according to figures posted by the American Wind Energy Association, as shown in Table 7.3.4.

Table 7.3.4 – Table of wind power class to power density conversion rates

Power class	Power Density (W/m^2)
1	25
2	150
3	200
4	250
5	300
6	366

Wind power density data require slightly more massaging than solar data due to the intermittency of wind. Wind farms never run at the full capacity listed above for an entire year. Instead, nearly all wind power facilities produce between 20 and 40 percent of the energy that would be possible if the wind blew at the power densities listed above. Therefore, all power density numbers were multiplied by a factor of 0.3, which is generally the assumed capacity factor for wind farms. The number obtained from this calculation was further multiplied by an efficiency factor of 0.85. This accounts for the mechanical parts of a wind turbine. These numbers and local energy prices gave a potential annual savings power for wind on campuses. Also, as with solar, an assumption was made about the average price of turbines (\$415 per m^2), which was then used to separate school into three groups: those with payback periods of less than seven years, those with payback periods greater than 20 years (the assumed lifetime of the equipment), and those in between these two values. The percentages of students living in those three areas are given by Figure 7.3.2.

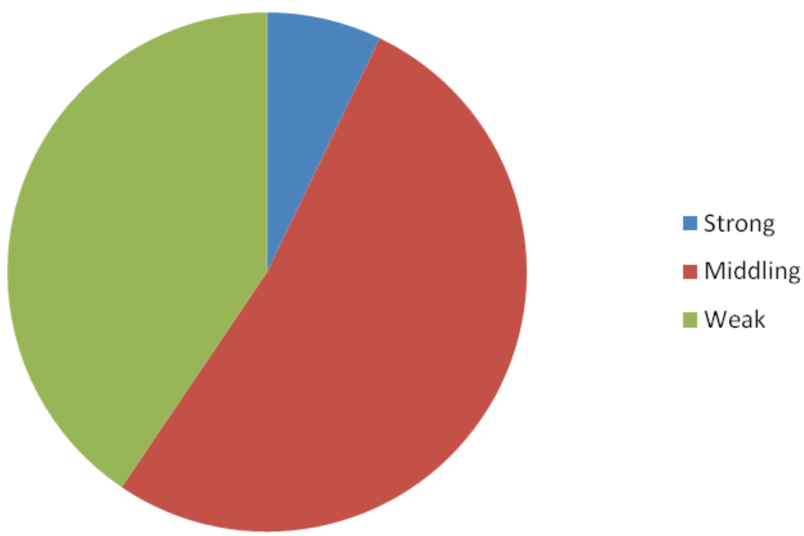

Figure 7.3.2 – Distribution of students by school wind revenue potential

7.3.3.2. Solar

The solar intensity data provided were measured at numerous stations across the United States and reported in units of average kWh per square meter per day. All ZIP codes were matched to the nearest station, and colleges were subsequently matched to solar intensity values by their ZIP codes. Schools were also matched to their electricity prices by state, using data from the EIA. Multiplying these two numbers together gives potential savings to a school in dollars per day per square meter. This number was multiplied by 365.25 to change the units to savings per year and additionally multiplied by nine-tenths as an efficiency factor that reflects on the current state of photovoltaic technology. Schools were characterized that might have notably high potential to save money using solar generating technologies or that might have prohibitively high costs given their lack of solar revenue potential. This calculation was done by assuming a cost of $1,400 per square meter of solar panel. Using these values, schools that would not make up this cost in 20 years (the accepted lifetime of solar panels) were determined in addition to institutions that recover initial capital expenses in seven years or less. Instead of giving the percentage of schools in each group, the percentage of students living in each is reported, as this information gives a general impression of solar power's capacity to lower the carbon footprint of colleges. Since such a large concentration was found in the middle group (as shown in Figure 7.3.3), this group was divided simply into those who are closer to the weak investment number (Middling-Lower) and those closer to the strong number (Middling-Upper).

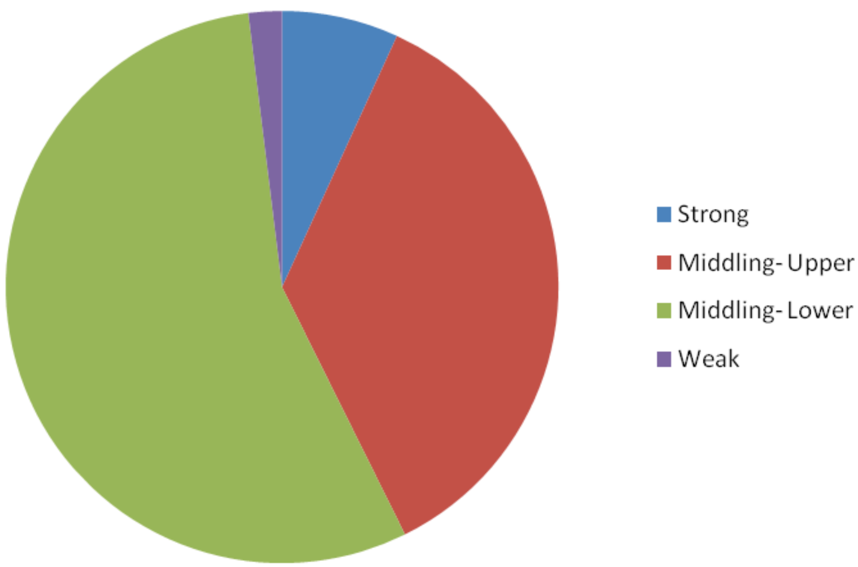

Figure 7.3.3 – Distribution of students by school solar revenue potential

7.4. Data Analysis

7.4.1. Overview

The two major datasets used to estimate electricity use in kilowatt-hours (kWh) for universities are the College Facilities Inventory (CFI) and the Commercial Buildings Energy Consumption Survey (CBECS). The CFI database from 2004 was used, because it was the year with the most reliable data. This database has a list of 200+ post-secondary educational institutions throughout the country, of which roughly 160 are four-year institutions. The most important data taken from this database were the square footage of buildings owned by each institution, broken down into categories like square footage used for laboratory space, office buildings, athletic facilities, and dorms. The CBECS database is a list of roughly 5,200 surveyed buildings from throughout the country, from which the energy intensities were pulled (kWh per ft^2) and correlated with the CFI database to measure electricity use for the 160 four-year schools. However, the overall goal of this project was to measure electricity use for all four-year universities. For schools not mentioned in the CFI database, publicly available school specific data such as research spending, number of undergraduates, and similar values were used to perform a regression analysis to predict square footage. Using the predicted square footage distribution and the aforementioned CBECS data, overall electricity was predicted for all schools for which such data were available. Once the electricity use is estimated for each school, the eGRID database, which gives information on fuel mix per area, can be used to estimate overall emissions that come from electricity use for each institution.

7.4.2. CFI Database

The CFI database breaks space usage for each school into 12 categories, which are as follows:

- Classrooms
- Laboratories (further broken down into class, open, and research laboratories)
- Offices
- Libraries and Study
- Athletic
- Special Use
- General and Campus Use
- Support
- Central Storage
- Vehicular Storage
- Health Care
- Residential

For each of the above categories, a square footage value is given for each school that shows how much space that school allots to that usage category. One major problem with the CFI database is that certain areas are excluded from the data that school supplies to the CFI database. For example, hallway and stairwell space is excluded from CFI reports. At Carnegie Mellon, hallways and stairwells account for nearly 25 percent of the total space usage for buildings on campus. Unfinished areas and individual laboratory spaces are also not reported to the CFI database. The fundamental problem with estimating electricity use from square footage is that these unreported areas are still using electricity. Therefore, the square footage values used from CFI will consistently be lower than the square footage that each university actual uses.

To combat this problem, each category in the CFI was multiplied by a scaling factor distribution so that a better indication of the true square footage could be determined before data were correlated with the CBECS database. The scaling factor distribution was determined by using detailed, internal building-by-building data for Carnegie Mellon. For 71 different buildings at Carnegie Mellon, the actual square footage in the building was compared to the square footage reported to CFI to determine a percent difference. These 71 data points of percent differences were converted into scaling factors (i.e., a percent difference of 0.25 becomes a scaling factor of 1.25) and a distribution was created.

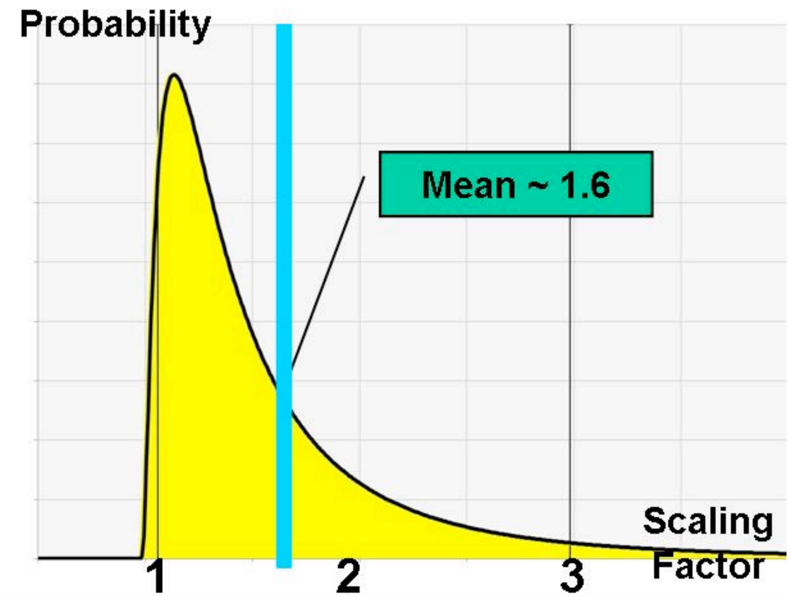

Figure 7.4.1 – Probability distribution for the square footage scaling factor of Carnegie Mellon

This distribution is a measure of the difference between Carnegie Mellon's internal building square footage measure and the measure of the data reported to the CFI database, as shown in Figure 7.4.1. The mean of the distribution of scaling factors is 1.6, but any value from the distribution could be chosen through simulation to be used as the multiplying factor.

7.4.3. CBECS Database

The CBECS database gives electricity and energy intensity data for each building in the survey. There are over 5,000 buildings in the survey, which can be filtered by primary building use, their associated climate zone, and building location. Buildings are broken down into many primary use categories, but for the purposes of this analysis (in order to correlate with CFI), and the following six primary building use categories were used.

- Public Assembly Buildings
- Office Buildings
- Laboratory Buildings
- Lodging Buildings
- Healthcare Buildings (Inpatient and Outpatient)
- Non-Refrigerated Warehouse Buildings

Furthermore, each building was classified as being in one of five different climate zones. The climate zone that a building belongs in is determined by the number of heating degree days and the number of cooling degree days in that geographical region. The climate zone breakdown is shown in Figure 7.4.2.

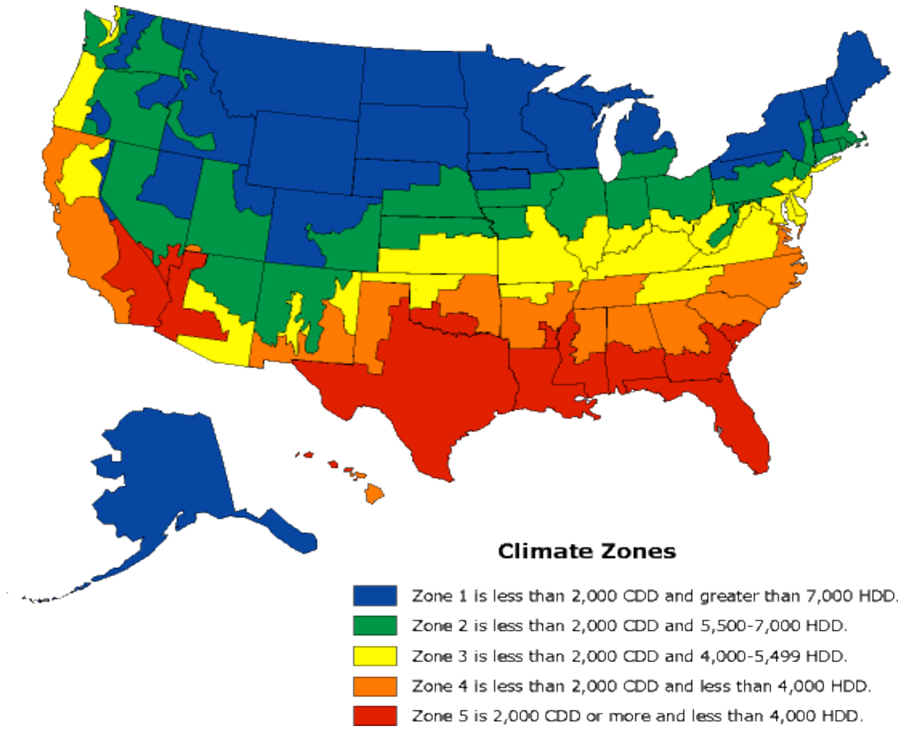

Figure 7.4.2 – Breakdown of Climate Zones from CBECS database (EIA)

Additionally, the CBECS database breaks down buildings surveyed by whether they are located in complexes, on college campuses, or by themselves. For each of these three categories of building locations, buildings were further broken down. For each climate zone, primary use category, and building location, a distribution of electricity intensities (kWh per ft^2) was determined. Using specific data points in each subset of buildings, the Microsoft Excel Add-In Best Fit® was used to create electricity intensity distributions for each subset of buildings, as broken down by the three filters described above.

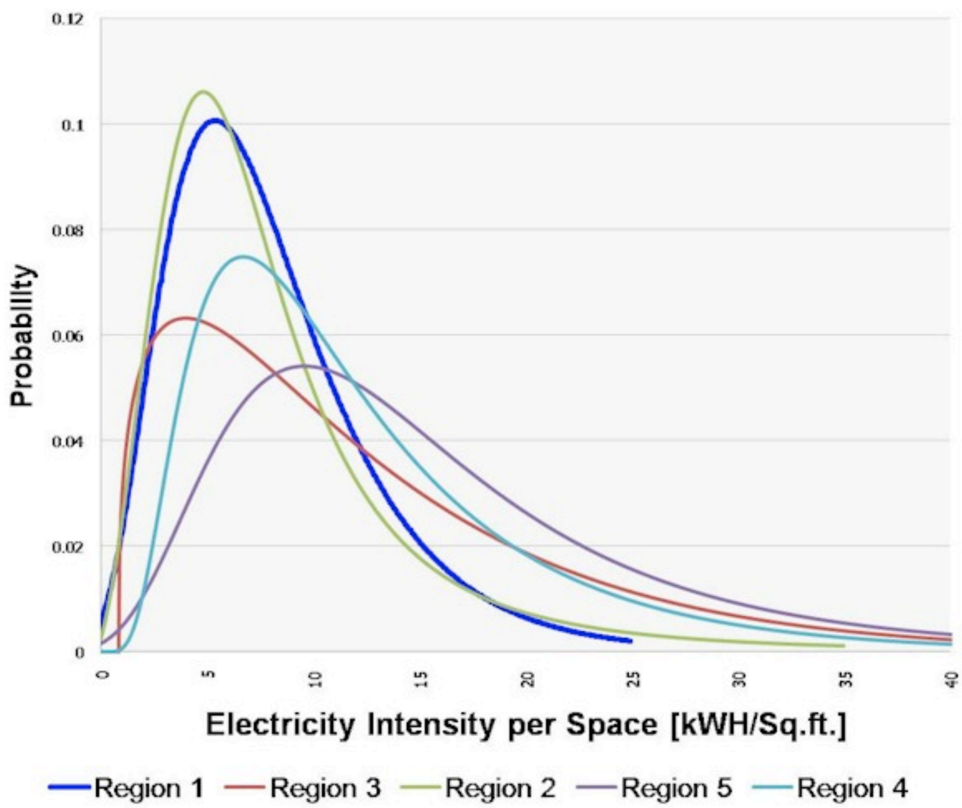

Figure 7.4.3 – Sample distribution of electricity intensity from CBECS database

Since there are five climate zones, six primary use categories, and three possibilities for building location, 90 distributions were created in all. However, there was not a statistically significant number of entries in any category involving only college campus buildings, so these distributions were discarded, which resulted in just 60 distributions. It is also important to note that the subcategory of "Data Center" (a subcategory of "Office Buildings") was also used to calculate a distribution, but this category was not broken down into climate zones. Only the building location category of "all" was used so that a statistically significant number of data points were available. Therefore, there were a total of 61 distributions into which the 12 CFI categories could be classified for each school. Figure 7.4.3 shows a sample distribution from the CBECS database of electricity intensity for office buildings for each of the five different climate zones for the building location category of all buildings. This figure shows five of the aforementioned 60 distributions that were created.

7.4.4. CFI to CBECS Correlation

To use the CFI and CBECS distributions in order to come up with an estimate of electricity use, the categories shown in the two bulleted lists above first had to be matched up with each other. The CFI and CBECS categories were matched up as shown in Table 7.4.1.

Table 7.4.1 – Mapping of CFI and CBECS categories

CFI Category	CBECS Category
Classrooms	Public Assembly
Laboratories	Laboratories
Offices	Offices
Libraries and Study	Public Assembly
Athletic	Public Assembly
Special Use	Public Assembly
General and Campus Use	Public Assembly
Support	Weighted Average of Non-Refrigerated Warehouse and Data Center
Central Storage	Non-Refrigerated Warehouse
Vehicular Storage	Non-Refrigerated Warehouse
Health Care	Outpatient HealthCare
Residential	Lodging

When possible, exact matches from CBECS were used to map CFI categories. For example, both CFI and CBECS have categories "offices" and "laboratories," so these classifications were mapped with each other. It also fits logically that the residential category from CFI was mapped with the lodging category from CBECS, since the CBECS lodging category is defined as "buildings used to offer multiple accommodations for short-term or long-term residents, including skilled nursing and other residential care buildings." Additionally, the CFI health care category was mapped with the CBECS category of outpatient health care, because all health care facilities that are sampled by the CBECS survey, excluding hospitals, are considered to be in the outpatient health care category. It was assumed that most health care facilities on campus were meant to be in this category. Also, both storage categories from CFI were mapped to the non-refrigerated warehouse category, which is defined as "buildings used to store goods, manufactured products, merchandise, raw materials, or personal belongings (such as self-storage)."

Considering that six CFI categories that had good matches between the two databases (laboratories, offices, central storage, vehicular storage, health care, and residential), there were six other CFI categories that had to be mapped using greater research discretion. Of these six, five were mapped to the CBECS category of public assembly. The public assembly category from CBECS is defined as "buildings in which people gather for social or recreational activities, whether in private or non-private meeting halls." Furthermore, the following list shows examples of buildings surveyed by CBECS that would be included in the public assembly category.

- Social or Meeting (e.g., community center, lodge, meeting hall, convention center, senior center)
- Recreation (e.g., gymnasium, health club, bowling alley, ice rink, field house, indoor racquet sports)
- Entertainment or Culture (e.g., museum, theater, cinema, sports arena, casino, night club)
- Library
- Funeral Home
- Student Activities Center
- Armory
- Exhibition Hall
- Broadcasting Studio
- Transportation Terminal

Classrooms were considered to be social or meeting places, since this category was assumed to be the best description of the discrete set of options available from the CBECS categories. Thus, it was classified as public assembly space. Libraries are explicitly mentioned as public assembly spaces. Examples of athletic spaces are listed in the recreation bullet point, so this CFI category was also classified as a public assembly space. Since the general and campus use category from CFI considers spaces like lounges, exhibition halls, and meeting rooms, it was assumed that the best fit for this category was the public assembly category. The special use category from CFI includes spaces that are too specific to fit into other categories but are general meeting areas, so this category was also mapped as a public assembly area. Finally, the CFI category of support contains mostly storage areas that do not fit into the category of central storage or vehicular storage like library stack storage areas and areas to store laboratory equipment. It also includes computer clusters and computer labs, which are much more energy intensive than storage areas. Therefore, for the CFI category of support, a weighted average of non-refrigerated storage and data centers (which covers computer labs) was used.

Figure 7.4.4 shows the overall process of calculating an electricity use estimate distribution for Carnegie Mellon. The same process was used for 160 of the other schools listed in the CFI database as well. To estimate electricity use, the process begins with the reported value for each of the 12 categories in the CFI database (blue boxes in Figure 7.4.4). It is important to note that only three of the categories are depicted in the figure, but it is understood that the process is repeated for all 12 categories. These values are multiplied by scaling factor distribution from the 71 CMU buildings as discussed in section 7.4.2 (yellow distributions in Figure 7.4.4). The distribution of square footage values after the application of the weighting factor for each CFI category is then multiplied by the corresponding CBECS distribution using @Risk® simulations. In these simulations a random value from the scaling factor distribution (yellow distributions in Figure 7.4.4) would be multiplied by a random value from the corresponding CBECS distribution (blue distributions in Figure 7.4.4) from Table 7.4.4, allowing for the corresponding probability of each random value occurring. The simulation was run 1,000 times and distribution of the results of these simulations is developed for each of the 12 CFI categories. To find an overall electricity use estimate distribution, the electricity use estimate for each CFI category is summed to estimate overall electricity use.

For example, Carnegie Mellon is located in Climate Zone 2 from Figure 7.4.2. To estimate the total electricity used in classrooms at Carnegie Mellon, the distribution of total square footage from classrooms at Carnegie Mellon was multiplied by the distribution of all public assembly buildings in Climate Zone 2 from CBECS. The same analysis was also done using only the distribution of public assembly buildings in Climate Zone 2 that were located in complexes to come up with two different estimates. This process determined an estimation for the electricity use value for each CFI category.

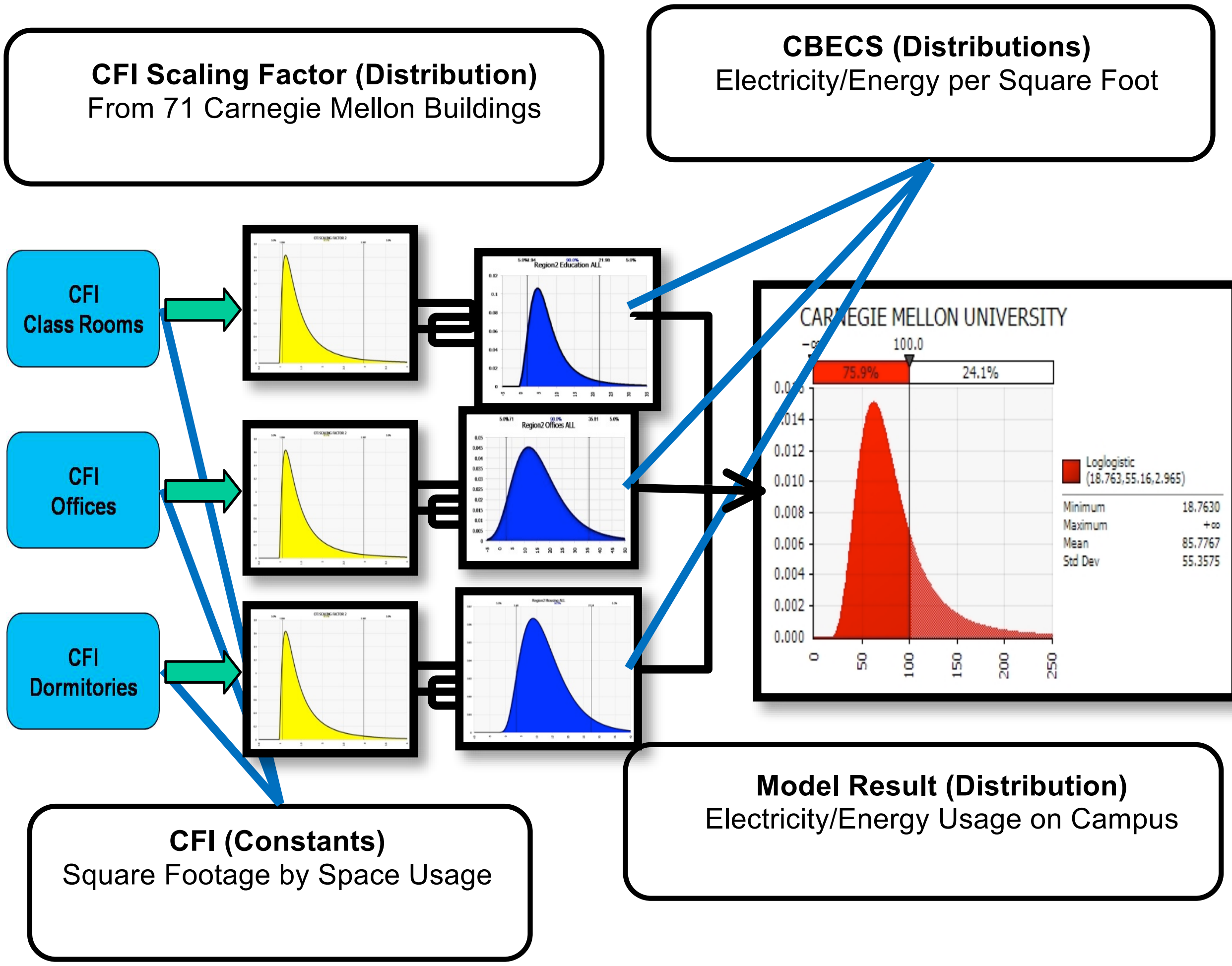

Figure 7.4.4 – Overall method of estimating electricity use for schools in the CFI database

Ideally, every school's self-reported electricity use would fall at the mean of these electricity use estimate distributions. It is important to note that this analysis was done for just the 160 schools in the CFI database and that these estimations do not account for individual schools' purchases of renewable electricity. These estimations are made to create relevant benchmarks, and they are not necessarily accurate. For schools not listed in the CFI database, regressions were done to come up with a distribution of square footage data. Regression analysis, using the datasets discussed in Section 7.3, was used to estimate the square footage that allows for electricity use estimates for roughly an additional 1,600 schools. Table 7.4.2 summarizes the level of detail at which estimations of electricity use can be made for a specified number of schools. A further discussion of the regression analysis is presented in Section 7.5. Using this method, the raw numbers of square footage from the CFI database (the blue boxes from Figure 7.4.4) are replaced by distributions predicting square footage using regression for each of the CFI categories. However, the remainder of the method to predict electricity use is the same.

This is shown in Figure 7.4.5, as the CFI data is replaced with the green regression distributions. Since a distribution is replacing a known value in this analysis, it is expected that the there will be more uncertainty, and the final range for the electricity estimate will be wider.

Table 7.4.2 – Accuracy and Feasibility of electricity consumption calculation methods

	Self-Reported Data	CFI-Based Estimation Model	Regression-Based Estimation Model
90% Confidence Interval for Carnegie Mellon	100 GWh	38 GWh-165 GWh	45 GWh-181 GWh
Information Needed	actual electricity consumption	square footage of campus buildings	"key facts" about the institution
Number of Institutions	~60	~160	1,600+

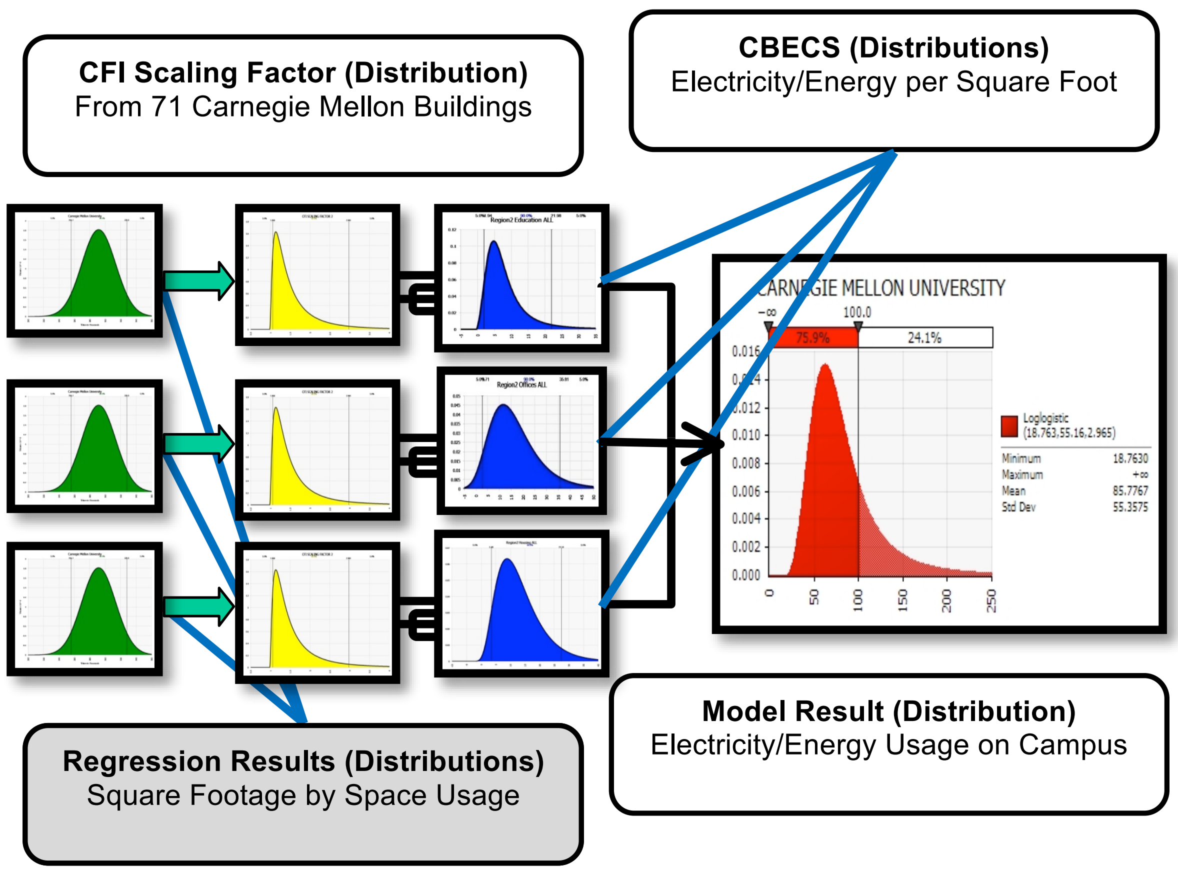

Figure 7.4.5 – Overall method of estimating electricity use for schools in CFI database

7.4.5. CFI Regressions

CFI data has a statistically significant number of schools with square footage data by primary usage, along with a number of other information about the schools such as enrollment and location. This allowed for a regression model to be created in order to estimate square footage given only these independent variables. These estimated square footages are then used with CBECS formulas to obtain electricity usage. CFI had broken down the total square footages into various subcategories: classrooms, class laboratories, open laboratories, research laboratories,

offices, libraries, athletics, special use, general and campus use, support, central storage, vehicular storage, health care, student residential, nonstudent residential, and inactive areas. To increase efficiency, this list was narrowed to ten categories compared with CBECS, which has seven categories of area types. The categories that were combined together were classrooms and class laboratories; open laboratories and research laboratories; athletics and special use; support, central storage, and vehicular storage; student residential and nonstudent residential.
This analysis began with the basic information that CFI data provided, and the categories were the total number of students, number of undergraduate students, number of graduate students, number of professional students, percent of graduate and professional students, number of full-time faculty, number of part-time faculty, and climate zone. After starting the regression analysis, it was found that full-time faculty is highly correlated with many of the subcategories, also displaying high adjusted R-squared values, when used in each of regression models.

Table 7.4.3 – Correlation between full-time faculty and CFI categories

CFI Category	Correlation Coefficient with Full-Time faculty
Classrooms	0.821
Laboratories	0.852
Offices	0.896
Libraries	0.792
Athletic and Special Use	0.725
General and Campus Use	0.805
Support and Storages	0.550
Health Care	0.450
Residential	0.722
Inactive Areas	0.413

However, full-time faculty information was available only for the schools in CFI, and this data was not able to be obtained for the analysis. Instead, other independent variables had to be found that were available for most of the schools.

An original database was developed and maintained for this analysis, which has a large number of information for a considerable number of schools. However, according to the needs of this study for accuracy and reliability, it was decided to remove two-year colleges and schools of less than 1,000 students. This gives better coverage of independent variables, since most of the available data were focused on larger schools.

By using a stepwise regression function, the best fit regression lines were able to be found. This analysis had to take special care with missing variables, since this would result in missing predicted values. Therefore, the number of independent variables had to be kept as small as possible for each model. The regression statistics are available in Appendix 7.D.

7.5. Model Results

This section shows the results of the electricity use analysis. The analysis was divided into three sections. First will be the estimate using square footage data from the CFI database, for which estimates were obtained of electricity use for 160 schools. In the interest of brevity, the data will only be presented for Carnegie Mellon and some of its peer institutions, as defined in Section 6.4.

More detailed analysis can be found in Appendix 7. Next, the analysis was done for schools not listed in the CFI database, for which regression statistics were used to estimate square footage. These data are available for more than 1,600 schools. Finally, electricity use for Carnegie Mellon's peer institutions is analyzed by converting electricity use into carbon dioxide emissions.

7.5.1. Electricity Use Estimation Using CFI Data

Figure 7.5.1 shows the distribution of the electricity use estimate for Carnegie Mellon using the method described in Figure 7.4.4, where CFI data is used. It is important to note that the true self-reported value of 100 million kWh of electricity used falls at the 75^{th} percentile of the estimate. This value of 100 million kWh is represented by the blue bar in Figure 7.5.1.

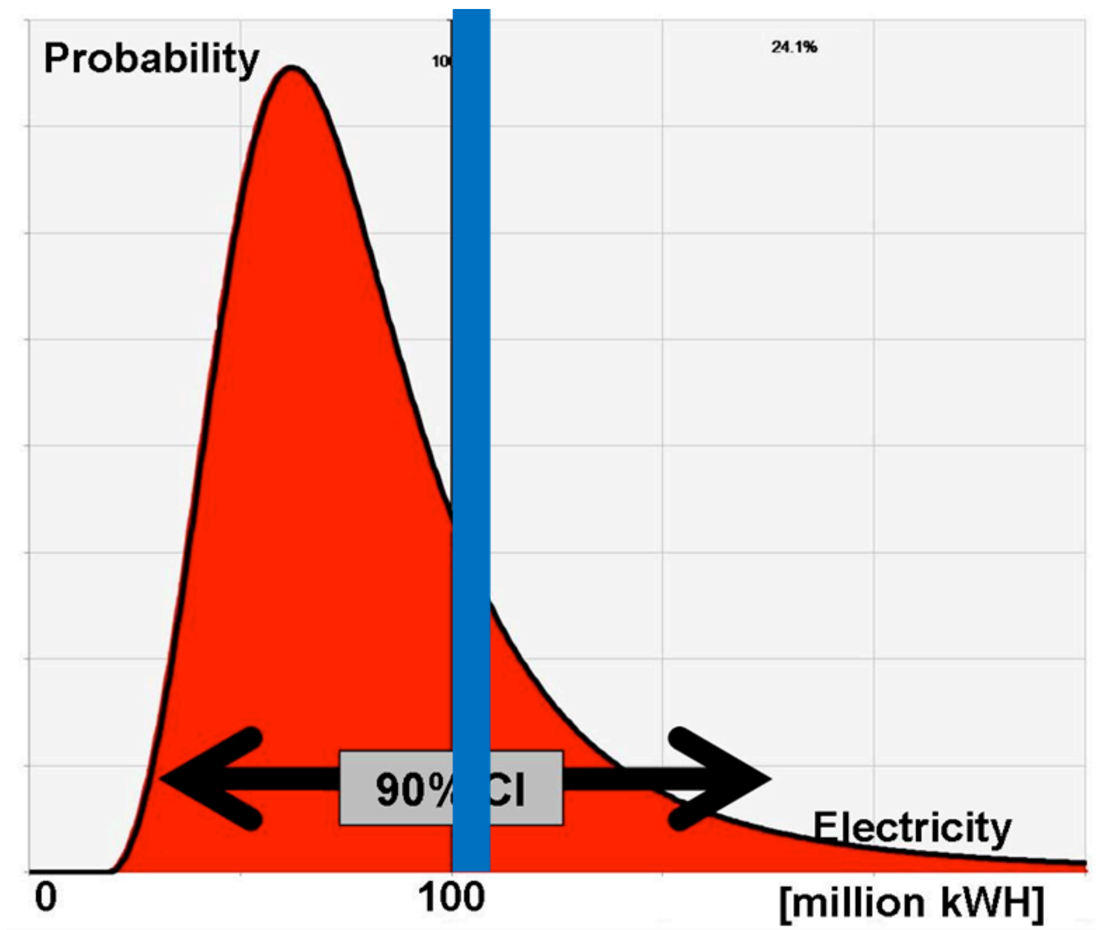

Figure 7.5.1 – Distribution of electricity use estimate for Carnegie Mellon using CFI data

The fact that Carnegie Mellon's actual electricity does not fall at the mean value of the distribution of 62.2 million kWh means one of two things. First, it could mean that the scaling factor distribution used does not truly account for the total difference between Carnegie Mellon's actual square footage and the value reported to the CFI database. Second, this could also mean that Carnegie Mellon's electricity intensity is simply higher than the average buildings sampled in CBECS from Climate Zone 2. In either case, the true value of 100 million kWh falls within the

90th percentile confidence interval range of 38 million kWh – 165 million kWh. Figures 7.5.2 and 7.5.3 show the same analysis for MIT and UC Berkeley, respectively. The true values of electricity for both universities are represented by the blue bars in the figures.

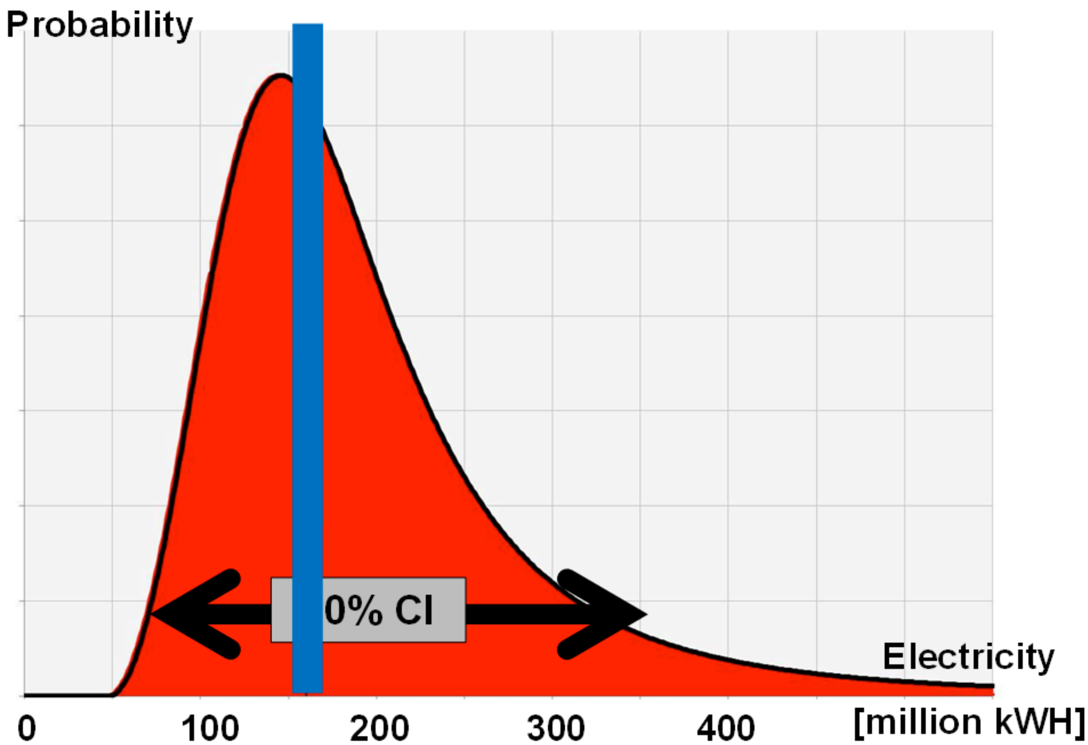

Figure 7.5.2 – Distribution of electricity use estimate for MIT using CFI data

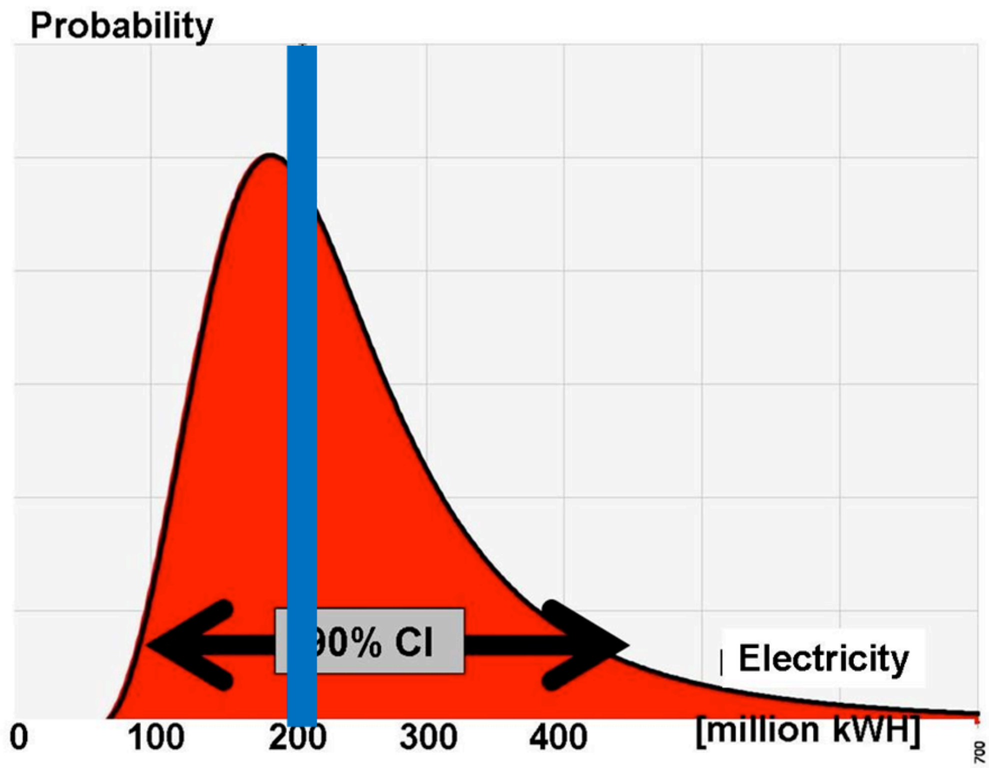

Figure 7.5.3 – Distribution of electricity use estimate for UC Berkeley using CFI data

MIT's true value for electricity use of 160 million kWh falls at the 43rd percentile of the estimated distribution, and UC Berkeley's self-reported value of 207 million kWh falls at the 57th percentile of the estimate distribution. The reason for different universities falling at different points in the distribution is to the unique nuances of each university. These reasons include location and variance from the CBECS mean, among others.

7.5.2. Electricity Use Estimation Using Regression Results

Figure 7.5.4 shows what the distribution of electricity use for Carnegie Mellon would have been if CFI data were not available. In this case, the square footage was predicted using the regressions discussed in Section 7.4.5. Linear regression was used to estimate square footage for each CFI category based on key information about the university. For example, the number of faculty in the university was used to estimate the office space at the university. This is discussed in greater detail in Section 7.4.5. Once the square footage for each CFI category was estimated, it was multiplied by the mapped energy intensities from CBECS to estimate the electricity use. Using this method, the distribution becomes shifted to the right, as the mean of the distribution is 71 million kWh, slightly higher than the value obtained using the CFI data. Since the distribution is shifted to the right, the true electricity use value of 100 million kWh occurs at the 68th percentile of this distribution.

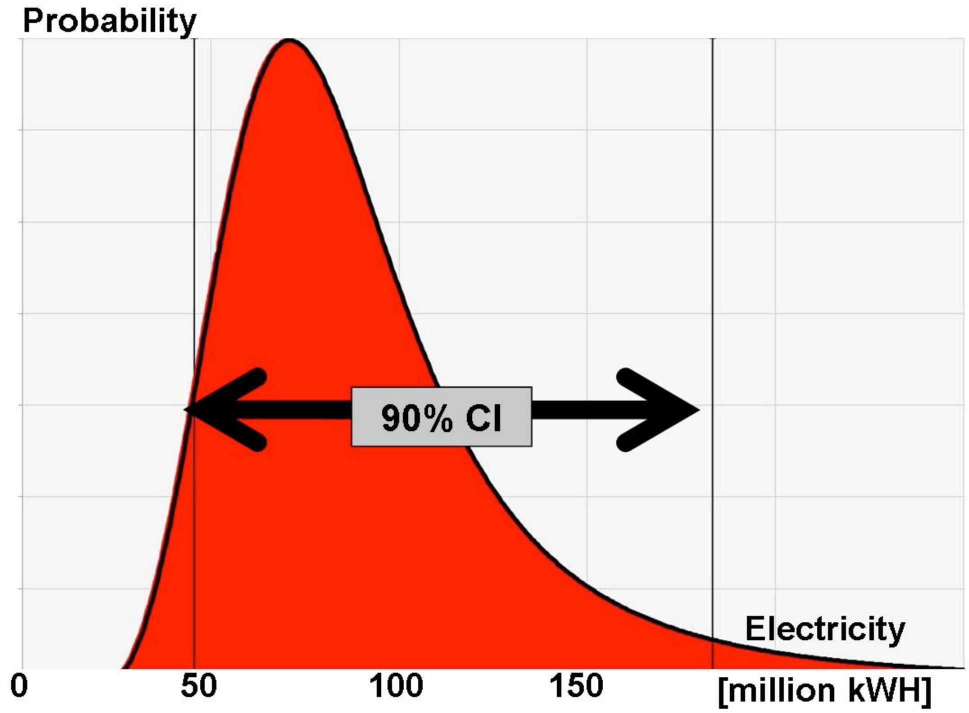

Figure 7.5.4 – Distribution of electricity use estimate for Carnegie Mellon using regression results

Once again, the true value of 100 million kWh falls within the 90th percentile confidence interval range of 45 million kWh-181 million kWh. This result shows that the regression results are a viable option to ultimately predict electricity use when actual square footage data is unavailable. It should also be noted that the confidence interval range using the regression results (45-181 million kWh) is slightly wider than the range using constant values from the CFI database (38-165 million kWh). This is to be expected, since there is more uncertainty associated with using the distribution from regression than constant values. The benefit behind this analysis is that this estimate can be made for over 1,600 schools (as shown in Table 7.4.2) instead of just the 160 schools in the CFI database.

7.5.3. Converting Electricity Use to CO_2 Emissions and Peer Group Analysis

Once electricity use has been estimated, the next step is to convert the kWh of electricity used into carbon equivalent dioxide emissions that come from electricity generation. The method used to accomplish this task is depicted in Figure 7.5.5. Essentially, the distribution of electricity use obtained from the analysis previously described is multiplied by a fuel mix of electricity generation that is obtained for each state. These data come from the eGRID database developed by the EPA, which gives the percentage of emissions of electricity generation that comes from each fuel source. These data are given for each state, and the fuel sources are broken down into the following categories:

- Coal
- Oil
- Gas
- Other Fossil

- Biomass
- Hydro
- Nuclear
- Wind
- Solar
- Geothermal

Each fuel source is associated with a net value of CO_2 emissions. The eGRID data are converted into a weighted average of CO_2 emissions per kWh based on the fuel mix percentages for each state and the CO_2 emissions associated with each fuel.

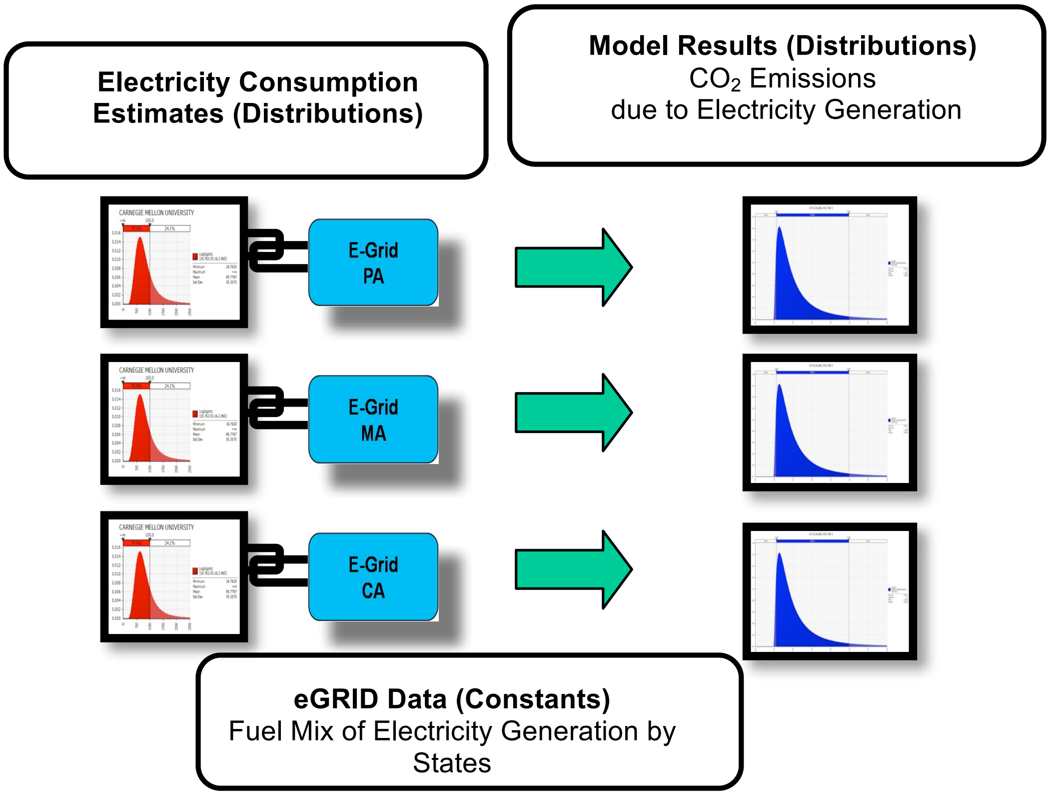

Figure 7.5.5 – Method used to convert electricity use into CO_2 emissions for each school

Next, each school's electricity use estimate is multiplied by the eGRID data for the state that the given institution is located to determine the equivalent CO_2 emissions from electricity use that each college emits into the atmosphere. Tables 7.5.1 and 7.5.3 show a comparison of this CO_2 conversion as well as electricity use estimates for Carnegie Mellon and some of its peer institutions.

Table 7.5.1 – Summary statistics of Carnegie Mellon's peer institutions using CFI data

Institution	Electricity (GWh/student)	Electricity (kWh/ft^2)	CO_2 (tons/student)	CO_2 (lb/ft^2)
Carnegie Mellon	5.9	20.6	8.5	36.6
MIT	13.3	20.9	18.9	36.6
Brandeis	-	17.1	-	22.4

It is important to note that Carnegie Mellon compares very well to its peers in terms of the electricity used compared to the number of students (gigawatt-hours per student) but is quite high in terms of the electricity used per square foot. This means that Carnegie Mellon has less square feet of space per student compared to its peer institutions. For example, if one examines the electricity and carbon footprints of Carnegie Mellon and MIT through metrics based on students, Carnegie Mellon appears less intensive in both. However, based on the metrics using total square footage of campus buildings, the two schools have very similar electricity and carbon profiles. It should also be noted that, although there is a correlation between the electricity used and the CO_2 emissions for each school, just because a school uses a lot of electricity does not necessarily mean that it emits a lot of CO_2. This is due to the location of the university and the fuel mix used in the area where the school is located. For instance, both the University of Rochester and the University of Chicago use more electricity than Carnegie Mellon but both also emit less CO_2 to the atmosphere.

It is worth stressing that this analysis is used to estimate each school's electricity and in general is not an exact prediction. The goals of this analysis are to create relevant benchmarks for all schools and to define a method for creating transparency in estimating electricity use and carbon dioxide emissions. Furthermore, the estimates of carbon dioxide equivalent do not include known data on renewable energy purchases for each school. The only additional input used to estimate the carbon footprint from the electricity estimate is the fuel mix data from eGRID, which is broken down by state. For example, 15 percent of the energy that CMU purchases each year comes from renewable sources. This fact is ignored in the CO_2 analysis presented here. Therefore, the data presented here can be considered an inherent footprint, since it is a high-end estimate. Using available data on renewable energy purchases from the EPA green partners program, a further analysis can be done to determine more accurately each school's carbon footprint based on how much renewable energy that that specific school purchases each year.

7.5.4. Non-CFI Schools Model Results

The regression models from CFI data represent the best fits that were available. The R-squared values indicate how well the series of data fits the model; a higher R-squared value yields narrower confidence intervals for predictions. The R-squared value for each model is meant to be optimal considering a number of independent variables used in each model, not necessarily the highest value possible, in order to use a low number of independent variables so that estimations could be made for a larger number of colleges and universities.

With these models, 1,600+ other schools' square footages were able to be calculated along with standard deviations and 95 percent confidence intervals. However, these models had about 1,000 predictions (65 percent) for health care and residential, 428 predictions (26 percent) for laboratories and offices, and only 216 predictions (13 percent) for libraries due to missing independent variables out of the 1,600 schools. A decision had to be made between having fewer predictions with high adjusted R-squared values and more predictions with low adjusted R-squared values. After having this information, the data could be plugged into CBECS formulas to predict the confidence intervals for each school's electricity usage.

Table 7.5.2 – Adjusted R-squared values and number of predicted schools for each CFI category

CFI Category	Adjusted R-squared (%)	Number of Predicted Schools
Classrooms	77.2%	1,566
Laboratories	83.7%	428
Offices	87.7%	428
Libraries	73.5%	216
Athletic and Special Use	45.4%	1,636
General and Campus Use	63.4%	1,593
Support and Storages	27.9%	1,636
Health Care	37.4%	1,076
Residential	66.0%	1,050
Inactive Areas	14.1%	1,636

Table 7.5.3 – Summary statistics of Carnegie Mellon's peer institutions using regressions

Institution	Electricity (GWh/student)	Electricity (kWh/ft^2)	CO_2 (tons/student)	CO_2 (lb/ft^2)
University of Rochester	7.5	13.8	1.9	4.3
University of Chicago	10.8	14.3	6.2	16.6
Case Western	10.6	13.7	9.5	24.3
Duquesne	6.0	13.1	3.7	16.0

Table 7.5.4 – Actual electricity consumption versus mean estimates

Institution	Actual Electricity Consumption (million kWh)	Mean Estimate (million kWh)
Carnegie Mellon	100	95.5
MIT	160	177.0
Brandeis	37	46.8
UC Berkeley	207	251.8
Duke	174	145.8
Yale	200	145.4
Syracuse	102	93.8
Duquesne	44	60.9
Michigan State	245	173.4

Table 7.5.3 shows the non-CFI model applied to schools in Carnegie Mellon's peer group. This model has larger error bounds than the CFI model due to the additional uncertainty. Table 7.5.4 compares actual and mean estimate usage values for schools in Carnegie Mellon's peer group, using both CFI and non-CFI models.

7.6. Conclusions and Recommendations

7.6.1. Conclusions

Without an estimation of other universities' carbon footprints, calculating Carnegie Mellon's footprint is not a worthwhile exercise. In addition to knowing other schools' footprints in general, it is crucial to find a peer group to add a deeper understanding of Carnegie Mellon's greenhouse gas emissions. From basic statistics made generally available to the public, regression analyses were performed, and the carbon footprints of 1,600 schools were estimated. A peer group analysis was also successfully completed, and comparisons to similar institutions can consequently be performed.

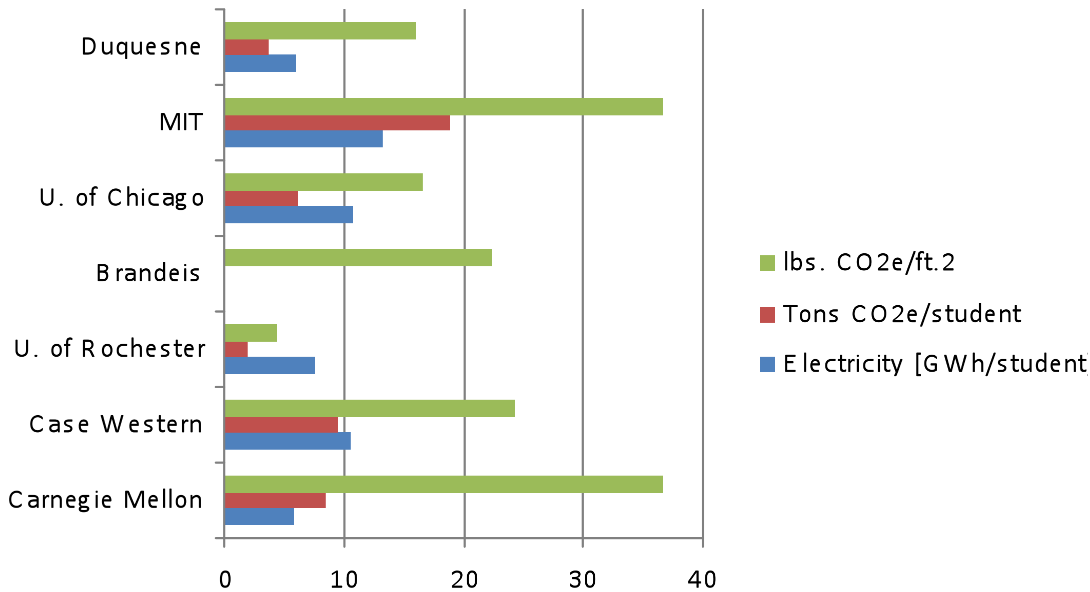

Figure 7.6.1 – Summary statistics of Carnegie Mellon's peer institutions

Tons of carbon dioxide equivalents per student are a strong metric for analyzing schools. They measure the amount of greenhouse gases that schools are emitting per unit of higher education serviced. Carnegie Mellon performs as an average institution on this mark, ranked in the middle of its peer institutions. Carnegie Mellon is actually ahead of most of other peer institutions in terms of electricity consumption per student, which suggests that the electricity generation portfolio mix may be partly to blame. This analysis did not have detailed electricity mix portfolios for other schools that were measured to the accuracy of Carnegie Mellon's fuel mix. Carnegie Mellon's performance on greenhouse gas emissions by floor space is larger than that of the other institutions, which could indicate poor performance by the school or perhaps more compact space use. Regardless, the data demonstrate that Carnegie Mellon has much room in which to improve its performance.

7.6.2. Recommendations

Useful estimates about energy usage and greenhouse gas emissions were performed for the four-year colleges of the United States using commonly available data. However, the uncertainty that accompanies these estimates based on statistics like student population and statewide average fuel mixes illustrates how desirable more self-reported data from the schools would be. If universities want to lead the U.S. to the frontier of green energy, they should begin collaborating to facilitate data collecting projects and to improve the accuracy of studies like this one. Every school has data on its yearly electricity expenditures, and also knows how much electricity it consumes. It is urgent that schools release information like this to the public in order to make it considerably easier for future analyses to understand the scope of the greenhouse gas abatement challenge in the U.S.

Furthermore, it is suggested that schools act together to form one organization to collect data and make it available online. With energy data submitted via surveys along with other basic schools statistics, the problem of studying university carbon emissions can be evaluated much more precisely. This would facilitate everything from grid-wide impacts of local energy consumption to collaboration on mitigation strategies by colleges with similar characteristics.

In the absence of this sort of collaboration, finding data is very difficult. Carbon footprints for this analysis were probably not available because not many schools dedicate the necessary resources to evaluate such problems in depth. However, even a statistic as basic as the number of faculty members at each university proved impossible to find. Electronically available data of many basic types was needed for large ranges of schools in order to construct the dataset for this research. Provision of these at one site would have dramatically sped up progress. For example, when the total square footage for the vast majority of schools could not be found, this data had to be estimated using numbers like student population and research spending, which took much time when compared with finding it quickly from one publicly available database. Such a site would be so useful that others could probably be developed as well for other types of businesses. For a problem as complex as the climate crisis, the necessary leadership to begin an initiative like this is very much needed.

8. Conclusions and Recommendations

8.1. Conclusions

Across the country, there is growing desire to address sustainability issues on university campuses; however, many lack the effort necessary to effect real and significant change. Part of the reason for their lack in effort is that many institutions do not understand what is at stake.

The approximate electricity carbon footprint of all U.S. institutions is 100 million MTCDE per year. Considering that an average REC costs $20 per MTCDE reduced (as detailed in Chapter 5), it would cost $2 billion per year to counteract these emissions. The total endowment value for all institutions is approximately $400 billion and receives an interest of five percent or $20 billion per year. However, the top 20 schools (out of 6,000) have over half of this total sum, meaning that most institutions would need to use all of their endowment interest to cover the mitigation costs. Therefore, additional funding is necessary. One option could be an average student fee of $200 per year, and with a national average tuition of $20,000, a $200 fee is only one percent of this cost. This exercise demonstrates that carbon reductions are an attainable feat, and there is comparably little at stake to lose. Institutions just need to make a dedicated commitment.

Several institutions have tried to demonstrate leadership in sustainability by signing climate commitments like the American College and University Presidents Climate Commitment (PCC). However, schools often sign these commitments and are unaware of the level of dedication necessary. Furthermore, these climate commitments often have nondescript goals for attaining "climate neutrality" and are non-binding with no required completion date or penalties for missing reduction targets. Due to these drawbacks, institutions are making little to no progress toward their reduction goals. Figure 8.1.1 illustrates the current decision-making framework for the PCC.

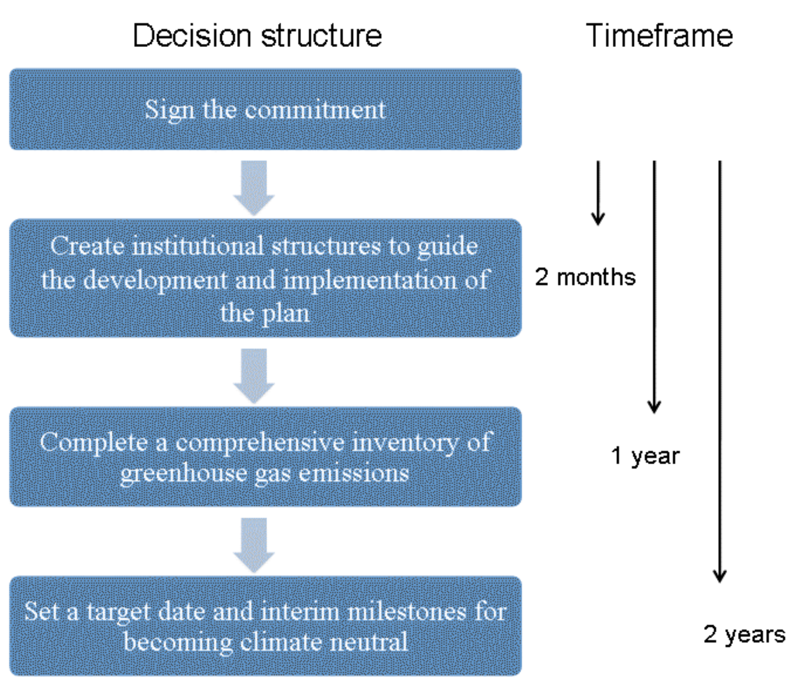

Figure 8.1.1 – Illustration of the PCC decision-making framework

Commitments such as the PCC demonstrate that universities are unclear about the scope of "climate neutrality," and they therefore need more specific goals with detailed timelines as well as quantitative and measurable reduction targets. Since the PCC framework is insufficient at aiding institutions toward attaining their goals of minimizing environmental impacts, a new decision making approach is proposed and illustrated in Figure 8.1.2.

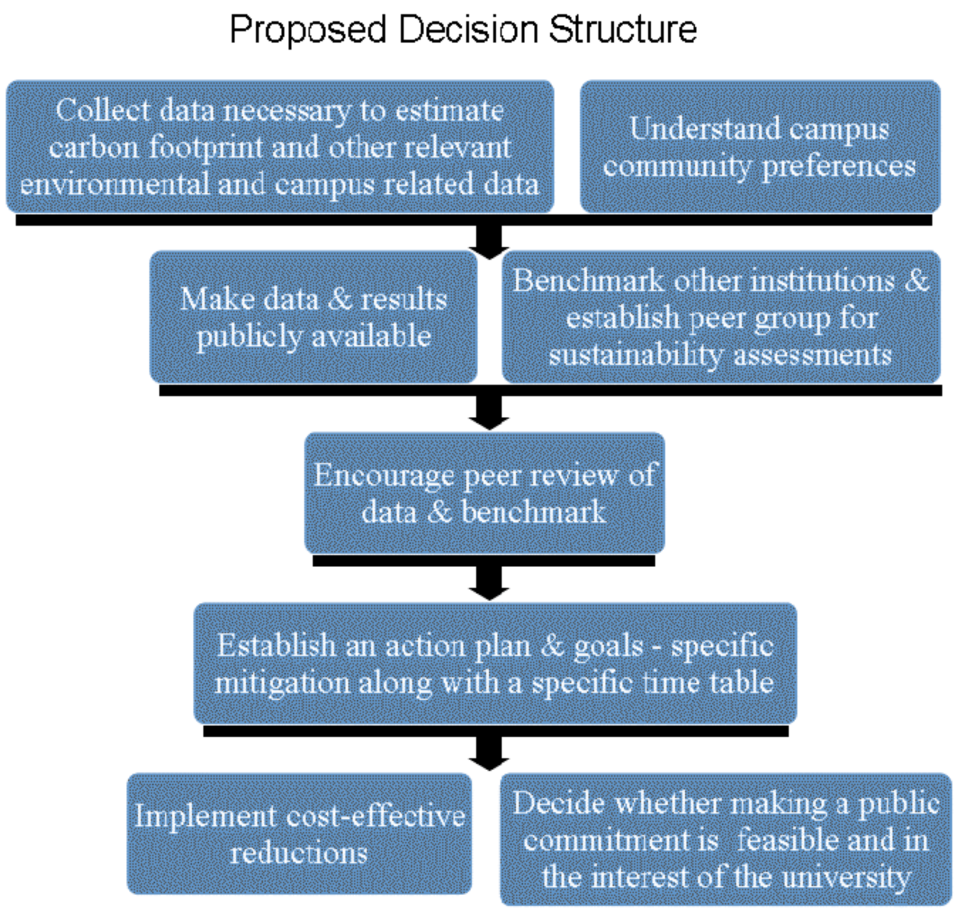

Figure 8.1.2 – Illustration of the newly proposed climate commitment decision structure

Figure 8.1.2 illustrates a detailed and encompassing decision framework that provides the necessary structure for institution to achieve their carbon reduction goals. First, an institution needs to collect environmental and campus data to estimate its carbon footprint and to make efforts to determine and understand the campus community's preferences. This stage is extremely important, because as the Carnegie Mellon Campus Environmental Survey discovered, public opinion may not align with optimal economic and engineering solutions. Next, the collected data need to be made public, and other institutions need to be benchmarked in order to establish a peer group for sustainability assessment.

Furthermore, peers need to be encouraged to review the collected data and institutional benchmarks, and an action plan and goals then need to be established that contain specific mitigation strategies and a specific timetable. Finally, cost-effective reductions strategies need to be implemented, and decisions need to be made on whether to make a public commitment. This decision should be made based on the feasibility of the commitment as well as university interest.

Furthermore, when utilizing the newly proposed decision-making framework, it is important that universities clearly define the boundaries of their carbon footprint and should include the following series of tiers.

- Tier 1: The MTCDE of all on-site activities as well as purchased electricity, heating, and cooling
- Tier 2: The MTCDE of all business-related transportation of faculty, staff, and students
- Tier 3: The MTCDE of all commuting faculty, staff, and students
- Tier 4: Should consist of another source of indirect emissions that greatly effects the campus community that could be determined using life cycle assessment

If institutions utilize this new climate commitment decision structure, they will have the organization necessary to effect real change and to increase the sustainability of their campus.

8.2. Recommendations

8.2.1. Data Monitoring

It is very important that, once a university or any institution begins to assess its carbon footprint thoroughly, there is a simple strategy to perform an assessment each year. The recommendations from this research are aimed to expedite data collection and analysis of Carnegie Mellon's footprint over time as well as any other universities that are striving to do the same thing. This analysis took approximately four months to perform an adequate carbon footprint assessment. It should now take Carnegie Mellon only a few hours to do the same if they properly use the new calculator and improve the data monitoring and accounting systems.

University accounting systems must be upgraded to track data easily within the major emission categories. Data that must be tracked accurately are faculty and student air travel, electricity consumption, steam and chilled water consumption, and any other data that contributes a significant portion to the overall footprint. Having an easy way to track the major contributors will make it easy to track the university or institution's progress once mitigation strategies are in place. Progress should be tracked at least once a year but quarterly data collection is recommended.

8.2.2. Student Perceptions

One original impetus behind this research was the signing of a petition that asked Carnegie Mellon to switch to the use of 51 percent "green" energy. Having originally let the students decide which energy sources they deemed green, it was found that over half of the respondents believed hydro power, solar power, wind power and fuel cells to be "green," while they considered coal, natural gas, nuclear power, and biofuels not to be "green." Along the same lines as the petition, the survey conducted asked, "What percentage of Carnegie Mellon's total electrical energy usage do you think should come from green energy? (%)." From the responses, the willingness to reduce was found for both the undergraduate student population and for the graduate student population in addition to the amount that these two groups would be willing to pay if Carnegie Mellon were to purchase 50 percent "green" energy. The undergraduate population on average wanted 56 percent of Carnegie Mellon's electrical energy to come from "green" energy, and they were willing to pay on average $86 a year so that Carnegie Mellon could purchase 50 percent "green" energy. It seemed the graduate population at Carnegie Mellon supported "green" energy more; on average, the graduate students wanted 60 percent of Carnegie Mellon's electrical energy to come from "green" energy, and they were willing to pay on average $102 a year.

Another question on the survey asked the respondents, "How many courses have you taken at Carnegie Mellon that dealt specifically with sustainability or environmental issues?" After calculations were made on this question and other knowledge based questions along with the two questions mentioned in the above paragraph, the difference between those that had taken at least one class and those that had not taken any was obvious. Individuals that had taken at least one class were able to provide correct answers to knowledge-based questions, such as which energy sources were "green" as well as believing that global warming is an important issue. These respondents that had taken a class had a desire to see a higher percentage of Carnegie Mellon's energy source be "green," and were also willing to pay a larger amount to purchase "green" energy. The greatest problem was not that the student desired for change to happen, but they just did not know what the best and most cost efficient ways were. Many of the students wanted to use such sources as wind and solar power, even though they were not extremely efficient for the Carnegie Mellon environment and were at much higher costs than the benefits. It was evident that education increased their awareness of the destruction caused by "non-green" energy sources; however, the education did not completely convey the best solutions for the existing problems.

It seems that the campus is not very well-educated in the best course to take in order to increase their "green" energy source both effectively and cost efficiently. Thus, it is crucial that the community be well-informed of the decisions and policies that Carnegie Mellon institutes. It is also vital for the community to understand the reasoning behind why those decisions and policies were made as well as openly thanking them for their support of these pertinent changes.

8.2.3. Education

According to the survey results conveyed in Chapter 4, taking environmental courses helped to raise students' concern toward environmental issues. However, it also showed that 76 percent of the students never took any environmental courses. While Carnegie Mellon and most of its peer institutions defined in Chapter 6 offered some kind of environmentally-related courses and research opportunities to promote sustainability practices, the results indicate that not many students utilize these chances effectively.

In order to get the students to develop interests and concern for environmental issues, they need education to help them develop critical thinking regarding environmental issues. Since there are high percentages of students that are never exposed to environmental courses, one method of addressing this problem is to make an environmental course mandatory for all students. It would also be more appealing if this mandatory environmental course is related to one's major. Students studying engineering, business, or other non-environmental fields can use interdisciplinary education to make a powerful impact on schools' sustainability initiatives. Interdisciplinary courses allow students to gain awareness of sustainability issues and to use knowledge and skills they learn in their major field of studies to address environmental problems. An instance of Carnegie Mellon's contribution to the community through interdisciplinary education would be the posters created by design students enrolled in Design and Social Change (Carnegie Mellon University 2008b). The posters promoted the use of reusable bags instead of the plastic or paper bags in a regional supermarket retailer. The students in the course not only promoted the use of reusable shopping bags through the use of communicative art but also sought to bring about behavioral changes among shoppers to promote safeguarding the environment.

Not all educational efforts have to take place in a classroom setting, however. To help raise green awareness on campus, creating an event during first-year orientation that introduces new students to environmental issues surrounding them is a great opportunity for learning. Perhaps the program could include distribution of "green gifts," such as reusable shopping bags that can remind the students to change their behaviors in order to increase environmental sustainability. The education can also reach beyond the school community. Carnegie Mellon has a program called C-MITES, which is an outreach effort offering programs and services for academically outstanding students from kindergarten through junior high school (Carnegie Mellon University 2008a). Similar programs could be implemented to raise awareness of sustainability in the greater community.

Education is less costly, and its impact is long-lasting. What the students learn through education will enable them make a difference in the steps toward minimizing the impact on the natural environment. The education that the students receive will also allow them to make smarter choices and to take just actions in terms of helping their broader community to become more sustainable.

8.2.4. Reductions

It is recommended that universities develop substantial and economically viable reductions and mitigation strategies to increase campus sustainability. The research in this report suggests that signing the Presidents Climate Commitment (PCC) should not be considered compulsory for any university, especially before reductions targets are evaluated. However, this conclusion does not negate the importance of establishing reductions goals. Instead, institutions should first evaluate the technological and economic feasibility of mitigation measures to ensure that such pathways are responsive to the particular constraints that are unique to each university. Only after going through the process outlined in Section 8.1 is a university adequately equipped to make a commitment to reduction goals that they can effectively meet.

As described in Section 5.6, multiple metrics should be considered when designing an optimal mitigation plan for an institution. The cost effectiveness (i.e., cost or savings per MTCDE reduced) informs decision makers of how the cost and savings of various options compare over their expected lifetimes. Options with net savings could be used to invest in more capital-intensive reduction projects or could reduce the carbon footprint immediately by purchasing RECs and offsets. The other significant cost-related consideration is upfront cost, since universities often have budget limitations for large capital projects and must strategic about their implementation to continue their reduction efforts. Furthermore, since low-cost options my have small reduction potentials, savings and impact need to be balanced. Thus, the extent of prospective reductions from an option is a significant factor. Finally, an institution may want to implement options that convey its commitment to sustainability or other environmental issues and in doing so place visibility over cost concerns. Small projects like installing a vertical wind turbine or several visible solar panels can serve as a permanent ecological billboard for a university and an important symbol to help focus attention.

Ultimately, continual ideological and financial commitments must be made on the part of the university to reduce its annual carbon footprint. Beginning a mitigation strategy as soon as possible can take advantage of the cost reductions that result from abatement options with short payback periods like installing occupancy sensors.

In order to facilitate reduction measures on an institutional level, individuals must be made more aware of the broad environmental ramifications that accompany their personal choices. Since the survey results in Chapter 5 suggest a large gap between student perceptions of mitigation options and their technical and economic realities, education must reflect the interconnections between behavior and its associated effects. For instance, the Carnegie Mellon printing quota, which limits total printing at on-campus locations each semester, was instituted in 2005 to eliminate paper waste and to encourage users to be more conservative about their printing habits. Likewise, one can imagine that a greater deal of attention would be paid to computer use and lighting habits if students were directly accountable for the monthly electric bill at their dormitory or were required to pay fines for excessive use of utilities. One practical way to bridge disparities in student awareness (while also saving money) is to institute a dormitory energy and water conservation competition, as recently done by schools like Indiana University and Harvard. These competitions serve not only to make reductions in a school's carbon and ecological footprints but more importantly help to foster a spirit of community involvement while promoting greater environmental sustainability.

Individuals should also be made more aware of low-carbon behavior choices that can have large impacts without particularly onerous efforts. As detailed in Section 5.5, faculty, staff, and students can take actions including webcasting, reducing beef consumption, adjusting thermostat settings, and simply turning off lights and electronic equipment to reduce their associated greenhouse gas emissions. It is empowering for individuals to know that a number of simple measures have the potential to mitigate nearly 40 percent of a student's personal carbon footprint.

8.2.5. Commitments

A thorough analysis of Carnegie Mellon's current environmental condition using ecological and carbon footprinting and the analysis of the community's preferences were both very important steps in working toward campus sustainability. Yet, despite the laudable achievement that these analyses were, there is still a very evident weakness: commitment. Without commitment toward further goals in the realm of sustainability, these analyses run the risk of becoming only analyses rather than becoming the change needed to make Carnegie Mellon a leader in green practices. Students challenged the university to purchase more green energy, and this report would like to reiterate a similar challenge to the administration and the community of Carnegie Mellon: start making a positive difference in environmental awareness and conservation now.

Carnegie Mellon can make perhaps the largest positive difference through transparency of data. Posting all data and benchmarking against peer institutions, while inviting them to review, respond, and join in doing the same, will have tremendous effects on cooperation and awareness of the problem. This perhaps is the greatest commitment of all, as it does not allow for colleges and universities to hide behind false commitments but rather shows all environmental affairs in the full light of accountability and transparent disclosure. Once this is completed, Carnegie Mellon must look toward actual reduction policies and programs to find which are and which are not economically viable.

However, in order for Carnegie Mellon to reduce emissions effectively, taking ecological considerations into account as well requires more resources to be put toward analyzing and instituting sustainable practices. This can be most successfully done with the assistance of an office dedicated to investigate reduction and mitigation options. This office should allow for the inclusion of student, staff, and faculty input, as these individuals on campus are most able to see where improvements can be made and where weakness can be remedied. Such an office will be central in providing a detailed action plan with set goals of mitigation and a specific timeline of when those goals should be reached. Furthermore, such an office would be the main driver in implementing and keeping notes upon the mitigation policies in place. With these steps completed, programs will be efficiently put into place with the distinct goal of reductions or at least the flattening out of greenhouse gas emissions in the future.

Carnegie Mellon University has been a leader in the areas of education and research regarding the most pressing issues of society since it was founded in 1900, and with the ever increasing importance of environmental issues, the university should continue its role by making a strong, public commitment to sustainability on college campuses.

Chapter 8 References

Carnegie Mellon University, 2008a: "C-MITES: Carnegie Mellon Institute for Talented Elementary and Secondary Students." http://www.cmu.edu/cmites/index.html (Accessed May 8, 2008).

Carnegie Mellon University, 2008b: "Environmental design students promote reusable shopping bags," Carnegie Mellon Design. http://www.design.cmu.edu/show_news.php?id=166&m=200804 (Accessed May 8, 2008).

Appendix 2.A. Carbon Calculator Information

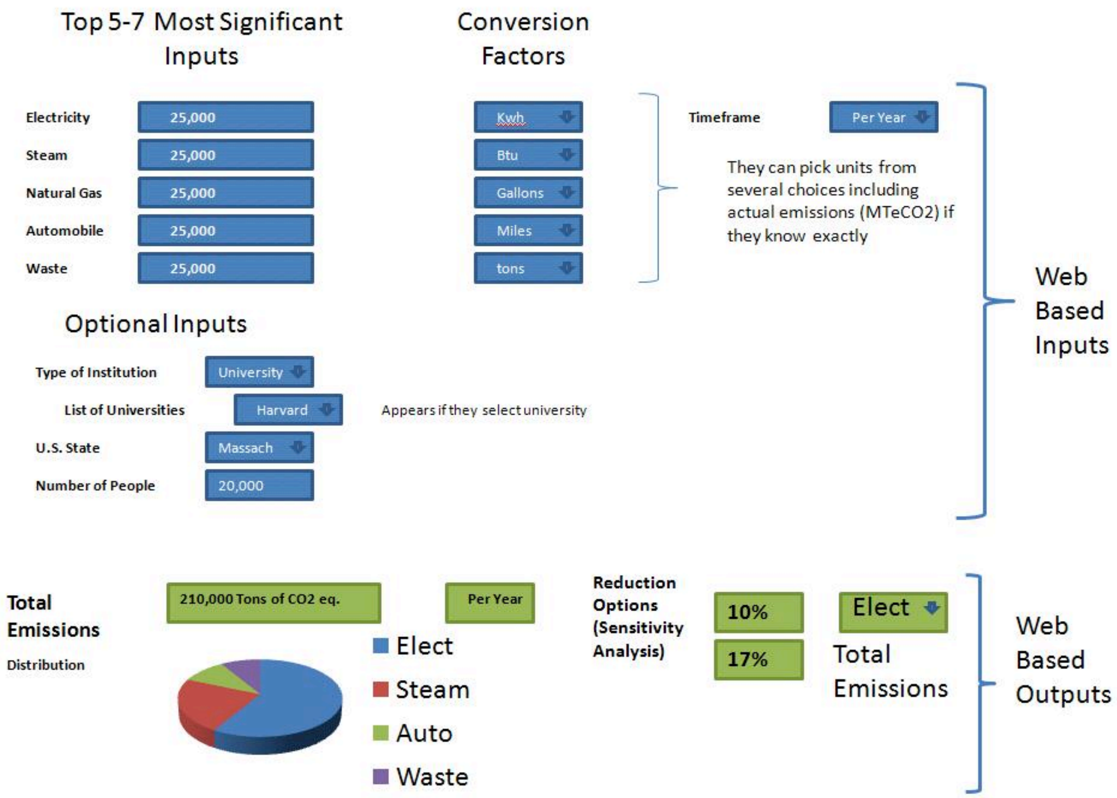

Figure 2.A.1 – Conceptual Design of Web/Excel Emissions Estimator Application

Table 2.A.1 – Breakdown of CACP calculator inputs, formulas, and outputs

Input Category	Quantity	Formulas and Conversions	Result (MTCDE)
INSTITUTIONAL DATA			
Energy Budget	$12,534,026.00		
FT Students	10,120		
Faculty	1,426		
Staff	2,458		
Building Space	4,724,720 ft^2		
Landfill	3,100 Short Tons	No CH_4 recovery	3,069
PURCHASED ENERGY			
Purchased Electricity	100,862,648 kWh	41.4% Coal, 41.4% Nuclear, 17.2% Renewable 49,552,889 kg CO_2, 0 kg CH_4, 1 kg N_20	49,553
Purchased Steam	382,577	37,309,871 kg CO_2 (98 kg	52,594

	MMBTU	CO_2/MMBTU) 4,063 kg CH_4 (0.01062 kg NH_4/MMBTU) 460 kg N_20 (0.00120 kg N_20/MMBTU)	
Purchased Chilled Water	189,541 MMBTU	14,985,431kg CO_2 (79 CO_2/MMBTU) 1,888 kg CH_4 (0.00996 NH_4/MMBTU) 88 kg N_20 (0.00046 N_2O/MMBTU)	
COMMUTING DATA			
Faculty/Staff Gasoline	904,229 gal	22.1 mpg (CACP 8.93 metric kg eCO_2/gal); 5,174 people, 260 days/year **(11.15 kg eCO_2/gal → incl. lifecycle, 8.15 without from Department of Energy)	8,079
Student Gasoline	20,515 gal	22.1 mpg, 20% Commuted, 160 days/year 453,376 miles (CACP 8.93 metric kg eCO_2/gal)	183
Student Diesel	0 gal	39.67 mpg (10.08 kg eCO_2/gallon),	0
Student Air	39,000,000 miles	(13,983,000 kg eCO_2, 0.777 kg eCO_2/mile) **emission factor is averaged, cannot show take-off emissions	30,298
Official Air Travel	45,000,000 miles	(13,983,000 kg eCO_2, 0.777 kg eCO_2/mile) **emission factor is averaged, cannot show take-off emissions	34,958
CMU Operations		50 gasoline consuming vehicles driving avg. 75,000 miles per year per vehicle (environmental report), 3 Diesel, 6 CNG, 7 Electric	0
TOTAL EMISSIONS AND SUMMARY METRICS			
Total Emissions			178,735
Demographic Emissions Summary		17.7 MTCDE per student 11.7 MTCDE per person (faculty, staff, students) 37.8 MTCDE per ft^2	

Table 2.A.2 – Input profiles for popular carbon emissions estimators

			Calculator Name (Type)												
		Units	CACP (Comprehensive)	EPA (Personal)	Green Tags (Personal)	Inconvenient Truth (Personal)	TerraPass (Travel)	Native Energy (Travel)	Stanford (Travel)	Abraxas Energy (Power Source)	Travel Matters (Travel)	Cleaner and Greener (Personal)	airhead.cnt.org (Personal)	Texas A&M (Power Source)	Penn State GHG (University)
DEMO-GRAPHICS	*Operating Budget*	$	✓												
	Research Budget	$	✓												
	Energy Budget	$	✓	✓											
	Full-time Students	#	✓	✓		✓							✓		
	Part-time Students	#	✓												
	Summer Students	#	✓												
	Faculty	#	✓												
	Staff	#	✓												
	Total Building Space	ft^2	✓												
	Total Research Building Space	ft^2	✓												
ENERGY	*Purchased Electricity*	kWh	✓		✓	✓				✓		✓	✓		✓
	Purchased Steam	MMBTU	✓												
	Chilled Water	MMBTU	✓												
	Stationary Sources	MMBTU	✓												
	On-Campus Co-Gen	MMBTU	✓												✓
	Natural Gas Bill	$	✓	✓		✓				✓			✓		✓

UNIVERSITY FLEET	*Gasoline Fleet*	Gallons	✓												✓
	Diesel Fleet	Gallons	✓												✓
	Natural Gas Fleet	Gallons	✓												✓
	Electric Fleet	kWh	✓												
	Other Fleet Source	MMBTU	✓												
AIR TRAVEL	*Faculty/Staff Business*	mileage	✓		✓	✓	✓	✓			✓		✓		
	Student Programs	mileage	✓		✓	✓	✓	✓			✓		✓		
COMMUTER INFO	*Students Commuting*	#	✓												
	Avg. Fuel Efficiency	%	✓	✓	✓	✓		✓	✓		✓				
	Commuting Alone	%	✓												
	Carpooling	%	✓												
	Trips per Day	#	✓						✓						
	Days per Year	#	✓						✓						
	Miles per Trip	miles	✓						✓						
	Total Distance (by Car)	miles	✓	✓	✓	✓		✓			✓		✓		✓
	Fuel Consumed (by Car/Truck)	gal	✓												✓
	Bus Fuel Efficiency (Diesel)	%	✓								✓				✓
	Students Commuting by Bus	%	✓												
	Trips per Day	#	✓												
	Days per Year	#	✓												
	Miles per Trip	miles	✓												
	Total Distance (by Bus)	miles	✓					✓			✓				✓
	Fuel Consumed (by Diesel Bus)	gal	✓					✓			✓				✓
	Fuel Consumed (by CNG Bus)	gal	✓					✓			✓				✓
	Students Commuting by Rail	%	✓												
	Trips per Day	#	✓												
	Days per Year	#	✓												
	Miles per Trip	miles	✓												
	Total Distance (by Rail)	miles	✓								✓				
	Total Distance by Bike	miles	✓								✓		✓		
	Total Distance by Foot	miles	✓								✓		✓		
AGRICULTURE	*Synthetic Fertilizer*	lbs	✓												

	Nitrogen	%	✓												
	Organic Fertilizer	lbs	✓												
	Nitrogen	%	✓												
SOLID WASTE	*Mass Burn Incinerator*	short tons	✓												✓
	RDF Incinerator	short tons	✓												
	Landfilled (No CH_4 Recovery)	short tons	✓												✓
	Landfilled (CH_4 Recovery and Flaring)	short tons	✓												✓
	Landfilled (CH_4 Recovery and Generation)	short tons	✓												✓
	Composted	short tons													✓
WASTE WATER	*Sludge*	tons													✓
	Waste Water	tons													✓
	Captured CH_4	mcf													✓
OTHER GHGs	*HFC-134a*	lbs	✓												✓
	HFC-404a	lbs	✓												✓
	HCFE-235da2	lbs	✓												
	HG-10	lbs	✓												
	Others	lbs	✓												✓
	HCFC-123	lbs	✓												✓
	HCFC-22	lbs	✓												✓
OFFSETS	*Renewable Energy Credits*	kWh	✓												
	Compost Produced	short tons	✓												
	Forest Preservation	MTCDE	✓												

Table 2.A.3 – URL, number of inputs, and category of calculators

	URL	Inputs	Category			
			Personal	Travel	Power Source	Comprehensive
Abraxas Energy	http://www.abraxasenergy.com/emissions/	1			✓	
Airhead	http://airhead.cnt.org/Calculator/	9	✓			
BioFleet Corp.	http://biofleet.net/index.php?option=com_wrapper&Itemid=58	2		✓		
CarboNZero	http://www.carbonzero.co.nz/calculators/school_emissions_calc.asp	16				✓
Clean Air Cool Planet	http://www.cleanair-coolplanet.org/toolkit/content/view/43/124/	80				✓
Cleaner and Greener	http://www.cleanerandgreener.org/resources/pollutioncalculator.htm	3			✓	
EPA	http://www.epa.gov/climatechange/emissions/ind_calculator.html	10	✓			
Green Tags USA	http://www.greentagsusa.org/GreenTags/calculator/	7	✓			
ICLEI	http://www3.iclei.org/co2/co2calc.htm	16	✓			
Inconvenient Truth	http://www.climatecrisis.net/takeaction/carboncalculator/	10	✓			
Native Energy	http://www.nativeenergy.com/pages/resrunner/286.php?afc=ResRunner	4		✓		
Pacific Gas & Electric	http://www.pge.com/myhome/environment/calculator/	4	✓			
Penn State	http://www.cira.psu.edu/Chris%20Steuer/University_GHG_Calculator.xls	62				✓
Stanford	http://transportation.stanford.edu/alt_transportation/calculator.shtml	7		✓		
TerraPass (Office)	http://www.terrapass.com/business-carbon-calculator/footprints/52582/office_emission/new	19		✓		
TerraPass (Travel)	http://www.terrapass.com/	3		✓		
Texas A&M	http://ecalc.tamu.edu/	9			✓	
The Nature Conservancy	http://www.nature.org/initiatives/climatechange/calculator/	17	✓			
Travel Matters	http://www.travelmatters.org/	27	✓			

Appendix 3.A. *Redefining Progress* Ecological Footprint Inputs

Table 3.A.1 – *Redefining Progress* calculator inputs for food

Categories	Number of Inputs	Units	Examples/Notes
Meat, Fish	5	kg	Beef (grain fed), pork, poultry
Produce	2	kg	Vegetable, potatoes, beans, other dried pulses
Liquids	5	l	Milk, juice, oils, ice cream, wine, beer, yogurt
Cereals	2	kg	Bread, rice
Coffee, Tea, and Sugar	2	kg	Coffee, tea, sugar
Cheese, Solid Oils	2	kg	-
Garden (for Food)	1	m^2	-
Eating Out	1	$	-
Eggs	1	number	-
Total	***21***		

Table 3.A.2 – *Redefining Progress* calculator inputs for housing

Categories	Number of Inputs	Units	Examples/Notes
House (living area)	3	m^2	Wooden house, brick house, yard
Hotels	1	$	-
Electricity	1	kWh	Input also includes area to add specific grid mix for more accurate results
Gas and Coal	4	m^3, l, kg	City gas (m^3), kerosene, coal
Utilities	2	m^3, $	Water, sewage, garbage service
Other	6	kg	Straw (insulation), construction wood, firewood, large/small appliances
Total	***17***		

Table 3.A.3 – *Redefining Progress* calculator inputs for transportation

Categories	Number of Inputs	Units	Examples/Notes
Mass Transit	4	pers. * km	Bus, train (transit/intercity)
Personal	4	km	Taxi, car with input of specific fuel efficiencies
Repairs (Parts)	1	kg	-
Airplane	1	pers. * hours	-
Total	***10***		

Table 3.A.4 – *Redefining Progress* calculator inputs for goods

Categories	Number of Inputs	Units	Examples/Notes
Clothing	3	kg	Cotton, wool, synthetic
Medicine	1	kg	-
Other	7	kg	Tobacco, leather, metal products, durable paper products, hygiene products
Total	***11***		

Table 3.A.5 – *Redefining Progress* calculator inputs for services

Categories	Number of Inputs	Units	Examples/Notes
Postal	2	kg	Domestic and international post
Other	6	$	
Total	***8***		

Table 3.A.6 – *Redefining Progress* calculator inputs for waste

Categories	Number of Inputs	Units	Examples/Notes
Waste	5	kg	Paper, glass, plastic, other metals, aluminum

Appendix 4.A. Carnegie Mellon Campus Environmental Survey

Campus Environmental Survey

In order to be ELIGIBLE to WIN the PRIZE you must ANSWER ALL QUESTIONS COMPLETELY.

1. Gender

○ Male ○ Female

2. U.S. Citizen

○ Yes ○ No

3. Age

4. Indicate which Carnegie Mellon school or college you are affiliated with (choose all that apply):

- ☐ Carnegie Institute of Technology (College of Engineering)
- ☐ College of Fine Arts
- ☐ College of Humanities and Social Sciences
- ☐ Tepper School of Business
- ☐ H. John Heinz III School of Public Policy and Management
- ☐ Mellon College of Science
- ☐ School of Computer Science

5. What is your current status at Carnegie Mellon:

○ Freshman ○ Sophomore ○ Junior ○ Senior ○ Graduate ○ Faculty ○ Staff

6. How many courses have you taken at Carnegie Mellon that dealt specifically with sustainability or environmental issues?

7. Are you a member of any environmental group(s)?

○ Yes (specify)

○ No

8. If you answered Yes to the previous question, please specify which group(s)?

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Figure 4.A.1 – Questions 1-8 from the campus environmental survey

Campus Environmental Survey

9. Below is a list of energy production technologies, indicate which ones you think are "green energy" sources. (You may choose more than one option.)

- [ ] Hydro-electric power
- [ ] Wind power
- [ ] Fuel cells/Hydrogen power
- [ ] Solar power
- [ ] Coal
- [ ] Natural Gas
- [ ] Nuclear power
- [ ] Biofuels

10. Approximately 20% of Carnegie Mellon's electricity currently comes from "green energy." What percentage of Carnegie Mellon's total electrical energy usage do you think should come from green energy? (%)

For the next three questions, consider the scenario where Carnegie Mellon increases its "green energy" purchases to 50% of its total electricity use.

11. Approximately how many total tons of CO2 emissions are prevented from entering the atmosphere each year? (Assume that a typical car or household's electricity use produces approximately 8 tons of CO2 per year.)

- ◯ 25,000
- ◯ 50,000
- ◯ 75,000
- ◯ 100,000
- ◯ 125,000

12. How much per student would the university need to charge annually if the students absorb the additionally energy costs? (Assume that there are 10,000 undergrad and graduate students at Carnegie Mellon.)

◯ $0-5	◯ $20-40	◯ $100-150
◯ $5-10	◯ $40-60	◯ $150-200
◯ $10-15	◯ $60-80	◯ $200-250
◯ $15-20	◯ $80-100	◯ $250-300

Page 2

Figure 4.A.2 – Questions 9-12 from the campus environmental survey

Campus Environmental Survey

13. How much would you be willing to pay annually to fund the additional energy costs? ($/yr)

14. Green energy prices are higher than traditional energy prices. Who should pay the additional costs associated with purchasing green energy at Carnegie Mellon? (You may choose more than one option.)

- ☐ Federal government
- ☐ State government
- ☐ City government
- ☐ Carnegie Mellon University
- ☐ Carnegie Mellon University Students (Undergraduate and Graduate)

15. What percent of carbon emissions from Carnegie Mellon operations do you think are produced by undergraduate activities? (%)

For the following questions indicate your level of agreement.

16. I fully understand the meaning of the term "sustainability."

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Choose One	○	○	○	○	○

17. Unless dramatic steps are taken, global warming will cause significant irreversible damage to global ecosystems and human populations.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Choose One	○	○	○	○	○

18. My concern towards environmental issues has grown due to Carnegie Mellon events, activities, and/or courses.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Choose One	○	○	○	○	○

19. Carnegie Mellon is a leader in sustainable practices among other universities.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Choose One	○	○	○	○	○

20. The Carnegie Mellon community is well informed about what is being done to make the campus more sustainable.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Choose One	○	○	○	○	○

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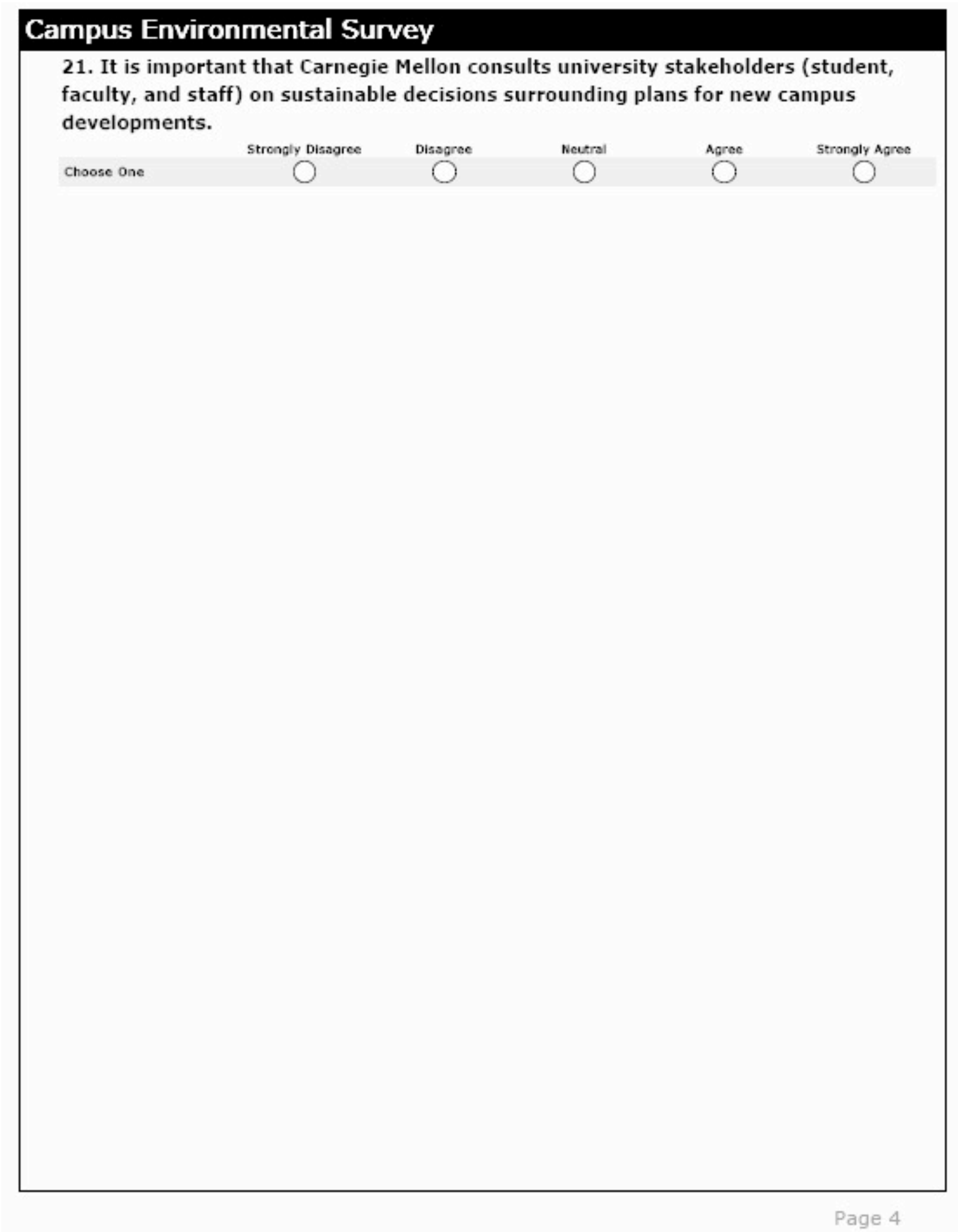
Figure 4.A.3 – Questions 13-20 from the campus environmental survey



Campus Environmental Survey

21. It is important that Carnegie Mellon consults university stakeholders (student, faculty, and staff) on sustainable decisions surrounding plans for new campus developments.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Choose One	○	○	○	○	○

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Figure 4.A.4 – Question 21 from the campus environmental survey

Campus Environmental Survey

22. Listed below are 16 proposals for changing energy usage at Carnegie Mellon. Each would have different effects on CO2 emissions. Rate each of the proposals on their relative ability to reduce CO2 emissions.

	Excellent	Good	Average	Fair	Poor
1. Purchase 10% of campus electrical power from Hydro-electric sources	○	○	○	○	○
2. Purchase 10% of campus electrical power from Wind Power	○	○	○	○	○
3. Purchase 10% of campus electrical power from Fuel Cells/Hydrogen Power	○	○	○	○	○
4. Purchase 10% of campus electrical power from Nuclear Power	○	○	○	○	○
5. Purchase 10% of campus electrical power from Solar Power	○	○	○	○	○
6. Install a Cogeneration Plant to provide both electricity and heat for Wean Hall	○	○	○	○	○
7. Install highly efficient windows in Baker/Porter Hall	○	○	○	○	○
8. Use biofuels to power all university vehicles	○	○	○	○	○
9. Reduce beef products sold on campus, and served in dining facilities by 50%	○	○	○	○	○
10. Eliminate "sleep mode" on campus computers, so they turn-off instead	○	○	○	○	○
11. Install motion detectors on lights in public spaces	○	○	○	○	○
12. Permit only compact fluorescent bulbs in dormitories and offices	○	○	○	○	○
13. In the winter lower thermostat settings in campus buildings by 3°F	○	○	○	○	○
14. Reduce the number of parking spaces on campus by 20%	○	○	○	○	○
15. Eliminate paper newspapers distributed on campus (online campus news only)	○	○	○	○	○
16. Purchase offsets (pay other organizations to reduce their emissions)	○	○	○	○	○

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Figure 4.A.5 – Question 22 from the campus environmental survey

Campus Environmental Survey

23. Listed below are the same 16 proposals. Each would have different economic effects. Rate each of the proposals on their relative ability to increase money-savings.

	Excellent	Good	Average	Fair	Poor
1. Purchase 10% of campus electrical power from Hydro-electric sources	○	○	○	○	○
2. Purchase 10% of campus electrical power from Wind Power	○	○	○	○	○
3. Purchase 10% of campus electrical power from Fuel Cells/Hydrogen Power	○	○	○	○	○
4. Purchase 10% of campus electrical power from Nuclear Power	○	○	○	○	○
5. Purchase 10% of campus electrical power from Solar Power	○	○	○	○	○
6. Install a Cogeneration Plant to provide both electricity and heat for Wean Hall	○	○	○	○	○
7. Install highly efficient windows in Baker/Porter Hall	○	○	○	○	○
8. Use biofuels to power all university vehicles	○	○	○	○	○
9. Reduce beef products sold on campus, and served in dining facilities by 50%	○	○	○	○	○
10. Eliminate "sleep mode" on campus computers, so they turn-off instead	○	○	○	○	○
11. Install motion detectors on lights in public spaces	○	○	○	○	○
12. Permit only compact fluorescent bulbs in dormitories and offices	○	○	○	○	○
13. In the winter lower thermostat settings in campus buildings by 3°F	○	○	○	○	○
14. Reduce the number of parking spaces on campus by 20%	○	○	○	○	○
15. Eliminate paper newspapers distributed on campus (online campus news only)	○	○	○	○	○
16. Purchase offsets (pay other organizations to reduce their emissions)	○	○	○	○	○

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Figure 4.A.6 – Question 23 from the campus environmental survey

Campus Environmental Survey

24. Consider your responses to the two previous questions and how you would be affected by the proposals. Rate each of the proposals according to your personal liking.

	Strongly Like	Like	Indifferent	Dislike	Strongly Dislike
1. Purchase 10% of campus electrical power from Hydro-electric sources	○	○	○	○	○
2. Purchase 10% of campus electrical power from Wind Power	○	○	○	○	○
3. Purchase 10% of campus electrical power from Fuel Cells/Hydrogen Power	○	○	○	○	○
4. Purchase 10% of campus electrical power from Nuclear Power	○	○	○	○	○
5. Purchase 10% of campus electrical power from Solar Power	○	○	○	○	○
6. Install a Cogeneration Plant to provide both electricity and heat for Wean Hall	○	○	○	○	○
7. Install highly efficient windows in Baker/Porter Hall	○	○	○	○	○
8. Use biofuels to power all university vehicles	○	○	○	○	○
9. Reduce beef products sold on campus, and served in dining facilities by 50%	○	○	○	○	○
10. Eliminate "sleep mode" on campus computers, so they turn-off instead	○	○	○	○	○
11. Install motion detectors on lights in public spaces	○	○	○	○	○
12. Permit only compact fluorescent bulbs in dormitories and offices	○	○	○	○	○
13. In the winter lower thermostat settings in campus buildings by 3°F	○	○	○	○	○
14. Reduce the number of parking spaces on campus by 20%	○	○	○	○	○
15. Eliminate paper newspapers distributed on campus (online campus news only)	○	○	○	○	○
16. Purchase offsets (pay other organizations to reduce their emissions)	○	○	○	○	○

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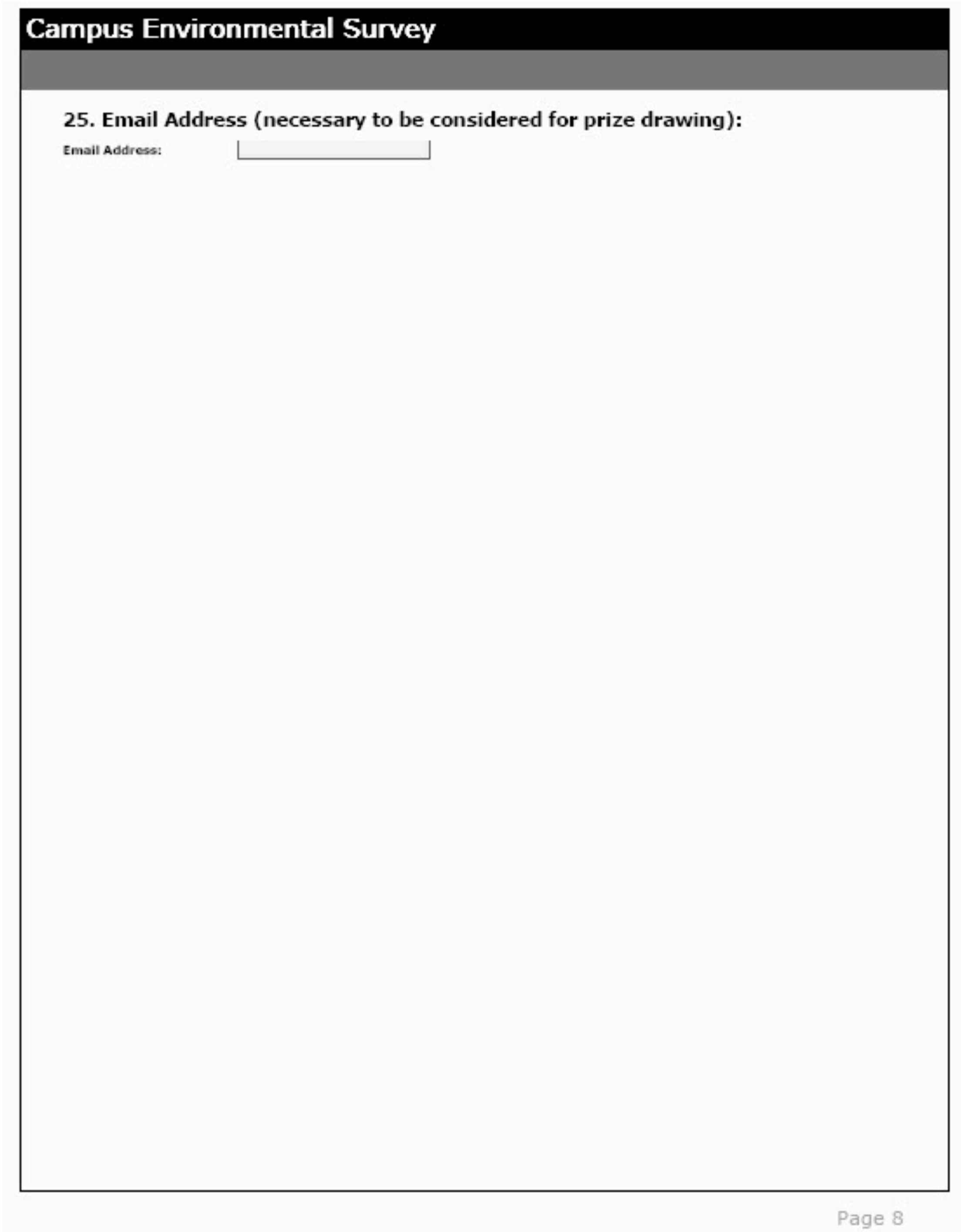
Figure 4.A.7 – Question 24 from the campus environmental survey



Campus Environmental Survey

25. Email Address (necessary to be considered for prize drawing):

Email Address:

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Figure 4.A.8 – Question 25 from the campus environmental survey

Appendix 4.B. Carnegie Mellon Campus Environmental Survey Results

1. Gender

	Response Percent	Response Count
Male	49.0%	1378
Female	51.0%	1437
answered question		2815
skipped question		13

2. U.S. Citizen

	Response Percent	Response Count
Yes	82.1%	2309
No	17.9%	504
answered question		2813
skipped question		15

3. Age

	Response Count
	2771
answered question	2771
skipped question	57

Figure 4.B.1 – Results from questions 1-3 from the campus environmental survey

4. Indicate which Carnegie Mellon school or college you are affiliated with (choose all that apply):

	Response Percent	Response Count
Carnegie Institute of Technology (College of Engineering)	27.4%	705
College of Fine Arts	14.1%	362
College of Humanities and Social Sciences	22.5%	579
Tepper School of Business	13.8%	354
H. John Heinz III School of Public Policy and Management	11.4%	294
Mellon College of Science	15.0%	386
School of Computer Science	19.0%	487
	answered question	2569
	skipped question	259

5. What is your current status at Carnegie Mellon:

	Response Percent	Response Count
Freshman	10.8%	301
Sophomore	8.5%	239
Junior	8.5%	239
Senior	9.4%	264
Graduate	27.5%	770
Faculty	8.5%	239
Staff	26.7%	747
	answered question	2799
	skipped question	29

Figure 4.B.2 – Results from questions 4-5 from the campus environmental survey

6. How many courses have you taken at Carnegie Mellon that dealt specifically with sustainability or environmental issues?

	Response Count
	2704
answered question	**2704**
skipped question	**124**

7. Are you a member of any environmental group(s)?

	Response Percent	Response Count
Yes (specify)	9.9%	278
No	**90.1%**	2522
answered question		**2800**
skipped question		**28**

8. If you answered Yes to the previous question, please specify which group(s)?

	Response Count
	341
answered question	**341**
skipped question	**2487**

Figure 4.B.3 – Results from questions 6-8 from the campus environmental survey

9. Below is a list of energy production technologies, indicate which ones you think are "green energy" sources. (You may choose more than one option.)

	Response Percent	Response Count
Hydro-electric power	76.3%	1807
Wind power	**97.0%**	2296
Fuel cells/Hydrogen power	52.5%	1244
Solar power	96.7%	2289
Coal	2.3%	54
Natural Gas	8.4%	199
Nuclear power	22.3%	527
Biofuels	42.0%	995
	answered question	**2368**
	skipped question	**460**

10. Approximately 20% of Carnegie Mellon's electricity currently comes from "green energy." What percentage of Carnegie Mellon's total electrical energy usage do you think should come from green energy? (%)

	Response Count
	2346
answered question	**2346**
skipped question	**482**

Figure 4.B.4 – Results from questions 9-10 from the campus environmental survey

11. Approximately how many total tons of CO2 emissions are prevented from entering the atmosphere each year? (Assume that a typical car or household's electricity use produces approximately 8 tons of CO2 per year.)

	Response Percent	Response Count
25,000	10.5%	242
50,000	20.0%	460
75,000	**26.2%**	604
100,000	26.1%	601
125,000	17.2%	397
	answered question	**2304**
	skipped question	**524**

12. How much per student would the university need to charge annually if the students absorb the additionally energy costs? (Assume that there are 10,000 undergrad and graduate students at Carnegie Mellon.)

	Response Percent	Response Count
$0-5	9.8%	226
$5-10	6.1%	141
$10-15	4.9%	113
$15-20	5.5%	127
$20-40	11.4%	261
$40-60	10.9%	250
$60-80	5.7%	130
$80-100	**16.6%**	380
$100-150	12.3%	282
$150-200	3.8%	88
$200-250	4.1%	95
$250-300	8.8%	202
	answered question	**2295**
	skipped question	**533**

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Figure 4.B.5 – Results from questions 11-12 from the campus environmental survey

13. How much would you be willing to pay annually to fund the additional energy costs? ($/yr)

	Response Count
	2283
answered question	2283
skipped question	545

14. Green energy prices are higher than traditional energy prices. Who should pay the additional costs associated with purchasing green energy at Carnegie Mellon? (You may choose more than one option.)

	Response Percent	Response Count
Federal government	61.3%	1422
State government	47.8%	1109
City government	37.4%	867
Carnegie Mellon University	**74.5%**	1727
Carnegie Mellon University Students (Undergraduate and Graduate)	37.7%	873
answered question		2318
skipped question		510

15. What percent of carbon emissions from Carnegie Mellon operations do you think are produced by undergraduate activities? (%)

	Response Count
	2267
answered question	2267
skipped question	561

Figure 4.B.6 – Results from questions 13-15 from the campus environmental survey

16. I fully understand the meaning of the term "sustainability."						
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Response Count
Choose One	2.5% (59)	9.4% (219)	17.0% (397)	**51.3% (1201)**	19.8% (464)	2340
					answered question	**2338**
					skipped question	**490**

17. Unless dramatic steps are taken, global warming will cause significant irreversible damage to global ecosystems and human populations.						
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Response Count
Choose One	4.1% (96)	6.0% (140)	12.8% (300)	37.8% (885)	**39.3% (921)**	2342
					answered question	**2341**
					skipped question	**487**

18. My concern towards environmental issues has grown due to Carnegie Mellon events, activities, and/or courses.							
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Rating Average	Response Count
Choose One	12.4% (290)	25.8% (604)	**34.5% (807)**	21.8% (510)	5.5% (128)	2.82	2339
						answered question	**2339**
						skipped question	**489**

19. Carnegie Mellon is a leader in sustainable practices among other universities.						
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Response Count
Choose One	2.4% (56)	10.4% (243)	**48.5% (1133)**	33.0% (772)	5.7% (133)	2337
					answered question	**2337**
					skipped question	**491**

Figure 4.B.7 – Results from questions 16-19 from the campus environmental survey

20. The Carnegie Mellon community is well informed about what is being done to make the campus more sustainable.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Response Count
Choose One	7.9% (184)	34.9% (814)	**36.1% (842)**	19.0% (444)	2.1% (49)	2333
					answered question	**2333**
					skipped question	**495**

21. It is important that Carnegie Mellon consults university stakeholders (student, faculty, and staff) on sustainable decisions surrounding plans for new campus developments.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Response Count
Choose One	1.2% (27)	2.8% (65)	13.2% (310)	**55.6% (1302)**	27.2% (638)	2342
					answered question	**2341**
					skipped question	**487**

22. Listed below are 16 proposals for changing energy usage at Carnegie Mellon. Each would have different effects on CO2 emissions. Rate each of the proposals on their relative ability to reduce CO2 emissions.

	Excellent	Good	Average	Fair	Poor	Rating Average	Response Count
1. Purchase 10% of campus electrical power from Hydro-electric sources	23.4% (466)	**44.6% (887)**	23.4% (466)	5.4% (107)	3.1% (62)	3.80	1988
2. Purchase 10% of campus electrical power from Wind Power	**41.8% (834)**	37.6% (749)	14.3% (286)	4.2% (83)	2.1% (42)	4.13	1994
3. Purchase 10% of campus electrical power from Fuel Cells/Hydrogen Power	14.7% (291)	**35.6% (703)**	30.5% (602)	11.3% (223)	7.9% (157)	3.38	1976
4. Purchase 10% of campus electrical power from Nuclear Power	19.0% (375)	**26.0% (513)**	25.3% (499)	15.7% (311)	14.1% (278)	3.20	1976
5. Purchase 10% of campus electrical power from Solar Power	**44.3% (879)**	36.0% (714)	13.6% (270)	4.1% (82)	1.9% (37)	4.17	1982
6. Install a Cogeneration Plant to provide both electricity and heat for Wean Hall	20.4% (401)	**39.2% (769)**	30.4% (598)	7.3% (143)	2.7% (53)	3.67	1964

Figure 4.B.8 – Results from questions 20-22 (1-6) from the campus environmental survey

7. Install highly efficient windows in Baker/Porter Hall	**38.9% (773)**	36.1% (717)	17.7% (351)	5.8% (116)	1.5% (30)	4.05	1987
8. Use biofuels to power all university vehicles	17.2% (339)	**27.9% (551)**	27.0% (533)	15.5% (306)	12.5% (246)	3.22	1975
9. Reduce beef products sold on campus, and served in dining facilities by 50%	14.6% (290)	16.8% (334)	23.3% (463)	19.0% (377)	**26.2% (519)**	2.75	1983
10. Eliminate "sleep mode" on campus computers, so they turn-off instead	16.4% (324)	24.3% (481)	**25.8% (511)**	20.6% (407)	13.0% (257)	3.11	1980
11. Install motion detectors on lights in public spaces	31.4% (623)	**35.3% (701)**	19.0% (377)	9.3% (185)	4.9% (98)	3.79	1984
12. Permit only compact fluorescent bulbs in dormitories and offices	32.9% (653)	**35.7% (708)**	18.6% (368)	8.2% (162)	4.6% (91)	3.84	1982
13. In the winter lower thermostat settings in campus buildings by 3°F	31.9% (629)	**34.5% (681)**	20.1% (397)	7.8% (153)	5.7% (113)	3.79	1973
14. Reduce the number of parking spaces on campus by 20%	8.1% (160)	13.4% (264)	22.3% (440)	20.2% (398)	**36.0% (711)**	2.37	1973
15. Eliminate paper newspapers distributed on campus (online campus news only)	18.4% (365)	21.6% (429)	**25.7% (510)**	21.9% (435)	12.3% (244)	3.12	1983
16. Purchase offsets (pay other organizations to reduce their emissions)	8.9% (176)	19.8% (392)	**33.3% (658)**	18.1% (358)	19.8% (391)	2.80	1975
						answered question	**1999**
						skipped question	**829**

Figure 4.B.9 – Results from question 22 (7-16) from the campus environmental survey

23. Listed below are the same 16 proposals. Each would have different economic effects. Rate each of the proposals on their relative ability to increase money-savings.

	Excellent	Good	Average	Fair	Poor	Rating Average	Response Count
1. Purchase 10% of campus electrical power from Hydro-electric sources	6.3% (123)	18.9% (367)	**32.3% (628)**	22.0% (429)	20.5% (399)	2.68	1946
2. Purchase 10% of campus electrical power from Wind Power	9.5% (185)	17.2% (334)	**28.5% (554)**	23.5% (458)	21.3% (415)	2.70	1946
3. Purchase 10% of campus electrical power from Fuel Cells/Hydrogen Power	4.3% (83)	13.8% (267)	**30.2% (586)**	23.9% (464)	27.8% (540)	2.43	1940
4. Purchase 10% of campus electrical power from Nuclear Power	8.6% (166)	19.7% (381)	**31.9% (616)**	20.8% (402)	19.0% (368)	2.78	1933
5. Purchase 10% of campus electrical power from Solar Power	10.6% (206)	18.3% (356)	**26.9% (523)**	21.9% (425)	22.3% (433)	2.73	1943
6. Install a Cogeneration Plant to provide both electricity and heat for Wean Hall	11.4% (220)	25.8% (498)	**32.2% (622)**	18.4% (355)	12.3% (238)	3.06	1933
7. Install highly efficient windows in Baker/Porter Hall	32.2% (627)	**34.6% (674)**	21.6% (422)	8.4% (163)	3.3% (64)	3.84	1950
8. Use biofuels to power all university vehicles	7.4% (143)	15.8% (308)	**30.5% (593)**	24.2% (471)	22.1% (429)	2.62	1944
9. Reduce beef products sold on campus, and served in dining facilities by 50%	14.6% (284)	21.1% (410)	**27.6% (535)**	17.4% (337)	19.3% (375)	2.94	1941
10. Eliminate "sleep mode" on campus computers, so they turn-off instead	25.3% (493)	**28.6% (557)**	24.8% (482)	13.6% (265)	7.6% (148)	3.50	1945
11. Install motion detectors on lights in public spaces	28.0% (542)	**35.5% (688)**	23.3% (452)	9.6% (186)	3.7% (71)	3.74	1939
12. Permit only compact fluorescent bulbs in dormitories and offices	31.4% (611)	**34.3% (666)**	22.0% (428)	8.7% (170)	3.5% (68)	3.81	1943
13. In the winter lower thermostat settings in campus buildings by 3°F	**47.6% (925)**	32.1% (625)	14.2% (277)	4.1% (79)	2.0% (39)	4.19	1945
14. Reduce the number of parking spaces on campus by 20%	9.0% (174)	12.2% (237)	25.4% (492)	21.0% (407)	**32.4% (629)**	2.44	1939

Figure 4.B.10 – Results from question 23 (1-14) from the campus environmental survey

15. Eliminate paper newspapers distributed on campus (online campus news only)	27.0% (523)	**28.0% (542)**	24.4% (473)	13.4% (259)	7.3% (141)	3.54	1938
16. Purchase offsets (pay other organizations to reduce their emissions)	3.8% (73)	8.7% (168)	23.9% (461)	19.6% (378)	**44.0% (850)**	2.09	1930
						answered question	1959
						skipped question	869

24. Consider your responses to the two previous questions and how you would be affected by the proposals. Rate each of the proposals according to your personal liking.

	Strongly Like	Like	Indifferent	Dislike	Strongly Dislike	Rating Average	Response Count
1. Purchase 10% of campus electrical power from Hydro-electric sources	25.2% (495)	**40.8% (801)**	26.5% (521)	4.8% (94)	2.7% (53)	3.81	1964
2. Purchase 10% of campus electrical power from Wind Power	**38.7% (761)**	36.6% (720)	19.2% (378)	3.1% (61)	2.3% (45)	4.06	1965
3. Purchase 10% of campus electrical power from Fuel Cells/Hydrogen Power	18.3% (358)	32.3% (633)	**34.4% (674)**	9.5% (186)	5.5% (108)	3.48	1959
4. Purchase 10% of campus electrical power from Nuclear Power	17.5% (343)	22.9% (447)	**31.7% (621)**	15.6% (306)	12.2% (239)	3.18	1956
5. Purchase 10% of campus electrical power from Solar Power	**41.9% (822)**	33.2% (652)	18.7% (367)	3.4% (67)	2.7% (53)	4.08	1961
6. Install a Cogeneration Plant to provide both electricity and heat for Wean Hall	22.5% (439)	29.6% (577)	**39.5% (770)**	5.9% (115)	2.5% (49)	3.64	1950
7. Install highly efficient windows in Baker/Porter Hall	**49.7% (977)**	31.6% (622)	15.5% (305)	2.4% (48)	0.8% (15)	4.27	1967
8. Use biofuels to power all university vehicles	19.6% (384)	26.6% (522)	**31.9% (626)**	11.6% (227)	10.4% (204)	3.33	1963
9. Reduce beef products sold on campus, and served in dining facilities by 50%	18.3% (359)	13.4% (264)	**24.6% (483)**	19.1% (375)	**24.6% (483)**	2.82	1964
10. Eliminate "sleep mode" on campus computers, so they turn-off instead	21.1% (414)	20.1% (394)	**25.9% (509)**	21.5% (422)	11.5% (225)	3.18	1964

Figure 4.B.11 – Results from questions 23 (15-16)-24 (1-10) from the campus environmental survey

11. Install motion detectors on lights in public spaces	**39.3% (770)**	30.8% (603)	16.6% (325)	8.4% (164)	4.9% (96)	3.91	1958
12. Permit only compact fluorescent bulbs in dormitories and offices	**41.8% (820)**	29.8% (585)	16.9% (331)	7.3% (144)	4.3% (84)	3.97	1964
13. In the winter lower thermostat settings in campus buildings by 3°F	**36.2% (710)**	24.9% (489)	18.5% (363)	13.7% (269)	6.6% (130)	3.70	1961
14. Reduce the number of parking spaces on campus by 20%	9.5% (187)	9.0% (176)	26.0% (510)	21.9% (429)	**33.5% (657)**	2.39	1959
15. Eliminate paper newspapers distributed on campus (online campus news only)	22.7% (445)	20.3% (399)	**26.0% (510)**	20.3% (398)	10.7% (210)	3.24	1962
16. Purchase offsets (pay other organizations to reduce their emissions)	7.9% (154)	14.3% (278)	**40.0% (778)**	17.3% (336)	20.6% (401)	2.72	1947
						answered question	1969
						skipped question	859

25. Email Address (necessary to be considered for prize drawing):

	Response Percent	Response Count
Email Address:	100.0%	1941
answered question		1941
skipped question		887

Figure 4.B.12 – Results from questions 24 (11-16)-25 from the campus environmental survey

Appendix 5.A. Photovoltaic Solar Calculations

Using a calculator from the solar website Findsolar.com, a value for the average solar irradiance of Pittsburgh was found. Using this value and the calculator, correlations could be found between the annual electricity production, the surface area, the cost per watt, and the total cost of an on-campus photovoltaic electricity generator.

The average solar irradiance of Pittsburgh was assumed to be 4.2 kilowatt hours per square meter per day (My Solar 2008). From a conversation with a representative from SUNELCO (a company specializing in installation of photovoltaic systems), it was determined that the price for a installed solar system could range from six to nine dollars per watt but would tend toward the low side. Using various calculations on the Findsolar estimator, low, medium, and high estimates for the capital cost of six, seven, and eight dollars per kilowatt hour produced annually.

Maintenance costs for the solar estimator assume that a photovoltaic system covering ten percent of the campus land area would cost about $60,000 worth of engineers and maintenance staff for regular fixing and cleaning annually.

Appendix 5.B. REC and Carbon Offset Analysis Data

The survey of carbon offset prices used for the analysis in Section 5.3 is presented in Table 5.B.1. These prices come from two different online sources, The Carbon Catalogue and EcoBusiness Links (Greenspan 2008; EcoBusinessLinks 2008).

Table 5.B.1 – Survey of prices of carbon offsets from various providers

Provider Name	Location	Type	Online Price* ($)	Source
PrimaKlima-Weltweit	Germany	NP	$3.15	Carbon Catalogue
AtmosClear Climate Club	USA	Co	$3.96	EcoBusiness links
Go Zero	USA - VA	NP	$4.00	Carbon Catalogue
Carbonfund.org	USA	NP	$4.30	EcoBusiness links
e-BlueHorizons	USA	Co	$5.00	EcoBusiness links
Carbonfund.org	USA - MD	NP	$5.50	Carbon Catalogue
Eco2Pass	USA	Co	$5.62	EcoBusiness links
DriveNeutral.org	USA	NP	$6.93	EcoBusiness links
Delta Offsets	USA - IL	NP	$7.50	Carbon Catalogue
LiveNeutral	USA - CA	NP	$7.50	Carbon Catalogue
DrivingGreen	Ireland	Co	$8.00	EcoBusiness links
Greenfleet	Australia	NP	$8.11	Carbon Catalogue
TIST	USA - OK	Co	$8.50	Carbon Catalogue
Atmosclear Climate Club	USA - MA	Co	$9.50	Carbon Catalogue
Coolaction	Canada	Co	$10.00	Carbon Catalogue
EcoVoom	USA - OH	Co	$10.00	Carbon Catalogue
Solar Electric Light Fund	USA	NP	$10.00	EcoBusiness links
Carbon Me	UK	Co	$10.04	Carbon Catalogue
MyCarbonTracker	USA - CA	Co	$10.50	Carbon Catalogue
Targetneutral	UK	Co	$10.52	Carbon Catalogue
TerraPass	USA - CA	Co	$10.90	Carbon Catalogue
Go Neutral	USA - NY	NP	$11.02	Carbon Catalogue
Carbon Counter	USA - OR	NP	$12.00	Carbon Catalogue
CELB	USA - VA	NP	$12.00	Carbon Catalogue
The CarbonNeutral Company	UK	Co	$12.64	EcoBusiness links
Envirotrade	UK	Co	$13.05	Carbon Catalogue
Native Energy	USA	Co	$13.20	EcoBusiness links
BeGreen Now	USA - TX	Co	$14.00	Carbon Catalogue
Carbon Offsets Ltd	UK	Co	$14.05	Carbon Catalogue
Carbon Clear	UK	Co	$14.61	EcoBusiness links
CO_2 Australia	Australia	Co	$14.75	Carbon Catalogue

Cleaner Climate	UK & Australia	Co	$15.00	EcoBusiness links
EcoNeutral	Canada	Co	$15.00	Carbon Catalogue
Standard Carbon	USA	Co	$15.00	EcoBusiness links
Carbon Clear	UK	Co	$15.05	Carbon Catalogue
Climate Care	UK	Co	$15.05	Carbon Catalogue
ZeroGHG	Canada	Co	$15.08	Carbon Catalogue
Sustainable travel International	US, Switzerland	NP	$15.25	EcoBusiness links
Climate Neutral	Netherlands	Co	$15.77	Carbon Catalogue
Climate Friendly	Australia	Co	$16.00	EcoBusiness links
C Level	UK	Co	$16.06	Carbon Catalogue
Cleanairpass	Canada	Co	$16.33	Carbon Catalogue
Standard Carbon	USA - WA	Co	$16.53	Carbon Catalogue
Cleaner Climate	UK	Co	$17.00	Carbon Catalogue
Carbon Neutral AU	Australia	NP	$17.52	Carbon Catalogue
GroPower	UK	Co	$18.00	Carbon Catalogue
BalanceCarbon	Australia	Co	$18.44	Carbon Catalogue
Canopy	Australia	NP	$18.44	Carbon Catalogue
Neco	Australia	Co	$18.44	Carbon Catalogue
Uncook the Planet	Australia	Co	$19.45	EcoBusiness links
CO_2 Neutraal	Netherlands	Co	$19.71	Carbon Catalogue
Climate Stewards	UK	NP	$20.07	Carbon Catalogue
The C-change Trust	UK	NP	$20.07	Carbon Catalogue
Offsetters	Canada	NP	$20.10	Carbon Catalogue
CO_2Balance	UK	Co	$21.07	Carbon Catalogue
Carbon Planet	Australia	Co	$21.21	Carbon Catalogue
Climate Friendly	Australia	Co	$21.21	Carbon Catalogue
Carbon Neutral	UK	Co	$21.58	Carbon Catalogue
Sustainable Travel International	USA - CO	NP	$21.72	Carbon Catalogue
CarbonZero Offsets	Canada	Co	$22.11	Carbon Catalogue
PURE	UK	NP	$22.70	Carbon Catalogue
Planetair	Canada	NP	$23.12	Carbon Catalogue
Correct Carbon	UK	Co	$23.58	Carbon Catalogue
mycarbondebt	UK	Co	$23.58	Carbon Catalogue
Action Carbone	France	NP	$23.66	Carbon Catalogue
Carbon Footprint	UK	Co	$23.68	Carbon Catalogue
Blue Ventures	UK	NP	$24.09	Carbon Catalogue
Tree Canada	Canada	NP	$24.12	Carbon Catalogue
carboNZero	New Zealand	Co	$27.09	Carbon Catalogue
Bonneville Environmental Foundation	USA	NP	$28.06	EcoBusiness links
Climat Mundi	France	Co	$29.96	Carbon Catalogue

Carbon Balanced	UK	NP	$30.11	Carbon Catalogue
GrowAForest	UK	NP	$30.11	Carbon Catalogue
Myclimate	Switzerland	NP	$33.00	EcoBusiness links
Carbon Passport	UK	Co	$33.52	EcoBusiness links
Clear	UK	Co	$35.60	EcoBusiness links
Clear Offset	UK	Co	$36.03	Carbon Catalogue
Atmosfair	Germany	NP	$36.27	Carbon Catalogue
CO_2solidaire	France	NP	$37.85	Carbon Catalogue
CompenCO_2	Belgium	NP	$39.43	Carbon Catalogue
Global Cool	UK	NP	$40.14	Carbon Catalogue
MyClimate	Switzerland	NP	$40.95	Carbon Catalogue
CLIMACT	Belgium	Co	$42.58	Carbon Catalogue
Green Tags	USA	NP	$44.50	Carbon Catalogue
CO_2Logic	Belgium	Co	$45.73	Carbon Catalogue
Impatto Zero	Italy	Co	$184.51	Carbon Catalogue

*Low value chosen if range given

The survey of REC providers was found entirely through the U.S. Department of Energy's *Green Power Network* website (Renewable 2008) and is presented in Table 5.B.2.

Table 5.B.2 – Survey of prices for RECs from various providers

Certificate Marketer	Product Name	Renewable Resources	Location of Renewable Resources	Residential Price Premiums
Carbonfund.org	MyGreenFuture	99% new wind, 1% new solar	Nationwide	0.5¢/kWh
NativeEnergy	CoolWatts	100% new wind	Nationwide	0.8¢/kWh
NativeEnergy		100% new biogas	Pennsylvania	0.8¢/kWh-1.0¢/kWh
3 Phases Renewables	Green Certificates	100% biomass, geothermal, hydro, solar, wind	Nationwide	1.2¢/kWh
BeGreenNow.com	BeGreen RECs	wind, solar	Nationwide	1.2¢/kWh
NativeEnergy	CoolDriver	New wind and biogas	Nationwide	~1.2¢/kWh, $12 per ton CO_2 avoided
NativeEnergy	WindBuilders	100% new wind	South Dakota, North Dakota	~1.2¢/kWh,

WindStreet Energy	Renewable Energy Credit Program	wind	Nationwide	~1.2¢/kWh
Premier Energy Marketing	Renewable Energy Credits	100% wind	Nationwide	1.5¢/kWh-2.0¢/kWh
Sterling Planet	Sterling Green Energy	100% new wind, hydro, geothermal, methane, or bioenergy	Nationwide	1.5¢/kWh
Clean and Green	Clean and Green Membership	100% new wind	Nationwide	1.6¢/kWh-3.0¢/kWh
Conservation Services Group	ClimateSAVE	95% new wind/hydro, 5% new solar	Kansas, New England (wind/hydro), New York (solar)	1.65¢/kWh - 1.75¢/kWh
Choose Renewables	CleanWatts	100% new wind	Nationwide	1.7¢/kWh
3Degrees	Renewable Energy Certificates	100% new wind	Nationwide	2.0¢/kWh
Bonneville Environmental Foundation	Denali Green Tags (Alaska only)	100% new wind	10% Alaska, 90% Nationwide	2.0¢/kWh
Bonneville Environmental Foundation	Green Tags Wind	100% wind	Nationwide	2.0¢/kWh
Bonneville Environmental Foundation	Zephyr Energy (Kansas Only)	50% new low-impact hydropower	Mid-West, West	2.0¢/kWh
Maine Interfaith Power & Light	Maine WindWatts	100% new wind	Maine	2.0¢/kWh
Maine Interfaith Power & Light/BEF	Green Tags (supplied by BEF)	99% new wind, 1% new solar	Nationwide	2.0¢/kWh
Renewable Choice Energy	American Wind	100% new wind	Nationwide	2.0¢/kWh
Waverly Light & Power	Iowa Energy Tags	100% wind	Iowa	2.0¢/kWh
Bonneville Environmental Foundation	Green Tags Blend	90% new wind, 10% new solar	Nationwide	2.4¢/kWh
SKY energy, Inc.	Wind-e Renewable Energy	100% new wind	Nationwide	2.4¢/kWh
Community Energy	NewWind Energy	100% new wind	Nationwide	2.5¢/kWh
WindCurrent	Chesapeake Windcurrent	100% new wind	Mid-Atlantic States	2.5¢/kWh
Renewable Ventures	PVUSA Solar Green Certificates	100% solar	California	3.3¢/kWh
Mass Energy Consumers Alliance	New England Wind Fund	100% new wind	New England	~5.0¢/kWh (donation)
Bonneville Environmental Foundation	Green Tags Solar	100% new solar	Nationwide	5.6¢/kWh
Sterling Planet	Sterling Solar	100% new solar	Nationwide	7.5¢/kWh

Appendix 5.C. Occupancy Sensor Analysis Data

The following assumptions and values were used for the occupancy sensor analysis found in Chapter 5:

- The discount rate is 7 percent.
- Average electricity cost of $0.0850 per kilowatt-hour is assumed.
- Estimates for number of spaces of each type on campus, number of units requiring replacement, and use data were found using limited sample of campus spaces (from EPP/SDS/Heinz 2001).
- Percentage data for savings were based on Department of Energy estimates.

As with the values in Chapter 5, all negative cost-related data values represent cost savings.

Table 5.C.1 – Method 1 inputs from 2003 Commercial Buildings Energy Consumption Survey (CBECS)

	Electricity Use (kWh/ft^2)	Energy Use ($MFBTU/ft^2$)
Type: Education ($PBA=14)		
Without Auto Controls or Sensors on Lighting	14.4	90.5
With Auto Controls or Sensors on Lighting	7.9	82.7
All	8.2	83.2
Type: Lodging ($PBA=18)		
Without Auto Controls or Sensors on Lighting	36.2	253.8
With Auto Controls or Sensors on Lighting	11.7	101.6
All	16.3	129.9
Type: Laboratory ($PBA=04)		
Without Auto Controls or Sensors on Lighting	No Data	No Data
With Auto Controls or Sensors on Lighting	39.4	390.3
All	39.4	390.3
Type: Office ($PBA=02)		
Without Auto Controls or Sensors on Lighting	23.8	115.6
With Auto Controls or Sensors on Lighting	17.7	116.3
All	18.1	116.2

Table 5.C.2 – Method 2 technical specifications

Building	Number	Capacity (kW/room)	Use (hrs/day)	Install Cost ($)
Office	1,500	0.25	6	$119.53
Classroom	300	1.1	8	$179.30
Corridor	500	1	24	$239.07
Dorm Room	1,500	0.2	6	$119.53
Restroom	300	0.2	24	$119.53
Open Area	50	1	24	$239.07

Table 5.C.3 – Method 2 savings data

Space	Total Annual Electricity (kWh/year)	Elec. Savings (%)	Annual Elec. Savings (kWh/year)	Annual CO_2 Saved (metric tons/year)
Office	821,250	32%	262,800	202
Classroom	963,600	43%	414,348	318
Corridor	4,380,000	55%	2,409,000	1850
Dorm Room	657,000	32%	210,240	161
Restroom	525,600	30%	157,680	121
Open Area	438,000	55%	240,900	185
TOTAL	***7,785,450***	**-**	***3,694,968***	***2,838***

Table 5.C.4 – Associated costs with both methods

	Method 1	Method 2
Capital Costs ($)	$579,728	$579,728
Maintenance Costs ($/year)	$0	$0
Annual Savings ($/year)	$2,063,395	$313,912
Theoretical Lifetime (years)	10	10
Lifetime NPV ($)	-$13,566,214	-$1,572,349
Annual Electricity Savings (kWh/year)	24,287,618	3,694,968
Incremental Levelized Annual Cost ($/year)	-$1,978,833	-$229,350
Internal Rate of Return (%)	355.92	53
Payback Period	0.29	2.06
Electricity Saved as Fraction of Campus (%)	27.1	4.1
Cost-Effectiveness – Electricity ($/kWh)	-$0.08	-$0.06
Carbon Savings (MTCDE/year)	18,641	2,836
Cost-Effectiveness – Emissions ($/MTCDE)	-$106.15	-$80.87

Appendix 5.D. Window Replacement Analysis Data

The following assumptions and values were used for the window replacement analysis in Chapter 5:

- New windows have a lifetime of 28 years.
- 60 percent of heat transfer occurs through windows.
- All steam in the buildings is used for heating.
- All chilled water in CFA is used for cooling.
- CFA has 21,600 square feet of window space, while E-Tower has 10,500.

As with the values in Chapter 5, all negative cost-related data values represent cost savings.

Table 5.D.1 – General window replacement data

New Windows:

Cost ($)	Width (Feet)	Height (Feet)	Cost/Area ($/ ft^2)	U-Value	Lifetime (Years)
$1,195.00	3	5	$79.67	0.29	28

Old Windows:

CFA Area (ft^2)	Morewood Area (ft^2)	Campus Area (ft^2)	U-Value
21,600	10,500	928,000	1.1

Table 5.D.2 – Energy use, cost, and emissions reductions for window replacements (CFA)

Heating

Current Steam Use (MLbs/year):	10,745	*Cost of Steam ($/MLb):*	$13.37
Steam Reduced (MLbs/year):	4,747	*Carbon Intensity (tons CO_2/MLb steam):*	0.104
Money Saved ($/year):	-$63,471.89		
CO_2 Saved (tons/year):	494		

Chilled Water

Current Chilled Water Use (MMBTU/year):	3,525	*Cost of Chilled Water ($/MMBTU):*	$6.95
Chilled Water Reduced (MMBTU/year):	1,557	*Carbon Intensity (tons CO_2/MMBTU):*	0.217
Money Saved ($/year):	-$10,823.99		
CO_2 Saved (tons/year):	338		

Total Annual Savings

Money Saved ($/year):	*-$74,296*
CO_2 Saved (tons/year):	*832*

Table 5.D.3 – Energy use, cost, and emissions reductions for window replacements (CFA)

Heating

Current Steam Use (MLbs/year):	4,553	*Cost of Steam ($/MLb):*	$13.37
Steam Reduced (MLbs/year):	2,012	*Carbon Intensity (tons CO_2/MLb steam):*	0.104
Money Saved ($/year):	-$26,895.07		
CO_2 Saved (tons/year):	209		

Chilled Water

Current Chilled Water Use (MMBTU/year):	0	*Cost of Chilled Water ($/MMBTU):*	$6.95
Chilled Water Reduced (MMBTU/year):	0	*Carbon Intensity (tons CO_2/MMBTU):*	0.217
Money Saved ($/year):	$0		
CO_2 Saved (tons/year):	0		

Total Annual Savings

Money Saved ($/year):	*-$26,895*
CO_2 Saved (tons/year):	*209*

Table 5.D.4 – Energy use, cost, and emissions reductions for window replacements (entire campus)

Heating

Current Steam Use (MLbs/year):	332,089	*Cost of Steam ($/MLb):*	$13.37
Steam Reduced (MLbs/year):	146,723	*Carbon Intensity (tons CO_2/MLb steam):*	0.104
Money Saved ($/year):	-$1,961,685.95		
CO_2 Saved (tons/year):	15,259		

Chilled Water

Current Chilled Water Use (MMBTU/year):	189,541	*Cost of Chilled Water ($/MMBTU):*	$6.95
Chilled Water Reduced (MMBTU/year):	83,743	*Carbon Intensity (tons CO_2/MMBTU):*	0.217
Money Saved ($/year):	-$582,011.49		
CO_2 Saved (tons/year):	18,172		

Total Annual Savings

Money Saved ($/year):	*-$2,543,697*
CO_2 Saved (tons/year):	*33,431*

Table 5.D.5 – Associated costs with window replacements

	CFA	Morewood	Campus
Capital Costs ($)	$1,720,800	$836,500	$73,930,667
Maintenance Costs ($/year)	$0	$0	$0
Annual Savings ($/year)	$74,296	$26,895	$2,543,697
Theoretical Lifetime (years)	28	28	28
Lifetime NPV ($)	$863,106	$526,017	$44,565,520
Incremental Levelized Annual Cost ($/year)	$74,765	$45,565	$3,860,399
Carbon Savings (MTCDE/year)	832	209	33,431
Cost-Effectiveness – Emissions ($/MTCDE)	$89.90	$217.80	$115.47

Appendix 6.A. How to Make a Sustainability Peer Group

This document assumes that a user has obtained a copy of the College Navigator schools that was developed for this study and included in the Excel spreadsheet of over 6,000 schools. Plans are currently underway to host these data online and to integrate it into a web-based interface. The steps outlined in the remainder of this appendix assume that the initial steps of obtaining data are already completed. From here, the process of filtering to determine a sustainability peer group for an institution is outlined in Figure 6.A.1.

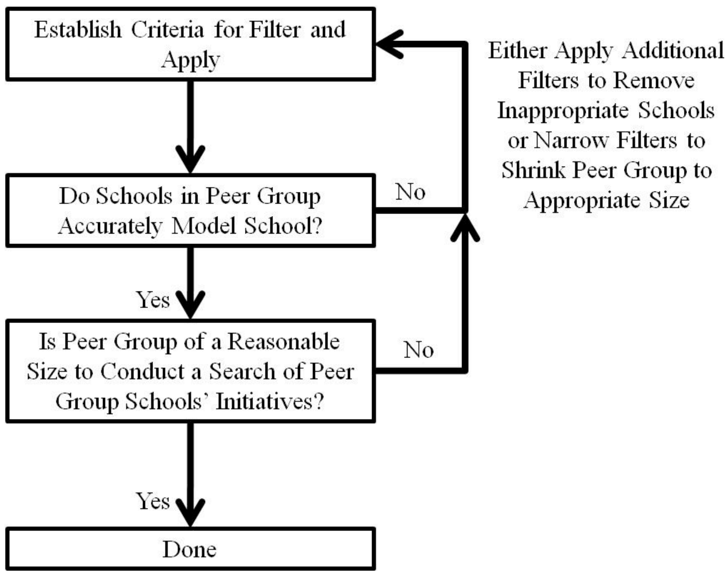

Figure 6.A.1 – Flow chart of peer group generation method

Step 1: Establish Criteria for Filter and Apply

This stage of the process consists of finding a particular characteristic of the user school that makes that school's sustainability challenges specialized. These characteristics can be either direct or indirect effects. For example, the Carnegie Mellon peer group used climate zone as one of its filters. An institution's climate zone has a direct effect on the sustainability challenges of a school. However, another filter criterion in the Carnegie Mellon peer group is the number of PhDs awarded. Awarding a PhD has nothing to do with sustainability, but schools that award many PhDs per year tend to be larger research universities. Research universities have specialized sustainability challenges due to specific energy use characteristics associated with laboratory space. Therefore, the number of PhDs awarded has an indirect effect on sustainability challenges. Once a filter has been decided upon, it should be applied. Each successive filter that is applied should not filter out the user school. The following recommended filters are the ones used for Carnegie Mellon's peer group:

- 2-yr vs. 4-yr institutions
- Campus housing vs. none
- Urban campus vs. rural campus
- For-profit vs. not-for-profit
- Private vs. public schools
- Population

- Awards PhDs or not (potentially filter on number of PhDs)
- Climate Zone (strongly recommended)

Step 2: Do Schools in Peer Group Accurately Model User School?

After the application of each filter, it should be clear whether the remaining schools accurately model the user school. For example, after the application of the two-year versus four-year filter for Carnegie Mellon, for-profit schools were still in the list. Realizing that these schools do not accurately model Carnegie Mellon, it was decided to apply another filter to remove these schools from the list. At some point, there will be schools that do not model the user school despite all appropriate filters available from the Excel datasheet being applied. At this point, the appropriate way to proceed is to gather information about what distinguishes the schools that do not fit from the user school and to collect data manually on all schools to apply the filter. The peer group should then be small enough to allow for a brute force approach to collecting the data. The example from the Carnegie Mellon peer group is that, after all filters were initially applied, there were still smaller regional schools that did not have the same sustainability challenges as Carnegie Mellon. A cursory search of initiatives at these schools demonstrated that they were lagging by far in sustainability initiatives compared to the rest of the peer group. More detailed profiles of the schools showed that they had very few, if any, PhDs awarded per year. Therefore, the PhD filter was modified from “Awards PhDs” to “Awards more than 50 PhDs per year.” These data had to be collected manually for each school in the peer group. However, after the filter was applied, the resulting peer group was much more appropriate.

Step 3: Is Peer Group of a Reasonable Size to Conduct a Search of Peer Group Schools’ Initiatives?

Once the peer group only has schools that appropriately model the user school, a decision must be made as to whether the peer group is too large. The method put forth for fair assessment necessitates a complete search for all peer group schools. Therefore, if the group is too big, it is unlikely that the individual(s) responsible for performing the search will complete it. When this situation occurs, returning to the filters and narrowing some of them will generate a group even more appropriate and manageable for the user school. This process was done for Carnegie Mellon’s peer group with the population filter. Using a filter of greater than 5,000 students meant that there were twenty-four schools in the peer group. However, if this number were too large for a peer group, the filters could be changed to undergraduate and graduate populations within 30 percent of Carnegie Mellon’s. This generated a peer group of under ten schools, which is a much more manageable data set.

Step 4: Done

After finishing the previous steps, the process of creating a peer group for the user school is complete, one can proceed to conduct a search of peer group schools’ sustainability initiatives.

Appendix 7.A. School Data Sources

National Center for Education Statistics
http://nces.ed.gov
Data exported from http://nces.ed.gov/collegenavigator/, March 2008.

National Science Foundation
http://www.nsf.gov
Data downloaded from http://www.nsf.gov/statistics/, March 2008.

National Collegiate Athletics Association (NCAA)
http://www.NCAA.org, accessed April 2008.

Paul Fischbeck
http://www.epp.cmu.edu/httpdocs/people/bios/fischbeck.html
Accessed continually throughout the semester.

Society for College and University Planning (SCUP)
http://www.scup.org/
Data sent via email, February 2008.

Appendix 7.B. Combining Summary Datasets

The process of combining summary datasets is a nontrivial task. The majority of datasets was in Excel format, making this program the natural choice for handling the datasets for this study. School-related information from various datasets was reported differently, and the schools where matched by name. However, the datasets did not all contain the same schools, and school names were labeled differently in each set. For example, the name "Carnegie Mellon University" was found in one dataset, but another set listed the university simply as "Carnegie Mellon." Despite the ease with which a reader can determine that these names refer to the same school, the inclusion of the additional word makes the two phrases seem very different to a computer, leading to a non-match. However, ignoring any instance of "college" or "university" at the end of the name was not a satisfactory solution to this problem. When one references Columbia, the New York school generally comes to mind. This school (Columbia University) is very different from Columbia College in Georgia. For the purpose of this report, an incorrect match is worse than no match at all. Also, more accurate data is more useful than more data of questionable accuracy. In addition to naming differences between sources, some databases used their own naming schemes. Some of these systems included adding asterisks before names, underscores to separate elements, nonprintable characters such as carriage returns, and additional spaces before or after school names. These sources represent potential stumbling blocks to computerized batch processing, even though such differences could easily be caught manually.

Manual matching, however, was not a viable option. Dealing with several datasets with hundreds to thousands of schools, this matching would take far too long. MATLAB was used to process the school names. This programming language was chosen due to its ease of use and its built-in capability to read Excel files. When the schools were read into the database, they were first stripped of all nonprintable and non-alphabetic characters that were not spaces. All multiple spaces were changed to a single space and leading and trailing spaces were deleted. Finally, for handling within MATLAB, the spaces were replaced with underscores, and all characters were converted to lowercase. Matching after these changes was much more successful, giving an approximately 80 percent match rate for the larger datasets and did not mismatch any schools. Owing to the fact that there were no guarantees that schools in the dataset existed in the master set, a 100 percent rate was sometimes impossible even if every school in both sets was matched correctly. Figure 7.B.1 shows a graphical overview of the matching process.

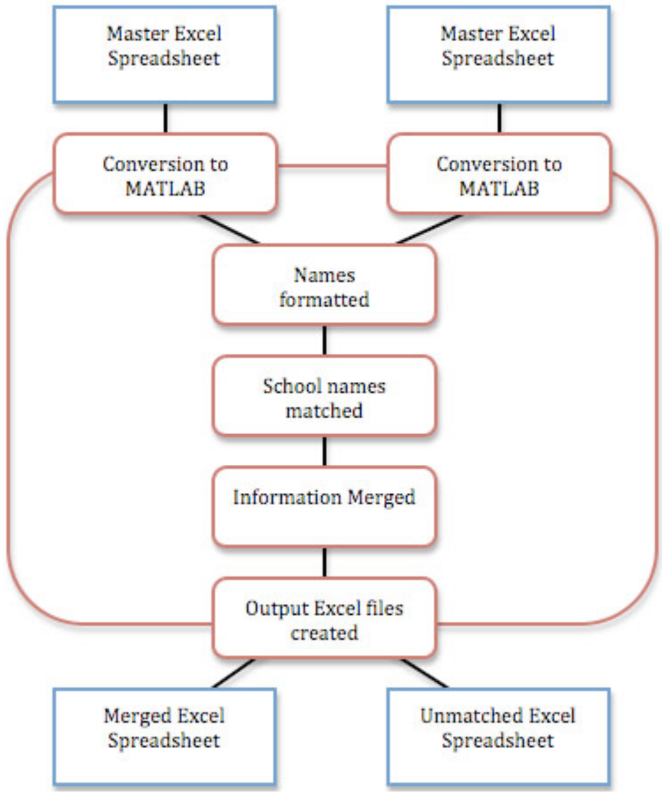

Figure 7.B.1 – Overview of matching process

The matching functions provide a simple, reliable, and fast way to combine summary school data. They are designed to eliminate as many potential causes of error as possible while still providing a high matching rate.

The combination process begins with a master spreadsheet. School names listed in the master spreadsheet are the standard to which other school names are matched. It is important to use the largest available spreadsheet as the master so that as many schools as possible can be matched. Fortunately, the database contained 6,000 two- and four-year schools. While there was not much information in this spreadsheet (only student enrollment and location), it had this information for what was assumed to be a comprehensive list of schools, and the naming of schools was consistent and accurate with no aberrant formatting.

The master spreadsheet and all supplementary spreadsheets were manually cleaned up and then automatically converted from Excel format to a MATLAB data structure. Additional rows and columns that do not contain information were removed from the spreadsheet beforehand so that the MATLAB scripts know where the useful information begins and ends. Within MATLAB, all school names have any formatting characters stripped, and the names are converted to lowercase letters. Each structure contains all of the information from the Excel file, arranged hierarchically by school, as well as a listing of all column names within the spreadsheet. Figure 7.B.2 provides an example of this structure.

Schools	Location	Enrollment	Tuition
School A	Location A	...	...
School B	Location B	...	...
School C	Location C	...	...
...			

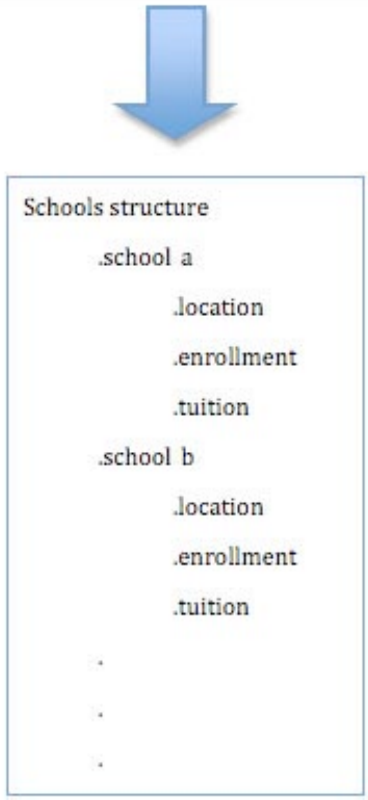

Figure 7.B.2 – Conversion from Excel to MATLAB

Next, the initial supplementary data structure is merged into the master spreadsheet. Due to the fact that each data structure contains a listing of field names within the structure, the merging function can check for overlaps between the two structures. For example, if an overlap exists, both spreadsheets originally contain a column titled “enrollment,” which many of the spreadsheets used in this study did, the function will output a warning listing the overlapping fields. If the same data exists in both structures, such as both structures containing information about Carnegie Mellon University’s enrollment, the resulting number in the merged structure is unchanged from the master structure, as the master structure is taken to be the most accurate structure available. However, if the data is not already in the master structure (e.g., Carnegie Mellon’s cell under “enrollment” in the master spreadsheet was empty), the supplementary value is inserted. In this way, blanks can be filled in the spreadsheet without losing any data. The merging function has two outputs, a combined data structure with the successfully merged information and an unmatched spreadsheet with all information for schools that did not match school names within the master spreadsheet.

After the first supplementary structure has been merged, the second is merged as well. Following this step, there are three output structures: the combined master structure, the structure with the unmatched information from the first merge, and the unmatched information from the second merge. At this stage, the two unmatched structure are merged together. This step leaves three structures again: the combined master structure, the structure with schools whose names did not match the master spreadsheet but did match names with another database, and the structure with completely unmatched schools. The two structures that did not match the master spreadsheet are then concatenated. There are only two structures at this point: the matched and combined data, and the unmatched data. This involved process is illustrated in Figure 7.B.3.

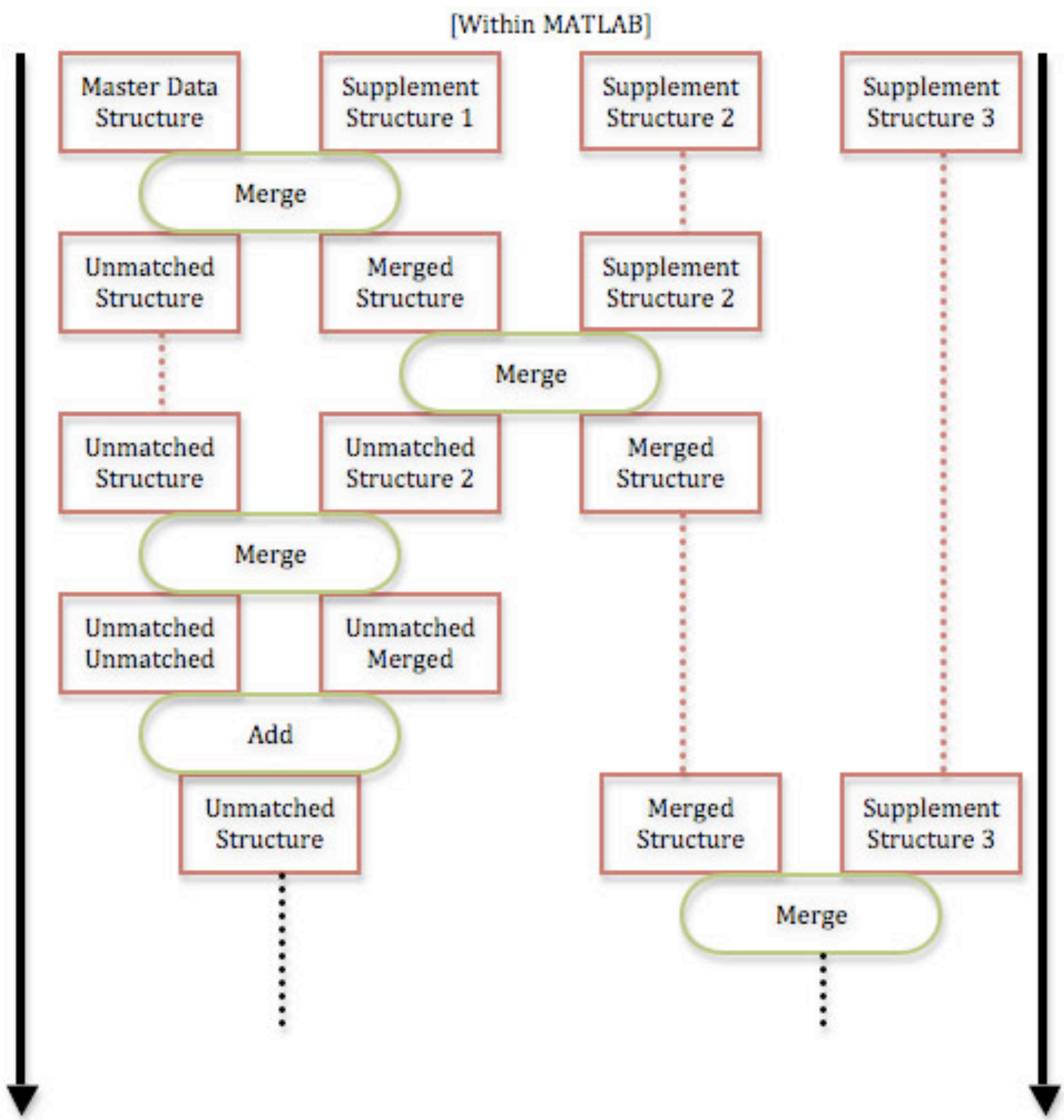

Figure 7.B.3 – Merging supplementary datasets

Merging the two unmatched datasets before concatenating them is necessary, as it eliminates duplicate entries. If two supplementary datasets both contain information for "Carnegie Mellon" but the master dataset contains information for "Carnegie Mellon University," the entries for Carnegie Mellon should still be combined rather than having two separate entries, which would happen if the datasets were concatenated without being merged first.

Other supplementary structures are merged in similarly to the third structure, ending each merge process with a structure for successfully combined data and a structure for unmatched data. After all structures have been merged, the two structures are converted to cell arrays (another MATLAB data type), from which two Excel files are written: one with merged data and one with unmatched data. The unmatched spreadsheet can be looked at manually to correct school name spelling. Since unmatched data from all spreadsheets is merged together, a row in the unmatched spreadsheet that contains many columns of information and few empty cells might indicate a nonstandard spelling of the school name within the master spreadsheet. This trend occurs due to the fact that multiple supplementary spreadsheets all contained the same spelling of a certain school, but the master did not. Once any manual changes are made to either the master spreadsheet or the unmatched spreadsheet, the unmatched spreadsheet can be merged into the master sheet just like any other dataset.

Appendix 7.C. Regional Data Sources

Environmental Protection Agency
http://www.epa.gov
Data downloaded from http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html, March 2008.

U.S. Department of Energy
http://www.doe.gov
Heating and cooling degree-day data downloaded from http://www.melissadata.com/lookups/zipweather.asp, March 2008.
Energy use by building type and climate zone downloaded from the Energy Information Administration, http://www.eia.doe.gov/emeu/cbecs/, February 2008.

National Renewable Energy Laboratories
http://www.nrel.gov
Data downloaded from http://www.nrel.gov/rredc/, April 2008.

Appendix 7.D. Regression Line Statistics

This appendix presents the equations and regression statistics used to estimate square footage for schools that did not report their square footage data to the Campus Facilities Inventory (CFI). These data are divided into usage categories. The predictors for each usage category are tabulated.

Regression Analysis: Classrooms + Class Labs

The regression equation is:

Classrooms + Class Labs = 104,148 + 12.8 undergraduate population + 27.0 Graduate population
+ 10,932 NCAA division - 25,452 climate zone

143 cases used, 3 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	104,148	26,075	3.99	0
Undergraduate Population	12.762	1.514	8.43	0
Graduate Population	27.045	4.57	5.92	0
NCAA Division	10,932	5,588	1.96	0.052
Climate Zone	-25,452	7,494	-3.4	0.001
S	R^2	R^2 - adj		
104,686	77.9	77.2		

Regression Analysis: Research + Open Labs

The regression equation is:

Research + Open Labs = 53,128 + 328 PhD sum + 1.08 Research Budget x 1,000

93 cases used, 53 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	53,128	21,091	2.52	0.014
PhD Sum	328.2	44.73	7.34	0
Research Budget (x1,000)	1.0793	0.1514	7.13	0
S	R^2	R^2 - adj		
163,952	84	83.7		

Regression Analysis: Offices

The regression equation is:

Office = - 4,729 + 78.8 Graduate population + 2.29 research budget x 1,000
+ 50,448 NCAA division

93 cases used, 53 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	-4,729	41,834	-0.11	0.91
Graduate Population	78.75	10.17	7.74	0
Research Budget (x 1,000)	2.2863	0.1432	15.96	0
NCAA Division	50,448	13,921	3.62	0
S	R^2	R^2 - adj		
217,278	88.1	87.7		

Regression Analysis: Libraries

The regression equation is:

Library sq ft = 47,151 + 777 PhD 2005 + 15,135 NCAA division - 4.78 Tuition
+ 37,512 Entrance difficulty rating

57 cases used, 89 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	47,151	48,795	0.97	0.338
PhD 2005	777.03	75.27	10.32	0
NCAA Division	15,135	6,982	2.17	0.035
Tuition	-4.776	1.893	-2.52	0.015
Entrance Difficulty Rating	37,512	15,249	2.46	0.017
S	R^2	R^2 - adj		
86,772.2	75.4	73.5		

Regression Analysis: Athletic + Special

The regression equation is:

Athletic + Special = 151,900 + 61.6 Graduate pop - 51,616 Climate zone + 54,064 NCAA division

Predictor	Coef	SE Coef	T	P
Constant	151,900	61,029	2.49	0.014
Graduate Population	61.567	7.209	8.54	0
Climate Zone	-51,616	17,376	-2.97	0.003
NCAA Division	54,064	12,912	4.19	0
S	R^2	R^2 - adj		
248,345	46.5	45.4		

Regression Analysis: General and Campus Use

The regression equation is:

General and Campus Use = 138,144 + 13.5 Total student population + 115 PhD sum - 38,964 Climate zone

145 cases used, 1 case contains missing values

Predictor	Coef	SE Coef	T	P
Constant	138,144	35,972	3.84	0
Total Student Population	13.519	1.146	11.8	0
PhD Sum	115.19	25.49	4.52	0
Climate Zone	-38,964	10,308	-3.78	0
S	R^2	R^2 - adj		
146,844	64.2	63.4		

Regression Analysis: Support + Central + Vehicle Storage

The regression equation is:
Support + Central + Vehicle Storage = - 1,989 + 103 Graduate population

Predictor	Coef	SE Coef	T	P
Constant	-1,989	63,563	-0.03	0.975
Graduate Population	103.27	13.65	7.56	0
S	R^2	R^2 - adj		
489,661	28.4	27.9		

Regression Analysis: Health Care

The regression equation is:
Health Care = 133,480 + 24.2 Graduate population - 60,642 Entrance difficulty rating

39 cases used, 107 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	133,480	52,120	2.56	0.015
Graduate Population	24.202	5.59	4.33	0
Entrance Difficulty Rating	-60,642	16,921	-3.58	0.001
S	R^2	R^2 - adj		
111,144	40.7	37.4		

Regression Analysis: Student + Non Residential

The regression equation is:
Student + Non Residential = 60,077 + 31.8 Total student population + 0.398 Research sum – 117,408 Climate zone + 15.4 Tuition

113 cases used, 33 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	60,077	155,061	0.39	0.699
Total Student Population	31.823	3.69	8.62	0
Research Sum	0.39783	0.06599	6.03	0
Climate Zone	-117,408	31,807	-3.69	0
Tuition	15.449	5.405	2.86	0.005
S	R^2	R^2 - adj		
388,651	67.2	66		

Regression Analysis: Inactive Areas

The regression equation is:
Inactive Areas = 53,173 + 119 PhD sum

105 cases used, 41 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	53,173	19,182	2.77	0.007
PhD Sum	118.51	27.93	4.24	0
S	R^2	R^2 - adj		
168,603	14.9	14.1		