Techno-Economic Assessment of CAES Technologies in Enhanced Geothermal Systems (EGS) in Alberta

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Summary

Growing concern with global climate change, depletion of cost-effective fossil resources, and adoption of stringent carbon emission policies caused a dramatic increase in demand for low carbon and sustainable renewable energy sources. Wind and geothermal energy are two energy sources alternative to hydrocarbons that have gained wide interest in electricity generation in Alberta. However, relatively high cost of geothermal energy and intermittent nature of wind energy hinder their widespread use in Alberta. In this work, using CMG STARS and Visual Basic Applications (VBA) platform, we develop a software to simulate the performance of conventional geothermal and Compressed Air Energy Systems (CAES) power plants with or without wind energy in a typical hot dry rock (HDR) reservoir (with different thermal conductivities). The results show that wind/CAES-geothermal scenario with McIntosh technology has the lowest levelized cost of energy (LCOE) (11.8 ¢/kWh) with the emission intensity of 0.12 ton-CO_2/MWh, which is comparable to other energy sources in Alberta.

Introduction

According to the transition plan approved by the Canadian federal government, all Canadian provinces should move toward a low carbon energy future by reducing 30% of greenhouse gas (GHG) emissions by 2030 with respect to 2005 emissions level and achieve up to 80% decrease of the baseline emissions level (2005 level) by 2050 [1]. Therefore, relying primarily on fossil fuels for electricity generation causes difficulties in adopting policies and regulations and meeting climate change goals [2]. The only solution to this challenge, especially for Alberta where approximately 90% of electricity is produced using fossil fuels, is to decarbonize the electricity in the grid system by utilizing the proven and commercialized technologies (e.g., nuclear, tidal, solar, geothermal, and wind energy) [3]. Alberta has the abundant geothermal energy stored in the low permeable basement rock as well as the best wind resources with the lowest LCOE compared to other Canadian provinces [4-6]. However, relatively high cost of geothermal energy and intermittent nature of wind energy hinder their widespread use in Alberta [7]. Therefore, this research outlines a novel geo-energy approach by developing a complete techno-economic model for a future field pilot of a wind-CAES in a typical HDR storage system to overcome major drawbacks of simultaneous exploitation of wind and geothermal energy sources.

Method

In this study, we develop a software called "Compressed Air and Geothermal Energy Evaluation Model (CAGEEM)" in Visual Basic for Applications (VBA) to model the surface facilities based on the conventional geothermal, CAES, and wind/CAES power-plant technologies and estimate the electricity production, the CO_2 emission, and the LCOE of geothermal resources. Project development in CAGEEM includes three blocks: input, main, and output blocks (Figure 1).
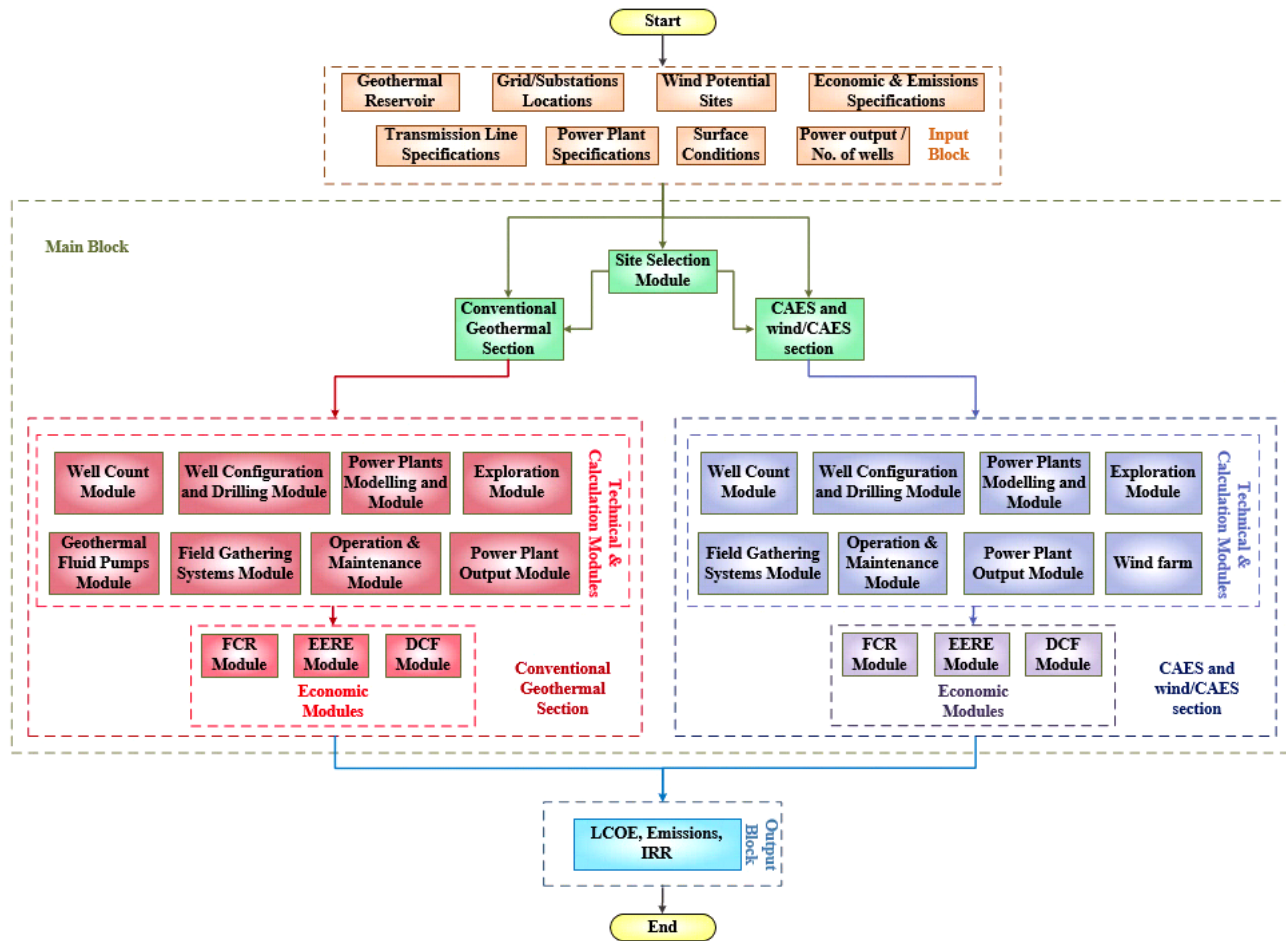
Figure 1. Best site selection flowchart.

Results and Discussions, Observations, Conclusions

According to the results of site selection module, we found that the best location for building a geothermal, CAES, or wind/CAES power plant across Alberta is located approximately 70 km south west of Lloydminster, and therefore, we call this region Lloydminster area. In this area, the depth at which the temperature of 150 °C is encountered is 6.5 km, whereas its distance to the grid is 3.7 km. The corresponding wind farm in this region has an actual capacity of 111.2 MW and is 4.4 km away from the grid, respectively. Therefore, we present the results of LCOE and emission estimations using CAGEEM with the assumption of drilling new wells for this region.

Note that based on the reservoir permeability of the matrix and fractures (1 and 350 md, respectively) and its moderate temperature (150 °C), we chose EGS-binary among various technologies for energy harvesting from conventional geothermal resources, i.e. hydrothermal-binary, hydrothermal-flash, EGS-binary, and EGS-flash. On the other hand, because for CAES-geothermal and wind/CAES-geothermal scenarios, no study has been conducted for assessing the performance of different CAES technologies in Alberta, we perform the assessment using three types of technologies (Huntorf, McIntosh, and Adiabatic). We also assume a plant size of 100 MW for the EGS-binary scenario, which is approximately equal to the power output of the CAES plant power (97-98 MW).

Figure 2 shows the temperature profiles for all scenarios (conventional geothermal and CAES-geothermal or wind/CAES-geothermal) and the power profile for the conventional geothermal scenario during the life of the project. For the EGS-binary (conventional geothermal scenario) because of the high annual thermal decline rate (4.2%), in the 11th year the field is depleted (the power production approaches to zero), which leads to the entire replacement of the well field. Similarly, the power sales from the geothermal scenario (EGS-binary) decreases from 100 MW gradually to 0 by the end of 11th year, which returns to its initial value by performing the well field replacement (Figure 2a and b).
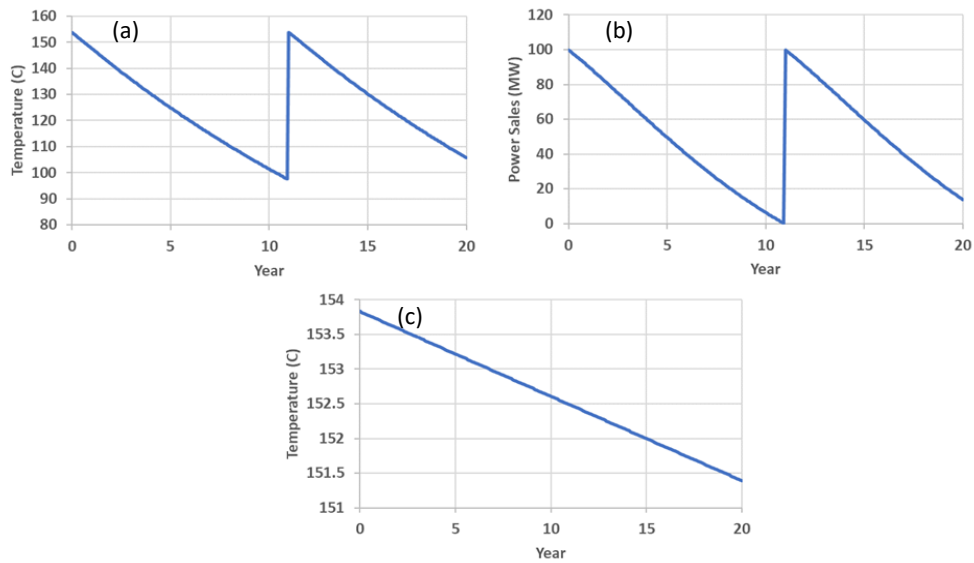
Figure2. Temperature and power sales profiles (isolated reservoir): a) EGS-binary scenario, b) EGS-binary scenario, and c) CAES-geothermal or wind/CAES-geothermal scenarios

The LCOE and the CO_2 emissions for all scenarios including the conventional geothermal, CAES-geothermal, and wind/CAES-geothermal are shown in Figure 3. Because of the well field replacement and the absence of fossil fuel consumption, the highest LCOE and the lowest CO_2 emission are observed in the EGS-binary scenario (73.4 ¢/kWh and 0 ton-CO_2/MWh, respectively), whereas among the CAES-geothermal scenarios, CAES-geothermal with McIntosh power plant technology has the lowest LCOE and emissions (30.8 ¢/kWh with 0.81 ton-CO_2/MWh). On the other hand, combining the wind with CAES power plants decreases the LCOEs and emissions of wind/CAES-geothermal scenarios significantly (3-4 times and 7-10 times, respectively). Among wind/CAES-geothermal scenarios, the one with McIntosh technology has the lowest LCOE (11.8 ¢/kWh with 0.13 ton-CO2/MWh), while the one with Adiabatic technology has the lowest emission (13.1 ¢/kWh with 0.09 ton-CO_2/MWh) because it does not consume any natural gas. Note that the lower power output of Adiabatic plant (≈59 MW) in comparison to other plants (97 MW for Huntorf and 98 MW for McIntosh), and the emissions due to the electricity bought from the grid (0.79 ton-CO_2/MWh) lead to the consequent higher LCOE and CO_2 intensity (51.1 ¢/kWh with 1.1 ton-CO2/MWh) for Adiabatic CAES-geothermal as compared to other CAES technologies.
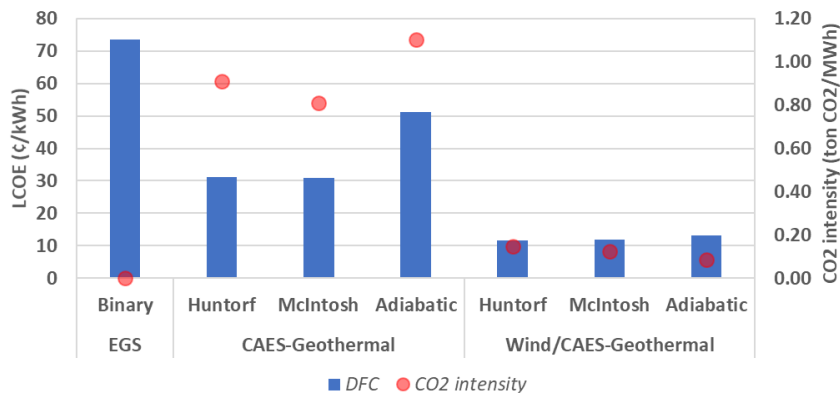

Figure3. LCOE for different technologies and working fluids.

Conclusions

This study provides a novel geo-energy approach to overcome major drawbacks of the traditional ways of exploiting wind and geothermal energy sources by their hybridization in HDR reservoirs. In this study, we developed a software (CAGEEM) in the VBA to find the best location of wind/CAES-geothermal

power plant across Alberta and performing techno-economic modelling for the future power plant of a wind and CAES in a typical HDR storage system. We considered several scenarios including CAES, wind/CAES, CAES-geothermal, wind/CAES-geothermal, and geothermal, where the EGS-binary power plant was the technology deployed in the geothermal scenarios, while for CAES three different technologies i.e., Huntorf, McIntosh, and adiabatic, were considered. Our benchmarks for the comparison of different scenarios were the LCOE and the CO_2 emission. The following results were obtained:

- The best locations in Alberta for hybridizing geothermal and wind energy sources is Lloydminster area.
- Building a geothermal power plant with current technologies (EGS-binary) led to a range of 70 to 75 ¢/kWh for the LCOE.
- With the assumption of drilling new wells, the wind/CAES-geothermal scenario with McIntosh technology outperformed other cases with 11.8 ¢/kWh and 126 g CO_2/kWh.
- Coupling the wind energy with CAES-geothermal plants have the capability to reduce the LCOE and emission by 70% to 80%.

References

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