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# A Case Study: Energy Hub

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**Abstract:** An energy hub is a grouping of various conversion, distribution, and storage technologies to bring various consumers of energy. The concept describes and manages the relation between input and output energy flows and can be used to optimize energy consumption.

**Keywords:** Various conversion, distribution, and storage technologies to bring various consumers of energy

## INTRODUCTION

In the past, different energy infrastructures have been operated separately in most cases. However, a trend towards rising integration can be observed in recent years. An example for this development is the rising number of distributed combined heat and power (CHP) plants, which establish a link between gas, electricity and, in some cases, district heating networks. The project "Vision of Future Energy Networks" at ETH Zurich aims at systematically analyzing systems that involve various energy carriers in order to design optimal structures for future energy systems in the long term. Within this project, the Energy Hub concept has been developed [1]. Usually speaking, an Energy Hub is an incorporated system of units that is able to convert and store multiple energy carriers. An illustrative example of an Energy Hub is shown in Fig. 1.

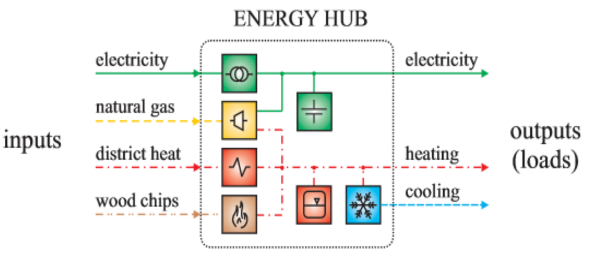


**Fig. 1: Example of an Energy Hub with the following elements: Micro turbine fired by natural gas, heat exchanger, wood chips furnace, heat storage and absorption chiller.**

In this paper, an Energy Hub is considered as a profit-maximizing generator that converts a certain number of input energy carriers into multiple output energy carriers. On the one hand, its elements can be viewed as multi-staged modular investment opportunities, i.e. a hub can be upgraded step-by-step with further elements. On the other hand, an Energy Hub provides operational flexibility in the sense that one output energy carrier can be provided by using different input energy carriers. In order to determine the monetary value of an Energy Hub including the value of the above described strategic options and flexibility, we use real options theory [2]. The real options approach has been applied to electricity generation assets as well as to cogeneration plants [3]-[5]. By modelling an Energy Hub as a real option, the real options approach is extended and generalized for an arbitrary number of input and output energy carriers. The remainder of the paper is structured as follows. Section 2 describes the methods and price models used for the real options analysis of Energy Hubs. Section 3 presents the results of a comparison between different hub configurations and a sensitivity analysis. Section 4 concludes the paper.

## METHODS

Following the approach of Cavus in [6], an Energy Hub is modelled as a series of call options. Owning an Energy Hub is analogous to disposing of a series of call options, where each option gives the right to generate energy carriers in exchange for paying the costs of the necessary input energy carriers and variable operation and maintenance costs. These choices represent a right and not an obligation because it can be decided not to generate energy if it is not profitable to do so. This means that Energy Hubs are able to profit from the upside potential of price uncertainty while they will not suffer to the same extent from the downside risk. In order to calculate option values, a Monte Carlo option model is used [7]. Monte Carlo methods are particularly suitable for complex valuation problems with multiple sources of uncertainty.

The Monte Carlo technique consists in simulating several thousands of possible price paths for input and output energy carriers. Price process models such as log-of-price mean reversion or the Pilipovic model, which assumes a two-factor representation of the price behavior, are assigned to the considered energy carriers. The option payoffs are calculated for each price path, averaged and discounted to a chosen date. In this way, the value of an Energy Hub is determined. Energy price paths are modeled as log-of-price mean reversion processes. Correlations between price paths of different energy carriers are taken into account applying the Cholesky decomposition to the correlation matrix.

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## RESULTS

At first, two different hub configurations are analyzed – a basic Energy Hub with a CHP unit and a more flexible Energy Hub being composed of a CHP and a gas furnace. The values of both hub configurations, which are characterized by the corresponding converter devices as well as the input and output energy carriers, are determined using the above described Monte Carlo method. These values are then compared with the investment costs for the respective configurations. By means of such an analysis, promising hub configurations for future energy systems can be identified.

Furthermore, sensitivity analyses with respect to factors such as the discount rate, the volatility of the electricity price and the correlation between electricity and gas prices are carried out for the basic hub configuration in order to determine the main parameters influencing the value of an Energy Hub.

## CONCLUSIONS

The option valuation model presented in this paper represents a generalization of real options applications to power generating assets or CHP plants. Using the Energy Hub concept, it is possible to model multi-generation plants with an arbitrary number of energy inputs and outputs as a series of call options. In so doing, the Energy Hub real options model can be used to identify prospective hub configurations for future energy systems given the uncertainty concerning the future development of energy prices.

In contrast to standard techniques for evaluating investment projects, such as the net present value method, the real options approach allows for including strategic and operational flexibility in the analysis. Although it might prove difficult to exactly estimate the parameters needed for real options analysis, the method provides also significant value in terms of qualitative insights. In this respect, the real options framework can serve as a guide for identifying crucial parameters for future investments in multi-energy generation plants.

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