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A critical review of Real Options thinking for valuing investment flexibility in Smart Grids and low carbon energy systems

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ABSTRACT

This paper aims at serving as a critical analysis of Real Options (RO) methodologies that have so far been applied to the flexible evaluation of smart grid developments and as a practical guide to understanding the benefits but more importantly the limitations of RO methodologies. Hence, future research could focus on developing more practical RO tools for application to the energy industry, thus making the utilization of powerful "real options thinking" for decision making under uncertainty more widespread. This is particularly important for applications in low carbon power and energy systems with increasing renewable and sustainable energy resources, given the different types of uncertainty they are facing in the transition towards a truly Smart Grid. In order to do so, and based on an extensive relevant literature review, the analogies with financial options are first presented, with various assumptions and their validity being clearly discussed in order to understand if, when, and how specific methods can be applied. It is then argued how option theory is in most cases not directly applicable to investment in energy systems but requires the consideration of their physical characteristics. The paper finally gives recommendations for building practical RO approaches to energy system (and potentially all engineering) project investments under uncertainty, regardless of the scale, time frame, or type of uncertainty involved.

Contents

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1. Introduction

1.1. Context

The energy and power system sectors are currently seeing a significant shift in the way energy is generated and transmitted to customers. Led by increasing environmental concerns and an ever-increasing dependence on energy, traditional high carbon-emitting plants are being replaced by low-carbon ones, and in many cases, are based on renewable sources such as wind, solar, wave energy, and so on. The fast and efficient integration of these renewable sources requires large infrastructure investments in new electricity generation, transmission and demand as well as flexible network management systems (the so-called "Smart Grid") [1]. These investments are usually subject to a number of different types of uncertainty, including techno-economic and policy changes brought about by deregulation and high levels of competitiveness [2], uncertainties in energy and carbon prices, demand evolution, technological advances, capital funding, financing models and an ever changing regulatory environment. All these uncertainties contribute to making strategic decisions extremely difficult and, as a result, make development of business cases uneasy for investments in low carbon energy systems. In particular, the irreversibility of these large capital investments increases the risk of asset stranding in the event that high uncertainty causes unexpected market conditions to materialize. A solution to this is to promote investment in non-network technologies such as storage [3–5], demand-side management (DSM) and demand response (DR) [6–9], FACTS [10,11], phase-shifters [12] and so on. These can help alleviate congestion by either shifting flexible loads from periods of high-energy demand and congestion to off-peak ones, by controlling the flow of power over the network, or act as a post-fault corrective action, thus enhancing the ability of the system to accommodate intermittent renewables [12]. In the context of planning under uncertainty, these flexible solutions can provide tremendous value in helping defer large irreversible investments until at least some uncertainty is resolved and the need for large capacity reinforcements is fully established [12,13]. Another such example of flexible investment to facilitate the development of high-efficiency low-carbon distributed energy systems can be found in [14]; in that work, it is shown how in order to optimally invest into complex smart multi-energy systems [15] and maximize the benefits that the interplay of several energy vectors can bring in terms of flexibility, it is critical to take into account different types of uncertainty (energy prices and loads, in primis) and respond by suitable investment over time, while uncertainties are resolved. Developing investment tools that can account for flexibility and uncertainty in such evolving energy scenarios as of today is therefore essential to encourage the deployment of cleaner and smarter technologies.

Real Options (RO) theory, based on financial option pricing theory, is an investment tool that has been proposed to specifically deal with investment planning under uncertainty. The recent application of RO theory to the profitability assessment of engineering projects, and more specifically to energy systems investment, is hence by no means a coincidence, as discussed in [16]. In fact, a robust RO approach is extremely valuable in a fast-changing energy context as it enables to identify possible flexible investment directions in the light of various uncertainties. It allows building a dynamic roadmap to decision-making in the case of future unforeseen events, thus minimizing exposure to risk, by considering the fact that management will act if conditions change over time. Nonetheless, RO are derived from financial theory, whose assumptions are often neither clear, nor understood or fully applicable when dealing with engineering problems. For instance, as it will be widely discussed later, the assumption that the uncertainty must follow a Wiener process limits the application of RO methods to more general problems, where the uncertainty may not follow a particular stochastic process. Another example involves the assumption of risk-neutrality and that the asset being valued is required to be traded on financial markets, thus limiting its application to non-traded assets. These all contribute to a misuse of "RO thinking" on the one hand, and to its limited adoption in industry due to lack of clarity on the other [17].

1.2. Contribution

This work presents a critical review of current RO methods applied to energy systems projects and, more importantly, explains their underlying assumptions so to create a framework of RO methods for a practical application to engineering. This is a key contribution to add clarity on many RO papers that often do not clarify the validity or sensitivity of their assumptions within the context discussed. The review is built on considering a framework based on the three levels of flexibility that, in our opinion, engineering RO are able to quantify, namely:

i) The value in having the flexibility over the project lifetime to *actively adjust* decisions based on future conditions.
ii) The value in having the flexibility to *wait* until at least some uncertainty is resolved before making an investment.
iii) The value in the ability to adapt to varying conditions by changing the system *design* of the project or investment [18–22]. This third type of flexibility is what truly separates RO from financial ones in an engineering context since the feature is simply not found in financial options.

As a result, this work aims at serving as a practical guide to any decision maker wishing to clearly understand how a RO approach can be useful and under what particular conditions it can be practically applied to engineering and in particular energy system investment projects, thus contributing to its wider adoption in industry.