UNIVERSITY OF CALGARY

Increasing efficiency of the University of Calgary's cogeneration plant by capturing surplus heat

by

Gary Boguslavsky Sayun

A RESEARCH PROJECT SUBMITTED
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

GRADUATE PROGRAM IN SUSTAINABLE ENERGY DEVELOPMENT

CALGARY, ALBERTA

AUGUST, 2022

Abstract

This study explores the feasibility of installing a new electricity generation technology that utilizes the surplus heat that exists today at the University of Calgary's cogeneration power plant during the warmer months periods. Using historical data from the cogeneration power plant, heating needs from campus buildings and 30-year average weather data, the available resource is calculated allowing to choose a technology that is capable of generating electricity taking advantage of that heat energy. Organic Rankine Cycle electricity generation was chosen for its versatility and ability to generate electricity from low to medium heat sources. Considering the resource available, the costs of purchase and installation and the capacity four IT 250 ORC generator have, a payback period of 14 years expected as well as a Scope 2 emissions reduction of 1,230 tonnes of CO2 per year allowing the University to move forward with its climate action plan that seeks to propel the University as a leading educational institution in sustainability, innovation, and climate action with the final goal of being net-zero by 2050.

Acknowledgements

I would like to thank Earl my industry supervisor for taking its time to explain to me the workings of the cogeneration power plant and sit down with me and being patient while we thought of different ways on how to come up with the data and information I needed for the project.

Dr. Li, my academic supervisor, for helping me to think differently and see the project from many different perspectives to be able to deliver a quality project.

A mi mamá, quien siempre me ha empujado a seguir mejorando y luchar por lo que quiero incluso si significa hacer sacrificios siempre buscando seguir creciendo y ser una mejor persona.

A mi esposa, Karen, gracias por aceptar hacer este viaje a otro país y dejar todo lo que conocemos atrás para buscar esta vida nueva en Canadá, gracias por todo el apoyo que más has dado en los días buenos y en los días malos siempre ayudándome a ver las cosas buenas que tengo.

A mi abuela Elena z"l, quien siempre se preocupó por mi educación. Siempre creyó en mí y me ayudó a salir adelante siendo mi ejemplo de fortaleza y perseverancia. Si no fuera por ti abuela, no estaría aquí.

Table of Contents

List of Tables

List of Figures

List of Acronyms

CAD	Canadian dollars
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
GHG	Green House Gasses
kWh	Kilowatt-hour
MWh	Megawatt-hour
ORC	Organic Rankine Cycle
SDG	Sustainable Development Goal
TIER	Technology Innovation and Emissions Reduction Regulation

Chapter 1: Introduction

As part of the effort to become a sustainability leader, the University of Calgary developed and installed a 12-Megawatt natural gas combined heat and power cogeneration power plant in 2012. This was done with the objective of reducing GHG emissions for day-to-day operations on the campus as well as becoming a learning lab for deep decarbonization following the University's Climate Action Plan (University of Calgary, 2019). Currently, the power plant supplies most of the University's electricity demand as well as the heating needed across the campus buildings allowing the University to reduce its GHG emissions by 40%. This is due to the difference in CO_2 emitted when burning coal compared to burning natural gas, as natural gas emits 43% less CO_2. Historically, a high percentage of the electricity produced in Alberta came from coal-burning power plants. For example, in 2010, when the University's cogeneration power plant was under construction, 58% of the electricity on the grid came from coal-fired power plants (Government of Alberta, 2011).

In 2015 the government of Alberta announced the elimination of emissions from coal power generation, setting the goal of eliminating them by 2030. But as of today, in 2022, just three coal-fired power plants remain operational, and they are expected to shut down or switch to natural gas by the end of 2023, seven years ahead of the deadline (Thibault et al., 2021). This means that the GHG emission reduction that the University's cogeneration power plant allowed in 2012 is decreasing with each coal power plant that ceases operations.

Today, the University’s cogeneration power plant produces the heat needed throughout campus, allowing students and faculty members to continue their regular schedules in a comfortable atmosphere during the cold Canadian winters. During warmer months, when heat is not needed, the heat energy produced by the combustion in the turbine is simply diverted from the system and vented into the exterior as waste (surplus) heat.

The objective of this project is finding ***what the optimal techno-economical solution that the University can implement in the cogeneration power plant to increase its efficiency by using the wasted surplus heat that exists today is?*** By answering this question, the power plant would be able to keep operating without having a negative impact on the GHG emissions when compared to the future Alberta grid that forecasts that 30% of the electricity generation will be through renewable means by 2030 and no coal-fired generation by 2023 (Alberta Electric System Operator, 2017).

Some studies were made to analyze the University's power plant's performance in the past. Still, the only conclusion was that some optimizations could be done and did not go into further detail.

1.1 Objective

My work will focus on the best solution to recover and use the surplus heat (waste heat in Figure 1) that exists today. First, quantifying the amount of heat (resource) available through data analysis of yearly, daily, and hourly heating demands and heating production. Once the available resource is known, existing technology will be chosen that best utilizes it helping to reduce the carbon intensity of the University's daily operations. Finally, an economic and emission analysis will be performed for the selected technology giving back the payback period and GHG emission reduction (Scope 2 emission reduction as the cogeneration power plant turbine will operate without any modification but a reduction of purchases electricity is expected).

Scope 1 emissions are those produced directly by sources that are managed or owned by an organization, such as those that result from burning fuel in boilers, furnaces, and cars. The emissions caused by the purchase of energy or heat are known as indirect GHG emissions or Scope 2 emissions. Even though these emissions are produced in the facility where they are generated, they are also considered in a company's GHG inventory (United States Environmental Protection Agency, 2021).

1.2 Multidisciplinary aspects

As a techno-economic analysis of an operating power plant that provides electricity and heating to the University, this project encompasses the following three main areas of study:

1.2.1 Energy

As the project's first objective, the calculation of the heat energy available as waste centers in the energy aspect of a cogeneration power plant. To achieve this objective, I need to fully understand the working of the actual cogeneration power plant at the University and how the district heating system functions. Added to this, it is also essential to understand the energy needs in the form of heating all the buildings in the University have, as that is the determining factor in the amount of available heat energy.

1.2.2 Environment

The environmental aspect is met in two different ways. The first is the need to perform environmental analysis in the form of weather and ambient temperature studies to determine the campus buildings' heating needs. To be able to do this study, considering an average temperature and not a specific year is critical to eliminate any error due to an extreme weather event or simply abnormal weather during the year studied.

The second way the environmental aspect is met is through the CO_2e emission reductions due to the optimizations achieved by the project. This is vital for the project as it is born from the commitment the University has to become a leader in sustainability.

1.2.3 Economy

An economic analysis is necessary to evaluate the feasibility of the proposal. The proposed solution would only be possible if the business case is compatible with the University's financial capabilities. Therefore, it is understandable that this is not an investment opportunity for external investors. However, it still needs to be economically viable for the University during a set period of time.

1.3 Sustainable Development Goals

In 2015, all United Nations member states adopted the 2030 Agenda for Sustainable Development which provides a shared blueprint for peace and prosperity for people and the planet for that moment and into the future (United Nations, 2015). At its center are the Sustainable Development Goals, which serve as the guideline to follow to achieve a sustainable future that would allow peaceful coexistence between all the people in the world.

This project focuses on 3 of the 17 SDGs (Sustainable Development Goals).

Goal 7, affordable and clean energy. Energy is being wasted during some parts of the year; my research will find a suitable way of using it, increasing the power plant's efficiency.

Goal 11, sustainable cities, and communities. An increase in efficiency of the power plant will translate to an indirect reduction of GHG emissions, making the University a better neighbour and a better contributor to the city.

Goal 13, climate action. Every effort to improve power plant efficiency and reduce GHG emissions contributes to the fight against climate change.

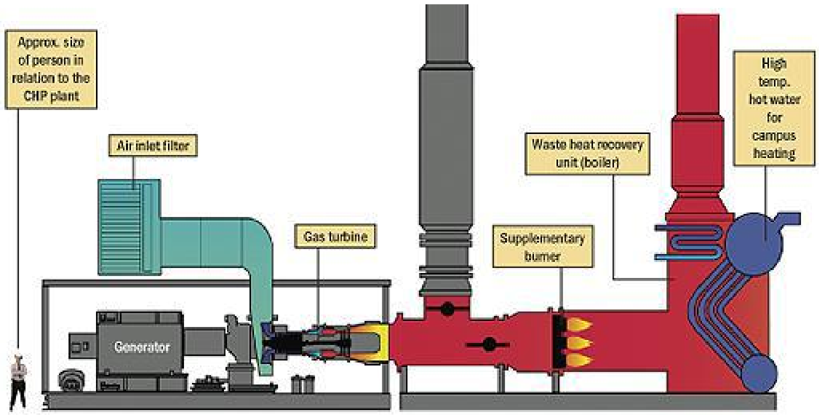
The SDGs serve as a guideline for all of us to achieve a sustainable future. We are still on time to prevent significant consequences that would affect our way of life in many ways.

Chapter 2: Conceptual Framework

2.1 Cogeneration power plants

Figure 1

Simplified cogeneration diagram



Note: From University of Calgary Central Heating & Cooling Plant 2020 TIER Quantification Methodology May 2021

Cogeneration power plants, also known as Combined Heat and Power (CHP), are power plants capable of generating more than one type of energy from a single fuel source. In most cases, as the name combined heat and power implies, these power plants generate electric power and heat (Wilson, 2018). Still, mechanical power to directly operate compressors, pumps and fans is also typical (Bhatia, 2014). In general, single-generation power plants are 50–70% less efficient than cogeneration plants.(Schleup, 2008); this difference in efficiency is achieved by cogeneration power plants utilizing the energy contained in the exhaust gases coming from the heat engines, whereas in regular power plants, that heat is simply wasted. This heat is then transferred to a different working fluid like water and used for heating or cooling, reducing or eliminating altogether the need to burn extra fuel for these purposes (Bhatia, 2014).

Cogeneration power plants first appeared in Europe in the late 18th century. Then, some industrial plants generated their own electricity with steam turbines and used the exhaust gases for industrial processes like heating or drying (Hinrichs, 2004). Nowadays, according to the United States Environmental Protection Agency (2022), cogeneration is used in over 4,700 facilities across the US alone.

2.2 District heating

District heating is the name given to the system responsible for heating a specified urban area (or district) that contains numerous buildings. It comprises a series of underground ducts that distribute thermal energy provided by a central energy plant. Hot water or steam is produced at the plant and then transported through insulated underground pipe networks, eliminating the need for individual boilers at each building (International District Energy Association, 2019).

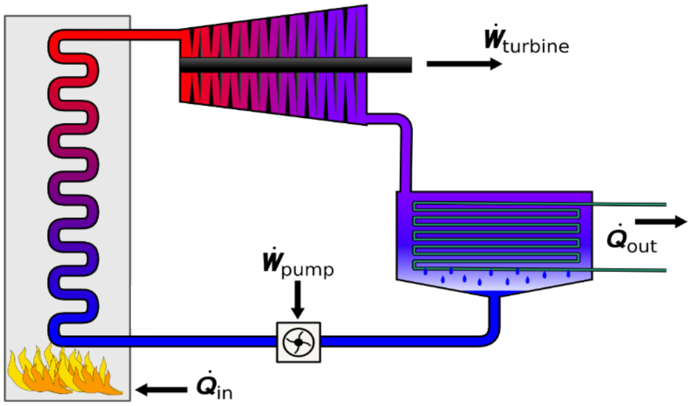
The pairing of a district heating system with a cogeneration power plant increases reliability and efficiency by producing electricity alongside the needed heat, reducing complexity and the number of individual boilers needed and eliminating labour and maintenance costs associated with individual systems (Energy Education, 2020).

2.3 Organic Rankine Cycle (ORC)

The Rankine Cycle, often known as the steam power cycle, is an ideal thermodynamic cycle in which heat released during the burning of fuel in a furnace is transferred to a working fluid (typically water) in a boiler to produce steam. After that, the steam expands in a turbine, spinning its rotor. Work on the shaft is continually produced using the heat energy (mechanical power) powering an electric generator. After the steam expands in the turbine, it condenses into liquid in a condenser. The condensate is then pumped back into the boiler, where the cycle is repeated (Venkateswarlu, 2020).

Figure 2

Diagram of an Ideal Rankine Cycle



Note: By Andrew Ainsworth, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.

The term "organic" in the Organic Rankine cycle refers to the employment of an organic, high molecular mass fluid whose boiling point occurs at a temperature lower than that at which the water-to-steam phase shift occurs (Venkateswarlu, 2020). The organic Rankine cycle allows the production of power from low or medium heat sources ranging from 80° C to around 350° C opening the possibility of using waste heat from industrial processes that would otherwise be wasted (Exergy International Srl, n.d.).

2.4 Alberta's electricity grid coal phase-out

In 2019, 76.1 TWh of electricity were produced in Alberta alone. That accounts for 12% of the total electricity generation in Canada in that year. This places Alberta's grid as the third largest in Canada, with a generation capacity of around 16,330 MW (Canada Energy Regulator, 2022).

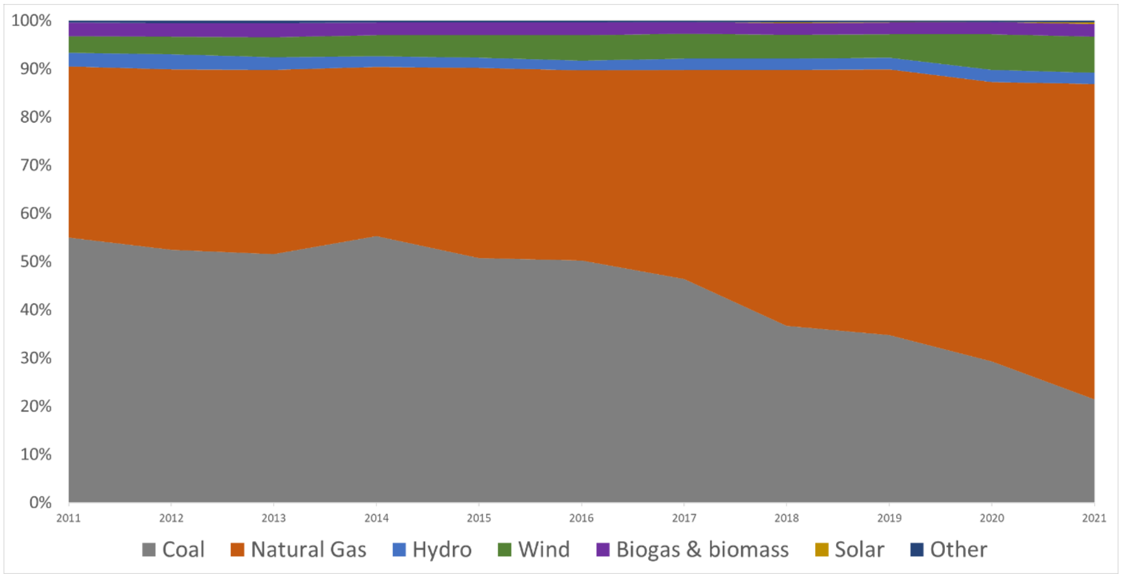
Of the total electricity generated, 89% came from fossil fuels, 54% from natural gas, 36% from coal and only 10% from renewables like wind, hydro, solar and biomass. That makes Alberta's coal generating capacity the biggest in the country, with 5,555 MW (Canada Energy Regulator, 2022).

Because of that, through 2015's climate change legislation, the government announced the complete elimination of any emission from coal electricity generation with the goal set for 2030 (Government of Alberta, 2015). However, most of the power generators in Alberta decided to expedite the phase-out process, and it is expected that no coal electricity generation will be operating by the end of 2023 (Canada Energy Regulator, 2022).

Figure 3 shows the steady decline of coal electricity generation from 2015 onward and how it was mainly substituted by natural gas and some wind.

Figure 3

Alberta electricity generation by fuel type 2011-2021



Note: (Alberta Utilities Commission, 2021)

2.5 University of Calgary's climate action plan

As a research university located in the province with the most profound connection to the energy industry and energy resources, the University of Calgary strives to be one of the leading institutions in sustainability, innovation and climate action (University of Calgary, 2019).

The University's climate action plan is a live document that serves as a short-term and long-term decision-making guide aiming to reduce GHG emissions setting ambitious goals regarding Scope 1 and Scope 2 emissions (University of Calgary, 2019).

Since its introduction in 2010, emissions (Scope 1 and 2 combined) decreased by approximately 30% when compared to the emissions from 2008 despite the more than 180,000 square meters of newly built space and 16% increase in student population in the same period of time (University of Calgary, 2019).

The plan aims to reduce emissions by 97% by 2050 compared to 2008 by switching to green energy sources, decarbonizing the district heating system, innovations in new buildings, retrofits in existing buildings and behavioural awareness.

Chapter 3: Methodology

The methodology of the project was divided into three steps as each step needed to be completed for the next step to start as the result from the previous step served as the input data for the next. First, the data analysis was done with data gathered during 2019 by the energy and utilities team at the University. Even though newer data exists, I used 2019 because it is the latest set of data not affected by the COVID-19 pandemic.

3.1 Calculating the resource available (waste heat).

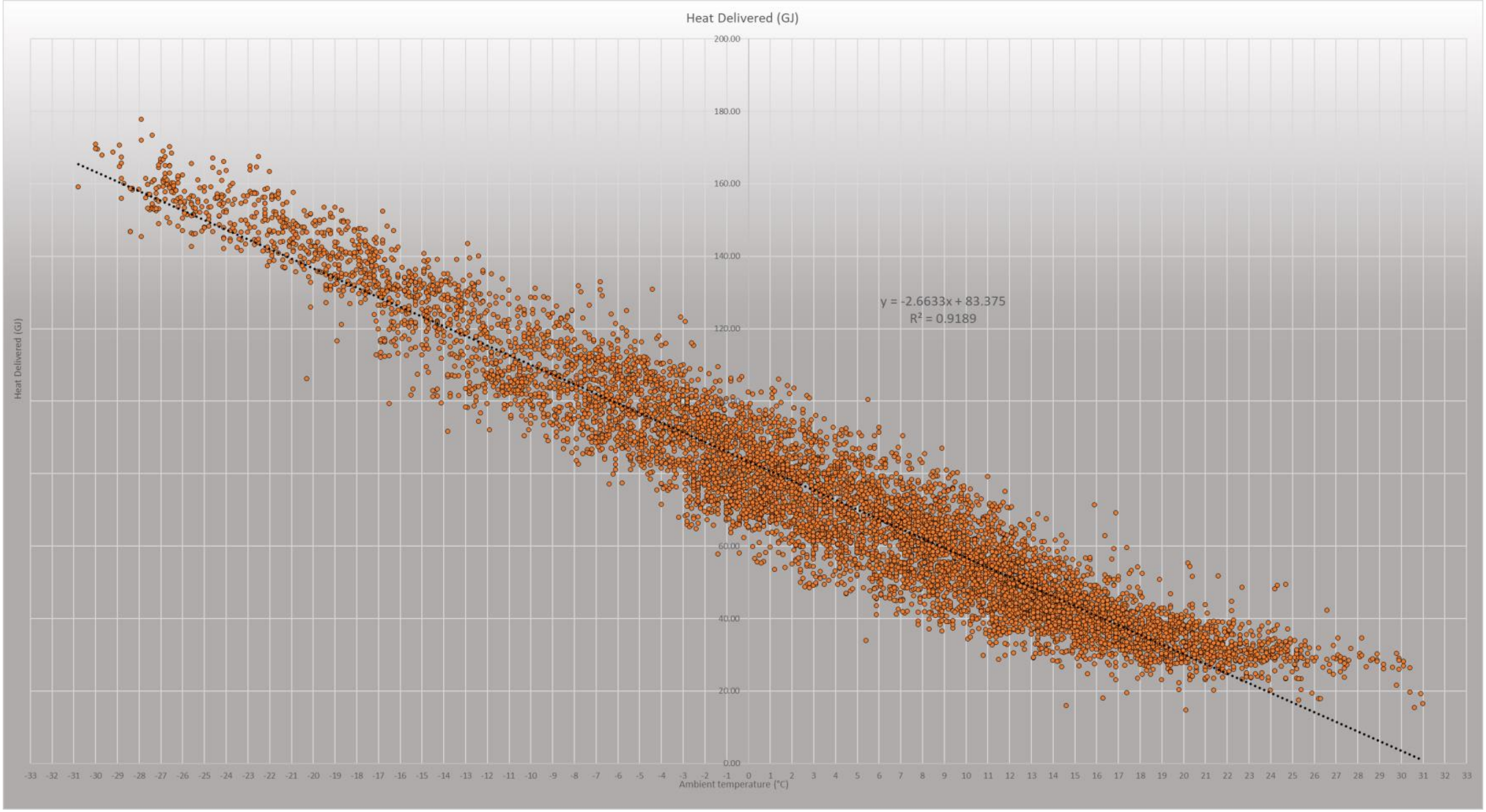
The first thing needed in this project is to know the amount of resource or available heat that can be captured and used to do any other work. Today, the power plant operates without knowing the amount of heat sent through the smoke stack via the bypass system. The only data measured is the angle of the damper valve located after the turbine exhaust before the heat exchanger. This limitation forced me to develop my own way of measuring the heat being wasted.

The first step was getting a clear understanding of the relationship between the amount of heating demanded by the campus buildings in relation to the ambient temperature (we know from before that ambient temperature is the main factor regarding heating demand; hence the heat wasted during warmer periods of the year).

For this, I made a graph (figure 4) comparing the hourly 2019 ambient temperature vs. 2019 hourly heat delivered by the power plant.

Figure 4

2019 hourly ambient temperature vs. 2019 hourly heat delivered

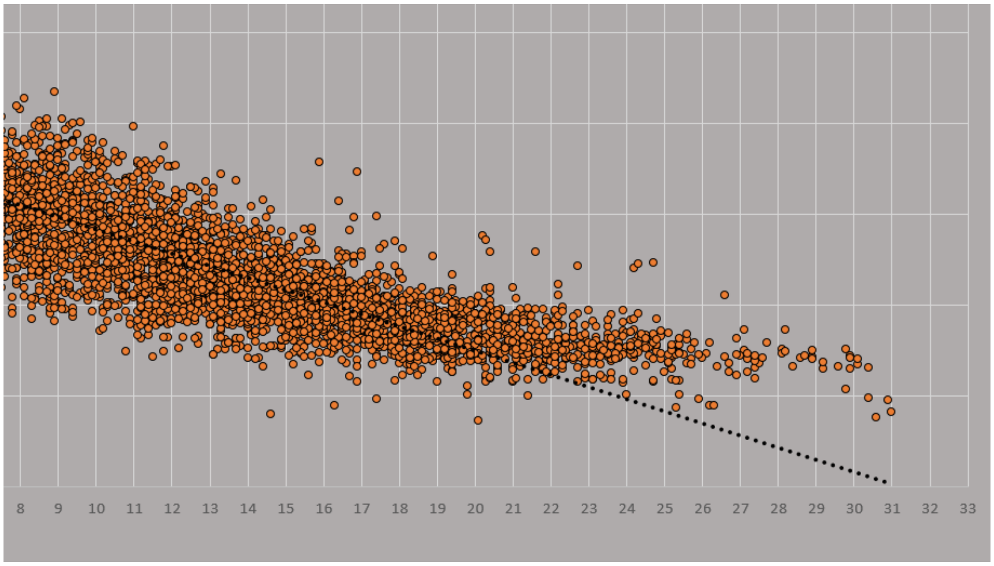


Note: (Author, 2022)

This graph shows a linear relationship between the ambient temperature and the heat delivered by the power plant from the coldest of temperatures to somewhere around 18°C. We can see the data points start to deviate from the trendline around that point.

Figure 5

Zoom into 2019 hourly ambient temperature vs. 2019 hourly heat delivered



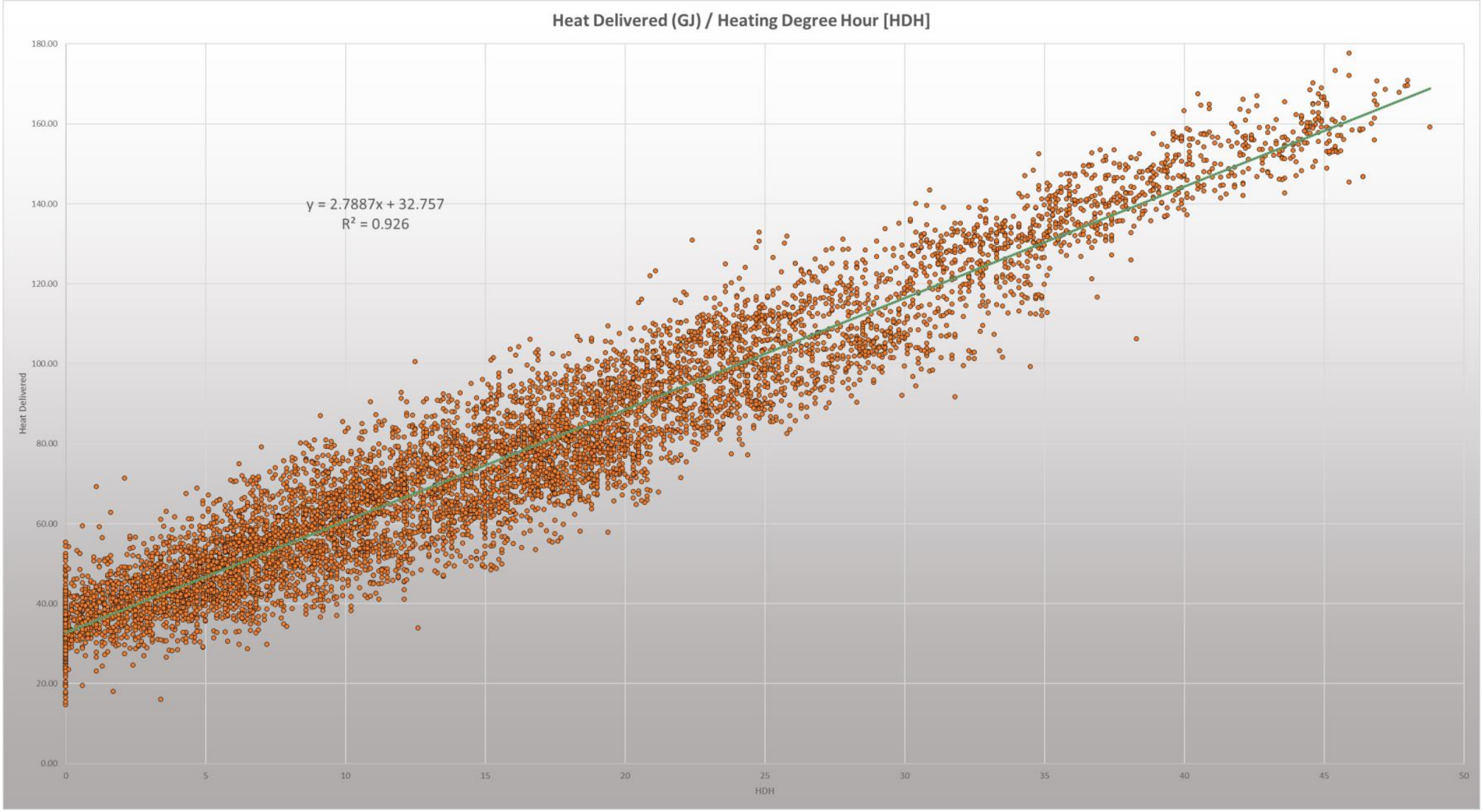
Note: (Author, 2022)

This deviation is due to the minimum heat demand by all the buildings being independent of the ambient temperature. This demand is for hot water, not space heating.

To have a better model with a trend line that better adjusts to the data, it was decided by me and my industry supervisor (the director of energy and utilities from the University) to use Heating Degree Hours vs. Heat delivered (Figure 6) to only consider the heating demand from buildings.

Figure 6

Heating Degree Hour vs. Heat delivered



Note: (Author, 2022)

With this graph, we obtain a model that adjusts to the trendline better without considering the deviation that occurs when the ambient temperature reaches 18°C, as demonstrated by the higher R^2 value.

$$R^2 = 0.926 > R^2 = 0.9189$$

With these graphs, we understood that the relationship between the ambient temperature and the heat provided by the cogeneration power plant is linear. We can easily create linear regression models to help calculate the energy available. *

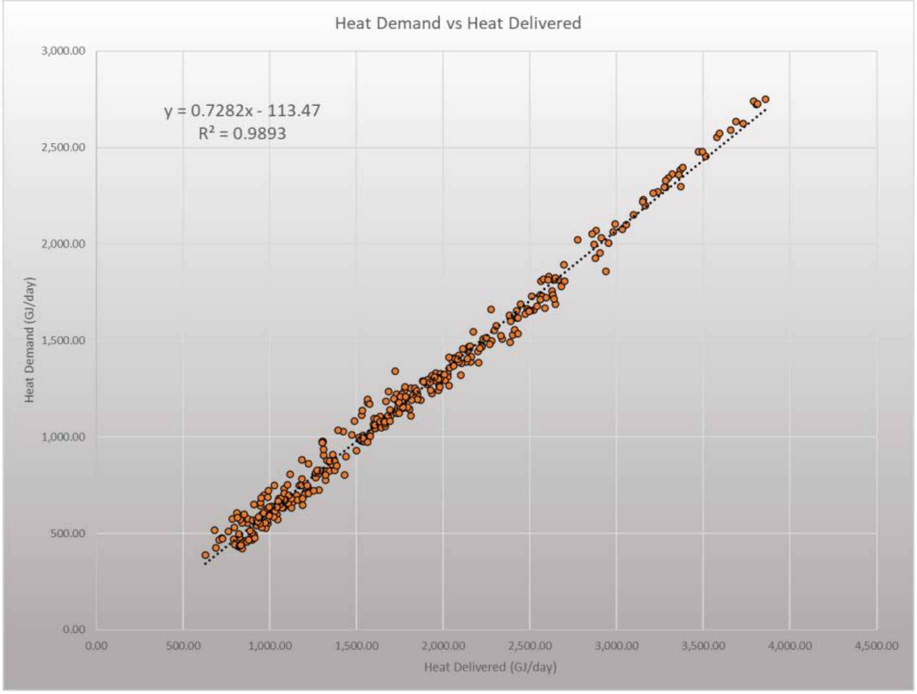
*As a note, during these steps, I was still figuring out the best way to calculate the resource available. These past calculations helped me understand the behaviour of the power plant and which step to follow next.

Following the calculations made before, I understood that the best way to know the resource available was by first understanding the heating demand of the buildings, which is directly proportional to the ambient temperature. For this, the energy and utilities team supplied the data for the daily building heating demand for 2019 and the daily heating supplied by the power plant for the same time period. It is worth noting that these numbers are not equal as there are some natural losses in the distribution system; thus, the power plant needs to supply more heat compared to what the buildings demand.

To find the losses, I used the data from 2019 to create a model (Figure 7) where the 2019 daily building heat demand was graphed vs. the 2019 daily power plant heat delivered.

Figure 7

2019 daily building heat demand vs. 2019 daily power plant heat delivered



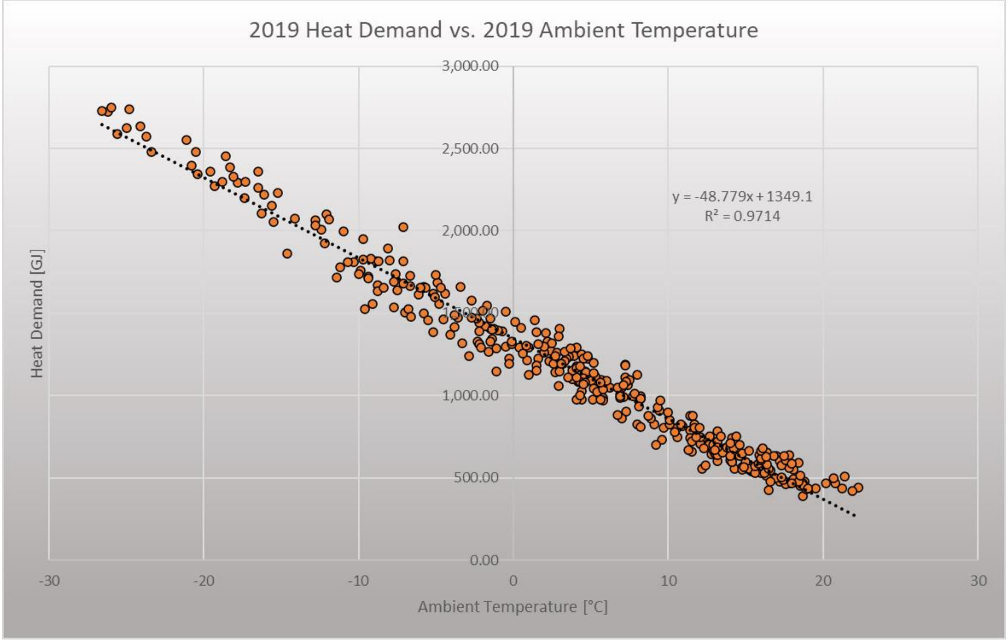
Note: (Author, 2022)

This graph and its linear regression formula allow us to find the losses in the heating system for any amount of heat demanded by the buildings.

The next step was the creation of a model using existing data for the daily heat demand by buildings in relation to the ambient temperature (Figure 8) and the heat vs. Heating Degree Day to eliminate the variability after 18°C (Figure 9) (daily data was used as that is the data available for heating demand).

Figure 8

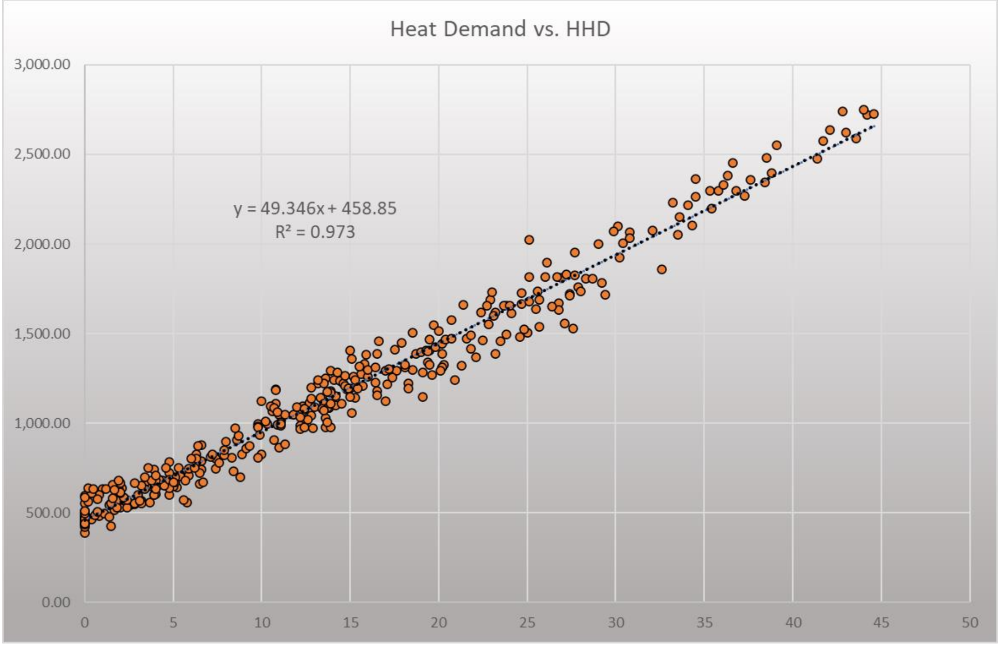
2019 Heat Demand vs. 2019 Ambient Temperature



Note: (Author, 2022)

Figure 9

Heat Demand vs. HDD



Note: (Author, 2022)

As mentioned before, data from 2019 was used for being the newest data available not affected by the COVID-19 pandemic. To eliminate any weather anomaly that might have occurred during 2019, I created a daily heat demand data set using the 30-year average daily weather from the previous 30 years using the weather station from Calgary International Airport (Environment and Climate Change Canada, n.d.).

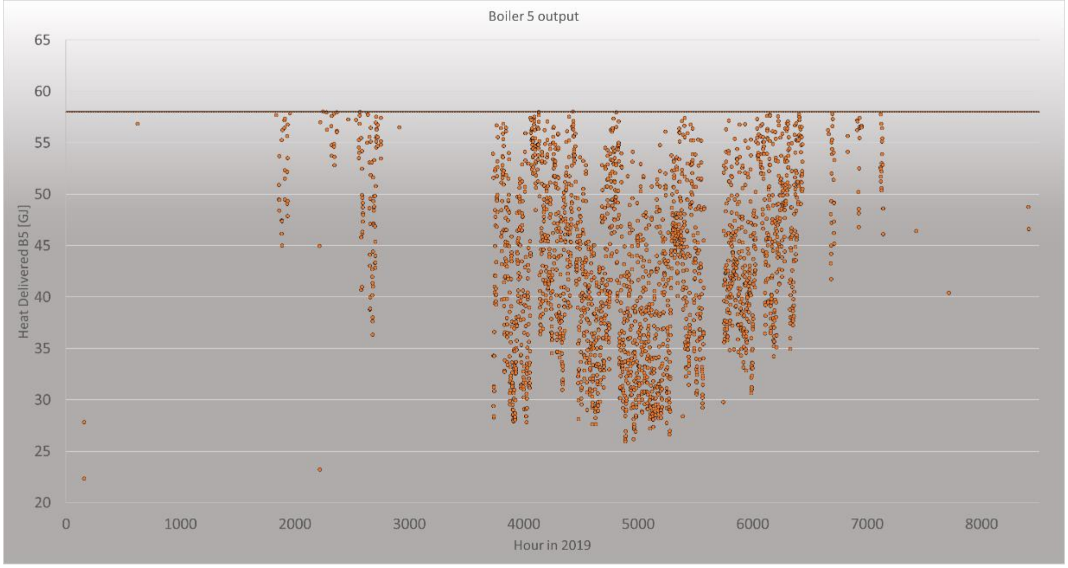
Using the model from Figure 9, we obtain a modelled heating demand by the buildings that considers the average weather pattern. Then, using the previous data together with the model from Figure 7, we get the heat demand for the plant on an average weather pattern for a whole year.

The final step in this process is to subtract the total demand at the plant from the maximum capacity of the boiler connected to the natural gas turbine (there are five boilers at the power plant, and only boiler five is connected to the turbine).

The maximum capacity of boiler five was empirically defined by reviewing actual boiler five hourly output data throughout 2019 (Figure 10).

Figure 10

Boiler hourly heat output 2019



Note: (Author, 2022)

Graphing the data shows that the maximum output is around 58 GJ, the highest output registered many times throughout the year.

Having this information allowed me to obtain the available resource throughout an average year, allowing me to start working on the second step of the project. Finding an off-the-shelf ORC electricity generator suitable for the characteristics present at the University's power plant.

3.2 Organic Rankine Cycle electricity generation

I chose the Organic Rankine Cycle electricity generation for the project for its ability to generate electricity with low or medium temperature heat sources. ORC generators are small in size allowing to transport one inside a regular size shipping container in a ready to use state without any major assemble necessary. This would simplify the installation process leaving only the connection to the heating system and connection to electric grid as the work needed to start operating.

Once the available resource was known, I started searching for an ORC generation that could work within the constraints in the power plant. Those being the heat available, the medium in which the heat is transported (in our case, water), the flow rate of the medium and the functional space for installation.

After considering all of the above, the Infinity Turbine IT 250 was chosen (Figure 11).

Figure 11

Infinity Turbine IT 250 on site

Note: (Infinity Turbine LLC, n.d.)

The IT 250 was chosen for its capacity to produce 250 kW of AC electricity from a relatively small footprint using R-245fa (Pentafluoropropane) as its working fluid, which reaches its boiling point at 14.9°C (Honeywell, n.d.).

The IT 250 spec sheet shows that the minimum flowrate of water needed to operate the generator is 600 GPM (Gallons Per Minute), and the maximum flowrate from boiler 5 is 2,777 GPM which gives us the ability to run four generators at the same time.

3.3 Economic analysis and carbon offsets

Having defined the generator to be used, the number of generators and the resource available to operate, I calculated the payback period for the whole project. I considered the amount of electricity that could be generated on an average year, the cost of the equipment, an estimated installation cost of 10% of the product cost, revenue from electricity production, TIER program carbon offsets (tonnes CO2/MWh), carbon pollution price for 2023, carbon pollution price increase of $15 per year until 2030.

Chapter 4: Findings and Interpretation

4.1 Energy resource available

After modelling an average heat demand from the buildings on campus on an average year using 30 years of weather data and accounting for the losses that the system suffers during the distribution, I developed a resource available during an average year graph (Figure 12) that shows the amount of resource available during a one-year time period.

This result comes from first knowing the maximum heat boiler five can produce. After that we subtract the heat demanded by the campus buildings, considering the losses that occur because of the distribution. This heat demand depends on the ambient temperature. The ambient temperature I used was a daily average temperature of the past thirty years.

To make it clearer I will show two examples:

Boiler five daily capacity 1,392 GJ

1. June 21st – Ambient temperature 14.62°C

   Heat demand at the plant 1014.70 GJ

   Resource available 377.3 GJ

Four IT250 can be powered with the resource available

2. December 21st – Ambient temperature -9.22°C

Heat demand at the plant 2630.30 GJ

Resource available -1238.30 GJ

No IT250 generator can be powered as we have a negative resource available, this means that other boilers need to supply energy to meet the demand.

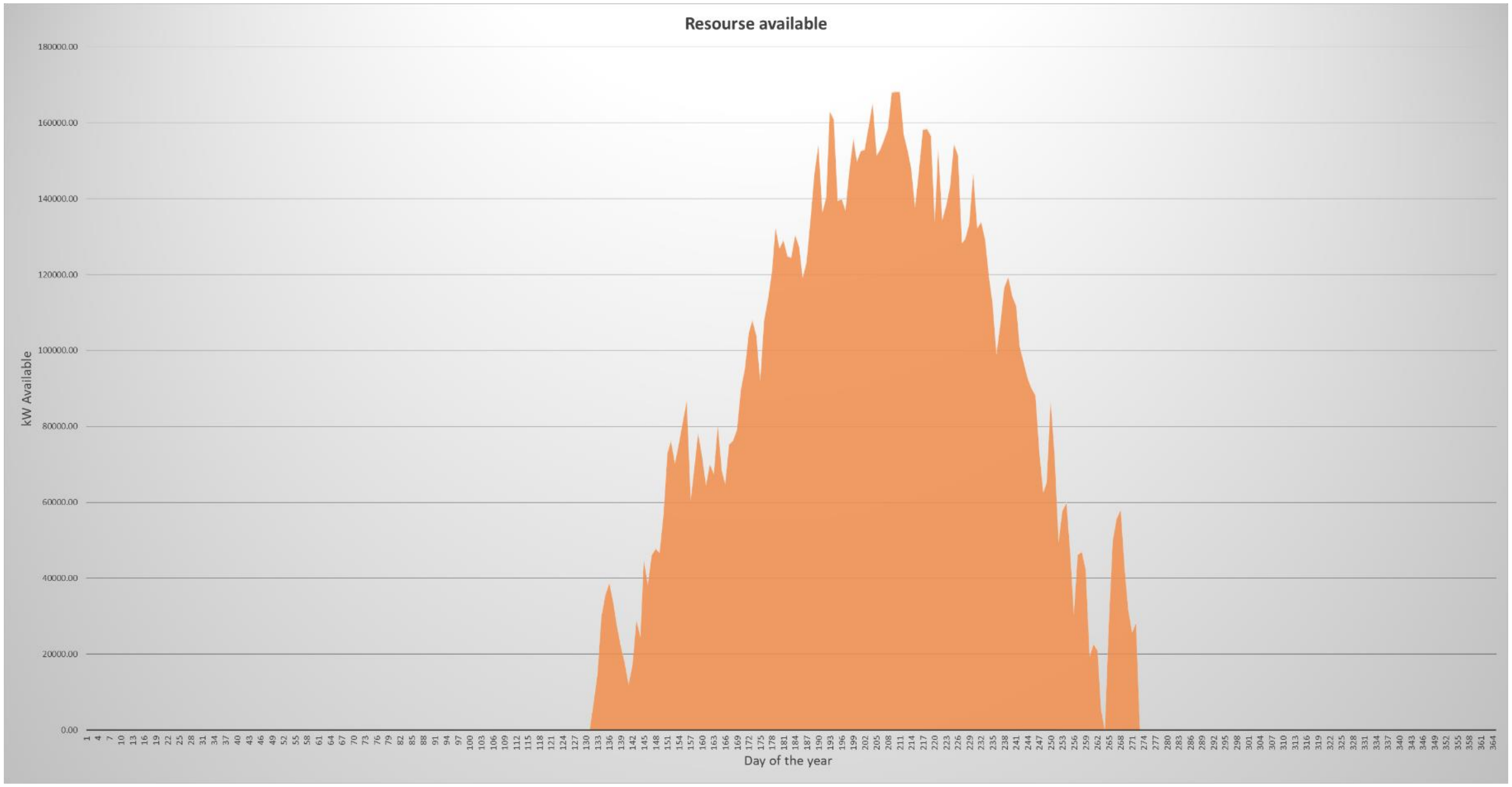
I made this analysis for each day of the year and considered the available resource to decide if none, one, two, three or four generators can be operated to produce electricity.

As mentioned before, another factor to consider is the flow rate of hot water coming from boiler five. Each generator needs 600 GPM of hot water at 110°C to operate. Boiler five can only supply a maximum of 2777 GPM at a time. That is why the number of generators is capped at four.

As we expected since before the project, during the warmer months of the year, there is a lot of heat available. The graph shows constant resource from day 131 to day 273 of the year, roughly from May 11 to September 30.

Figure 12

Resource available on an average year



Note: (Author, 2022)

The resource is available roughly for one-third of the year, giving the opportunity to increase the generating capacity of the whole power plant by 1 MW for that time period. However, even though there is enough resource to power more than 4 ORC generators, the limiting factor ended up being the flow rate of water coming out of boiler five. That flowrate is just capable of powering four generators at the same time.

To have four generators operating at the same time, it is necessary to install them as close as possible to the heat source to minimize any losses from the distribution system. These losses increase with the length of the system as there is more area from where heat dissipates into the surroundings. At the same time, the closer the generators are to the source, the less material is needed for the heating system coupling as well as the electrical connection to the existing grid.

As a possible location for installing the ORC generators, I chose the parking lot next to the power plant, as shown in Figure 13 and Figure 14. This location needs next to no modification or major infrastructure modifications to accommodate the generators, it is a flat surface with sufficient area to accommodate the four generators. Also, the costs of new piping and electric cable interconnection are reduced by being this close to the power plant.

Figure 13

Possible location for ORC generators

Note: (Google LLC, 2022)

Figure 14

Possible layout for the ORC generators

Note: (Google LLC, 2022)

4.3 Economic analysis and carbon offsets

4.3.1 Economic analysis

I calculated a payback period (Table 1) for the project as that is an important data point to have. The power plant has a finite operating life that could extend at a maximum to 2050, as that is the year the University made the commitment to achieving deep decarbonization (University of Calgary, 2019). You can't achieve decarbonization with an operating natural gas-fired generation station. Because of that, it is crucial to know if the payback period is less than the 27 years left before 2050.

For the analysis I considered the carbon tax (carbon pollution price [\$ CAD/tonne CO_2e]) that is currently used under the law in Alberta which is the same set by the federal government. This tax is defined as \$ 50 / tonne CO_2e for 2022 increasing by 15 each year capping at \$ 170 / tonne CO_2e in 2030.

The next value I used is the estimated 3,324 MWh of yearly electricity production by the four ORC generators. These values are an average as the electricity production are susceptible to weather changes impossible to predict.

The 0.37 CO_2 tonnes /MWh come from the TIER program where they are defined as the number of tonnes of CO_2 abated per MWh of electricity generated (Government of Alberta, 2020).

I calculated the number of tonnes of CO_2 that would be abated by the new electricity production and multiplied it by the carbon tax giving a new revenue stream.

Finally, I subtracted that yearly revenue stream from the total costs of the project considering the yearly increase for the carbon tax until 2030.

Table 1

Payback period

Year	2023	2024	2025	2026	2027	2028	2029	2030
Carbon tax [$]	65	80	95	110	125	140	140	170
MWh of production	3,324	3,324	3,324	3,324	3,324	3,324	3,324	3,324
CO_2 tonnes /MWh	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Tonnes of CO_2	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88
Carbon tax revenue [$]	79,942.20	98,390.40	116,838.60	135,286.80	153,735.00	172,183.20	172,183.20	209,079.60
Cost remaining	$6,220,897.80	$5,823,347.40	$5,407,348.80	$4,972,902.00	$4,520,007.00	$4,048,663.80	$3,558,872.40	$3,050,632.80

Note (Author, 2022)

Table 2

Payback period cont.

Year	2031	2032	2033	2034	2035	2036	2037
Carbon tax [$]	170	170	170	170	170	170	170
MWh of production	3,324	3,324	3,324	3,324	3,324	3,324	3,324
CO_2 tonnes /MWh	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Tonnes of CO_2	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88	1,229.88
Carbon tax revenue [$]	209,079.60	209,079.60	209,079.60	209,079.60	209,079.60	209,079.60	209,079.60
Cost remaining	$2,542,393.20	$2,034,153.60	$1,525,914.00	$1,017,674.40	$509,434.80	$1,195.20	-$507,044.40

Note (Author, 2022)

The payback period came back at a little more than 14 years. That number considers the total cost of 4 ORC generators and their installation costs.

4.3.2 Carbon offsets

As mentioned before, there is no emissions reduction by the power plant. The power plant will operate the same as its primary goal is the production of electricity which does not change across the year; hence the amount of fuel burnt remains the same no matter the efficiencies we achieve with this project. The real CO_2e abatement occurs by the newly generated electricity that did not exist before. Therefore, we are producing more electricity without using more fuel for it.

The CO_2e abatement was calculated according to the established proportion of CO_2 per MWh of electricity generated listed by the TIER program of 0.37 tonnes of CO_2e / MWh.

With the 3,324 MWh of expected electrical production, 1,229.88 tonnes of CO_2e will be abated every year of the operating life of the power plant since the ORC generators start operation.

Chapter 5: Conclusions, Recommendations, Limitations, and Future Research

5.1 Conclusions

As of today, the cogeneration power plant at the University of Calgary has helped the University achieve its goal of being an educational institution leader in sustainability, serving as an example to every other institution in the country by helping with the reduction of 30% of GHG emissions compared to 2008 (University of Calgary, 2019). But with every coal-fired power plant serving the Alberta grid that ceases operation, its help is diminished, leaving a clear need for improvements.

From the results obtained in this project, we can identify a substantial amount of resource (energy in the form of heat) that is currently being wasted. Therefore, the University can make an investment to add the technology necessary to harness that energy and put it to good use in the form of extra electricity generation. That solution would not only increase the power plant's energy output but will do it without increasing emissions in any way.

The ORC electricity generation is seeing considerable growth thanks to its ability to produce electricity from low heat sources and its ability to pair up easily with existing infrastructure, especially with renewables like solar thermal and geothermal electricity generation. Because of this, there are many options to choose from, many of them being Canadian companies.

5.2 Recommendations and future research

A lot of energy is available during the warmer months of the year. It even surpasses the capacity of the studied generators to use it entirely because of the limited flow rate of water coming from boiler five. For this, I could recommend future research of an option of thermal storage that would not only allow the use of more if not all the energy available but extend the generator's operation times to include some of the colder months.

5.3 Limitations

The project had two main limitations, the first being the lack of accurate data because of the inability to measure the amount of heat available directly. The power plant only monitors the percentage or position of the valve that allows or restricts the flow of exhaust gasses from the turbine to the heat exchanger. An accurate measure would allow for a more precise analysis of the technologies that could be implemented to use the energy.

The second limitation was the reluctance of ORC generator manufacturers to share information about their products. At the very least, the minimum specifications for operation are needed to perform the analysis, but it proved really hard even to get that. At the same time, as this was just a feasibility project with no factual commercial purposes, the costs were hard to obtain for the economic analysis.

References

Alberta Electric System Operator. (2017). *AESO 2017 Long-term Outlook*. 19. www.aeso.ca

Alberta Utilities Commission. (2021). *Annual electricity data*.

Bhatia, S. C. (2014). Cogeneration. *Advanced Renewable Energy Systems*, 490–508. https://doi.org/10.1016/B978-1-78242-269-3.50019-X

Canada Energy Regulator. (2022). *Provincial and Territorial Energy Profiles – Alberta*. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-alberta.html

Energy Education. (2020). *District heating*. https://energyeducation.ca/encyclopedia/District_heating

Environment and Climate Change Canada. (n.d.). *Daily Data Report*. https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

Exergy International Srl. (n.d.). *Organic Rankine Cycle*. https://www.exergy-orc.com/technology/orc

Google LLC. (2022). *Google Maps*. https://www.google.com/maps/@51.0756289,-114.137427,743m/data=!3m1!1e3

Government of Alberta. (2015). *Climate Change Legislation*.

Government of Alberta. (2020). Technology Innovation and Emissions Reduction (TIER) Regulation. *Emissions Management and Climate Resilience Act*.

https://open.alberta.ca/publications/2019_133#summary

Hinrichs, D. (2004). Cogeneration. *Encyclopedia of Energy*, 581–594. https://linkinghub.elsevier.com/retrieve/pii/B012176480X000930

Honeywell. (n.d.). *Genetron® 245fa (R-245fa)*. https://www.honeywell-refrigerants.com/europe/product/genetron-245fa/

Infinity Turbine LLC. (n.d.). *IT 250*. https://infinityturbine.com/it250.html

International District Energy Association. (2019). *District Heating*. https://www.districtenergy.org/topics/district-heating

Schleup, J. (2008). *How Does Cogeneration Provide Heat and Power?* Scientific American. https://www.scientificamerican.com/article/how-does-cogeneration-provide-heat-power/

Thibault, B., Jeyakumar, B., Brown, G., & Olmsted, K. (2021). *From Coal to Clean Canada's progress toward phasing out coal power*.

United Nations. (2015). *Sustainable Development Goals*. https://sdgs.un.org/goals#history

United States Environmental Protection Agency. (2021). *Scope 1 and Scope 2 Inventory Guidance*. https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance

United States Environmental Protection Agency. (2022). *What is CHP?* https://www.epa.gov/chp/what-chp

University of Calgary. (2019). *Climate Action Plan*.

Venkateswarlu, K. (2020). *Engineering Thermodynamics. Fundamental and Advanced Topics*

(1st ed.). CRC Press.

Wilson, J. K. (2018). *Cogeneration power plants : Planning and evaluation*. PennWell Books, LLC.