Proceedings World Geothermal Congress 2023
Beijing, China, October 9-11, 2023

Modeling and optimizing research on geothermal plus multi-energy district heating system in China

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Key word: Geothermal plus, Multi-energy, Feasibility, Capex, Opex, IRR

ABSTRACT

Geothermal as its clean and high efficiency nature is the ideal baseload in clean energy district heating system. Pure geothermal district heating system may not give the best output for the whole system therefore multi-energy integrated system is considered as the optimized approach in more and more projects. This study focuses on the technical and financial feasibility modeling of integrated system with geothermal as the baseload. Other clean energy such as natural gas, shallow geothermal, solar, clean electricity is taken into account for this Geothermal plus complementary heating system. Conditions from different regions in China including weather data, tariff, and energy fee as basic assumptions, combined with geothermal well condition and project scale are the main inputs of the model. Heat load duration curve, percentage and consumption of different energy source as well as Capex and Opex of the project are calculated and optimized. Python language is applied in this study to carry out a modeling software with the output of optimized technical scheme and internal rate of return (IRR) in terms of financial assessment which will give a comprehensive advice for project designers and decision makers.

1. INTRODUCTION

Clean and renewable energy district heating is the trend everywhere in the world since the common goal of carbon neutrality. Geothermal due to the stable and clean nature plays a very important role as the ideal base load in district heating system, other available energy combined into the system can provide better return of the whole investment project. Therefore, this study is to set up a model to analyze and optimize the feasibility of different alternatives of multi-energy clean district heating system with geothermal as the base load.

A model of typical multi-energy district heating system is developed to analyze the technical and financial feasibility. The main work is as follows:

- Establishment of thermodynamic model based on geothermal energy.
- Algorithm research of each component in this model. With the idea of modular programming, various energy forms such as natural gas, solar and clean electricity are packaged into multiple components, and the algorithm of each component needs to be studied.
- Research on the software of the model: interactive interface and data visualization.
- Study on the algorithm of system optimization: boundary conditions and optimization algorithms.
- Research on historical data analysis system: data processing algorithm.

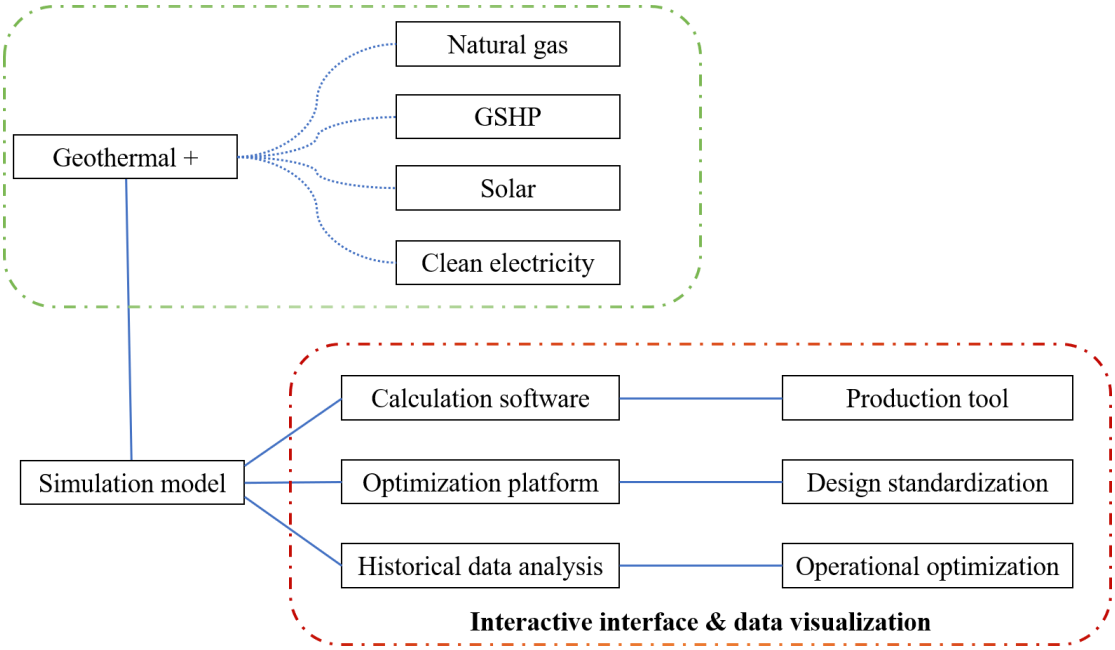

Figure 1: geothermal + simulation model schematic diagram

The aim of the work is to set up a “geothermal plus” multi energy simulation model to analyze and optimize the system technical and financial feasibility. Develop the software expansion module of the "geothermal plus" model, which can quickly complete the feasibility study of the company's heating project, carry out load analysis, thermal economic analysis, technical economic analysis, etc., and draw the main conclusions of the feasibility report based on the calculation. The system optimization expansion module of the "geothermal plus" model is developed to optimize and analyze the heating system designed under different geothermal resource conditions, study the characteristics of different design schemes, and compare the optimal design schemes under different resource conditions. The data analysis extension module of "geothermal plus" model is developed to automatically process and analyze the historical data of the existing system operation, and the analysis results can be used to optimize the operation mode.

2. SYSTEM DESIGN AND MODELING

2.1 Design and modeling of the multi-energy district heating system

Geothermal plus multi-energy district heating system is designed based on the principle of “indirect heat transfer, cascaded utilize, balance of production and reinjection and rational peak load” for the modeling and optimization. The outdoor air temperature is the precondition for the district heating system heat load design. This weather data is collected from the National Meteorological Center as the imported data for the modelling construction. Then the necessary technical and financial data are collected as the inputs for the whole system design. The schematic diagram is shown as follows:

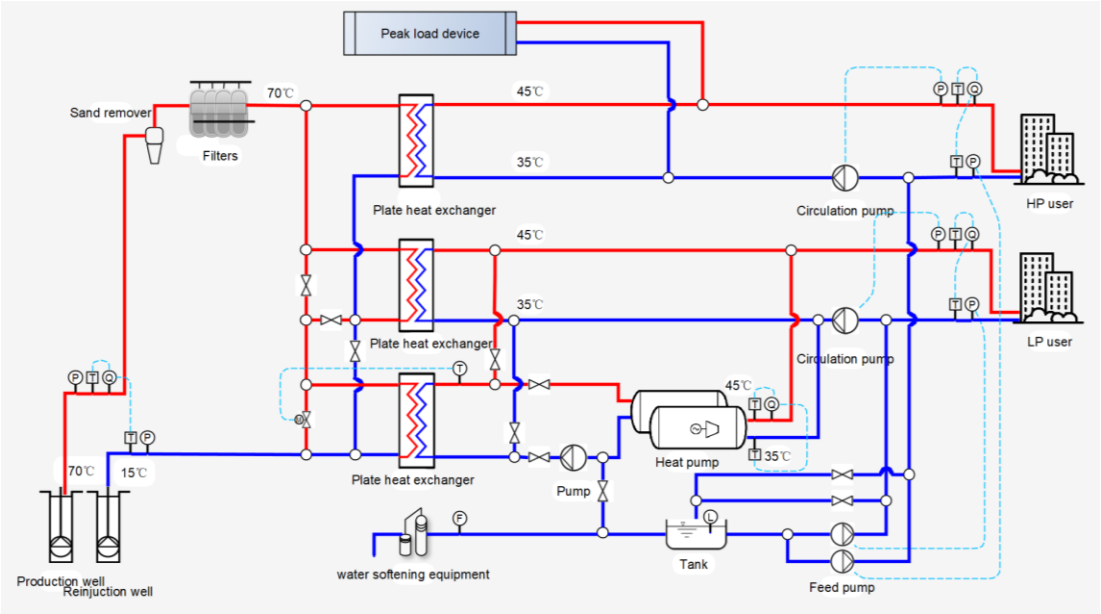

Figure 2: Geothermal plus multi-energy system schematic design diagram

Main components:

- Production and reinjection wells
- Plate heat exchanger
- Heat pump
- Circulation and feed pump, including variable frequency drive and motor
- Submersible pump
- Reinjection filter, deaerator, etc
- Water softener
- Instrumentation

This simulation modeling is based on geothermal plus multi-energy district heating system design in north China regions. The project location typical year outdoor temperature distribution data is imported as the basic condition so as to use this modeling in different locations. The project scale and end user system are the variable data of the design. The base load design principle is to fully use geothermal as the heat source with reinjection temperature as around 15 °C. The geothermal resource condition mainly includes wellhead temperature and flow rate as well as the chemical content should be available from the drilling report or resource assessment report. The rest peak load combined energy is considered can be natural gas, solar heat, shallow geothermal ground source heat pump and clean electricity storage system. Therefore, the overall parameters for the model design and optimization are listed below:

Data imported:

- Hourly or per three-hour outdoor temperature data at the project location.

Input parameters:

- Heating area
- Heating fee per m^2
- Connection fee per m^2
- Geothermal well depth
- Geothermal wellhead temperature
- Reinjection temperature
- Number of geothermal production wells

- Number of geothermal reinjection wells
- Heat pump (Yes/no)
- Gas boiler or other peak load input
- Heat load per m^2
- Electricity price
- Gas price
- Water price
- Primary pipeline length
- Geothermal resource tax
- Enterprise income tax
- Operational staff number
- Heat load deploy rate
- Occupancy

Output parameters:

- Heat consumption for heating season GJ
- Heat consumption per m^2 for heating season GJ/m^2
- Electricity consumption for heating season kWh
- Electricity consumption per m^2 for heating season kWh/m^2
- Water consumption for heating season m^3
- Water consumption per m^2 for heating season m^3/m^2
- Gas consumption for heating season m^3
- Gas consumption per m^2 for heating season m^3/m^2
- Geothermal water consumption for heating season m^3
- Geothermal water consumption per m^2 for heating season m^3/m^2
- Geothermal resource tax Yuan
- Geothermal resource tax per m^2 $Yuan/m^2$
- Total investment Capex Yuan
- Investment per m^2 Capex sqm $Yuan/m^2$
- Operational cost Opex Yuan
- Operational cost per m^2 Opex $Yuan/m^2$
- Internal rate of return IRR %
- Net present value NPV Yuan

Based on the technical calculation and modeling, to meet the demand of a specific district heating project, the energy source combination is performed according to the availability. Then the main components of the whole system can be designed to make an investment cost estimate which is the rough Capex of the project. And the financial feasibility can be assessed based on the Capex and Opex calculation.

3. OPTIMIZATION OF THE TECHNICAL AND FINANCIAL MODEL

This research is to make a simulation and optimization of the multi-energy district heating system with geothermal as the base load. Python language is used for this modeling and optimization work. Therefore, for any project, according to the building design and outdoor temperature condition, the heat load can be calculated and the heat source combination can be designed according to the availability. The structure of the energy combination is calculated and percentage of each energy consumption is carried out respectively. the optimization is carried out based on the financial calculations.

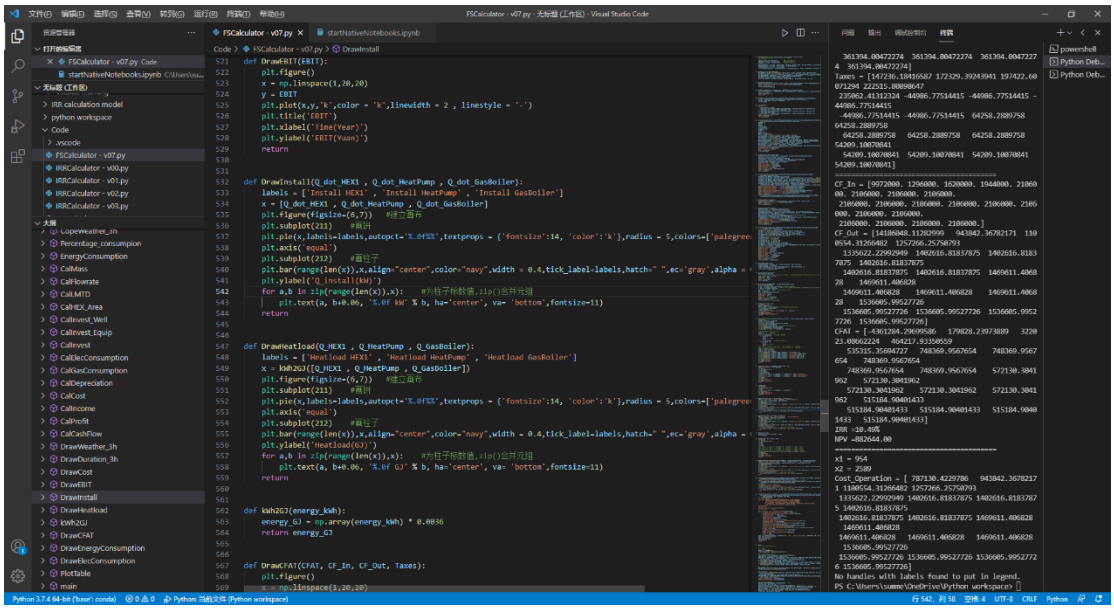

Figure 3: Geothermal plus multi-energy system modeling

Below is an example of the modeling and optimization based on a specific project in Xiong'An New Area: The outdoor temperature is shown as Figure 4:

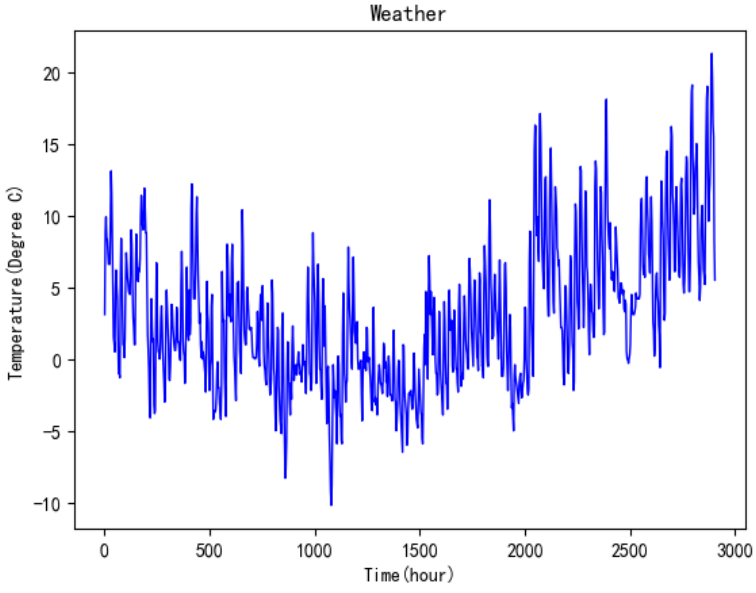

Figure 4: Example outdoor temperature distribution

The parameters are input in the table below as main concern factors, heating area and heat load per m^2 are provided from the defined project. The geothermal resource conditions are referred from the drilling report in project area where is rich in geothermal with about $65°C$ and $80m^3/h$. And the key related design parameters should be input to

the model such as price policies, well depth and number, as well as some basic cost price which is related to the Capex and Opex estimate. Figure 5 below shows the interface of the simulation model for this research programmed with Python.

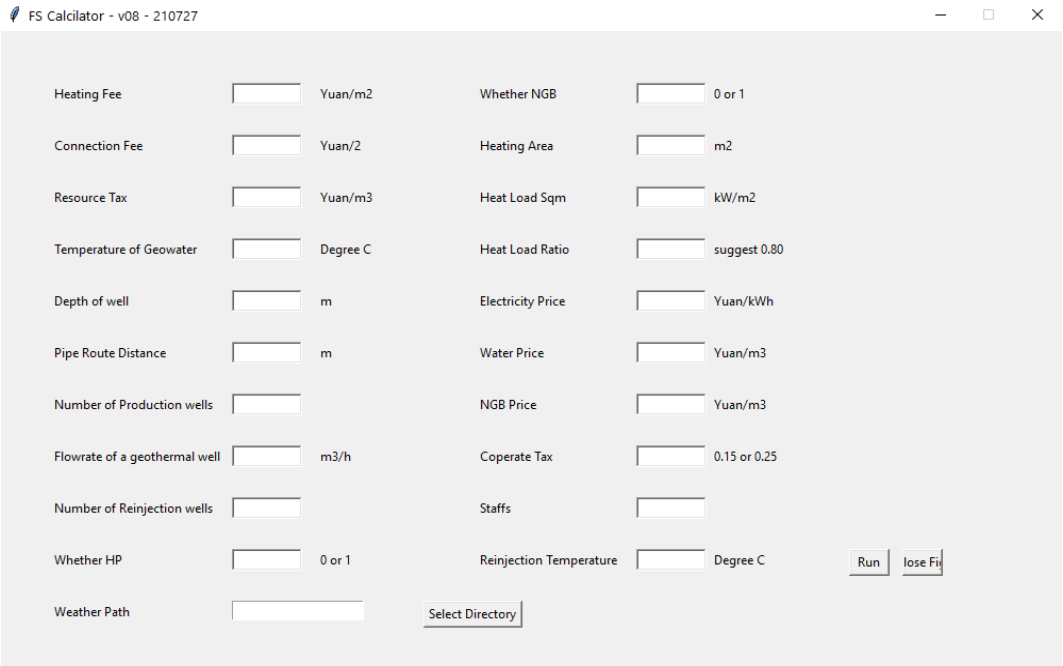

Figure 5: Input interface of the simulation model

Through programming and simulation, the heat load duration curve is provided as Figure 6 which shows that geothermal plus heat pump as the base load and natural gas boiler as the peak load supplier.

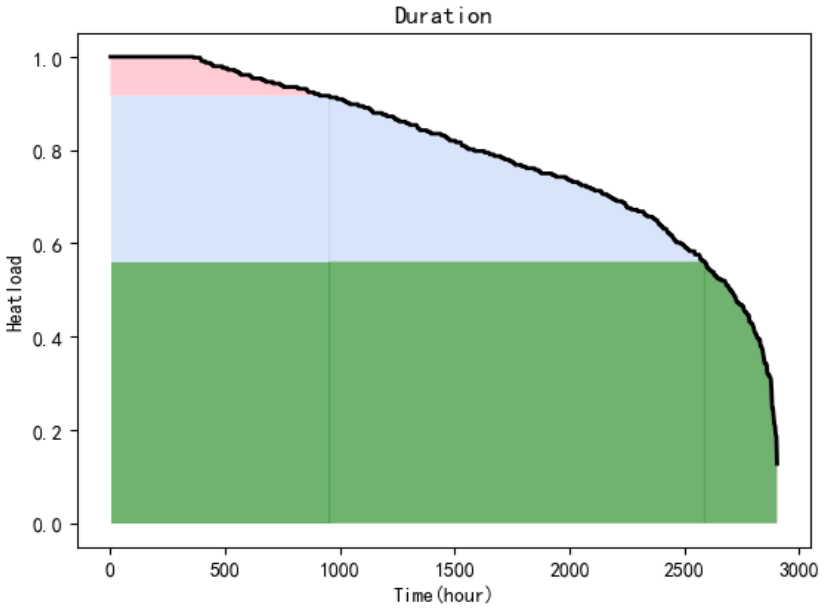

Figure 6: Heat load duration curve

The installed capacity of heat exchangers and heat pumps is calculated based on the boundary and conditions, and the percentage of each factor for energy consumption is also shown below which indicates that the peak load or combined energy source capacity occupies 19% kW in total, but only 8% occupied in terms of energy consumption. Natural gas boiler is the relatively ideal peak load supplier since its low Capex and high Opex where gas price is relatively higher in China. From the investment perspective, this geothermal plus natural gas multi-energy district heating system gives better performance in terms of internal rate of return (IRR).

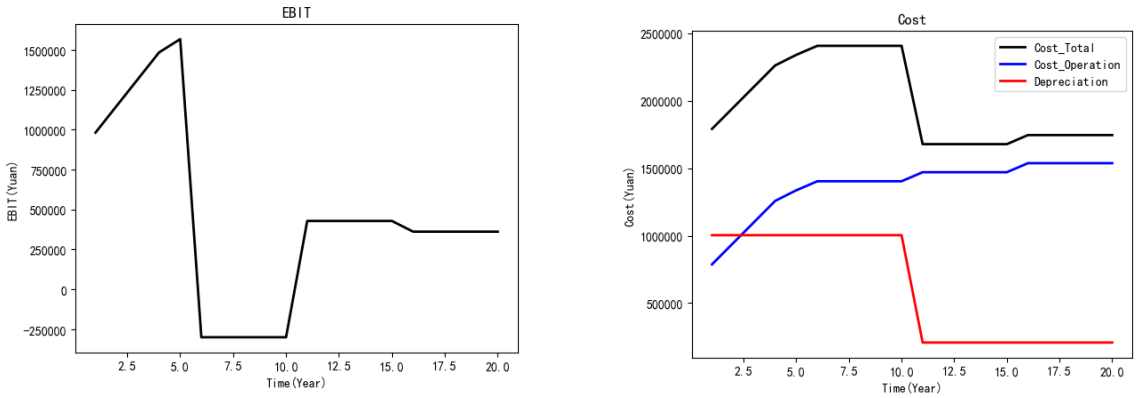

Figure 7: Installed capacity and energy consumption analysis

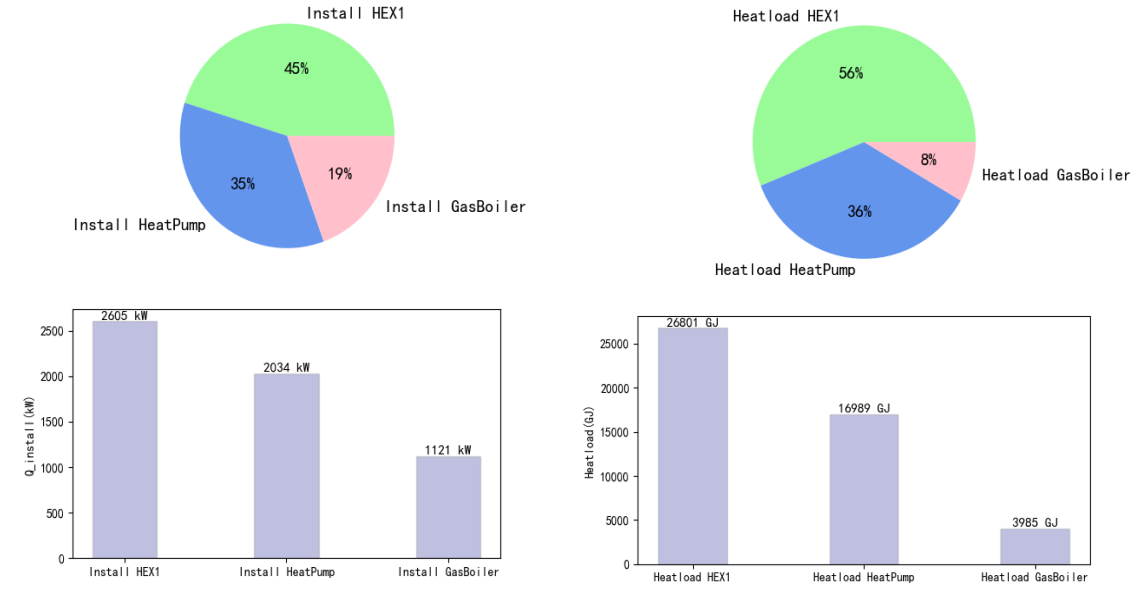

Figure 8: Financial feasibility modeling and optimization analysis

In the financial optimization modeling, it shows clearly much higher IRR than purely geothermal district heating system.

The results of the modeling is given in Figure 9 below as the output interface in this program. Through the modeling and optimization the final IRR for this system is 10.49% which is much higher than the bench mark 8% as investment requirement.

Item	Unit	Value
Heating Area	m^2	180000
Temperature of geothermal water	degree C	65
Flowrate of geothermal well	m^3/h	80
Production wells	-	1
Reinjection wells	-	1
Depth of well	m	2000
Heat load	kW	5760.0
Delivered thermal energy	GJ	47775.74
Delivered thermal energy per sqm	GJ/m^2	0.27
Geothermal Water	t	228618.4
Geothermal Water per sqm	t/m^2	1.27
Electricity	kWh	1418340.43
Electricity per sqm	kWh/m^2	7.88
Natural Gas	m^3	121728.45
Natural Gas per sqm	m^3/m^2	0.68
Capex	Yuan	13398917.69
Capex per sqm	$Yuan/m^2$	74.44
Opex	Yuan	1335622.23
Opex per sqm	$Yuan/m^2$	4.82
IRR	%	10.49%
NPV	Yuan	882644.0

Figure 9: Output interface of the optimization results

The purpose of this study is to carry out a model to design and optimize a combined clean energy district heating system with geothermal as the baseload. From the technical perspective, to determine a best approach to synchronize available energy to provide heat source for a district heating project with an objective to perform the best system COP meanwhile from the financial perspertive, the comhensive approach should yield a optimized IRR of the whole investment by analysizing the Capex and Opex based on the local energy price, tariff policies, etc. Above is an example shows the geothermal + natural gas mutiple energy district heating system modeling and optimizing results. It will be a quick guidance and tool for project dicision makers. This work is still under construction to extend to differernt clean energy with availablity according to the project site boundary.

4. CONCLUSION AND SUGGESTIONS

Based on the high efficiency utilization ratio of geothermal energy as the base load in district heating system, using python as the simulation language to model the multi-energy system to carry out a standard energy analysis and optimization work is feasible and effective. This work is to be continued to complete with different energy resource to optimize the best approach in variable project. The following work is to be deployed:

- Complete the construction of geothermal energy thermodynamic simulation model core, completed the construction of five modules such as air source, sewage source, waste heat and clean electricity;
- Complete the programming of geothermal computing software and applied for 1 software copyright;
- Complete the establishment of the system optimization platform, and publish the standardized design scheme of the geothermal addition platform based on the analysis of the calculation results of different geothermal resources;
- Complete the construction of the historical data analysis platform and put it online to be a guidance for future project.

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