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Ground Source Heat Pump Systems in North Dakota: Economics and Greenhouse Gas (GHG) Emissions Analysis

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ABSTRACT

Skyrocketing energy bills and global warming concerns due to space heating and cooling needs have made it mandatory that stakeholders think and act quickly on all necessary innovating ideas that can continue to increase the efforts in advancing technologies that can help reduce the dependence of North Dakotans on fossil fuel-based heating and cooling systems. The continental climate of North Dakota has hot summers and cold winters that drive high energy demands with an average temperature of 41.5 °F annually. Our review of energy demand in North Dakota shows that 45% of electricity demand for heating and cooling is met by natural gas, mainly in commercial and apartment buildings. Another 16% is met using propane fuel, the preferred option in rural communities' townships with more single-family homes. The remaining demand is met with electric heating from coal-fired power plants. This paper uses a system dynamics modeling approach to understand how the complexities and interconnectivity of different variables influence energy demand within the North Dakota Energy mix, and then optimize the system to see how Ground Source Heat Pumps (GSHPs) can be used for heating and cooling. The result from our model shows that power demands for space heating and cooling in North Dakota could be met with GSHPs, which also help reduce GHG emissions and bring about substantial cost savings in the range of $1200 to $1700 annually for households.

1. INTRODUCTION

North Dakota's 700,000 persons distributed across 374,741 buildings need space heating due to the very low temperatures in the fall and winter seasons. The State's location closer to the North Pole allows for temperatures lower than -17.8^{0}C on an average of 40 to 70 days in the year Weather Atlas (2020).

Space heating in the State is primarily powered by coal, natural gas, electricity, and propane. The latter, propane being the preferred option for single-detached family homes, while natural gas and coal serve apartment complexes and districts such as universities. A small percentage of the population in sparsely occupied farms and remote buildings make do with wood and fuel oil for space heating EERC (2020).

The drivers for these choices are rooted partly in the history of the State, the nature of its natural resources, supporting infrastructure, and partly government policy. The State has significantly large coal and natural gas reserves to the tune of about 351 billion tons EIA (2020) and 22 trillion cubic feet EIA (2019), respectively, which are arguably more than enough to meet the State's energy demand for the foreseeable future.

Government policy in the State has fully encouraged utilizing state resources to produce energy for the local market and supply it to the rest of the country. This suggests that these choices are not likely to change significantly except for major paradigm shifts in the coming years. Conversely, there is growing acceptance continent-wide, and beyond that, burning fossil fuels accumulate greenhouse gases in the atmosphere, adversely affecting global climate patterns.

Therefore, there is a need for boldness in deploying alternatively resourced technologies for meeting end-use demand in the State of North Dakota, which has the second-highest emission per capita at 72 metric tons Trans (2015) and had an estimated total emission of 90 million metric tons Friedrich (2017) as of 2014.

Although notably, the State has experienced steady growth in the penetration of carbon-neutral wind power, which currently accounts for more than 27% of locally-sourced electricity, our work with this report attempts to investigate the emission reduction prospects of another abundant renewable resource in the State – ground source heat.

In our analyses, we attempt to reconstruct the carbon emissions trend in the current space heating market using public information and then introduce ground source heat pumps as a replacement in propane heated buildings to examine the dynamics in the space heating market as a system and the broad effects of its application on the overall carbon emissions stock. The study further establishes the marginal cost baseline for these ground source heat pumps in buildings in the State to facilitate comparison with those other resourced options – propane, electricity, coal, and natural gas.

The succeeding sections of this paper in sequential order review the current space heating market in-state; explain ground source heat pump technologies, including potential installation configurations; detail our hypothesis, assumptions, and model built using the Vensim software; and finally, use an arbitrarily chosen set of deployment scenarios to illustrate the tremendous carbon and cost-saving potential of more ground source heat pumps use in the State of North Dakota.

2. LITERATURE REVIEW

2.1 Energy Supply and Dependency in North Dakota

North Dakota is the nation's second-largest energy producer after Texas, with opportunities in oil, gas, coal, and renewable energy production. North Dakota is a forward-thinking producer that serves as a model for developing creative, long-term strategies to meet USA's rising energy demand.

In developing its diverse energy market, the State aims for an “all of the above” strategy, thus addressing the need for energy protection in an environmentally friendly manner. North Dakota provides a comprehensive package of incentives to promote development in all energy sectors while developing a broad-based energy policy that maximizes the State's resources.

Some of North Dakota's energy facts are outlined below:

1. North Dakota ranks 18th in worldwide oil production.
2. Williston Basin crude oil export capacity included nearly 1.4 million barrels transported by pipeline per day and 1.3 million barrels by rail per day, totaling nearly 2.7 million barrels per day.
3. Forty million megawatt-hours of electricity generated.
4. North Dakota has the largest known lignite deposit in the world.
5. 33 North Dakota facilities process natural gas and have a capacity of over four million cubic feet per day.

North Dakota has a continental climate characterized by large temperature variations, irregular precipitation, abundant sunshine, low humidity, and nearly continuous wind. North Dakota has many rivers flowing through its slopes and has harnessed hydropower from these resources. Winds move unobstructed across the State, creating a renewable resource that generates an increasing amount of the state electricity. North Dakota-rich soils produce many crops, including corn for ethanol production and abundant sunshine provides the energy for North Dakota's small but growing solar energy generation.

North Dakota has a smaller population compared to the other 49 states; however, it uses a significant amount of energy due to its cold climate. As shown in figure 1, most of the energy needed is for space heating EIA (2020). However, North Dakota's energy consumption per capita and the amount of energy needed to produce each dollar of the State's gross domestic product (GDP) rank among the top five States, mainly because of its energy-intensive industrial sector. The industrial sector accounts for more than half of end-use energy consumption in the State. The energy-intensive oil and natural gas extraction industries, mining that includes coal production, and agriculture are major contributors to the State's economy. The transportation sector accounts for about one-fifth of end-use energy consumption in the State. The residential sector accounts for about one-seventh, and the commercial sector makes up about one-tenth of energy use.

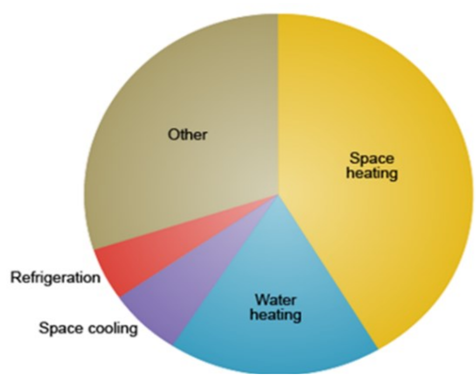

Figure 1: The pie chart shows the energy consumption in North Dakota (Source: EIA, 2020)

North Dakota's total energy production is almost six times greater than its energy consumption. Over the past decade, a surge in energy production has come from developing the State's oil reserves. About three-fifths of North Dakota's total primary energy production is in the form of crude oil. Natural gas accounts for almost one-fourth of the State's energy production, and coal makes up about one-tenth. Renewable energy, including biofuels, accounts for the remainder of the State's energy output. Figure 2 shows how North Dakota consumes energy EIA (2020); even though the oil reserves are the largest energy production, the State uses coal as its highest consumed product for energy.

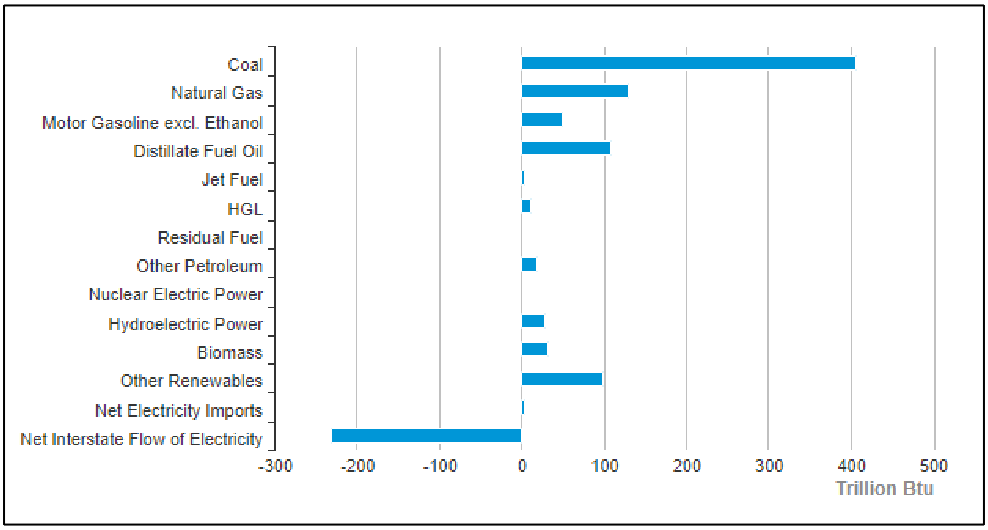

Figure 2: North Dakota Energy Consumption 2018 (Source: EIA, 2020)

2.2 Effects of Renewable Energy Resources on North Dakotan Policies

North Dakota is one of the top ten ethanol-producing states, producing around 3% of the nation's total. The State's five ethanol plants use corn as feedstock and have a capacity of approximately 500 million gallons per year. The State also has one biodiesel production plant with an annual capacity of 85 million gallons that uses canola oil as its primary feedstock.

North Dakota introduced a voluntary target in March 2007 to procure 10% of the State's electricity retail sales from renewable sources by 2015 and recover and use energy that would otherwise be lost to produce electricity. The goal, which applied to all retail electricity suppliers, was exceeded. In 2019, renewable energy sources provided approximately 34% of the electricity produced in North Dakota. North Dakota was one of the first states to introduce net metering in 1991, which allows residents and businesses with small renewable energy systems and combined heat and power systems with a capacity of up to 100 kilowatts to sell surplus electricity to investor-owned utilities.

Renewable energy production in North Dakota is represented in layers inspired by Aslani (2013). The layers are strategic, policy, and realistic, covering a range of political, technical, managerial, social, and cultural issues, as seen in Figure 3. Table 1 summarizes each layer and the schemes associated with it.

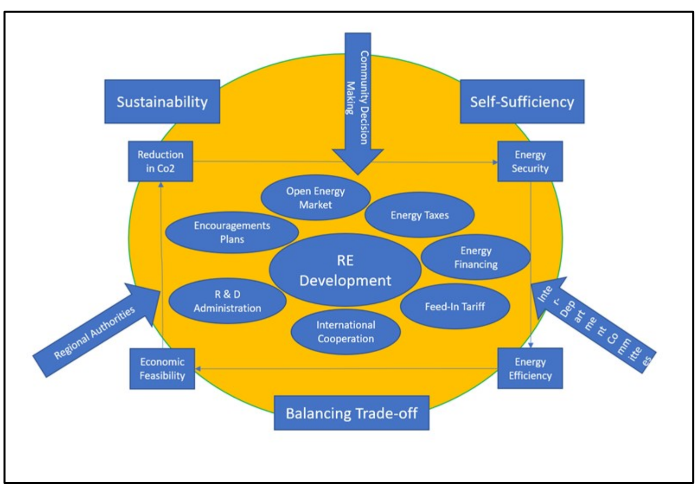

Figure 3: Layers of Renewable Energy Development in North Dakota

Table 1: Different Layers of Diffusion of RE in North Dakota

Layer	Description	Scheme	Aim
Dimensions	To demonstrate the goals of RE utilization diffusion	Self-sufficiency/Balancing trade-off/sustainability	To reduce the use of fossil fuels and increase reliance on indigenous resources. To contribute to the economic and technological development of the regions. To lessen pollution and its adverse effects on the climate.
Characters	Identifying key stakeholders that influence public policy and decision-making processes.	Participatory Decision Making/Interdepartmental Committees/Authority of Regional Offices	Obtaining the backing of community organizations and residents To have a regional decision-making authority that is systematic and coordinated. To strengthen the position of regionals (municipalities) in decision-making.
Objectives	To demonstrate various perspectives on RE diffusion	Energy Security/Energy Efficiency/Economic feasibility/CO_2 reduction	Reduce reliance on external resources (energy imports). To deliver a certain number of services while using fewer resources. - Technical effectiveness - Allocative effectiveness To reduce CO_2 emissions from fossil fuel combinations caused by human activity.
Key Schemes	To define various policies or regulations pertaining to the spread of RER utilization	Energy Financing/Energy Taxes/Open Energy Market/Encouragement Packages/Administration of Research/International Cooperation/Feed-in-tariff	To direct government spending on renewable energy technology and energy-efficiency solutions. To limit the increase in energy consumption. To make use of renewable energy more sustainable. To increase citizens' knowledge and understanding of RERs. To control research and development assets. To disseminate create.

2.3. Geothermal Energy Development Opportunities in North Dakota

Western North Dakota is well-suited for deep enhanced geothermal systems. In western North Dakota, oil wells have been drilled deep into the earth. Scientists and researchers are using data from deep oil wells to aid in the expansion of geothermal energy production in the State. Developers are working on ways to produce Enhanced Geothermal Systems (EGS) by generating electricity from oil field waters.

Local North Dakota residents could save money on their utility bills by using geothermal energy. Geothermal ground source heat pumps can both heat and cool a house. Most new schools and other public buildings incorporate geothermal heat pumps into their heating systems.

Hoffman (2002) researched estimated annual heating costs for different energy sources in North Dakota. Table 2 shows the annual heating costs in terms of fuels for residents in North Dakota. The use of energy corresponds to the price in Kwh that covers over a use time, and this includes costs of generating power, operation and maintenance, and the distribution and transmission of the energy. Fuel Cost Charge is a kWh charge for the cost of coal, uranium, and natural gas and purchased power used to provide electricity. These actual costs vary by month and sometimes depend on the fuel source. A relative cost comparison chart showing heating values for fuels and biomass can help decide what type of fuel to use.

The table is arranged so the equivalent prices of each fuel, the cost to deliver a given amount of heat based upon a specific heating efficiency. As energy costs rise, more efficient ways to provide heat become more attractive even though they may be more expensive to install. Heat pumps that extract heat from the air have been used for several years. Extracting heat from the earth with heat pumps is a newer and more efficient method. The efficiency of air-source heat pumps varies widely. As the outside air temperature goes down, the efficiency of the heat pump decreases to less than 100 percent near 0 degrees F. Over the entire heating season, the air source heat pump will usually show a significant cost advantage over electric resistance heating, and during the summer it will convert to an air conditioner.

It is estimated that ground source heat pumps may show over 300% advantage in efficiency over electric and other energy sources for heating. Generating heat requires another source of energy generation. These include feed grains, alcohols, vegetable oil, gasoline, and diesel fuel. A comparison of heating costs needs to include capital and labor costs if a homeowner wants to estimate annual home heating costs, the following chart may give some assistance. A well-insulated, 1,500 square foot home in North Dakota will require about 80 million BTUs of heat during a year. A 3,000 square foot well-insulated home will require about two times as much energy. An older, poorly insulated 1,500 square foot home may require up to five times as much heat compared to a well-insulated home. The table shows estimates of prices for various energy sources for space heating.

Table 2: Estimated Annual Heating Cost for Selected Fuels in North Dakota (Source: Hoffman, 2002)

Fuel Type	Heating efficiency	Fuel cost	Energy use per year for a 1500 square foot home	The energy cost for a well-insulated 1500 square foot home
Elec. Res….3413 Btu/kWh	100%	$0.3/kwh	23440 kWh	$703.20
Propane...92,000 Btu/gal	92%	$0.90/gal	945 gal	$850.50
Natural Gas….100,000 Btu/therm	92%	$0.70/therm	870 therms	$609.00
Fuel Oil….140,000 Btu/gal	70%	$1.00/gal	816 gal	$816.00
Coal…..6600 Btu/lb	65%	$60.00/ton	9.32 tons	$559.20
Vegetable Oil….130,000 Btu/gal	70%	$1.50/gal	879 gal	$1318.50
Shelled Corn…..8,500 Btu/lb	65%	$2.00/btu	258 bushels	$516.00
Wheat Straw….7,500 Btu/lb	65%	$30.00/ton	8.20 tons	$246.00
Wheat (Grain)….8,700 Btu/lb	65%	$3.00 btu	236 bushels	$708.00

2.4. Overview of the System Dynamics Approach

System thinking is the method of realizing how objects interact as parts of a larger whole. It is a problem-solving technique that views ‘‘problems" as components of a larger structure rather than responding to individual parts Ackoff (2017). System dynamics is a tool focused on system thinking that explains and models the behavior and activities of complex systems over time Radzicki (2008). System dynamics examines how the system responds and behaves to patterns using control variables such as feedback loops and time delays. It can help policymakers and decision-makers when a system's behaviors are complex and diverse.

Figure 4 depicts the technique of system dynamics and the stages involved. As all stages attempt to provide input for system understanding, the primary focus of system dynamics is ''system understanding" Sushil (1993).

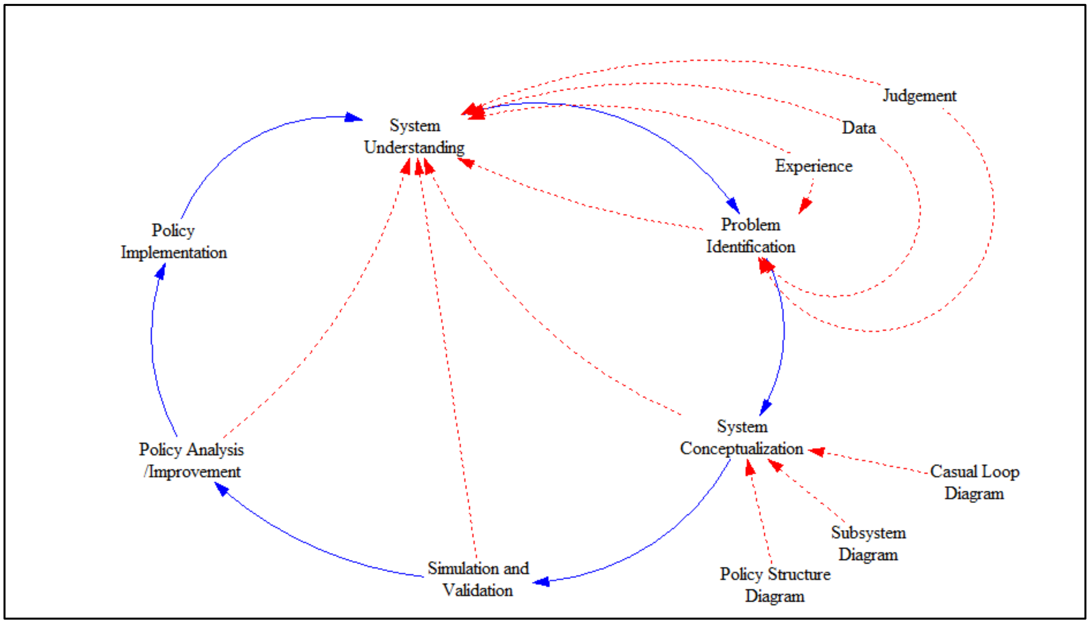

Figure 4: System Dynamics Methodology

The first stage of system dynamics research is problem recognition and description. Determining the status of the problem and defining priorities are two problems that should be clearly defined at this stage. This stage materials include data and facts, experiences, and judgments.

The second stage is system conceptualization, which involves defining boundaries, identifying causal relationships, and developing a policy structure (qualitative analysis). The system conceptualization introduces and analyzes three separate diagrams: a subsystem diagram, a policy structure diagram, and a causal loop diagram. Diagrams assist researchers and experts in communicating a summary of the research topic, highlighting what is included and omitted from the report. A causal loop diagram is a causal chart that depicts how interconnected variables influence one another. The diagram comprises nodes (variables) and their connections (arrows). The relationship between two variables can be positive (+) or negative (-). If one variable has a delayed effect on another, it is also depicted in the diagram. This diagram, along with the stock-flow diagram (system dynamics model), is critical in system dynamics modeling Morecroft (1982). Stocks (levels), flows (rates), connectors, and auxiliaries are all shown in a stock-flow diagram.

The third stage of system dynamics methodology is the discovery of mathematical equations and simulation. The analyst must also evaluate the model's reliability and validity during this phase. The next stage is policy/decision review, which analyzes the system simulation results and plans acceptable policies. Finally, a policy/decision can be put into action in the real world.

2.5 Review of the System Dynamics Research of Energy Policies

System dynamics have been used for more than 30 years to conceptualize energy processes. Some researchers have used system dynamics to assess the physical structure of energy systems and create various scenarios Connolly (2010). Researchers also assess energy demand to determine the relationship between economic variables such as GDP and energy indicators to forecast energy market and price scenarios Naill (1977). The second group of researchers used system dynamics models to evaluate the environmental impacts of CO_2 emissions in energy systems Jin (2009). Researchers also created several dynamic platforms to help policymakers improve urban sustainability and calculate the cost of CO_2 emissions. The third category of research of system dynamics and system thinking approach is energy policy in terms of energy supply protection Shin (2013). These models assist experts in identifying main energy components to introduce in a specific country within the context of indicators or policies.

A few works even concentrate on the complex modeling of Renewable Energy (RE) policies. These studies look at the substitution of Renewable Energy Resources (RERs) with oil and nonrenewable fuels. Figure 5 depicts an example of a causal loop diagram used to depict the fatigue trends of world fossil fuels and their potential replacement by RERs.

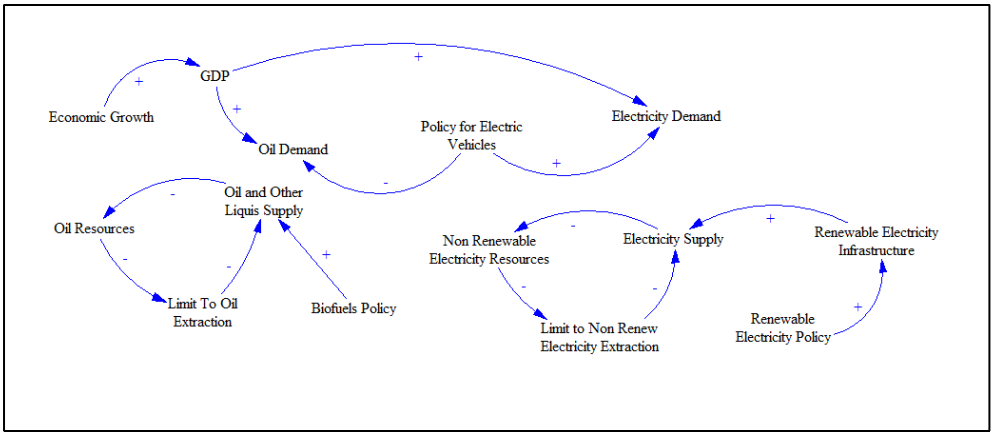

Figure 5: Example of Causal Loop Diagram Defined in Research to Assess the RE Resources

As previously stated, despite various system dynamics work on energy science, the number of studies conducted on the effects of RE on dependence and energy protection is minimal, and to quantify the effects on renewable energy growth and its relationship with government policy is a needed step in building a proper model. The current study aims to fill a portion of this research gap to assist experts and policymakers in revising their RE promotion strategies in order to achieve a desirable level of dependence and energy supply security.

3. SUITABILITY OF GROUND SOURCE HEAT PUMPS (GSHP) FOR NORTH DAKOTA

North Dakota is suitable for space heating using ground source heat pumps. Heat flow maps of the State (Figure 6) show sufficient thermal energy in most parts to operate low-temperature applications such as GSHP, albeit the temperatures below the approximately 75-inch frost line are said to be about 36^0 F (10^0 C) for significant periods of the year Blackwell et al. (2011). Compared to atmospheric temperatures in the winter season, which fall below 5^0 F(15^0 C) for most parts, the more than 30^0 F temperature differential makes it perfect from a resource standpoint to consider GSHPs in the State.

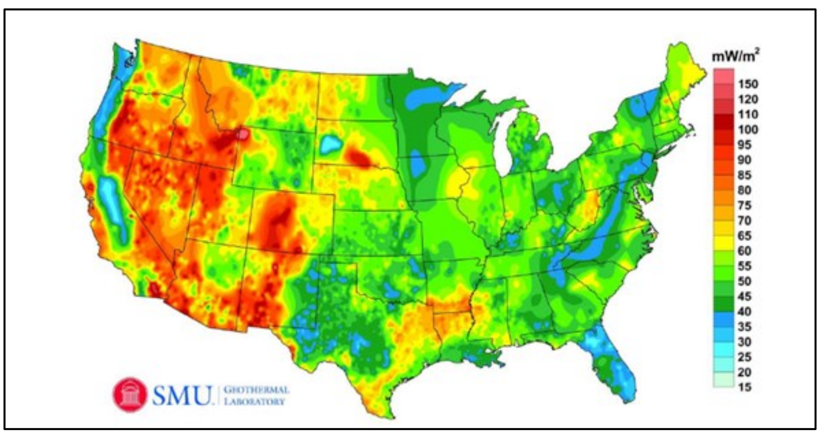

Figure 6: Heat Flow Map of the Continental U.S. (Source: Blackwell et al., 2011).

The 10 – 100 m subsurface region in most of the State is fairly accessible with moderate drilling costs reported to be in the range of \$26-\$64 per foot HomeGuide (2020). These costs of drilling would optimize installation costs of GSHP which must be drilled vertically instead of horizontally due to space limitations. Besides, several friendly national incentive programs could be relied upon to alleviate some of the upfront cost in areas Kevin (2017), and there is growing experience with installations of GSHP throughout the State. As experience grows in the construction of GSHP, the cost for installation will gradually decline, which helps lower the overall cost for the end-user.

Regarding experience in the State, figures 7 and 8 show locations and several buildings where a recent analysis was conducted by the North Dakota State University Yu (2017). These buildings have become a great resource in designing the systems dynamics model to examine GSHP's impact in the State. Most of the GSHP reviewed were on commercial-style applications, but GSHP designs are relatively the same for commercial and residential except for the system sizes. Figure 9 shows in one particular case the comparison between the outputs for ground source heat pumps, air-source heat pumps, and distributed ground source heat pumps at the Minot Airforce Base (AFB) Nelson (2006). The data from Minot AFB is an excellent example of how GSHP is suitable for the State and how GSHPs positively impact the economy by cutting energy costs for space heating and cooling. In this case study, it can be observed that for eleven months- the GSHP was working more efficiently through one year. Moreover, in this case, energy savings can be seen in the summer months when cooling is needed instead of heating.

Figure 7: Target Building Allocation by Building Type (Source: Yu, 2017)

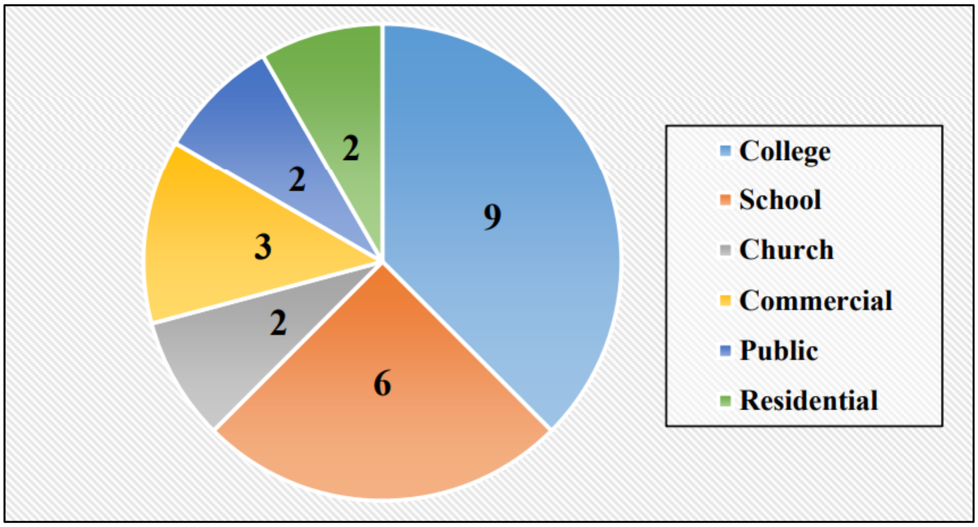

Figure 8: The Final List of the Target Buildings (Source: Yu, 2017)

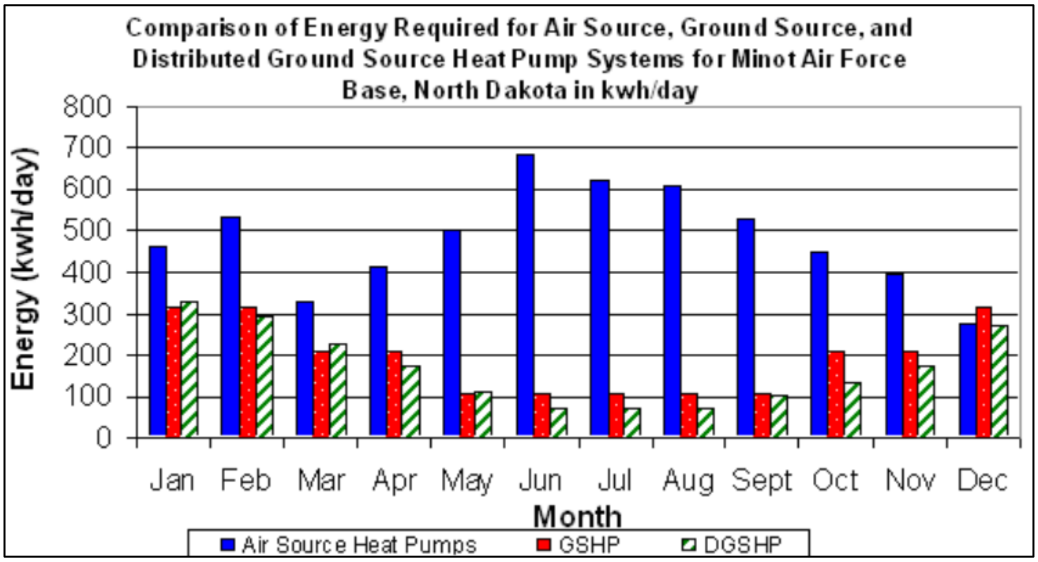

Figure 9: Results of Analysis for Minot Air Force Base, North Dakota (Source: Nelson, 2006)

In addition, the annual cost saving is enormous. An average homeowner would have completely recovered their investment within about 15 years if current natural gas prices remain constant, less if they increase, as they are likely to do. With a payback period of 15 years, building a geothermal heating and cooling system in a home will not be worthwhile unless the homeowner plans to stay put for the duration of the GSHP lifetime. The ND Department of Commerce provided the data in table 3 in 2006. Our research continues the same approach in investigating whether using the GSHPs would benefit North Dakotans.

Table 3: General comparison of geothermal against conventional heating costs for a 3,000-square-foot residence in North Dakota. (Source: Manz, 2007)

	Geothermal	Conventional
Initial investment	$10,000	$4,000
Annual heating cost	$26 (@ 3.5 per kWh)[a]	$640 (@ $8 per dkt[b]) $960 (@ $12 per dkt[c])
Annual savings	$380 (@ $8 per dkt[b]) $700 (@ $12 per dkt[c])	
Payback	15.8 years (@ $8 per dkt[b]) 8.6 years (@ $12 per dkt[c])	

4. MODELING APPROACH

This model (Figure 10) represents the carbon emissions produced from space heating over one year in North Dakota. The model accounts for seven months taking temperature inputs on an hourly basis from 2019, excluding the summer months due to the focus on just the space heating periods, not the cooling periods. Figure 11 shows the model portion focusing on the temperature control and the average building sizes in North Dakota. This portion of the model helps in the simulated average building and house sizes in North Dakota to see how much energy is needed to heat the house for the given hourly temperature. Integrating these two sections would help us better analyze the effect of GSHP on the overall emissions in North Dakota.

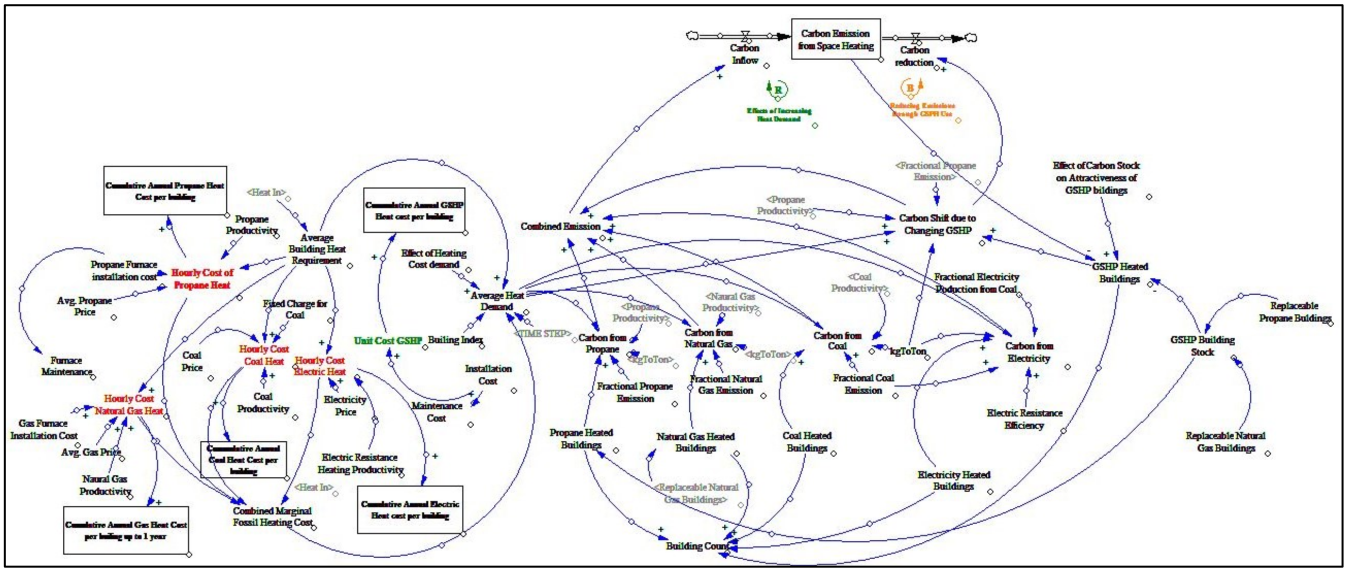

Figure 10: Carbon Emissions from Space Heating Model as well as Annual Costs of Heating in North Dakota for Fall, Winter, and Spring 2019

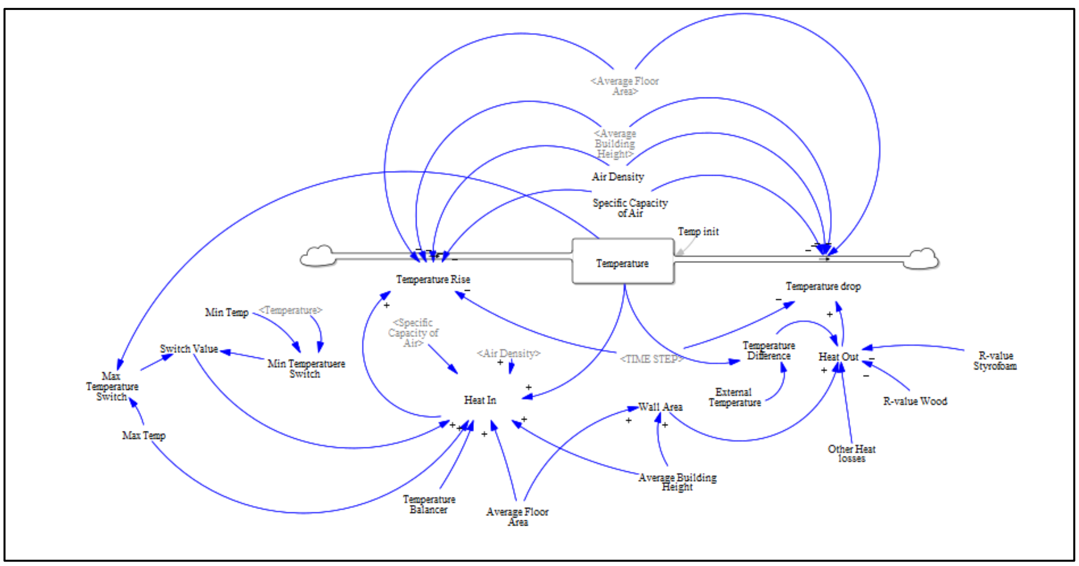

Figure 11: Temperature Model and BTUs Required to Heat the Average Home in North Dakota for Fall, Winter, and Spring 2019

A systems dynamics model is referred to as a good model if its actions closely resemble the system in the real world while not violating the fundamental rules of system thought. Building a model is influenced by individual subjectivity or organizations, so we must strive for excellence in continuously searching for relevant potential and knowledge Winardi (1989). There are many benefits of using modeling in system approach research Barlas (1996), including:

1. Allow us to conduct a wide range of research without regard to research areas.

2. Allow us to play with the device without causing it to fail.

3. It is possible to determine the objectivity of maintenance device operation.

4. Can be used to forecast future activity and condition the system.

This model was created to build a tool for scholarly discussion and analysis of the effect of using renewable technologies, focused on GSHPs in this case, on North Dakotas energy requirements and overall carbon emissions. The model uses different variables which can be expanded to make it more efficient and realistic. The current model has become an effective tool to analyze the desired outcomes allowing the users to compare the impact of different space heating sources on carbon emissions and cost analysis on energy costs in the

State. This model uses the 2019 datasets, and the model results will be discussed in the next section. Using system dynamics models help expand the current model by including data from previous years and adding more variables that would affect space heating in North Dakota. In addition, updating the model with further research would help us forecast future activities and conditions in the State and show how GSHPs or other renewable energy sources would impact the State.

5. KEY FINDINGS

Electric and natural gas-based heating in North Dakota contributes more than 80% of the carbon emissions from space heating in the State. Emissions from electric heat are generally high since the generation mix in the State is approximately 66% coal-based. This suggests that the highest reductions in emissions from space heating may be achieved by revising the electricity mix in the State.

However, we found that a significant reduction could be made through programs that replace propane and natural gas furnaces in buildings with GSHP. Specifically, replacing all propane furnaces could cut space heating emissions by 10% (260,000 metric tonnes annually). Then, pairing that with natural gas furnace replacements in half the building stock with this form of heating could increase the reductions to more than 34% (880,000 metric tonnes) from figure 12.

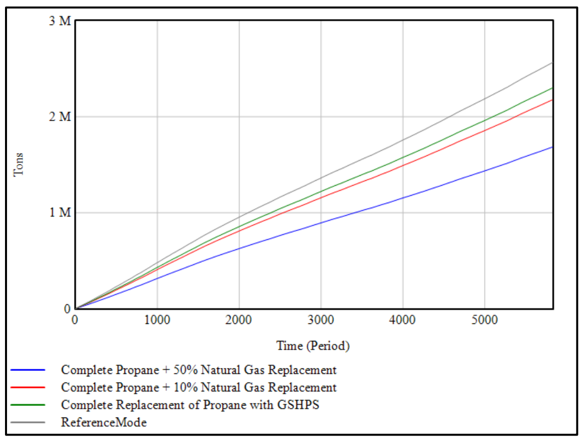

Figure 12: Emissions Saving from Propane to GSHP in North Dakota Over the Analysis Period of an Hourly Basis (~7 months of the year)

The average North Dakota household would save approximately $1219 annually by replacing their propane furnaces with GSHPs, $1044 annually by replacing electric heaters, and approximately $756 annually by replacing natural gas furnaces as shown in figure 13.

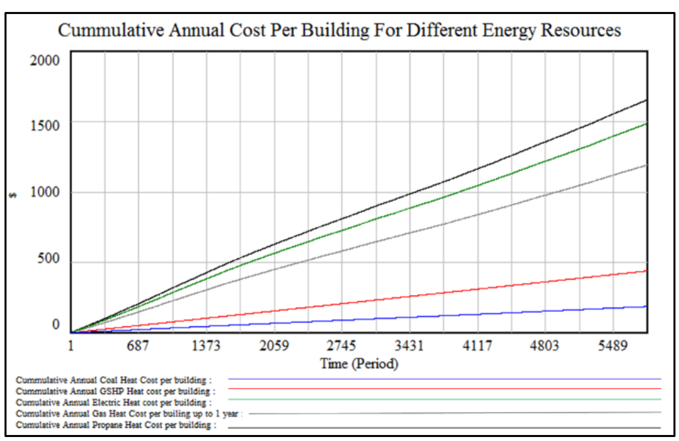

Figure 13: Annual Costs of Different Sources of Space Heating in North Dakota

The GSHPs have longer operating life cycles that extend far beyond the 25 years used for the cost simulations in this model. When accounted for, this operational longevity further reduces the annualized cost, making this option the perfect choice for the long run.

6. CONCLUSION

This study concludes that:

1. GSHP is one of the most effective ways to heat and cool buildings in North Dakota. Over time homeowners will see cost savings more significant than traditional air source heat pumps. The State of North Dakota will benefit from GSHP as less power will be used for space heating, creating a less energy-dependent state and greater energy security overall.

2. Replacing traditional air source heat pumps and propane-powered heaters with GSHPs can reduce carbon emissions produced by space heating up to 34%. The reduction in traditional greenhouse gasses would help the State build a healthier place, due to the cleaner air, for the current and future citizens of North Dakota.

3. The effects of using GSHPs and other renewable energy methods are complex systems that require system modeling to project the effect of the RE methods over time. Due to the lack of current data on the effect of government policy on renewable energy, the model for North Dakota is not complete. However, a direct correlation to government policy affecting the use of renewable energy technology is established based on data seen from other states in the United States. Further studies are recommended on continuing quantitative analysis on government policy's effect on renewable energy growth in the State of North Dakota.

The model in this study and its simplified supporting assumptions enable us to easily articulate the business case for ground source heat pumps in the State. More importantly, it was supported from the analyses that the need for initial support to cover the upfront cost of installing GSHP systems should be considered, and government policy can take a direct role in assisting in expanding the installation and use of GSHP systems.

As a direct effort for one particular technology that goes against North Dakota's stance of improving all low emissions technology equally (House Bill No. 1452, 1), such incentives would need to be modeled and discussed widely with all potential stakeholders before government policy is put into action. For example, any intentional displacement of the market for propane in the State could prompt action from unionized institutions such as the North Dakota Propane Gas Association. Therefore, such policy interventions by the government would need to be judged on merits far beyond emissions reduction and cost. It is hoped that the knowledge brought forward by this work could help spark more conversations among relevant stakeholders in the State about the prospects for decarbonizing the space heating market in the State with ground source heat pumps.

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