

A Pledge of Sustainability: The Feasibility of Integrating
Geothermal and Climate Analysis at Wesleyan University

by
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Table of Contents

Chapter 1 Introduction

Chapter 2 The Presidents' Climate Commitment

Chapter 3 Introduction to Geothermal Energy

Chapter 4 GZA GeoEnvironmental, Inc.

Chapter 5 The Social Cost of Carbon

Chapter 6 Methodology, Results and Conclusions

Chapter 7 Conclusion

References

Chapter 1- Introduction

"We need a new Clean Energy System to drive our economics forward and bring more people out of poverty - without despoiling our planet - and therefore the countries, communities, and companies that invent and deploy clean power technologies most effectively will have a dominant place in tomorrow's global economy. Because in a world that is hot, flat, and crowded- where energy, water, land, natural resources, and energy resources are all being stress - everybody, in time, is going to be forced to pay the true cost of the energy they are using, the true cost of the climate change they are causing, the true cost of biodiversity loss they are triggering, the true cost of petrodictatorship they are funding, and the true cost of the energy poverty they are sustaining." – Thomas Friedman

Addressing global warming will be the defining challenge of the 21st century. Significantly reducing CO2 emissions will require more than major changes in energy production, infrastructure, and use.

As the global demand for fossil fuels grows, the U.S. energy system continues its unsustainable path of reliance on foreign non-renewable resources. Over the coming decades, energy demand will grow to increasingly higher levels as nations' economies and populations expand, putting pressure on the global supply chain and causing serious global problems. As global energy supplies start to dwindle, nations of the world will

become increasingly hostile and political conflict may ensue. What's worse, as global temperatures increase due to the ongoing release of carbon dioxide into the atmosphere, the many varied effects of global warming will have serious repercussions on mankind, causing large economic and human losses. However, as new technologies permeate the energy system, hope remains as more renewable and energy-efficient technologies become less expensive and increasingly available to the public.

This thesis will address present and future energy consumption at Wesleyan University, the greenhouse gas emissions produced in both time periods, and how a future-oriented analysis takes into consideration the social cost of our decisions may lead to different conclusions regarding investments by the University in energy projects.

Chapter 2 will offer a brief background on the American College and University Presidents' Climate Commitment and the position of Wesleyan University. Chapter 3 will present a brief discussion of a how geothermal system works and Chapter 4 will review a study of four potential geothermal projects on the Wesleyan campus that was done by GZA Geoenvironmental, Inc.

Chapter 5 presents an important discussion of the Social Cost of Carbon and maintains that SCC should be included in the process of making decisions about energy use by Wesleyan. Chapter 6 presents analytical data on the economic feasibility and the investment payback periods for the four projects studied by GZA. Unlike GZA this analysis includes SCC as an

important variable in the long-term decision about what energy sources Wesleyan should use. Underlying this thesis is the premise that decisions about energy use at Wesleyan must take into consideration the Social Cost of Carbon.

What is the responsibility of every individual and institution in regard to climate change? The problem is that acting in a responsible way to improve the climate may put one at a competitive disadvantage. Paying for externalities such as reducing greenhouse gas emissions may put one person, institution or company at a competitive disadvantage because it results in extra costs which do not necessarily have economic value in the market. So how can we get everyone to do the right thing? Why should anyone – Wesleyan included - do the right thing? If only one institution or person acts responsibly the climate will not improve much. How do we go from unilateral actions to a society that is acting responsibly? These are the challenges of our time.

Chapter 2 – The Presidents’ Climate Commitment

The American College and University Presidents’ Climate Commitment, (“ACUPCC” or the “Presidents’ Climate Commitment”), is an initiative of U.S. universities and colleges that are concerned about the varied and real effects of global warming and are committed to the reduction of greenhouse gas emissions in an effort to re-stabilize the Earth’s climate. As stated in the ACUPCC Mission History (2011) [*“ACUPCC MH (2011)”*], the Pledge is also to help “accelerate progress toward climate neutrality and sustainability by empowering the higher education sector to educate students, create solutions, and provide leadership-by-example for the rest of society”.

According to *ACUPCC MH (2011)*, the ACUPCC came into existence out of planning sessions among a small group of university and college presidents and their representatives, Second Nature, ecoAmerica and the Association for the Advancement of Sustainability in Higher Education, (“AASHE”), at the AASHE conference in October 2006 at Arizona State University. In early December 2006, 12 presidents agreed to launch the ACUPCC, to sign the Commitment, and to send invitations to nearly 400 other schools to encourage them to sign the document. The twelve founding signatories of the Commitment were Pacific Lutheran University, Arizona State University, Oberlin College, Ball State University, College of the Atlantic, University of Florida, Bainbridge Graduate Institute, Cape Cod Community College, Lane Community College, Ohlone College, Los Angeles Community College District, and California State University, Chico. By June

of 2007, the number of university and college signatories had grown to 284 and it was then that the ACUPCC was launched publicly at the first annual Climate Leadership Summit.

The Presidents' Climate Commitment details the various steps and timeframes which a university or college must complete in order to meet the organization's goal of carbon neutrality. With development of a comprehensive plan in mind, the document lays out defined implementation schedules. *Dautremont-Smith* (2009) explains in the Implementation Guide that:

- Within two months of signing the document, schools must create “institutional structures” which will help guide the progress of the plan. This term is loosely interpreted to mean the formation of a committee, taskforce, council or other body which will oversee the advancement of the ACUPCC goals.
- Within a year of signing and every year thereafter, the signer must to create a comprehensive inventory of all its greenhouse gas emissions. A few of the components the inventory requires are emissions from electricity, heating, commuting, and air travel.
- Within two years of signing, schools must develop an Action Plan for becoming carbon neutral. This Action Plan must

include several important goals and objectives. First, the school must choose a target date for when carbon neutrality will be achieved. Second, the university or college must set temporary targets for actions that will lead to the end goal. Third, the school must plan to make climate neutrality and sustainability “a part of the curriculum and other educational experience for all students”. Fourth, the institution must work to expand research or other comparable endeavors to accomplish carbon neutrality. Finally, the school must state its methodology for how it plans to track progress on goals and actions.

The ACUPCC provides a strong framework for America’s universities and colleges to pursue the difficult task of carbon neutrality. *ACUPCC MH* (2011) describes that there are a number of benefits schools can achieve by signing this pledge and implementing this commitment.

- First, the university and college presidents who join and lead this campaign recognize that institutions of higher education have a unique responsibility to serve as role models to their communities in educating those who will develop the, “social, economic, and technological solutions to reverse global warming and help create a thriving, civil and sustainable society”.
- Second, the signatories believe that fulfilling the commitment will stabilize and, “reduce long-term energy costs, attract excellent

students and faculty, attract new sources of funding, and increase the support of alumni, business and local communities”.

- Third, signatory colleges and universities will provide students with the knowledge and skills needed to, “address the critical, systemic challenges faced by the world in this new century and enable them to benefit from the economic opportunities that will arise as a result of solutions they develop”.
- Fourth, signing the commitment shows that the most educated Americans are concerned about the effects of global warming and are willing to address those effects before the situation deteriorates further. It is hoped that this example will have an effect on the citizens of the U.S. as well as the government. If the citizens see institutions of higher education making this commitment, it could affect political campaign strategies and public policy. Citizens with knowledge about sustainable living as well as the negative effects of global warming will be able to make more informed decisions with their votes.

In November of 2007, President Michael Roth of Wesleyan University signed the ACUPCC, formally pledging that Wesleyan would commit to minimizing its global warming emissions and to provide the knowledge and tools for its students to live sustainably and promote carbon neutrality. This pledge was not a spontaneous act of President Roth but was the result of a long process involving students, faculty and staff of Wesleyan University.

As far back as 2001, the University had pledged to support reducing its carbon emissions. The 2001 New England Governors/Eastern Canadian Premiers Climate Change Action Plan was the first call to arms the University pledged to support. As stated in the *Wesleyan University Action Climate Plan: A Dynamic Approach to Carbon Reduction at Wesleyan University* (2010) [“the Plan”], the 2001 resolution called for a reduction in greenhouse gas emissions to 1990 levels by 2010, “at least 10% below 1990 levels by 2020, and a 75-85% reduction of 2001 levels as a long term goal”. The 2001 Action Plan was a rough guide to reducing carbon emissions because it did not have strict enough timelines and did not include enough stakeholders in the plan.

Wesleyan University made significant progress towards becoming a more environmentally conscious campus in 2006. According to *Nelligan* (2008), at that time the Recycling Committee, consisting of Wesleyan faculty, staff and student members, was asked how it could best recognize and reduce Wesleyan’s carbon impact. After deliberation, they made a proposal to form an advisory council to focus on climate change at Wesleyan. The next spring, in April 2007, the Finance and Facilities Committee, (“FiFac”),

comprised of 6 elected WSA student members, formed a subcommittee named the Wesleyan Sustainability Advisory Group for Environmental Stewardship (“SAGES”) that would report to the University’s Board of Trustees. Consisting of volunteers from the faculty, staff and the student body, SAGES immediately recognized that even though some work had already been done to reduce the Wesleyan footprint, there were still many opportunities to improve sustainability. In November 2007, Wesleyan formally added ‘environmental sustainability’ to the title and job description of the Director of Environmental Health and Safety, to support SAGES’ commitment.

As *Nelligan (2008)* states, SAGES is comprised of concerned Wesleyan staff, faculty, students, and community members. There are 8 faculty members from the Departments of Economics, Government, Physics and Biology. There are 14 staff members including members of Wesleyan’s Finance and Administration department, Physical Plant, and ITS. The committee includes 7 student members, two of which are sustainability interns, and also includes a WSA Representative. Finally, the group has 1 community volunteer, who is the Recycling Coordinator of the City of Middletown. William S. Nelligan, The Director of Environmental Health, Safety and Sustainability at Wesleyan, is the Administrator of the committee.

At the first meeting of SAGES, Wesleyan student members from the Environmental Organizers Network (“EON”) proposed several initiatives. EON succeeded the previous campus student environmental group at Wesleyan, E3, in 2003 and has about 50 regular members. The first proposal

was a timeline which the University should adopt in order to meet the goals established in the 2001 Action Plan. The second proposal was that Wesleyan's new president, Michael Roth, should sign a new pledge, the ACUPCC. The second proposal was adopted and SAGES representatives gathered the appropriate paperwork to present to President Roth. President Roth reviewed the details of the commitment and pledged his signature in November 2007.

SAGES has established a number of important goals and tasks for Wesleyan University in the coming years and decades. The Plan affirms that most importantly, SAGES has been charged with creating an institutional structure to oversee the development and execution of Wesleyan's commitment towards carbon neutrality. The group was established specifically to fulfill the requirements of the ACUPCC, which includes drawing up the Wesleyan's climate action plan, target dates and timetables for progress assessment, and integrating sustainability in the Wesleyan curriculum, as well as the overall education experience.

SAGES produced the first of two Green Reports in May 2008, detailing Wesleyan's current condition of sustainability and setting preliminary goals. In the Green Report, SAGES announced that the first greenhouse gas emissions inventory had been conducted that year at Wesleyan and that in 2009, a second more comprehensive inventory would be taken. With the two years of greenhouse gas emission inventory, SAGES had the appropriate information and produced the first Action Plan in May 2010. Based on the

previous Green Reports, the Action Plan is a comprehensive assessment of the many different inefficiencies and emissions on campus.

The Wesleyan Action Plan is a detailed report outlining different ways to make Wesleyan a more sustainable and environmentally conscious campus. It focuses on several different areas including, Academics/Education, Utilities, Waste, Facilities, Transportation, and the Sustainable Vision for Wesleyan. This thesis will be primarily concerned with the Utilities section.

One important component missing from the Plan is Wesleyan's intended year of carbon neutrality. Though the Plan discusses many ways to reduce carbon emissions and promote sustainable living, it does not define the intended deadline for reaching zero carbon emissions. The Plan does, however, give a rough estimate of the amount of carbon that must be eliminated stating that at a minimum the University would have to eliminate, "approximately 1,000 tons of eCO₂ (carbon dioxide equivalent) emissions annually for the next 40 years to reach carbon neutrality".

The Utilities section of the Plan lists five goals that Physical Plant and the University Administration wish to achieve. Specifically, the University has stated that it wants to reduce energy consumption by 30,000 MMbtu (8% of 2009 consumption) by 2020, and 100,000 MMbtu (25% of 2009 consumption) by 2050.

The first goal is to accurately measure energy use at every location on campus. By continuing to meter all energy use at the point of consumption,

whether it is electricity, steam or chilled water, the University can gather real-time information which is useful in establishing priorities for future projects. Having such information helps to see the different patterns of consumption that occur on campus, information that can be used to increase overall campus efficiency over the long term.

The second goal is to promote making the appropriate technology shifts to reduce energy use. One example would be to install programmable thermostats in all campus locations. Another important example would be to replace inefficient systems that produce steam, hot and chilled water with newer, more efficient systems. Another example is to phase out the use of fuel oil #6 by 2012 and to replace it with fuel oil #2 because it produces fewer greenhouse gas emissions. A final but very important technology shift would be to incorporate thermographic and infiltration analysis of energy loss, from windows, walls, and doors, into the audit process which would allow for better identifying and addressing heat loss on campus.

The third and perhaps most important goal of the Utilities section of the Plan is to make the behavioral shifts necessary to reduce energy use. The main purpose here is for the University to develop and implement policies and procedures that somehow compel or incentivize the community to reduce energy consumption at the individual level. In my conversations with Mr. Peter Staye, Associate Utilities Director at Wesleyan University, I learned that the University believes that installing submeters, described in the first goal, would not only help students and other community members to see patterns,

but would also help to reduce individual consumption, especially in residential locations such as dormitories. One study in particular, *Petersen, Shunturov, Janda, Platt and Weinberger (2007)*, found that in residential buildings, personal choices influenced electricity and water consumption. More specifically, having information feedback can stimulate resource conservation. In the case of Oberlin College, the study found that the introduction of feedback, education, and incentives resulted in a 32% decrease in electricity use. More importantly, the study found that dormitories that had received high resolution feedback (i.e. real-time or instantaneous data) consciously reduced their consumption by 55% compared to 31% for dormitories with low resolution (i.e. aggregated monthly data). The results of this research provide conclusive evidence that real-time resource feedback systems, “when combined with education and an incentive, motivate and empower college students to reduce resource use in dormitories”. Another initiative that would be effective would be to require compact fluorescent lights (“CFLs”), which use less power and have longer lifetimes while providing the same amount of visible light, to be used everywhere on campus, especially in student appliances. While this would be an expense for Wesleyan students, it would help promote energy savings and a real commitment to reduce individual energy footprint. Lastly, the University hopes to phase out the wood framed residences and replace them with larger, more efficient dormitory style residences, much like the Senior Fauver Apartments.

The fourth goal that Wesleyan would like to realize is to purchase more renewable energy. In order to meet the requirements of the 2001 New England Governors/Eastern Canadian Premiers Climate Change Action Plan, Wesleyan decided to purchase renewable energy in order to offset greenhouse gas emissions. Once again, offsetting carbon emissions by purchasing renewable energy would be a great way to reach the ACUPCC's goal of carbon neutrality. In order to do so, the Plan states that more time must be spent determining the budget for additional renewable energy purchases to replace non-renewable energy purchases.

The last goal in the Utilities section of the Plan is to develop on-site generation of renewable energy that would replace non-renewable energy now purchased and to “generate excess energy credits to offset non-renewable energy needs”. The first renewable energy source to analyze would be photovoltaic solar panels (“PV”). Physical Plant anticipates generating 200kW of electricity from PV by 2020 and 500kW by 2050. Another idea is to generate 200kW of solar hot water by 2025 and 500kW by 2050. An unlikely source discussed in the plan is to explore use of hydrogen-powered fuel cells. The Plan also calls for the use of geothermal energy, a more likely and impactful project and the subject of analysis of this thesis. Wesleyan's Physical Plant has set a goal to explore the idea of a geothermal plant under Andrus field or other locations on campus in order to generate 4 MW of geothermal energy by 2050.

The Plan maintains that the next Climate Action report will be submitted in January 2012. It will not only be more specific but it will include the action steps for how and when Wesleyan will undertake the actions needed to move Wesleyan towards carbon emission neutrality.

Chapter 3 - Introduction to Geothermal Energy

Geothermal energy can be found everywhere in the world. As *Barbier* (2002) states, geothermal energy is the energy stored as heat in the interior of the Earth.

Modern geothermal energy has been used for two purposes: electricity generation and heating/cooling. The high-temperature energy needed to drive electric generation stations is found in places of active or recently active volcanism and will only be covered briefly as it is beyond the scope of this paper. Low-temperature geothermal energy that can provide energy for heating/cooling buildings is abundant, immensely useful, and is the main topic of this paper. Residential geothermal systems are among the most advanced and energy efficient heating/cooling technologies today. Geothermal systems utilize heat pump technology, much like refrigerators or air conditioners.

Geothermal energy has been utilized by man for many centuries. Geological conditions in some parts of the world are such that the heat from the interior of the earth reaches very near the surface of the earth. People have utilized hot springs for bathing and washing of clothes since the dawn of civilization in many different locations around the world. From *Friedliefsson* (2001), archaeologists unearthed evidence of a Japanese culture that lived near and used the Yuda hot springs, dating from before 11,000 B.C. There are written records of geothermal use in China that are over 2,000 years old. Public baths were common at hot spring localities in the Roman Empire, anywhere from England to Tunisia and Syria. In addition, hot springs have

been recognized by many different cultures since ancient times to have healing properties. *Duffield and Sass (2003)* found that prehistoric and early historical uses of geothermal features were effectively limited to those located at the Earth's surface. Technical limitations and lack of knowledge prohibited ancient societies from reaching any further into the Earth and developing deeper, hotter geothermal energy.

Mock, Tester, and Wright (1997) state that most geothermal heat is generated in two different ways; from the upward conduction and convection of heat energy within Earth's core and mantle and from the generation of heat due to radioactive decay of naturally occurring elemental isotopes.

The study asserts that regions of higher than normal heat flow occur at tectonic plate boundaries and in areas of geologically recent volcanic events. These are the areas targeted for geothermal electric generation plants. Some well known areas of higher geothermal temperatures include Iceland, New Zealand, Japan, and, more specifically, Yellowstone National Park.

Associating geothermal energy only with higher temperatures and electricity generation neglects to consider the uses of geothermal energy available from lower temperature heat in other regions. The second form of geothermal heat, the lower temperature heat generated by radioactive decay, is actually a far more useful source of geothermal energy. Several meters below the surface of the Earth, there exists a constant temperature gradient that has the capability of providing energy for heating/cooling buildings year-round. *Mock, Tester, and Wright (1997)* state that for centuries, natural

geothermal fluids have been used for basic human needs, but it was not until the early 1900's that geothermal energy was used for industrial purposes and for the generation of electricity.

The Three Basic Components

Geothermal heat pump systems ("GHP") rely on three basic components in order to provide heating/cooling for a building. The first is the heat pump, which is a closed system that transfers heat from one location to another. An everyday example of a heat pump is a refrigerator, which pumps heat out of the unit in order to keep food cold. The second component is the geothermal loop, a piping system which can be either an open or closed loop depending on the design. The geothermal loop circulates a working fluid through the ground, disposing of or taking on heat as it circulates back up towards the building structure. The geothermal loop interacts indirectly with the heat pump system by giving off/gaining its heat to reduce the amount of work the compressor must do. The third component is the ductwork inside the building. Whether one is retrofitting a house or designing a new one, an air distribution system is necessary to raise or lower the temperature of the building. These three essential components of a GHP system must work in unison in order to maximize efficiency.

Heat pumps are systems that transfer heat from one location to another. As described by *How Stuff Works* (2011), a heat pump utilizes the processes of condensation, expansion, evaporation and compression to

move heat. Several components are necessary to create a heat pump: a compressor, an expansion valve, heat-exchanging pipes outside the unit, heat-exchanging pipes inside the unit, and a refrigerant. The process starts with a compressor that compresses the refrigerant gas, causing it to become hot and under high pressure. The high temperature gas then runs through heat-exchanging coils outside the unit, allowing the refrigerant to dissipate the heat it gained from pressurization. As it releases heat, the refrigerant condenses into liquid form and flows through an expansion valve into heat-exchanging coils inside the unit. At this happens, the condensed refrigerant moves from a high pressure zone to a low pressure zone, causing the liquid to expand and evaporate becoming a gas again. As this evaporation happens, it absorbs heat from the surrounding area, cooling the area. The refrigerant gas passes through the heat-exchanging coils inside the unit, absorbing heat, and then returns to the compressor where the cycle begins again.

The refrigerant is a key element of a heat pump as it is the medium that carries and transfers heat. It is often referred to as a “working fluid” or a “heat transfer medium”. As stated in *Ochsner (2008)*, a refrigerant has a low boiling point (well below the temperature the heat pump is trying to achieve), a high heat of vaporization, a moderate density in liquid form, a relatively high density in gaseous form, and high critical temperature. Suitable substances for working fluids also need to have large specific heat capacities and which also evaporate at low temperatures. These many different properties are

important because they allow the compressor to do less work by making it easy to raise and lower the temperature. In addition, refrigerants allow for more heat to be released during condensation and then absorb more heat during evaporation than other fluids, ex. water, would allow.

A geothermal heat pump is a variation of existing heat pump technology. *Ochsner* (2008) asserts that GHPs utilize traditional heat pump technology but with one major difference. A traditional heat pump uses electricity from a power grid as its energy source and uses this electrical energy to run the compressor which is the key to heat transfer. A GHP however, relies on the warm temperature of the Earth as a heat sink to deliver approximately three-quarters of its energy and obtains the rest from the power grid. Because it draws upon the near-constant temperature of the Earth to heat the medium that transfers the heat, the GHP has a smaller required temperature difference and thus the compressor has to do less work to lift the temperature of the heat transfer medium. The smaller the temperature difference between the transfer medium and the desired ambient temperature, the more efficiently and economically the GHP operates.

Geothermal systems have flexibility in their operation because of their reversing valve. The reversing valve reverses the heat transfer process, once again drawing upon the heat of the Earth. This time however, the system absorbs heat from inside a building and transfers it into the ground. Because of the earth's reliable constant temperature and the system's ability to reverse

the process, geothermal can provide heating in the winter and cooling in the summer.

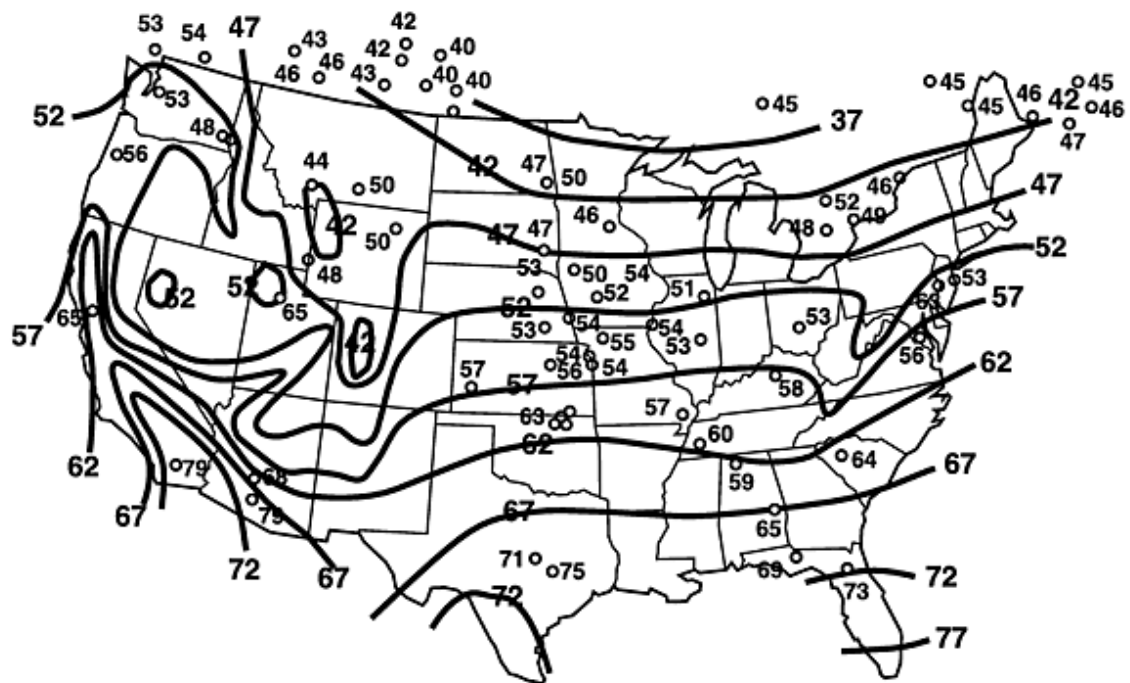
Here's an example of how a geothermal system works. On a cold winter day in Connecticut, the temperature outside may be 22 degrees Fahrenheit and students are bundled up inside for warmth. Let's assume the desired temperature inside is 70 degrees. In order to achieve this temperature, a traditional heat pump would take 22 degree air heat from outside and would heat it using a compressor powered by electricity from the power grid. However, with a temperature difference of 48 degrees (70-22), a traditional heat pump would have to work very hard and use a lot of energy in the process. In contrast, a geothermal pump draws upon the constant temperature of the Earth (let's say in our example, 55 degrees) to heat the heat transfer medium. In this case, the temperature difference is only 15 degrees (70-55). This means the compressor will have to work less and therefore use significantly less electrical energy to reach the desired temperature.

Considerations in Designing GHP Systems

In designing a GHP system, several factors must be taken into consideration. First, it is important to know the seasonal variation in subsurface temperature at the location where the system is being considered. According to *Geo4VA 1* (2011), soil temperature varies from month to month,

“as a function of incident solar radiation, rainfall, seasonal swings in overlying air temperature, local vegetation cover, type of soil, and depth in the earth”. Changes in soil temperature deep in the ground are much less than, and lag significantly behind, season changes in overlying air temperature due to the higher heat capacity of soil and the thermal insulation offered by surface soil layers and vegetation. In addition, soil temperature is relatively constant at depths greater than 30 feet below the surface, which corresponds roughly to the water temperature measured in groundwater wells 30-50 feet deep. This steady level is referred to as the “mean earth temperature”. Figure 3.1 shows the mean earth temperature contours in degrees Fahrenheit across the United States.

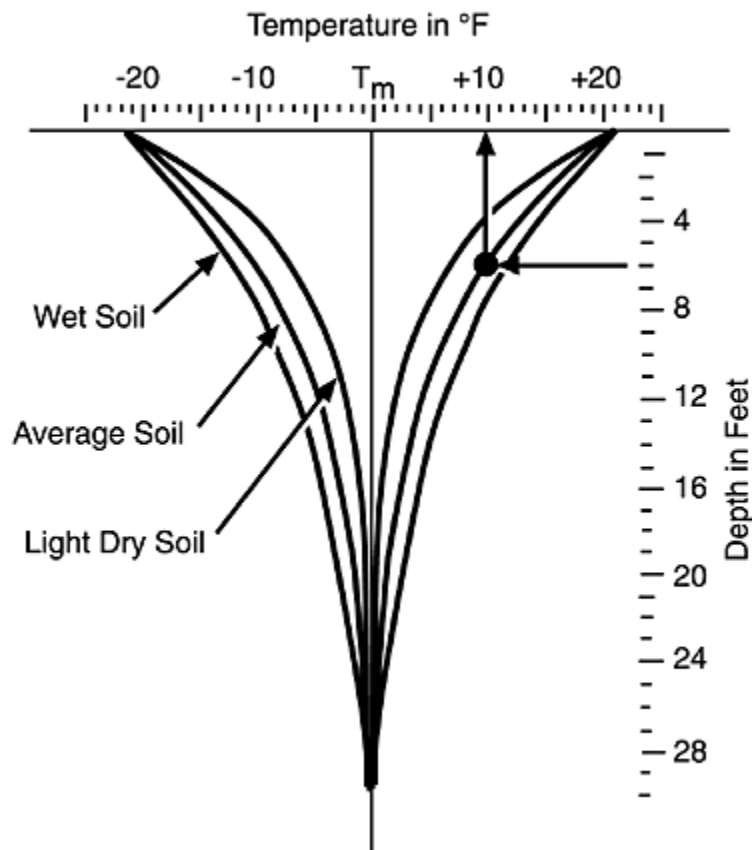
Figure 3.1



Information from Geo4VA

In Connecticut, the mean earth temperature is between 47 and 52 degrees Fahrenheit. Figure 3.2 shows how the, “amplitude of seasonal changes in soil temperature on either side of the mean earth temperature depends on the type of soil and depth below the surface”.

Figure 3.2

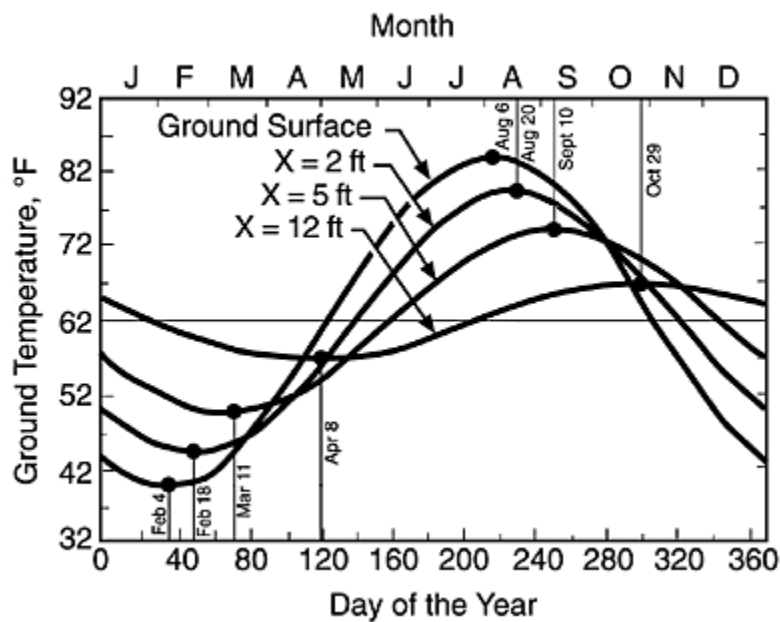


Information from Geo4VA

Once again, at depths greater than 30 feet below surface, soil temperature stays relatively constant year-round. It follows then that deeper soils not only experience less extreme seasonal variation in temperature but the changes that do occur lag farther behind those of shallower soils. This

lag shifts the soil temperature profile later in the year, matching more closely to the demand for heating/cooling. *Geo4VA 1* (2011) writes, “thus in spring, the soil naturally warms more slowly and to a lesser extent than the air, and by summer, it has become cooler than the overlying air and is a natural sink for removing heat from a building...likewise in autumn, the soil cools more slowly and to a lesser extent than the air, and by winter it is warmer than the overlying air and a natural source for adding heat to a building.”

Figure 3.3



Information from *Geo4VA*

Figure 3.3 shows that, “the maximum soil temperature occurs in late August (when cooling demand is high) at a depth of 5 feet below the ground surface, but occurs in late October (after the heating season has begun) at a depth of 12 feet below the surface”.

Geo4VA 1 (2011) upholds that a deeper ground loop installation would therefore lower the annual operating cost for electrical energy to run the heat pumps, and over the life of a GHP system, these accumulated savings, “may more than offset the higher capital cost of burying the ground loop more deeply”. In order to determine the optimal burial depth however, it is important to accurately know how the seasonal change in soil temperature varies with depth, which is mainly determined by the soil's thermal properties.

Second, it is important to determine the subsurface materials inherent capability to store and transmit heat, specifically its heat capacity and thermal conductivity. *Geo4VA 1* (2011) contends that soil thermal properties are highly dependent on soil porosity and moisture content. Heat capacity is one measure of a substance's ability to store heat energy, in British Thermal Units (“Btu”) per °F of temperature change. The greater a substance's heat capacity, the more heat it can gain (or lose) per unit rise (or fall) in temperature. Dry soil has one-fifth the heat capacity of water, indicating that moist or saturated soils have higher heat capacities than dry soils. Consequently, light dry soils experience greater seasonal temperature swings at a given depth than do wet soils.

Another important soil property is thermal conductivity. It indicates “the rate at which heat will be transferred between the ground loop and the surrounding soil for a given temperature gradient”. An example of a finer soil is a granite or a limestone rock, whereas an example of a coarser soil is a sand or loamy sand. Specifically, heat transfer capability tends to increase as

soil texture becomes increasingly fine because finer soils have more particle-to-particle contact and smaller insulating air gaps between particles than do coarse soils. In addition, the thermal conductivity of any soil is greatly improved when the soil is saturated with water because the thermal conductivity of water is two to three times greater than that of solid soil particles. This effect is much greater for coarser soils than for finer soils because the former soils are much more porous and therefore hold more water when saturated. The thermal conductivity of the soil and rock therefore becomes the critical value to determining how deep a GHP must be which has a direct effect on the length of the pipe required, the installation costs, and the energy requirements for pumping working fluid through the ground loop.

Other important factors discussed in *Geo4VA 1* (2011) for designing a GHP are groundwater level and the depth to bedrock. Groundwater level and the annual change is important because it will impact the extent to which the soil is routinely saturated with water and therefore change the thermal properties of the soil. Also, depth to bedrock is important for GHP system designs because it affects the feasibility of certain ground loop configurations. Depth to bedrock is another way of measuring the thickness of the soil layer. If the depth to bedrock is close to the surface, it allows for standing column wells whereas if the depth to bedrock is far away from the surface, it permits the development of vertical closed-loop systems.

Another factor to consider in designing a GHP system is what type of geothermal loop to use. There are two different basic kinds of geothermal circuits: open and closed loops. An open loop uses a surface or subterranean water source as its heat sink and continuously uses new water as its transfer medium. A closed loop uses either the ground or a body of water as a heat sink circulating a set amount of fluid within the loop to transfer the heat required. Open loops continuously draw in new liquids to serve as the medium to transfer heat whereas closed loops do not, only relying on one set volume of liquid.

Closed loop systems (“CLS”) have many advantages over open loop systems (“OLS”) according to *BG&E 1* (2011) and *BG&E 2* (2011). First, CLS need minimal permitting. OLS usually require environmental permitting and are subject to intense local and state regulation due to the disposal and discharging of potentially polluted water. CLS, because they maintain all the liquids/refrigerants in the loop, are less likely to contaminate the local water resources or cause environmental damage. Second, the wells required for CLS can be located in any undeveloped area, including parking lots and open areas of athletic fields. OLS need an abundant and clean water source nearby, limiting their use to one of two options. They are often found in coastal areas and areas beside a lake, river, or well. The other option is to use water from the water table, requiring drilling down to depths of as much as 1,500ft. A potential issue for OLS is that water tables, especially today due to increased demand for aquifers, are subject to fluctuation over time and

could cause future problems. Third, OLS are more expensive than CLS. OLS most often utilize water wells for their pumping needs, which are expensive to drill and can also be unknown at the outset due to unknown soil/geologic conditions. Additionally, OLS using wells must also include the construction of disposal wells, which are also very costly. Another reason OLS are more expensive is that they require more maintenance. Even if water resources have been cleared for initial use, over time the properties of the water can change resulting in corrosion in the piping. Furthermore, maintenance issues like clogging and mineral deposits are likely to occur, increasing the costs over the life of the system. Lastly, CLS are eligible for Clean Energy Funding or other tax incentives while OLS aren't, making OLS relatively more expensive.

While OLS have higher costs in the production of heating/cooling, they are in fact more efficient than closed systems. *Geo4VA 2* (2011) states that OLS actually achieve more efficient performance because they avoid thermal degradation associated with heat transfer across the piping wall from the ground or water body to antifreeze solution, as is the case in CLS. This is a small upside when compared with the many different shortcomings of OLS.

When it comes to geothermal CLS, *Geo4VA 2* (2011) states that there are four basic configurations: horizontal, vertical, submerged, and spiral. Which system is most efficient depends on the specific conditions of the location where it is being installed.

Horizontal systems are shallow systems, with pipe loops laid in trenches only 4 to 10 feet deep. Horizontal loops require the most land surface area per ton of any configuration. These systems are most appealing for those who have sufficient land area to support trenching and in areas where a high water table exists, in order to ensure good heat transfer in the shallow trenches. Trenching costs are relatively low compared to well-drilling and there are a large number of contractors equipped to handle horizontal loop production. However, the annual performance of horizontal loops is heavily affected by season, rainfall, and burial depth. In addition, because of the system's heavily reliance on the water table, drought potential must be factored into the estimations.

Vertical loop systems are the second configuration of geothermal loops. As opposed to horizontal, vertical loops are perfect for locations where limited surface area is available. In this case, vertical wells are bored to depths that typically range from 200 to 300 feet deep. Because the bore wells are drilled to such depths, seasonal soil temperature swings are a non-factor, thus providing constant geothermal energy year-round. In addition, vertical loops typically use the least total piping compared to other closed loop systems, reducing the total cost of implementation. High-density polyethylene (HDPE) is the preferred material for ground loop piping because of its durability, high resistance to corrosion, and inexpensive. However, vertical systems tend to be the most expensive closed loop systems, especially with the high fixed costs of drilling.

As said by *Geo4VA 2* (2011), spiral loop systems are another configuration that is often used for geothermal purposes. Named for their circular shape and overlapping structure, spiral or “slinky” loops can be laid either horizontally or vertically, depending on the conditions of the location. Spiral systems, whether horizontally or vertically laid, require only trenching to a depth where the coils do not experience large temperature swings. As well, spiral systems require nearly three to five times less surface area than horizontal systems, which is great for places with limited space. While installation costs may be significantly less than horizontal loops, spiral systems have some disadvantages. Spiral loops require more pumping energy than horizontal loops, which means increased electrical demand. Also, backfilling the trench can pose a problem because in certain types of soils, it is very easy to accidentally damage the coils or even leave voids around the spiral. Because air is a poor heat conductor, voids reduce the overall efficiency of the system.

Submerged loop systems are the final basic option for closed loop systems. Essentially, submerged loops rely on bodies of water as a heat sink. Water, as mentioned before, is an extremely good conductor of heat energy and would thus provide extremely efficient heat transfer. Ponds or lakes make for the best locations while rivers are dangerous because moving rocks and boulders on the bottom can cause damage to the piping system. Bodies of water must be at least 10 feet deep and generally speaking an acre large in order to be considered for use. Submerged loop systems can require

the least total pipe length and least expensive of all CLS if a body of water exists nearby. However, a concern for building such a system is the vulnerability a body of water might have to drought. Also, another concern is that submerged loops are likely to require more regulatory permitting than ground loop systems because they involve potential drinking sources. A concern that I had with submerged systems was that water temperature ranges a lot during the course of year. With people ice skating in the winter and swimming in the summer, it would seem the water would not provide a good constant temperature year-round. However, after much searching, I could not find any evidence to back it up and thus rescind my concern.

In addition to Open loop and closed loop systems, there is also a third, less known option: Direct Exchange (“DX”) systems. Unlike CLS, DX systems do not use an intermediate working fluid or intermediate heat exchanger but instead employ closed loops of soft copper tubing to directly transfer heat between the ground and the refrigerant. In other words, the heat pump’s refrigerant loop is the only closed loop running underground transferring heat. By eliminating the intermediate heat exchanger, the temperature of the refrigerant is closer to the mean earth temperature than would be in either OLS or CLS. This lowers the work the heat pump compressor must do, which in turn reduces its size and electricity consumption. Also, because copper has a higher thermal conductivity rate than polyethylene (19 Btu/sq.ft-hr-°F per inch of wall thickness vs 2.7), the system is much more efficient at transferring heat than the conventionally

used polyethylene piping. In this way, a shorter ground loop is required, reducing costs further. DX ground loops can be installed horizontally or vertically, much like the dynamic nature of spiral loops. However, several disadvantages exist for DX systems. First, DX systems have a smaller supporting infrastructure in GHP industry (only two manufacturers offer DX geothermal heat pumps in North America). In addition, fitting DX systems requires greater care and higher skill which accordingly means higher installation costs. Second, heat from DX systems can bake fine-grained soils, which decreases their thermal conductivity and therefore overall functioning of the system. Finally, the copper ground loops for DX systems are more prone to corrosion from acidic soils than polyethylene piping, requiring more maintenance costs and replacements over time.

Benefits of Geothermal Energy

Geothermal energy has numerous benefits over today's conventional heat pumps and fossil fuel systems. First, geothermal is significantly more energy efficient than traditional systems. By using the constant temperature of the Earth, geothermal systems are able to drastically raise the coefficient of performance of the heat pump. In relation to *Energy Star* (2011), the Coefficient of Performance, ("COP"), is a measure of efficiency in the heating mode that represents the ratio of total heating capacity to electrical energy input. According to *Ochsner* (2008), a properly sized system using modern equipment can deliver, "between 2.5 and 4.5 units of heat (kWhth) for every 1

unit of electricity consumed (KWhe). Second, the process of a heat pump can be reversed delivering cooling temperatures to buildings. Consistent with *Energy Star* (2011), just as the COP describes the efficiency of a system's heating capacity, a system's Energy Efficiency Ratio, ("EER"), is a measure of efficiency in the cooling mode that, "represents the ratio of total cooling capacity to electrical energy input". This reversal of the pump allows for heating and cooling production all year round.

A second benefit of geothermal systems is the relatively fewer costs associated with maintenance compared with conventional fossil fuel systems. A geothermal system's piping and distribution is either underground or underwater, making it invisible and unobtrusive. Buried distribution lines mean less likelihood of corrosion or breaking of polyethylene piping due to weather, animals, bacteria, and human tampering. Fossil fuel systems require combustion to take place, which causes dirty emissions to clog up pipes as well as other damage to the system over time. Geothermal systems utilize non-corrosive material in the refrigerant cycle as well as the working medium passing through the well field underground. Geothermal typically has lower life cycle costs over a 20-year cycle, yielding even more savings over fossil fuel systems. Other monetary benefits include the fact that most geothermal CLS receive state or federal tax incentives or even utility incentives for implementing them.

A third benefit is that GHP systems offer on-site emission-free operation. *Ochsner* (2008) maintains that heat pumps deliver heat without

producing on-site soot or any other toxic exhaust, unlike fossil fuel heating/cooling systems. By drawing on up to 75 percent of the required energy from the heat underground, heat pumps transfer heat efficiently and require only electricity to operate. Subsequently, there is an overall reduction in CO₂ emissions by using GHP systems because even the electricity for the GHP is efficiently produced, thanks to the efficiency of today's power plants, compared to individual condensing boilers.

Yet another benefit is that GHP systems offer greater comfort and ease of operation over traditional fossil fuel heating/cooling systems. *Ochsner* (2008) contends that they even offer the highest possible living comfort because of the heat distribution systems that offer, "low temperature radiant floor and wall heating", which minimizes overheating and excessive air and dust turbulence. Moreover, GHP systems operate quietly, automatically and are maintenance free. They are also free of the constraints imposed on fossil fuel systems, like fuel deliveries, ash disposal, and chimney cleaning. Described already but still significant, geothermal heat systems are reversible, enabling them to provide cheap air conditioning in the summer. However, GHP systems can serve multiple functions, including providing hot and chilled water, improving ventilation, and also dehumidifying the ambient air. Finally, GHP systems can be easily retrofitted into existing buildings, both feasibly and monetarily.

As fossil fuels become scarcer and prices rise, there is a question whether we will be able to afford our current fossil fuel heating systems in 20

years. *Ochsner* (2008) writes that the selection of a heating system should be a decision for decades. Consumers taking a long-term view will undoubtedly arrive at one conclusion: GHP systems are the best long-term solution. Even today, correctly implemented heat pumps can be the heating system with the lowest operating costs. With each increase in fossil fuel prices, the cost of heating with heat pumps becomes even more competitive when compared to fuel oil, natural gas, or even wood pellets. The savings will increase as well because with heat pumps, three-quarters of the energy remains free, even if electricity costs increase.

The last benefit GHP systems offer is energy security for the future. *Ochsner* (2008) observes that as the imminent impacts of a limited fossil fuel supply as well as the rapidly increasing demand for that supply draw nearer, it becomes increasingly dangerous to continue our dependence on foreign energy sources. As the world population increases and developing nations increase their use of fossil fuels, the strain on fossil fuel availability will increase, leading to scarcity as well as price. Political instability may be at risk as nations try to gain access to the precious resource and political conflict may result. By installing GHP systems and relying on the renewable energy resource of the Earth, GHP users will have a nearly unlimited resource in terms of quantity, availability and time. Because of their efficient use of local ambient energy resources, GHP systems will help nations reduce their dependence on imported fuel supplies significantly.

Chapter 4 – GZA GeoEnvironmental Inc

Wesleyan's Physical Plant hired GZA GeoEnvironmental Inc., ("GZA") in the fall of 2010 to do a feasibility study for integrating geothermal energy at Wesleyan University. Founded in 1964, GZA is a consulting firm that provides environmental and geothermal expertise to its clients. Based in Glastonbury, CT, GZA is a privately owned company that has been in the environmental consulting and remediation market since 1978 and has proven to be one of the premier geothermal consulting firms in the northeast.

Upon reaching the campus, GZA quickly made some assumptions about the work they would be doing and laid the foundation of the work based on them.¹ First, GZA selected to use Closed Loop geothermal systems ("CLS") over Standing Column or Open Loop Systems ("OLS") at Wesleyan. Representatives from GZA chose CLS for several reasons. The first few reasons for CLS was that it needs minimal permitting, requires minimal well field operation and maintenance, and produces no fouling from formation water. Also, closed loop well fields can be located beneath parking lots or open areas of athletic fields. As well, Wesleyan has sufficient open space to construct geothermal well fields. In addition, unlike Standing Column and OLS, closed loop geothermal is eligible for Clean Energy Funding from the state/federal government.

¹ All of the following assumptions and numbers were summarized in a packet presentation provided by GZA.

The next step in GZA's approach was to survey the local geology on Wesleyan's campus. Their analysis found that the bedrock geology was made of Portland Arkose. More specifically, the detail of the geology was that it was, "reddish-brown to maroon micaceous arkose and siltsone and red to black fissile silty shale". This description of the bedrock is not commonly known. It is more commonly known to New Englanders as brownstone. After determining the local bedrock formation, GZA investigated the subsurface soil conditions. Test boring data revealed that the overburden soil was comprised of a reddish-brown medium to fine sand overlying glacial till. In addition, the depth of the bedrock varied based on location anywhere from 4.5 to 45 feet based upon the existing boring log data.

Subsequently, GZA tested the soil conditions for its approximate thermal conductivity value. Based on the formation type, GZA judged the overburden soil to have a thermal conductivity value most similar to sandstone, with a value ranging between 1.2 – 2.0 Btu/hr ft F.

Figure 4.1

Thermal Conductivity Values	
Formation Type	Thermal Conductivity (Btu/hr ft F)
Clays	.3 - 1.1
Sand	.5 - 1.2
Sand & Gravel	1.2 - 2.2
Granite	1.3 - 2.1
Limestone	1.4 - 2.2
Sandstone*	1.2 - 2.0
Shale	.6 - 1.4
*Expected values based upon Site bedrock formation	

Information from Oklahoma State

Additional Assumptions

GZA made additional assumptions for its analysis of the campus for potential geothermal locations/projects. These assumptions are as follows:

- 1) Independent energy sources considered were natural gas, fuel oil, propane or other energy sources not connected to the central heating plant. However, for the actual analysis, only values for natural gas, No.2 fuel oil, and No.6 fuel oil were tallied.
- 2) Each project was designed to include a manifold vault. A manifold vault is a location where all the piping and feed lines go in and out, essentially the heart of the system, without the duty of pumping the fluids. While the analysis marks where each manifold vault is located, it is relatively unimportant for the analysis and thus only the description/purpose of the manifold vault is necessary.

- 3) Once installed, geothermal will replace the energy source requirements from both the central plant and independent sources, supplying both heating and cooling year-round. In addition, an advantage of these systems is that each building connected to the well field will have independent building temperature control.
- 4) The total energy source percentages are based on: (total structure square feet/total square feet of the total area) times the percentage of the energy source from either the central plant or independent sources.
- 5) Some portions of existing piping may be reused for geothermal. Examples of such are the chilled and hot water lines; however, a full piping assessment needs to be done to determine which pipes could be used. That said, geothermal requires both feed and return lines from the well field to the proposed building locations entailing more construction and piping than existing capabilities. Additionally, GZA deemed that the existing steam and condensate piping distribution lines are improbable for use because of sizing, corrosion and potential leaks.
- 6) While it is unclear which technology it will use, the company assumes that heating and cooling will either utilize Water to Air or Water to Water heat pumps, depending on existing construction.
- 7) Greenhouse gas emissions reductions reflect the elimination of both CHP and independent energy source use to provide heating/cooling to each zone.

- 8) The survey does not account for electrical demand for the geothermal heat pumps.
- 9) Finally, the proposed geothermal well fields were estimated based upon peak loads. It is possible that reduced costs could be realized if geothermal was used for typical loads and the central heating plant was used for peak loads/demands; however, this was not assessed in the study and remains unknown.

Project Locations

GZA proposed four different locations for geothermal implementation at Wesleyan University. All four locations have different individual specifications, including costs associated, total area to be heated/cooled, greenhouse gas emissions reduced, number of boreholes, and percent of heating/cooling energy coming from independent sources.

The first location, Project A, would bring geothermal heating/cooling to 53 Undergraduate and Graduate Housing units, an academic building (Dance Studio), an administrative building (E&ES storage house), and the Freeman Athletic Center. The undergraduate and graduate housing units to be brought online would be nearly all the residences on Pine St., Fountain Ave, Warren Ave, and Cross St. A few residences were left out of the analysis because there was no current energy information for them. The total area to be brought online would be 340,138 sq. ft. All of the buildings except for the athletic facility are fueled entirely by independent energy sources, namely

natural gas and fuel oil #2. Only the Freeman Athletic Center is fueled by the central heating plant but it too relies on natural gas for 8% of its heating/cooling needs. The area dedicated for the geothermal boreholes would be the football practice fields next to the University track. Running perpendicularly to the fields, the survey suggests that 360 boreholes in two grids, drilled to a depth of 500ft, would be sufficient to provide these locations with enough heating/cooling. The pump house would be constructed on the corner of Pine and Fountain (next to the Pine St. parking lot), providing enough pressure to move hot and cold water efficiently to and from buildings. GZA estimated that 2,300 metric tons of greenhouse gas emissions could be reduced per year because of the construction of Project A.

The second location, Project B, would bring geothermal energy to 8 academic buildings (Center for the Arts), 3 Assembly Hall buildings (Crowell Concert Hall, World Music Hall, CFA Theater), and an administration building (Admissions Office). The total square footage of the proposed project is 165,384 sq. ft, considerably less than Project A. Unlike Project A, the majority of the buildings are currently fueled by the central heating plant, with only the Admissions Office receiving energy from independent sources, 59% from natural gas. The land allotted for the boreholes would be located on Jackson Field, the Wesleyan Men's and Women's Soccer and Men's Lacrosse Fields. Laid out in two grids running perpendicularly to the field, the 200 boreholes would once again be drilled to a depth of 500ft. The pumping mechanism for this location would be situated in the basement mechanical

room in one of the CFA buildings nearest the fields. Finally, the construction of this geothermal zone is estimated to reduce the emission of 680 metric tons of greenhouse gas per year, according to GZA.

The third location proposed by the environmental consulting company, Project C, plans to bring geothermal energy to 9 academic buildings (Olin Library, PAC, Albritton, Judd Hall, '92 Theater, Memorial Chapel, Zelnick Pavilion, Center for the Americas, Van Vleck Observatory), 4 administration buildings (South College, North College, President's House, Fayerweather), 2 dining facilities (Usdan University Center Floor 1 and 2) and 12 undergraduate and graduate housing units (Foss Housing, Fauver Apartments, and 200 Church). The total area of the project is estimated at 672,554 sq. ft. Similar to Project B, most of these buildings' energy source is the central heating plant. The Usdan University Center and the undergraduate housing indicated receive some of their energy from independent sources, 21% and 14% respectively, coming from natural gas and No.2 fuel oil. The proposed geothermal site would be located on Andrus Field, underneath both the football field and baseball field. The two grids running parallel to the football field would have 400 boreholes drilled, once again to a depth of 500ft. The pumping mechanism would be located in a basement mechanical room in Fayerweather and would even provide enough pressure to send the thermal liquids uphill to the Foss dormitories. The estimated per annum emissions reductions with the implementation of this

project would be approximately 2,662 metric tons, the most of any proposed project.

The fourth location, Project D, would connect the geothermal source to 3 undergraduate and graduate housing units (The Bayit, 151 Church Street, 146 A/B/C High Street) and an academic building (Religious Studies Center). The total area to be included would be approximately 23,302 sq. ft. Unlike all the other locations, buildings in Project D receive their energy exclusively from independent sources, specifically natural gas and No. 2 fuel oil. The geothermal boreholes would be positioned beneath the existing Wes Wings parking lot and the backyard of the Bayit. Since the area is much smaller than the others, only 32 boreholes, drilled at a depth of 500ft, would be needed to provide the adequate heating and cooling. Another deviation from the rest of the projects, the pumping mechanism for Project D will not have a central location but instead, the geothermal pumps will be located in the individual buildings. The reduction in greenhouse gas emissions has been estimated to be roughly 120 metric tons, far less than any of the other projects.

After thoroughly reviewing the different projects and taking into account numerous different variables, GZA reasoned that a sequenced approach would be best for the University. The company proposed that the University implement Project D first. Their rationale is that adding geothermal to this area would completely eliminate the need for fossil fuels, which currently provide 100% of heating/cooling energy. Additionally, they suggest that

because of the small number of boreholes and the minimal cost to install the system, this project could be used as a very successful pilot program.

Separately, it was noted that by expanding the geothermal well field in the future, i.e. increasing the number of boreholes, it would be feasible to connect more buildings to the system, specifically 124, 132, 136, and 156 High Street. With a total cost of \$675,000 and a cost per square foot of \$28.97, the implementation of Project D is the most cost-effective way to begin introducing geothermal to Wesleyan University.

The project which would have second priority to undertake according to GZA would be Project A. GZA's reasoning is that 55 structures, solely reliant on natural gas and oil, would no longer be dependent on such fossil fuels, getting their heating/cooling needs from a more renewable energy source. Additionally, the Athletic Facility as well as these structures would now be supplied with cooling. Another upside to this project is that significant additional open space, specifically the track and the surrounding fields, exists and could be used to increase the planned geothermal well field in the future. However, if the geothermal well field was expanded for additional use on Wesleyan's campus, new feed and return distribution lines would have to be piped under Cross Street and would therefore increase costs and the project timeline due to construction and city permitting. With a much greater total cost of \$8,852,000 but a reduced cost per square foot of \$26.02 compared to Project D, development of Project A would have a significant reduction in the

University's fossil fuel use and therefore reduce the University's carbon footprint.

The project which ranked third in priority was Project B. The motivation behind this priority is that by powering the Admissions building with geothermal energy, it would promote Wesleyan's commitment to sustainable energy in a very public way. This would be done in two ways. First, it would make a statement to potential applicants, Wesleyan faculty, and the community at large that Wesleyan is dedicated to meeting the President's Climate Commitment by implementing geothermal at the hub of Wesleyan's future, the Admissions Office. The second reason is because it would literally increase the amount of renewable energy as a percentage of Wesleyan's energy portfolio. Another good reason is that construction, and therefore costs, could be reduced because geothermal could be distributed throughout the CFA by means of the existing tunnel system. This could be done because the existing chilled water distribution lines may be usable for geothermal water distribution, due to their ability to retain thermal energy efficiently. In addition, the existing tunnels could be utilized for supplementary geothermal water distribution piping to other places on campus. However, one of the large issues with this project is that the available open space for geothermal is restricted to the athletic field. Because of this, there is limited potential for an expansion possibility to the geothermal well field proposed. With a total cost of \$4,997,000 and a cost per square foot of \$30.21, endorsement of Project B is limited because of the cost and amount of

thermal energy already provided by the central heating plant but still remains a viable location for geothermal.

The last ranked project by GZA was Project C. The justification for the poor ranking is because the project may not be economically feasible due to the fact that 94% of the buildings are connected to the energy efficient central plant which has an expected life of more than 20 years. Another downside of the project is that Foss Hill's sloped face would limit the project's ability to expand the geothermal well field. One of the small advantages of the project would be to add chilled water to the dormitories. In the assessment, there is mention that an alternative to the existing plan would be to only connect the dormitories to geothermal. This would make sense because only the Usdan University Center and the undergraduate housing units use fossil fuels in addition to getting energy from the central heating plant. Another side-note the assessment makes is that the Foss II dormitories could feasibly be added if expansion to the geothermal well field was possible. Although such assessment was not done in this study, it can be reasoned that it would be difficult due to Foss Hill's sloped face. At a total cost of \$18,507,000 and a cost per square foot of \$27.51, the feasibility of undertaking Project C is very unlikely because of such high costs and because thermal energy is already provided efficiently from the central heating plant.

Figure 4.2

	Project A	Project B	Project C	Project D	Total
Construction/ Restoration	\$1,220,000	\$642,000	\$2,547,000	\$94,000	\$4,503,000
Equipment	\$1,877,000	\$1,094,000	\$4,112,000	\$137,000	\$7,220,000
Energy Management System	\$1,034,000	\$503,000	\$2,054,000	\$71,000	\$3,662,000
Boreholes, Trenching, Piping	\$4,458,000	\$2,480,000	\$9,239,000	\$351,000	\$16,528,000
Plumbing/Electrical	\$263,000	\$278,000	\$555,000	\$22,000	\$1,118,000
Total	\$8,852,000	\$4,997,000	\$18,507,000	\$675,000	\$33,031,000
Total Area (Sq. Ft.)	340,138	165,384	672,554	23,302	1,201,378
Cost /Square Foot (\$/sq. ft.)	\$26.02	\$30.21	\$27.52	\$28.97	-
# of Boreholes	360	200	400	32	992
Energy Source (% from Central Plant)	64%	91%	91%	0%	-
Energy Source (% from Independent)	36%	9%	9%	100%	-
Greenhouse Gas Emissions Reductions (metric tons per year)	2,300	680	2662	120	5,762

The GZA feasibility study for geothermal projects on campus fits very nicely into Wesleyan's long term plan for reaching carbon neutrality. In the University Action Plan Utilities section, SAGES specifically states that it is a goal for the University to, "develop on site generation of renewable energy to replace non-renewable energy now purchased". In addition, building any one of the different projects would also help the University reach its goal of reducing its energy consumption, by 100,000 MMBtu by 2050. While the Action Plan does not have an established target date for carbon neutrality, constructing any or some combo of the geothermal projects will help Wesleyan take a positive step in the right direction.

In the report, GZA addresses why implementing geothermal systems would be a beneficial investment of University funds. The feasibility study acknowledges how a decreased reliance on fossil fuels will result not only in the reduction of our carbon footprint but also help the University along the path of meeting the American College & University President's Climate Commitment. However, the GZA study does not take into account some very important factors which would influence the future impact of implementing any such projects.

First, the assessment does not account for future forecasts of energy prices or the future growth rates of fossil fuels. Consequently, the feasibility study does not address how the supply or demand of energy will be affected by such forecasted energy prices. Second, the analysis does not include the potential pricing of carbon in the future and how that might affect the future

demand for geothermal systems. Additionally, the assessment does not include how the President's Climate Commitment might entice the University to set a Social Cost of Carbon, based on its willingness to meet those commitments that it pledged to fulfill. These factors are not to be overlooked, as forward looking assessments are important when considering cost-benefit analyses for different projects. In the next chapter, we will see why pricing carbon is an important factor and how it might affect the decision making process in choosing which geothermal project(s) from the feasibility study GZA performed.

Chapter 5 – The Social Cost of Carbon

The Social Cost of Carbon, or the SCC, is a concept used to estimate the impact of climate change and to indicate a desirable level of climate policy. According to *Workshop Summary (2010)*, economically speaking, it is the net present value of damage done, over some period of future time, by one additional ton of greenhouse gases emitted to the atmosphere at a specific point in time. The SCC continues to be the most important estimate of the benefits of avoided climate change used in cost-benefit analysis (CBA) for a climate change policy. In *Anthoff, Tol, and Yohe (2009)*, the SCC is considered the standard measure of how much future damage could be avoided if today's emissions were reduced by one ton. The paper states, by discounting the value of the damage over time, the SCC is the closest estimate of the economic benefit that would be gained by a marginal reduction in carbon emissions.

As said in *Yohe (2010)*, the SCC is based on estimates that are difficult to quantify due to the subjective valuation of many social costs as well as the uncertainty in predicting the extent of climate change. Since climate sensitivity is a key feature of damage estimates, a high degree of uncertainty around a central estimate could result in a socially unacceptable level of risk of severe outcomes. The *Workshop Summary (2010)* says that without considering a given range of uncertainty, economists wouldn't be accurately measuring how much society values reducing its risk. However, by building a wider range of uncertainty into models, economists give more understanding

to society about what their risks are and the different costs associated with reducing these risks. With this, society is better able to conclude how much risk it is willing to take on based on potential damages and mitigation costs. Because the SCC allows for uncertainty, a range of possible outcomes is possible. In this way, it is important to look at how discounting affects the calculation of the socially optimum point because the costs of emission abatement must be justified by the benefits of avoided impacts well into the future, discounted back to the present.

The discount rate is one of the most critical factors in determining the relative magnitude of any particular estimate of the SCC. Looking at a model of people's willingness to pay, as per *Anthoff, Tol, and Yohe (2009)*, people discount future consumption for two reasons. First, they expect to become richer in the future, and therefore give less value to an additional dollar at some future time than they do about an additional dollar today. Secondly, they are impatient. These two assumptions lead us to the Ramsey discount rule,

$$r = \rho + \eta g$$

where r is the discount rate, ρ is the rate of pure time preference, g is the growth rate of per capita consumption, and η is the elasticity of marginal utility of consumption. Calculating the Ramsey discount rate is an essential step in obtaining a value for the SCC. The Ramsey rule most fundamentally identifies the rate of interest that promotes optimal savings but also describes these other parameters, ρ , g , and η . Initially, ρ and η are important in

specifying an optimal consumption discount rate. The paper asserts that the pure rate of time preference ρ is appropriately included in climate change work because impacts can be expected for centuries into the future; discussions of the climate policy problem must address the long-term timing issues. The growth rate of per capita consumption, g , is sometimes taken to be an exogenous variable that has been calculated from historical records. In other cases, it is endogenous, taking account of future interactions across nations and sector as the future unfolds. The study contends that the elasticity of the marginal utility of consumption, η , captures the three key characteristics of the climate issue, making it one of the most crucial variables in the SCC equation. First, it indicates the degree to which an additional dollar brings less joy as one's income increases, or in other words, describes how one manages his consumption smoothing over time. Secondly, η is used as a measure for how one values a gain of a dollar for a rich person compared to a dollar gain for a poor person. This can be characterized simply as the parameter of inequality aversion in different locations in the world. Finally, the marginal utility of consumption can be viewed as a measure of relative risk aversion. This explains why people are willing to pay a premium, proportional to parameter η , in order to eliminate variability in outcomes because doing so increases people's expected utility.

As stated by *ToI* (2008), the social cost of carbon in year t is defined as, "the first partial derivative to carbon dioxide emissions in year t of the net present value of the damage costs of climate change from year t to infinity".

The SCC therefore depends on a considerable number of variables for its estimations, including:

- 1) future development of population and economy;
- 2) future emissions of greenhouse gas emissions;
- 3) future climate change;
- 4) future impacts of climate change;
- 5) values of these impacts;
- 6) the rate of pure time preference;
- 7) the rate of risk aversion; and
- 8) the rate of inequity aversion

1- 4 are positive variables but have uncertain values because they are in the future. Variables 5-8 are a combination of positive and normative elements; as a result, their values are not only controversial but uncertain as well.

Consequently, the social cost of carbon is highly uncertain. Figure 5.1 shows the probability density of the social cost of carbon.

Figure 5.1

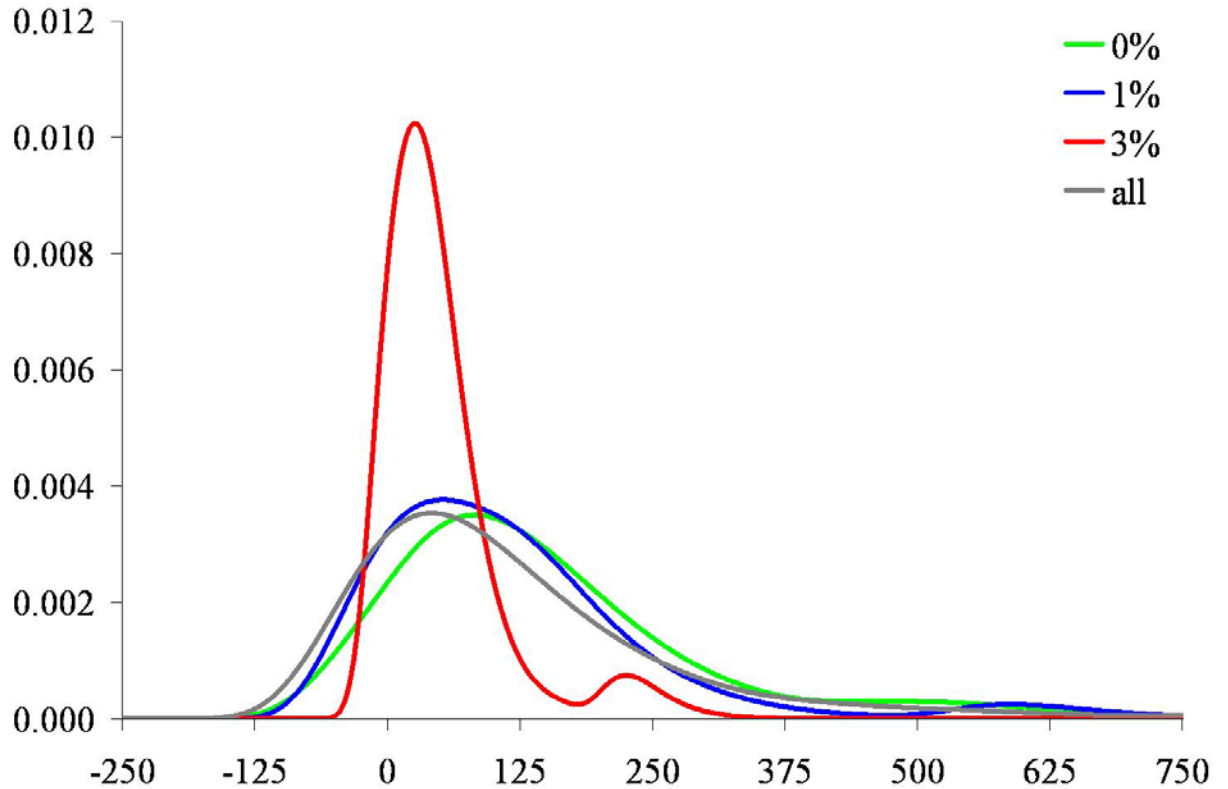


Figure 5.1 Source: Tol (2008) - "The probability density of the social cost of carbon. The probability density function or ("PDF") results from over 200 point estimates of the SCC. Each one assumes a Fisher-Tippett distribution, with the mode equal to the estimate and the standard deviation equal to the sample standard deviation. The composite PDF is the quality-weighted sum of the individual PDF's. Besides the composite PDF for all estimates, the figure also shows the composite PDF for those estimates based on a 0%, 1%, and 3% rate of pure time preference."

This graph depicts all the estimates that Tol reviewed in his meta-analysis. The negative values in the graph represent negative estimates for the SCC found in some works of literature. These published negative costs of SCC, or in other words benefits, indicate that there are some winners from the impacts of global warming, based on specific local characteristics.

However, those estimates depreciate very quickly and turn into damages,

which are associated with an appropriate cost. For those benefits to dominate the whole calculation, it must be true that the future is discounted more significantly than otherwise done by the climate community.

Several other assumptions and caveats underlie the social cost of carbon. SCC estimates are dependent on many different assumptions about future emissions, climate sensitivity (warming associated with increases in greenhouse gas concentrations), and the seriousness of impacts over time. It is a problem that is compounded by uncertainty and it is a problem whose impact affects people with different income in different ways. In *Workshop Summary* (2010), the SCC is most often expressed in dollars per metric ton of carbon and the SCC increases over time as the concentration of atmospheric CO₂ rises and the future gets closer to the present. However, our knowledge of climate change impacts is incomplete and as a result, may be biased downwards. *Anthoff, Tol, and Yohe* (2009) argue that the net present value of a series of escalating impacts equals the net present value of a series of constant impacts evaluated at a lower discount rate. Because of this, it becomes apparent that the rate of escalation of impacts is just as important as the rate of pure time preference and the rate of risk aversion. Finally, the SCC can be monetized on a local scale, national scale, and even aggregated on a global scale, to get the global social cost of carbon.

This thesis will be using a range of estimates of the SCC as reported by the EPA in their endangerment finding – estimates based on computing the total, monetized discounted impact of climate change along a business as

usual paths. In *Yohe* (2010), the IPCC (2007a and 2007b) reported that estimates of the SCC vary widely and change over time. The U.S. EPA reviewed this literature so that it could offer its own recommended estimates that could be applied in studies of a wide range of regulations that might have either positive or negative implications with respect to carbon emissions. The EPA produced four values for 2007; \$5, \$21, \$35, and \$65 per ton of carbon dioxide. In addition, the IPCC reported that any estimate is time specific and should as the future approaches increase in real terms by 2% to 4% per year.

While the SCC is the best estimate in analyzing the economic impact of climate change and therefore the economic benefit of climate policy, there is still a large amount of uncertainty in climate change science. A great deal of uncertainty is due to the lack of research in the climate economics field. The matrix shown in Figure 5.1 summarizes the existing knowledge climate scientists possess and the varying degrees of uncertainty away from it that alter the economic impact of climate change.

Figure 5.2

“Coverage of Existing Economic Analysis of the Impacts of Climate Change Related Risks. Most existing studies have been limited to market-based sectors, though a few have moved beyond region I to include non-market impacts along project trends (region IV), bounded risks in market and non-market sectors (region II and V) and abrupt change to selected market sectors (region III).” Source: Downing, T., and Watkiss, P. (2003)

		Uncertainty in Valuation ----->		
Uncertainty in Predicting Climate Change		Market	Non-Market	(Social Contingent)
	I	I. <u>Coastal Protection</u> <u>Loss of Dryland</u> <u>Energy</u> <u>(heating/cooling)</u>	IV. <u>Heat Stress</u> <u>Loss of</u> <u>Wetland</u>	VII. <u>Regional Costs</u> <u>Investment</u>
	II III IV V	II. <u>Agriculture</u> <u>Water</u> <u>Variability</u> <u>(drought, flood,</u> <u>storms)</u>	V. <u>Ecosystem</u> <u>Change</u> <u>Biodiversity</u> <u>Loss of Life</u> <u>Secondary</u> <u>social effects</u>	VIII. <u>Comparative</u> <u>advantage & market</u> <u>structures</u>
	V	III. <u>Above, plus</u> <u>Significant Loss of</u> <u>Land and</u> <u>Resources</u> <u>Non-marginal</u> <u>effects</u>	VI. <u>Higher Order</u> <u>Social Effects</u> <u>Regional</u> <u>Collapse</u>	IX. <u>Regional Collapse</u>

As stated in *Yohe* (2010), the columns are divided vertically, “by the degree to which the complication of uncertainty in climate change science is captured by benefits analysis”. Also, the rows are divided horizontally, “by the degree to which the corresponding impacts can be calibrated in monetary terms”. As the diagram suggests, most of the knowledge climate scientists have about the economic costs of climate change has come from Zone I only. Zones II – V has a very limited amount of literature that discusses the economic effect of climate impact, while the existing literature has almost nothing to say about impacts and vulnerability, “calibrated in the non-market impacts of abrupt change in and the multiple metrics of socially contingent impacts Zones VI – IX”.

Chapter 6 – Methodology, Results and Conclusions

This chapter highlights and quantifies the impact of four geothermal projects that Wesleyan University has considered for the heating and cooling of certain locations on campus. It illustrates in a real example the difference between a concerned world which has implemented an SCC to reduce the emission of greenhouse gases and the real world in which we live. The focus here is on specific actions that can be taken by Wesleyan University through its use of geothermal energy. While any action that Wesleyan takes will have only a minor impact on the overall climate change problem, the issue addressed is whether taking that contribution into account could have a real effect on the decision-making process as Wesleyan tries to implement sustainable and cost saving investments in alternative energy.

Model Assumptions

In order to calculate internal rates of return and payback periods for the four Wesleyan projects based on social cost of carbon projections offered by the EPA and informed by the IPCC, a representative sensitivity analysis was used. Simulation models were run to show the impact of several different variables on the geothermal economic analysis for four geothermal projects done by GZA. Using several exogenous variables and other important assumptions, the simulation models attempt to calculate the difference

between a concerned world with climate policy and the reality of the world we live in today.

Fixed Inputs

The first inputs for the model were components of the initial investment cost, which were the costs of construction, equipment, energy management system, boreholes and plumbing/electrical. These were all exogenous variables, provided by the GZA feasibility study.

The next fixed inputs for the model were prices of the sources of energy that geothermal sources would replace: natural gas, No. 2 fuel oil, and No. 6 fuel oil (\$ per MMBtu); they were based on average prices as of October 2010 (see Table 6.1). No. 2 and No. 6 fuel oil were assumed to be the same price. Other fixed inputs were carbon values for natural gas and both fuel oils, in kg/MMbtu. The values for those numbers are 53.02, 73.96, and 75.10 in kg CO₂/MMbtu, for natural gas, No. 2 fuel oil, and No. 6 fuel oil, respectively.

Table 6.1 – GZA Fuel Cost Data

Fuel Type	Fuel Unit Cost	Fuel Unit of Measure	Price per Million Btu
Coal	\$269.00	Ton	\$14.39
No. 2 Fuel Oil	\$2.94	Gallon	\$27.17
Natural Gas	\$1.11	Therm	\$14.23
Propane	\$2.76	Gallon	\$38.74
Wood	\$225.00	Cord	\$18.75
Electricity	\$0.125	kWh	\$37.00
Wood Pellets	\$260.00	Ton	\$19.70
Kerosene	\$3.30	Gallon	\$30.55
Geothermal	\$0.125	kWh	\$11.10
<p>Note: Fuel Unit Costs are based on average prices as of October 2010 Source: Average costs from suppliers in Maine, Massachusetts, Connecticut, Vermont, and New York; Alternative-Heating-Info.com</p>			

The final fixed inputs were the values of natural gas, No. 2, and No. 6 fuel oil that would be consumed by each project location in the absence of a geothermal alternative. These values came from the Energy Use data sheets provided by Wesleyan’s Physical Plant from June 2008 – June 2009, one calendar school year. Each building’s fossil fuel sources, whether generated independently, i.e. on-site, or generated by Central Power Plant (“CPP”), were taken into account. Following the GZA feasibility study, the natural gas, No. 2 fuel oil and No. 6 fuel oil use was assumed to be replaced to project specific degrees by the geothermal system. If the fuel source was independent, the building was heated / cooled by natural gas or No. 2 fuel oil. If the fuel source was from the CPP, more calculations were necessary to determine the fossil fuel amount. For the energy consumed by the CPP, GZA

first determined the amount of cooling and thermal load in each building and each zone. Both the cooling load (in tons) and thermal load (in lbs/hr of steam) were provided by Wesleyan's Physical Plant. Using the assumption that it takes 10lbs/hr of steam to produce one ton of cooling from the CPP's absorption chillers, the cooling load was able to be converted into units of lbs/hr of steam. With these like units, the cooling and thermal loads (in lbs/hr) were added together. Next, the percentage of cooling/thermal load was calculated by dividing the cooling/thermal load in a particular zone by the total load used on campus. This percentage of the total was then multiplied by the natural gas and No.6 fuel oil consumed at the CPP. This methodology assumes that all fuel consumed at the CPP was used to generate the steam used for cooling and thermal loads for the campus.

Variables

The simulation analysis used several variables. First, a number of assumptions about energy prices and rates of increase in these prices was made. Low and a high estimates, for the rate of growth for No. 6 fuel oil and for natural gas, were derived from projections published by the U.S. Energy Information Administration for the years 2009-2035. The Gas Wellhead Price (\$/MMBtu) was used as a proxy for natural gas, with a low estimate of 2.05% and a high estimate of 6.15%. Averaging the growth rate of Low Sulfur Light Price (\$/barrel) and Imported Crude Price (\$/barrel) yielded an approximate proxy for No.6 fuel oil, with a low estimate of 2.25% and a high estimate of

6.75%. The rate of growth for No. 2 was the same as No. 6 fuel oil in every trial.

Second, a range of SCC prices was used. As expressed in *Yohe* (2010), the U.S. Environmental Protection Agency (“EPA”) reviewed the literature of SCC estimates and offered its own estimates to be applied in, “analyses of a wide range of regulations that might have positive or negative implications with respect to carbon emissions”. The EPA offered 4 values for 2007; \$5, \$21, \$35, and \$65 per ton of carbon dioxide. In the model, only 3 values were used to generate the range, using \$5 as the low estimate, \$35 as the mid estimate, and \$65 as the high estimate. A growth rate for the SCC was also assumed. With regard to the value of SCC, the *IPCC* (2007) reported that any estimate is time specific and should, “as the future unfolds, increase in real terms by 2-4% per year”. For the purposes of the model, a low and a high estimate of 2% and 4% respectively were used for the growth rate of SCC.

The final variable used was the cost of maintaining the geothermal system. Assumptions were made to model long term costs because maintenance costs were not provided by GZA representatives². Two maintenance costs were chosen based on the initial investment costs for each system. Equipment and the Energy Management system were assumed to be the components that would need the most maintenance. They were also the two largest non-construction inputs for the system and would

² Perhaps because they had no way of telling except to say that they were not zero

therefore tend to bias the IRRs downward. The values chosen were 10% and 5% of initial Equipment and Energy management system costs per year.

Methodology

Components of the initial investment cost plus the estimate for maintenance cost were summed together yielding the 'Total Investment Cost' for year 2012. Every year afterward, only the estimated annual maintenance cost was added to this total expense. An assumption for the simulation models was that after 20 years, each project's equipment would have fully depreciated and would therefore need replacing. Even though the life expectancy of geothermal systems is 20-50 years, it would be a safer assumption to downward bias the model and assume higher costs when modeling future predictions. This one-time expense would be reflected in the year 2032 and added to the total expense.

The next step in the representative sensitivity analysis was to compute the energy savings and their impact on the model. In order to generate the payback period and payback period with Carbon ("with C"), several calculations were made. First, the total consumption of natural gas, No.2 and No. 6 fuel oil in MMBtu were added up for each project; then, each fuel was multiplied by its respective energy price, in \$/MMBtu; and finally, that number was multiplied by the fuel's respective estimated growth rate, raised by the number of years after the start date. The number resulting from that calculation is the 'Value of the Potential Energy Savings' of that fuel source

for Wesleyan University in that year. For example, in Project B, in 2012, the first year of operation, 8,312.87 MMbtu's of natural gas were consumed. At a price of \$14.23, with a high estimated fuel growth rate of 6.15%, the value of the potential energy savings in 2012 was:

$$1) (8,312.87) \times (\$14.23) \times [(1+.0615)^0] = \$118,292.14$$

And

$$1') (8,312.87) \times (\$14.23) \times [(1+.0615)^t] \quad \text{for year } (2012+t)$$

This calculation was then done for No.2 and No.6 fuel oil as well. Adding the three fuel sources together yielded the total value of potential energy savings due to the discontinued use of fossil fuels in year 1. This aggregate value was then subtracted from the total investment cost to generate 'Net Savings' for year 1. For every year after, the annual maintenance cost was subtracted from this total.

The next step was to assess the potential carbon savings from switching to geothermal energy. The energy savings of each fuel source was multiplied by its carbon value and then divided by 1000 to get KgCO₂/MMbtu. Then, the carbon savings were multiplied by an estimated SCC price and then by an estimated SCC growth rate, raised by the number of years after the start date. So, for the same example, in Project B, in 2012, the 8,312.87 MMbtu's of natural gas have a carbon value of 53.02 KgCO₂/MMbtu, at a low estimated SCC price of \$5 and high estimated 4% growth rate, the value of the carbon savings in 2012 was:

$$2) \{(8,312.87) \times (53.02)\} / 1000 = \text{Carbon Savings in metric tons} = 441 \text{ tons}$$

$$3) (441) \times \{(\$5) \times (1+.04)^0\} = \$2,204$$

This same calculation was again done for No.2 and No.6 fuel oil. Added together, they equal the 'Total Value of Potential Carbon Savings' for year 1.

With these calculations, payback period and payback period with C could now be calculated. To find the payback period, the values of Net Savings (whose first value was negative because of the large initial investment costs) were aggregated from years 2012 to 2050, accounting for each year's maintenance costs (subtracted from Net Savings), the value of each year's energy savings (added to Net Savings), and the one time fixed cost of replacing the equipment (subtracted from Net Savings). Over time, the rate of growth of energy prices causes the energy savings to increase in monetary value from year to year, making the net savings positive, which leads to the payback period. The payback period is the number of years it takes for the value of the project to go "into the black", as having broken even with the investment cost, or passing \$0, going from negative values into positive values.

In order to find the payback period with carbon, the same calculation is done with one exception. The payback period with C takes into the account the value of the carbon savings. To find the payback period with C, the values of Net Savings are once again aggregated using the same

methodology except this time, the values of carbon savings are added. In this respect, the payback period with C reflects the real effect of carbon savings and thereby reduces the time it takes for each project to pay for itself. In order to analyze the many different scenarios of internal rates of return, more calculations were necessary. Using a discount rate of 5%, applied as an interest rate to compute the present value of net benefits for representative projects, the value of net savings and the value of carbon savings were both discounted, similar to the calculations done for the growth rates. For Project B, with a 5% discount rate, the discounted value of year 2 net savings and carbon savings would be:

$$4) (\$174,592) / [(1+.05)^1] = \$168,950$$

$$5) (\$3,530) / [(1+.05)^1] = \$3,416$$

To find the IRR, the discounted values of net savings for all years between 2012 – 2050 were added together. Then, using the excel function, goal seek, the total discounted value was set equal to zero by changing the discount rate cell, yielding IRR.

To find the IRR with C, the same calculation was done with one exception. The aggregated discounted value of net savings and the aggregated discounted value of carbon savings for all years between 2012 – 2050 were added together first. Then, once again the excel function, goal seek, was used to determine the IRR with C.

Results

The results of the simulation model show the effects of climate projections, fuel costs and growth rates, and maintenance costs on the project payback periods and internal rates of return (“IRR”) for the four geothermal projects. Using these findings, the various geothermal options were ranked in order of best to worst.

Some key abbreviations and other information are needed to understand the results. When referencing specific scenarios, the parameter sequence will be in parentheses and is always in the following order unless otherwise specified: (Fuel Oil Growth Rate, Natural Gas Growth Rate, SCC, Growth of SCC, Maintenance Cost). Also, for the purposes of eliminating repetition, the fuel oil growth rate has been abbreviated to, “FO”. Additionally, the natural gas growth rate has been abbreviated to, “NG”.

The simulation models for the four geothermal projects showed some interesting results:

Project A Results:

In Project A simulations, including carbon analysis made a great difference in comparing the different projects. First and most importantly, in every trial, there was an increase in the IRR when carbon analysis was included. Second, in every instance, there was an increase in the IRR with Carbon (“with C”) when the price of SCC increased, as well as when the growth rate of SCC increased. In Project A, the smallest IRR was 8.46% and had the longest payback period (13yrs) when the parameters (Low, Low, Low, Low, High- Trial #2) were used. IRR with C was lowest at 8.64% and also had the longest payback period (13yrs) in the same scenario (Low, Low, Low, Low, High). In contrast, the IRR was highest (14.29%) and payback period shortest (10yrs) when (High, High, High, High, Low). IRR with C was highest (16.21%) with a 10 year payback in Trial #47 (High, High, High, High, Low). Also, the payback period with C was shortest (9yrs) under these parameters, one year less than the standard payback period.

Another major finding was that as No. 6 fuel oil and the natural gas growth rate increased (Low/Low → High/High), payback period and payback period with C decreased. Another interesting finding was that in every trial, the low estimate of maintenance cost had a higher IRR and a higher IRR with C than the high estimate of maintenance, when all other parameters were

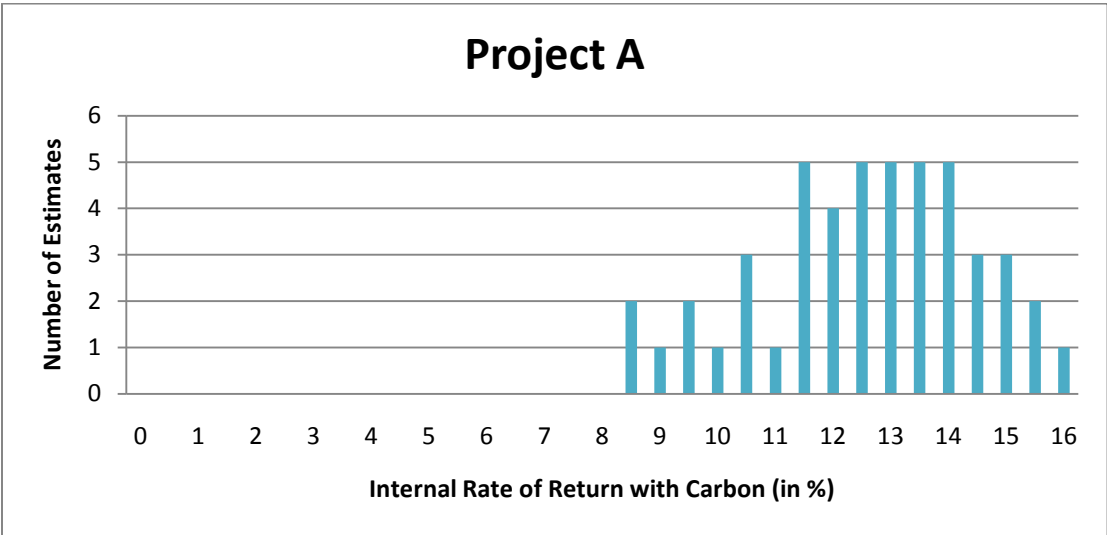
held constant. Consequently, in 3 of the 4 fuel cost growth rate scenarios (low #6/low NG, low #6/high NG, high #6/low NG, NOT high #6/high NG), the low estimate of maintenance cost had a shorter payback period time than the high estimate of maintenance cost, with all other parameters held constant. The final significant finding was that in 3 of the 4 fuel cost growth rate scenarios (low #6/low NG, high #6/low NG, high #6/high NG, NOT low #6/high NG), using the high Est of SCC caused the payback period with C to decrease in both low Est Maintenance and high Est Maintenance. Table 6.1 summarizes the data from Project A. Graph 6.1 shows the dispersion of the IRR with Carbon for Project A.

Table 6.1 – Project A Results

Trial	No.2 and No.6 Fuel Oil Growth	Nat Gas Growth	SCC	Growth of SCC	Maintenance Costs	IRR	IRR w C	Payback Period	Payback Period w C
1	Low Est	Low Est	Low Est	Low Est	Low Est	9.27%	9.45%	12	12
2	Low Est	Low Est	Low Est	Low Est	High Est	8.46%	8.64%	13	13
3	Low Est	Low Est	Low Est	High Est	Low Est	9.27%	9.50%	12	12
4	Low Est	Low Est	Low Est	High Est	High Est	8.46%	8.68%	13	13
5	Low Est	Low Est	Mid Est	Low Est	Low Est	9.27%	10.51%	12	12
6	Low Est	Low Est	Mid Est	Low Est	High Est	8.46%	9.69%	13	13
7	Low Est	Low Est	Mid Est	High Est	Low Est	9.27%	10.80%	12	12
8	Low Est	Low Est	Mid Est	High Est	High Est	8.46%	10.00%	13	13
9	Low Est	Low Est	High Est	Low Est	Low Est	9.27%	11.56%	12	12
10	Low Est	Low Est	High Est	Low Est	High Est	8.46%	10.74%	13	13
11	Low Est	Low Est	High Est	High Est	Low Est	9.27%	12.04%	12	11
12	Low Est	Low Est	High Est	High Est	High Est	8.46%	11.24%	13	12
13	Low Est	High Est	Low Est	Low Est	Low Est	12.34%	12.48%	10	10
14	Low Est	High Est	Low Est	Low Est	High Est	11.69%	11.83%	11	11
15	Low Est	High Est	Low Est	High Est	Low Est	12.34%	12.50%	10	10
16	Low Est	High Est	Low Est	High Est	High Est	11.69%	11.85%	11	11
17	Low Est	High Est	Mid Est	Low Est	Low Est	12.34%	13.31%	10	10
18	Low Est	High Est	Mid Est	Low Est	High Est	11.69%	12.64%	11	11
19	Low Est	High Est	Mid Est	High Est	Low Est	12.34%	13.50%	10	10
20	Low Est	High Est	Mid Est	High Est	High Est	11.69%	12.83%	11	11
21	Low Est	High Est	High Est	Low Est	Low Est	12.34%	14.16%	10	10
22	Low Est	High Est	High Est	Low Est	High Est	11.69%	13.47%	11	11
23	Low Est	High Est	High Est	High Est	Low Est	12.34%	14.50%	10	10
24	Low Est	High Est	High Est	High Est	High Est	11.69%	13.81%	11	11
25	High Est	Low Est	Low Est	Low Est	Low Est	12.21%	12.35%	11	11
26	High Est	Low Est	Low Est	Low Est	High Est	11.56%	11.70%	11	11
27	High Est	Low Est	Low Est	High Est	Low Est	12.21%	12.38%	11	10
28	High Est	Low Est	Low Est	High Est	High Est	11.56%	11.73%	11	11
29	High Est	Low Est	Mid Est	Low Est	Low Est	12.21%	13.18%	11	10
30	High Est	Low Est	Mid Est	Low Est	High Est	11.56%	12.51%	11	11
31	High Est	Low Est	Mid Est	High Est	Low Est	12.21%	13.37%	11	10
32	High Est	Low Est	Mid Est	High Est	High Est	11.56%	12.71%	11	11
33	High Est	Low Est	High Est	Low Est	Low Est	12.21%	14.04%	11	10
34	High Est	Low Est	High Est	Low Est	High Est	11.56%	13.35%	11	11
35	High Est	Low Est	High Est	High Est	Low Est	12.21%	14.37%	11	10
36	High Est	Low Est	High Est	High Est	High Est	11.56%	13.69%	11	11
37	High Est	High Est	Low Est	Low Est	Low Est	14.29%	14.42%	10	10
38	High Est	High Est	Low Est	Low Est	High Est	13.70%	13.82%	10	10
39	High Est	High Est	Low Est	High Est	Low Est	14.29%	14.44%	10	10
40	High Est	High Est	Low Est	High Est	High Est	13.70%	13.84%	10	10
41	High Est	High Est	Mid Est	Low Est	Low Est	14.29%	15.17%	10	10
42	High Est	High Est	Mid Est	Low Est	High Est	13.70%	14.55%	10	10

43	High Est	High Est	Mid Est	High Est	Low Est	14.29%	15.32%	10	10
44	High Est	High Est	Mid Est	High Est	High Est	13.70%	14.70%	10	10
45	High Est	High Est	High Est	Low Est	Low Est	14.29%	15.95%	10	9
46	High Est	High Est	High Est	Low Est	High Est	13.70%	15.31%	10	10
47	High Est	High Est	High Est	High Est	Low Est	14.29%	16.21%	10	9
48	High Est	High Est	High Est	High Est	High Est	13.70%	15.58%	10	10

Graph 6.1 – Project A Dispersion



Project B Results:

In Project B simulations, similar results to A were found. Once again, there was an increase in the IRR for every trial when carbon analysis was included, an increase in the IRR with C when the price of SCC and growth rate of SCC increased. Further, the low estimate of maintenance cost had a shorter payback period than the high estimate of maintenance cost in every fuel cost growth rate scenario when all other parameters the same. Additionally, IRR and IRR with C were once again all lowest in Trial #2 (Low, Low, Low, Low, High) and highest in scenario (High, High, High, High, Low). Also, payback period, and payback period with C were again longest in the first scenario and shortest in the second scenario. In Project B, the smallest IRR was 2.30% and had the longest payback period, 29yrs. IRR with C was lowest at 2.43% and corresponded with the largest payback period with C, 29yrs. In contrast, the IRR was highest at 8.44% when the payback period was shortest, 16yrs. IRR with C was highest at 9.53% while the payback period with C was shortest at 16yrs under these parameters (Trial #47).

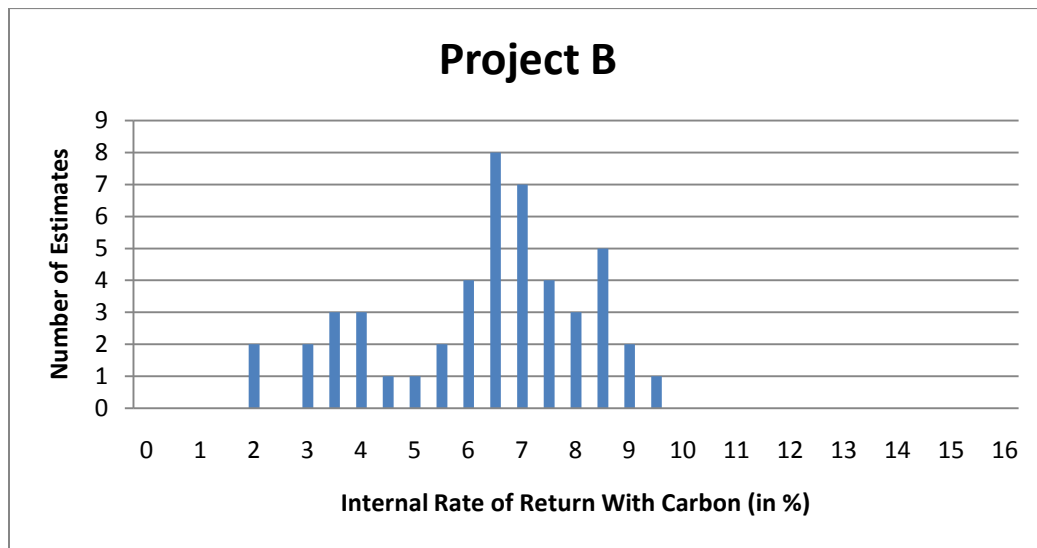
Like Project A results, in every trial of Project B, the low estimate of maintenance cost had a higher IRR/higher IRR with C and lower payback period/payback period with C than the high estimate of maintenance, when all other parameters were held constant. Interestingly, payback period with C only deviated from payback period in one scenario Trial #11 (Low, Low, High, High, Low), decreasing by 1 year (26yrs → 25yrs). Finally, as was the case in Project A, as #6 and NG growth rate increased (Low/Low → High/High), payback period and payback period with C decreased. Table 6.2 summarizes these results. Graph 6.2 displays the dispersion of the return rates with Carbon in Project B.

Table 6.2 – Project B Results

Tri I	No.2 and No.6 Fuel Oil Growth	Nat Gas Growth	SCC	Growth of SCC	Maintenance Costs	IRR	IRR w C	Payback Period	Payback Period w C
1	Low Est	Low Est	Low Est	Low Est	Low Est	3.34%	3.46%	26	26
2	Low Est	Low Est	Low Est	Low Est	High Est	2.30%	2.43%	29	29
3	Low Est	Low Est	Low Est	High Est	Low Est	3.34%	3.51%	26	26
4	Low Est	Low Est	Low Est	High Est	High Est	2.30%	2.49%	29	29
5	Low Est	Low Est	Mid Est	Low Est	Low Est	3.34%	4.17%	26	26
6	Low Est	Low Est	Mid Est	Low Est	High Est	2.30%	3.18%	29	29
7	Low Est	Low Est	Mid Est	High Est	Low Est	3.34%	4.48%	26	26
8	Low Est	Low Est	Mid Est	High Est	High Est	2.30%	3.53%	29	29
9	Low Est	Low Est	High Est	Low Est	Low Est	3.34%	4.84%	26	26
10	Low Est	Low Est	High Est	Low Est	High Est	2.30%	3.89%	29	29
11	Low Est	Low Est	High Est	High Est	Low Est	3.34%	5.36%	26	25
12	Low Est	Low Est	High Est	High Est	High Est	2.30%	4.46%	29	29
13	Low Est	High Est	Low Est	Low Est	Low Est	6.69%	6.77%	18	18
14	Low Est	High Est	Low Est	Low Est	High Est	6.00%	6.08%	19	19
15	Low Est	High Est	Low Est	High Est	Low Est	6.69%	6.80%	18	18
16	Low Est	High Est	Low Est	High Est	High Est	6.00%	6.11%	19	19
17	Low Est	High Est	Mid Est	Low Est	Low Est	6.69%	7.24%	18	18
18	Low Est	High Est	Mid Est	Low Est	High Est	6.00%	6.54%	19	19
19	Low Est	High Est	Mid Est	High Est	Low Est	6.69%	7.40%	18	18
20	Low Est	High Est	Mid Est	High Est	High Est	6.00%	6.72%	19	19
21	Low Est	High Est	High Est	Low Est	Low Est	6.69%	7.70%	18	18
22	Low Est	High Est	High Est	Low Est	High Est	6.00%	7.00%	19	19
23	Low Est	High Est	High Est	High Est	Low Est	6.69%	8.00%	18	18
24	Low Est	High Est	High Est	High Est	High Est	6.00%	7.31%	19	19
25	High Est	Low Est	Low Est	Low Est	Low Est	6.40%	6.50%	18	18
26	High Est	Low Est	Low Est	Low Est	High Est	5.70%	5.78%	22	22
27	High Est	Low Est	Low Est	High Est	Low Est	6.40%	6.51%	18	18
28	High Est	Low Est	Low Est	High Est	High Est	5.70%	5.80%	22	22
29	High Est	Low Est	Mid Est	Low Est	Low Est	6.40%	6.95%	18	18
30	High Est	Low Est	Mid Est	Low Est	High Est	5.70%	6.25%	22	22
31	High Est	Low Est	Mid Est	High Est	Low Est	6.40%	7.13%	18	18
32	High Est	Low Est	Mid Est	High Est	High Est	5.70%	6.43%	22	22
33	High Est	Low Est	High Est	Low Est	Low Est	6.40%	7.43%	18	18
34	High Est	Low Est	High Est	Low Est	High Est	5.70%	6.72%	22	22
35	High Est	Low Est	High Est	High Est	Low Est	6.40%	7.74%	18	18
36	High Est	Low Est	High Est	High Est	High Est	5.70%	7.04%	22	22
37	High Est	High Est	Low Est	Low Est	Low Est	8.44%	8.51%	16	16
38	High Est	High Est	Low Est	Low Est	High Est	7.84%	7.91%	17	17
39	High Est	High Est	Low Est	High Est	Low Est	8.44%	8.53%	16	16
40	High Est	High Est	Low Est	High Est	High Est	7.84%	7.93%	17	17
41	High Est	High Est	Mid Est	Low Est	Low Est	8.44%	8.91%	16	16

42	High Est	High Est	Mid Est	Low Est	High Est	7.84%	8.30%	17	17
43	High Est	High Est	Mid Est	High Est	Low Est	8.44%	9.03%	16	16
44	High Est	High Est	Mid Est	High Est	High Est	7.84%	8.43%	17	17
45	High Est	High Est	High Est	Low Est	Low Est	8.44%	9.31%	16	16
46	High Est	High Est	High Est	Low Est	High Est	7.84%	8.69%	17	17
47	High Est	High Est	High Est	High Est	Low Est	8.44%	9.53%	16	16
48	High Est	High Est	High Est	High Est	High Est	7.84%	8.92%	17	17

Graph 6.2 – Project B Dispersion



Project C Results:

Project C, like the previous projects, had most of the same results. Once again, there was an increase in the IRR for every trial when carbon analysis was included. An increase in the IRR with C due to the increases in the price and growth rate of SCC occurred once again. Further, the low estimate of maintenance cost having a higher IRR/higher IRR with C and shorter payback period/payback period with C than the high estimate and in every fuel cost growth rate scenario, when all other parameters were held constant. Scenario (High, High, High, High, Low Trial #47) once more produced the highest IRR and IRR with C with the shortest payback period and payback period with C. In addition, scenario (Low, Low, Low, Low, High) produced the smallest IRR and IRR with C as well the longest payback period and payback period with C.

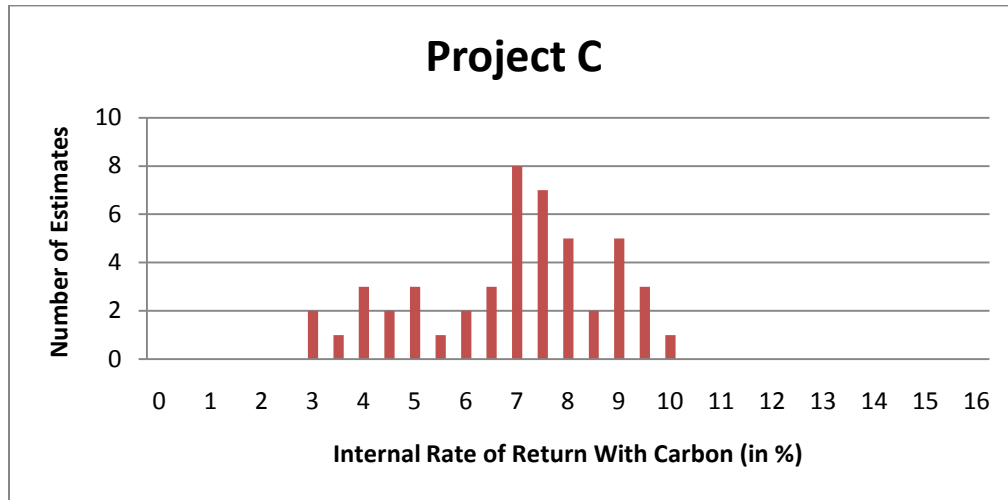
In Project C, the smallest IRR was 2.98% and had the longest payback period, 27yrs. IRR with C was lowest at 3.11% and also had the largest payback period, 27yrs. In contrast, the IRR was highest at 8.95% and produced the shortest payback period, 15yrs. IRR with C was highest at 10.08% and had the shortest payback period with C at 15yrs. Unlike Projects A and B, payback period with C never decreased relative to payback period. As FO and NG growth rate increased (Low/Low → High/High), payback period and payback period with C decreased. Table 6.3 summarizes Project C simulations. Graph 6.3 depicts the dispersion of the internal rates of return with C for Project C.

Table 6.3 – Project C Results

Trials	No.2 and No.6 Fuel Oil Growth	Nat Gas Growth	SCC	Growth of SCC	Maintenance Costs	IRR	IRR w C	Payback Period	Payback Period w C
1	Low Est	Low Est	Low Est	Low Est	Low Est	3.89%	4.01%	24	24
2	Low Est	Low Est	Low Est	Low Est	High Est	2.98%	3.11%	27	27
3	Low Est	Low Est	Low Est	High Est	Low Est	3.89%	4.06%	24	24
4	Low Est	Low Est	Low Est	High Est	High Est	2.98%	3.17%	27	27
5	Low Est	Low Est	Mid Est	Low Est	Low Est	3.89%	4.73%	24	24
6	Low Est	Low Est	Mid Est	Low Est	High Est	2.98%	3.86%	27	27
7	Low Est	Low Est	Mid Est	High Est	Low Est	3.89%	5.04%	24	24
8	Low Est	Low Est	Mid Est	High Est	High Est	2.98%	4.20%	27	27
9	Low Est	Low Est	High Est	Low Est	Low Est	3.89%	5.42%	24	24
10	Low Est	Low Est	High Est	Low Est	High Est	2.98%	4.58%	27	27
11	Low Est	Low Est	High Est	High Est	Low Est	3.89%	5.93%	24	24
12	Low Est	Low Est	High Est	High Est	High Est	2.98%	5.13%	27	27
13	Low Est	High Est	Low Est	Low Est	Low Est	7.13%	7.21%	17	17
14	Low Est	High Est	Low Est	Low Est	High Est	6.51%	6.59%	18	18
15	Low Est	High Est	Low Est	High Est	Low Est	7.13%	7.23%	17	17
16	Low Est	High Est	Low Est	High Est	High Est	6.51%	6.61%	18	18
17	Low Est	High Est	Mid Est	Low Est	Low Est	7.13%	7.70%	17	17
18	Low Est	High Est	Mid Est	Low Est	High Est	6.51%	7.07%	18	18
19	Low Est	High Est	Mid Est	High Est	Low Est	7.13%	7.87%	17	17
20	Low Est	High Est	Mid Est	High Est	High Est	6.51%	7.25%	18	18
21	Low Est	High Est	High Est	Low Est	Low Est	7.13%	8.18%	17	17
22	Low Est	High Est	High Est	Low Est	High Est	6.51%	7.55%	18	18
23	Low Est	High Est	High Est	High Est	Low Est	7.13%	8.48%	17	17
24	Low Est	High Est	High Est	High Est	High Est	6.51%	7.86%	18	18
25	High Est	Low Est	Low Est	Low Est	Low Est	6.98%	7.06%	17	17
26	High Est	Low Est	Low Est	Low Est	High Est	6.35%	6.43%	19	19
27	High Est	Low Est	Low Est	High Est	Low Est	6.98%	7.09%	17	17
28	High Est	Low Est	Low Est	High Est	High Est	6.35%	6.46%	19	19
29	High Est	Low Est	Mid Est	Low Est	Low Est	6.98%	7.55%	17	17
30	High Est	Low Est	Mid Est	Low Est	High Est	6.35%	6.92%	19	19
31	High Est	Low Est	Mid Est	High Est	Low Est	6.98%	7.72%	17	17
32	High Est	Low Est	Mid Est	High Est	High Est	6.35%	7.10%	19	19
33	High Est	Low Est	High Est	Low Est	Low Est	6.98%	8.04%	17	17
34	High Est	Low Est	High Est	Low Est	High Est	6.35%	7.41%	19	19
35	High Est	Low Est	High Est	High Est	Low Est	6.98%	8.35%	17	17
36	High Est	Low Est	High Est	High Est	High Est	6.35%	7.73%	19	18
37	High Est	High Est	Low Est	Low Est	Low Est	8.95%	9.02%	15	15
38	High Est	High Est	Low Est	Low Est	High Est	8.41%	8.48%	16	16
39	High Est	High Est	Low Est	High Est	Low Est	8.95%	9.04%	15	15
40	High Est	High Est	Low Est	High Est	High Est	8.41%	8.50%	16	16
41	High Est	High Est	Mid Est	Low Est	Low Est	8.95%	9.44%	15	15
42	High Est	High Est	Mid Est	Low Est	High Est	8.41%	8.89%	16	16
43	High Est	High Est	Mid Est	High Est	Low Est	8.95%	9.56%	15	15
44	High Est	High Est	Mid Est	High Est	High Est	8.41%	9.01%	16	16

45	High Est	High Est	High Est	Low Est	Low Est	8.95%	9.86%	15	15
46	High Est	High Est	High Est	Low Est	High Est	8.41%	9.30%	16	16
47	High Est	High Est	High Est	High Est	Low Est	8.95%	10.08 %	15	15
48	High Est	High Est	High Est	High Est	High Est	8.41%	9.53%	16	16

Graph 6.3 – Project C Dispersion



Project D Results:

Project D simulations produced similar results as the other projects. Increases in the price and growth rate of SCC caused increases in IRR with C, as FO and NG growth rate increased (Low/Low → High/High), payback period and payback period with C decreased, and the low estimate of maintenance cost had a higher IRR/higher IRR with C and lower payback period/payback period with C than the high estimate in nearly all cases, when all other parameters were held constant.

In Project D, the smallest IRR was 6.19% with the longest payback period of 16yrs and the IRR with C was lowest at 6.32% with the largest payback period at 16yrs, when the parameters (Low, Low, Low, Low, High) were used. In contrast, the IRR was highest (12.13%) with the payback period at its shortest (12yrs) and IRR with C was highest (13.42%) when

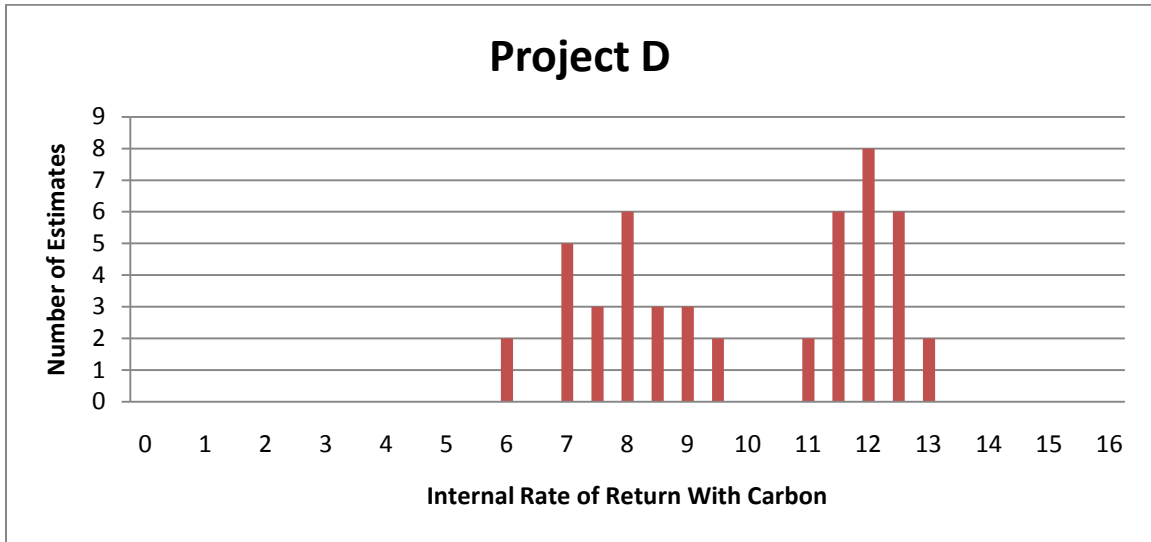
payback period with C was shortest at 11yrs, in scenario (High, High, High, High, Low). Table 6.4 summarizes these results while Graph 6.4 shows the dispersion of the internal rate of returns with carbon.

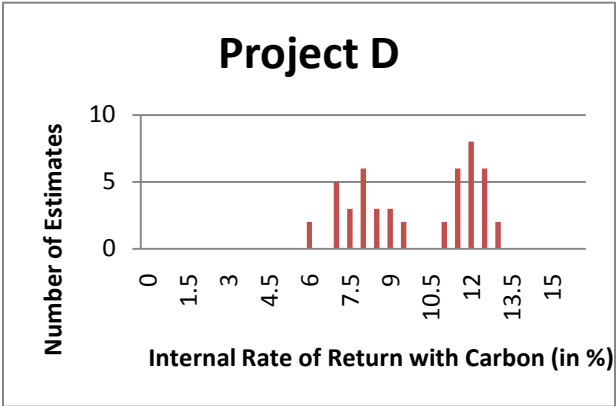
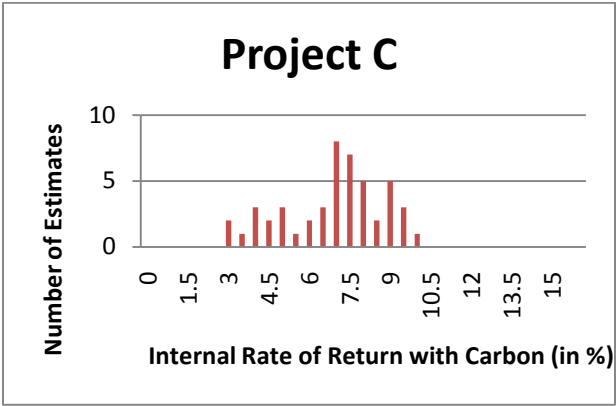
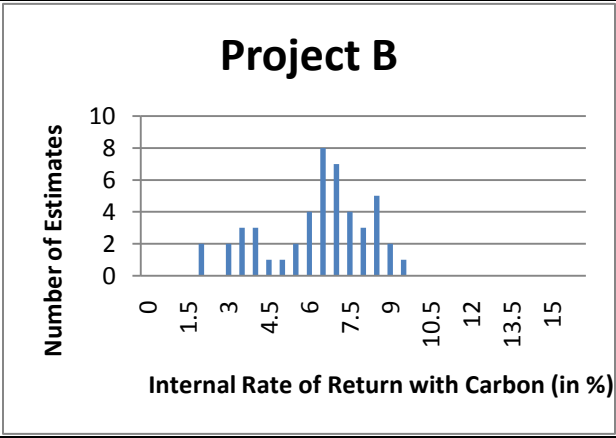
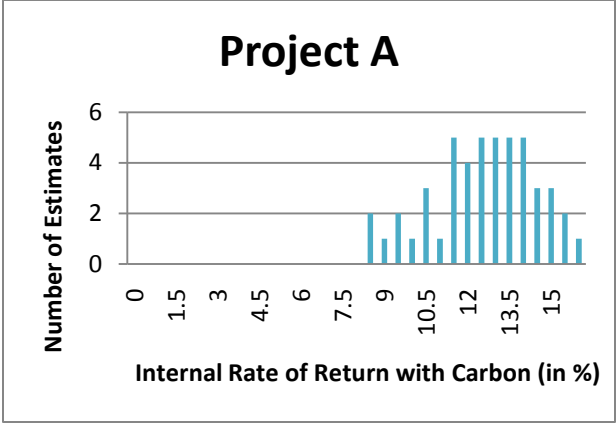
Table 6.4 - Project D Results

Tri I	No.2 and No.6 Fuel Oil Growth	Nat Gas Growth	SCC	Growth of SCC	Maintenance Costs	IRR	IRR w C	Payback Period	Payback Period w C
1	Low Est	Low Est	Low Est	Low Est	Low Est	6.97%	7.10%	15	15
2	Low Est	Low Est	Low Est	Low Est	High Est	6.19%	6.32%	16	16
3	Low Est	Low Est	Low Est	High Est	Low Est	6.97%	7.14%	15	15
4	Low Est	Low Est	Low Est	High Est	High Est	6.19%	6.37%	16	16
5	Low Est	Low Est	Mid Est	Low Est	Low Est	6.97%	7.86%	15	15
6	Low Est	Low Est	Mid Est	Low Est	High Est	6.19%	7.09%	16	16
7	Low Est	Low Est	Mid Est	High Est	Low Est	6.97%	8.12%	15	15
8	Low Est	Low Est	Mid Est	High Est	High Est	6.19%	7.36%	16	16
9	Low Est	Low Est	High Est	Low Est	Low Est	6.97%	8.61%	15	15
10	Low Est	Low Est	High Est	Low Est	High Est	6.19%	7.84%	16	16
11	Low Est	Low Est	High Est	High Est	Low Est	6.97%	9.04%	15	15
12	Low Est	Low Est	High Est	High Est	High Est	6.19%	8.30%	16	16
13	Low Est	High Est	Low Est	Low Est	Low Est	8.06%	8.17%	14	14
14	Low Est	High Est	Low Est	Low Est	High Est	7.36%	7.48%	15	15
15	Low Est	High Est	Low Est	High Est	Low Est	8.06%	8.21%	14	14
16	Low Est	High Est	Low Est	High Est	High Est	7.36%	7.51%	15	15
17	Low Est	High Est	Mid Est	Low Est	Low Est	8.06%	8.85%	14	14
18	Low Est	High Est	Mid Est	Low Est	High Est	7.36%	8.15%	15	15
19	Low Est	High Est	Mid Est	High Est	Low Est	8.06%	9.06%	14	14
20	Low Est	High Est	Mid Est	High Est	High Est	7.36%	8.37%	15	15
21	Low Est	High Est	High Est	Low Est	Low Est	8.06%	9.51%	14	14
22	Low Est	High Est	High Est	Low Est	High Est	7.36%	8.82%	15	15
23	Low Est	High Est	High Est	High Est	Low Est	8.06%	9.88%	14	14
24	Low Est	High Est	High Est	High Est	High Est	7.36%	9.20%	15	15
25	High Est	Low Est	Low Est	Low Est	Low Est	11.63%	11.72%	12	12
26	High Est	Low Est	Low Est	Low Est	High Est	11.10%	11.18%	13	13
27	High Est	Low Est	Low Est	High Est	Low Est	11.63%	11.73%	12	12
28	High Est	Low Est	Low Est	High Est	High Est	11.10%	11.20%	13	13
29	High Est	Low Est	Mid Est	Low Est	Low Est	11.63%	12.22%	12	12
30	High Est	Low Est	Mid Est	Low Est	High Est	11.10%	11.67%	13	13
31	High Est	Low Est	Mid Est	High Est	Low Est	11.63%	12.35%	12	12
32	High Est	Low Est	Mid Est	High Est	High Est	11.10%	11.80%	13	12
33	High Est	Low Est	High Est	Low Est	Low Est	11.63%	12.74%	12	12
34	High Est	Low Est	High Est	Low Est	High Est	11.10%	12.17%	13	12
35	High Est	Low Est	High Est	High Est	Low Est	11.63%	12.96%	12	12
36	High Est	Low Est	High Est	High Est	High Est	11.10%	12.40%	13	12
37	High Est	High Est	Low Est	Low Est	Low Est	12.13%	12.21%	12	12
38	High Est	High Est	Low Est	Low Est	High Est	11.60%	11.68%	12	12
39	High Est	High Est	Low Est	High Est	Low Est	12.13%	12.23%	12	12
40	High Est	High Est	Low Est	High Est	High Est	11.60%	11.70%	12	12
41	High Est	High Est	Mid Est	Low Est	Low Est	12.13%	12.70%	12	11
42	High Est	High Est	Mid Est	Low Est	High Est	11.60%	12.16%	12	12

43	High Est	High Est	Mid Est	High Est	Low Est	12.13%	12.82%	12	11
44	High Est	High Est	Mid Est	High Est	High Est	11.60%	12.28%	12	12
45	High Est	High Est	High Est	Low Est	Low Est	12.13%	13.21%	12	11
46	High Est	High Est	High Est	Low Est	High Est	11.60%	12.65%	12	12
47	High Est	High Est	High Est	High Est	Low Est	12.13%	13.42%	12	11
48	High Est	High Est	High Est	High Est	High Est	11.60%	12.87%	12	12

Graph 6.4 – Project D Dispersion





Dispersion Graphs

For drawing conclusions from the different projects, histogram graphs were very informative of each project's given circumstances. Graphing the number of estimates within a range against the internal rate of return with carbon showed how the dispersion of IRR with C was affected by the different scenarios modeled in each simulation model.

Project A had a highly clustered dispersion distribution at a very high IRR with C, around the 11.5-14% IRR with C. The low end of the IRR with C was characterized by Low FO/Low NG estimates, while the high end was characterized by the opposite, High FO/High NG estimates. The low end was also considerably affected by lower estimates of SCC, in the low and mid range, while the high end was affected by higher estimates of SCC, in the mid to high range. The total dispersion was roughly 8%, ranging from 8.64% to 16.21%. When compared to the University target (a 5% return on investment at the very least), Project A cleared the barrier easily making one of the most attractive options.

Project B had a bunched dispersion range, around the 6-8.5% IRR with C. The low end of the IRR with C dispersion distribution was characterized by Low FO/Low NG estimates. The high end of the IRR with C distribution was characterized by the opposite, High FO/High NG. Total dispersion was roughly 7%, ranging between 2.43% – 9.53%. It is possible that the SCC can make the IRR rise above 5%, depending on the growth rate of SCC, with the combination of low maintenance cost and high SCC. When compared to the

University target, roughly a quarter of the IRR with C did not break the barrier and therefore, the future growth of energy prices had a significant impact on Project B.

Project C had a similarly bunched dispersion range to Project B, with no obvious breaks between the low and the high internal rates of return with C. The low end of the IRR with C dispersion distribution was characterized by Low FO/Low NG estimates, while changes in estimated SCC price, growth rate and maintenance cost caused no significant results. The high end of the IRR with C was therefore characterized by High FO/High NG, once again with varying results from the other estimated variables. The total dispersion was approximately 7%, from 3.11% - 10.08%. A sixth of the distribution was unable to break the University target return rate of 5% and therefore, energy prices forecasts have an influence on Project C. It is possible that the SCC can make the IRR rise above 5%, depending on the growth rate of SCC, with the right combination of low maintenance cost and high SCC.

Project D had a bi-modal dispersion distribution, separated by a gap in internal rate of return with C. The lower IRR distribution was characterized by low estimated fuel oil price growth rates while the higher IRR with C distribution was characterized by the high estimated fuel oil price growth rates. When the low fuel oil estimate was used, representing the lower mode, the IRR with C ranged from 6.32%-9.88%, while when the high fuel oil estimate was used, representing the upper mode, the IRR with C ranged from 11.18%-13.42%. The total dispersion was roughly 7%, from 6.32% - 13.42%.

It is important to note that regardless of the estimates, all of the IRR with C were above the University target IRR of 5%.

Simulation Conclusions

The representative sensitivity analysis simulation models indicated a number of interesting conclusions, including a logical ranking of the projects from best to worst, based on different parameters. First, the results are logical and make sense. Each model simulation came back with very similar trends in the information. Secondly, including carbon analysis in the assessment caused increases in every project's internal rates of return (more so for the highest IRR than for the lowest IRR) and reductions in their payback period, further making the case for using climate projections that factor in uncertainty. Finally, as those SCC and other variable estimates grew in size, from low to high, so did each project's value to the University over time due to the discontinued use of fossil fuels by converting to geothermal energy.³

Conclusions:

Project A proved to be the most promising potential geothermal system because it had the highest values of IRR, both including climate analysis and excluding, and had the shortest payback period ranges of any of the four

³ This does not imply size of the project. It just says that as estimates of price of SCC, growth rate of SCC, maintenance cost, and growth rate of fossil fuel prices increased, each project increased in value - specifically from the lowest IRR scenario (Low, Low, Low, Low, High) to the highest IRR scenario (High, High, High, High, Low).

projects. Generating nearly as much energy and carbon savings as Project C but with less than half the initial investment costs, Project A is the clearest choice for geothermal implementation. Different estimates for maintenance costs had little effect on the IRR/IRR with C as the energy savings growing over time outweighed the annual fixed cost of maintenance. Calculating the project's sensitivity to carbon analysis by finding the percent difference between IRR and IRR with C showed that Project A was the most sensitive of the projects. With an increase of 13.44% from the highest values of IRR to IRR with C, Project A benefits greatly from incorporating forward-looking climate projections (see Table 6.5 and 6.6). Finally, even when assuming the baseline scenario in the absence of carbon analysis, a zero growth rate in the price of both fuel oils and natural gas, the IRR of Project A was greater than the University target rate of 5% in both the low and high estimate of maintenance costs. It was the only project to do so.

The second best project was proven to be Project D also because of its high values of IRR and relatively short payback periods, in both the carbon case and excluding. Project D was more heavily impacted by the rate of growth of fossil fuel prices than Project A which helped create the bi-modal distribution of the IRR with C. 2nd in every category behind Project A, Project D also did not have nearly as many instances of payback period decreasing after climate projections included, 9 for Project A vs 4 for Project D. This was likely due to the much larger size and scale of Project A projected area and reductions in fossil fuel use. In addition, in the baseline scenario of zero

growth for fossil fuel prices, Project D did not generate enough IRR to reach the University target of 5%, in either estimate of maintenance costs. With that being said, both IRR and IRR with C in their respective ranges were able to beat the University target in all cases. Therefore, Project D would be cleared for development and implementation by University standards.

The next ranked project was Project C. Due to its very high initial investment costs, Project C was doomed to have one of the lowest IRR and one of the largest payback periods of all the different projects. The only reason it ranks better than Project B is that the project area uses more fossil fuels on an annual basis, thereby generating more energy and carbon savings. This is due mostly to the fact that the area size in terms of heating/cooling load is significantly larger. While its initial IRR with C value is only 3.11%, with the right combination of estimated SCC prices, growth rates and energy prices, Project C values for IRR with C could reach the point where implementation is worth it (see Table 6.5 and Table 6.6). Especially in the case of high fossil fuel price growth rates, Project C could potentially become a valuable investment, surpassing the University IRR target of 5%.

Project B ranks last among all the projects because it consistently has the lowest IRR and has the longest payback period among the different scenarios. In the worst estimated case scenario, Project B's payback period is almost 3 decades long, much too long to be considered a valuable investment for a non-profit. With an IRR with C of only 9.53% in its best case scenario, Project B just doesn't compare with the other projects.

Implementing climate analysis for Project B would only make the project more attractive for certain futures (see Table 6.5 and Table 6.6). With one quarter of the IRR and IRR with C below the 5% University target, implementation of Project B is highly unlikely. However, as was the case in Project C, should the high estimates of fossil fuel price growth rates prove to be true and climate projections included, Project B could one day become worth the investment.

Table 6.5

	Lowest IRR	Highest IRR
Project A	8.46%	14.29%
Project B	2.30%	8.44%
Project C	2.98%	8.95%
Project D	6.19%	12.13%

Table 6.6

	Lowest IRR with C	Highest IRR with C
Project A	8.64%	16.21%
Project B	2.43%	9.53%
Project C	3.11%	10.08%
Project D	6.32%	13.42%

Chapter 7 – Conclusion

President Roth's decision to pledge his support to the ACUPCC was a momentous step in Wesleyan University's history. Committing to achieve carbon neutrality in the next 50 years sends a strong statement not only to the academic community but to the world at large that it is time to make a fundamental change in the way humans live. This pledge arises from a belief that climate change is real and is a threat to life as we know it.

Several questions arise from the Presidents' Climate Commitment. First, has the University been contributing to the climate change problem? If the answer to that question is yes, then what actions should the University take to reverse its contribution to climate change? This is a very important, far-reaching issue concerning what responsibility individuals and institutions should take for their actions.

This thesis has attempted to analyze the feasibility and impact of developing geothermal projects at Wesleyan to replace our reliance on climate-damaging fossil fuels. Until only recently, geothermal energy was not considered a realistic energy source by the University to provide heating and cooling on campus. Because installing geothermal can reduce the University's emission of greenhouse gases as well as reduce its dependence on the inelastic demand of ever-increasing price of fossil fuels, Wesleyan's Physical Plant as well as student groups like SAGES have recently been pushing for renewable initiatives. The problem is that there is a significant

economic cost associated with converting to geothermal energy and there is no societal or legal requirement for the University to do so.

This thesis used representative sensitivity analysis to simulate models characterizing the span of “non-implausible” futures to predict the potential value of the different geothermal projects to Wesleyan University with and without climate assessment. The results of this analysis maintain that the internal rate of return and payback period, both with and without carbon assessment, are the best predictors of value to the University. The results conclude that using future-oriented carbon assessment is extremely useful to risk averse decision-makers and is beneficial not only for the University, but for the world, as they help to mitigate the emission of harmful greenhouse gases.

The simulation models showed that while some of the projects are promising, not all the geothermal projects are attractive investments.

The results of the simulation models are very similar to the sequenced approach that GZA Environmental Inc suggested earlier in this paper.

Ranked from best to worst, the models’ results proved the project order to be A, D, C, B. GZA results, however, concluded the order to be D, A, B, C.

While Project A is ranked the best option by the simulation models because it has the highest IRR with and without carbon analysis and the shortest payback periods of all the projects modeled, GZA reasoned that Project D is the best option because it is heated/cooled entirely by fossil fuels, costs the least of all projects to install, and could be used as a pilot program at

Wesleyan. Regardless, both analyses ranked D and A to be the most feasible projects, while B and C the least feasible.

However, GZA looked at the project from a traditional, 20th century perspective. The cost analysis is fine; project costs are as good as a consulting firm can produce. There is nothing wrong with it. It is good Project analysis 1.0. It is good pre-climate change era thinking. It quantifies the costs of the project and helps decision-makers to choose which project to undertake, if any.

The problem is that it does not have a future orientation. It does not consider the future cost of fossil fuels or the SCC. What is needed in order to make a better project decisions for the future is Project Analysis 2.0 and that is what this thesis has attempted to do. By adding a future orientation and bringing in a major externality – the SCC – into the decision making process, 2.0 is a methodology for the Climate Change Era. It is a new analysis for the 21st century world.

From both a social and economic perspective, it would seem that geothermal projects should be built and that Wesleyan can be a pace setter and an example for society. The problem is that to reach this conclusion, decision makers need to employ a long-term view and often it takes prodding from the government or sanctions to get them to take actions that benefit society as a whole. It is often hard to get people and institutions to take such actions voluntarily.

Economists call the negative effects that companies, institutions, and individuals have on society, but which cost them nothing, “externalities”. A classic example of an externality is air pollution which is harmful to society and which would be a significant expense to clean up. Greenhouse gas emissions are another example and their impact on society has only recently been addressed, but not accepted by all. To address the problem of climate change, it is necessary to get decision-makers to include “externalities” – harmful climate changing impacts – in their investment decisions. They are not forced to do so now and they do not think they should have to pay that cost.

What is required to address the problem of climate change is for individuals and institutions to understand the impacts of their actions and to change to decrease their harmful actions. This may take legal action as well as peer and moral persuasion. As we have seen in this thesis, institutions can make an impact at a reasonable cost and a change to geothermal energy is one of the steps that can be taken.

The journey of a thousand miles begins with the first step.

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