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Real option valuation in renewable energy literature: Research focus, trends and design

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ABSTRACT

In light of intensive development of the renewable energy (RE) sector, a growing number of academic papers address the complexity of RE investment planning and valuation. To take account of the high-risk profile and irreversibility of RE investments, researchers have resorted to sophisticated real options (RO) approaches that enable flexibility to be incorporated into project design in the face of an uncertain environment. The variety of different frameworks and models adopted as well as a lack of aggregated analysis of the field suggest a need for a critical review of RO methodology and design in RE assessment. This study describes the research focus, trends and design found in contemporary academic literature devoted to RE valuation with a RO approach. Particular attention is given to RO in project and policy design. The results give a comprehensive picture of existing research on the topic, thus providing researchers with a solid foundation for further study and indications of directions for future development. Furthermore, the findings provide policymakers and project planners with valuable insights into key aspects of RE project and policy design.

1. Introduction

Climate change issues are receiving urgent attention from the global community, and mitigation of and adaptation to climate change is an essential part of national agendas. Among other measures, renewable energy (RE) development has considerable potential to reduce greenhouse gas emissions by replacing conventional fossil fuel based energy.

Global annual investment in renewable energy reached $286 billion in 2015, starting from four times less a decade earlier [1]. Such rapid growth owes a great deal to the widespread introduction of policies supporting renewable energy, which have been implemented in 146 countries around the world [2]. Nevertheless, investors in RE projects encounter many risks and uncertainties that have to be adequately evaluated and addressed to ensure investment profitability. RE projects in the power generation sector are characterized by relatively high upfront investment costs and lower operation and maintenance expenditures compared to conventional energy projects, which implies a high degree of irreversibility in the investment and has invoked a search for flexibility in project design. Projects in the bioenergy sector, in contrast, possess operational flexibility, seen in an ability to change raw material and fuels used, or an ability to modify output products in response to the volatile price environment. These features of RE projects have prompted decision-makers and researchers to employ real options (RO) approaches, which are able to value both uncertainty and flexibility in investment valuation and planning.

Several published reviews explicitly demonstrate a number of models and approaches to RO valuation design for renewable energy investments [3–6]. These papers, however, provide only a fragmentary overview, limiting their samples to a few selected studies and focusing on specific aspects of RE valuation. Moreover, a substantial number of papers published in recent years are absent from these reviews.

Therefore, in order to provide a more comprehensive picture of current research focuses, trends and designs, the current work aims to present a more thorough review of academic papers that apply RO approaches to renewable energy projects or policy valuation. The objectives of the paper are to review the body of scientific literature that considers real options approaches to renewable energy projects or policies, to describe the general research focus and trends in the field, to provide a comprehensive overview of the design methodology and models employed, to characterize cutting-edge research directions and to present implications for project planners and policymakers. The paper combines a state-of-the-art procedure for literature review, the strengths of existing reviews in the field and an exhaustive data sample. The work provides a cogent summary of the literature reviewed and

Abbreviations: B & S, Black and Scholes model; CCGT, Combined cycle gas turbine; CCS, Carbon capture and storage; DCF, Discounted cash flows; DP, Dynamic programming; FIT, Feed-in tariff; GBM, Geometric Brownian motion; EIA, Energy Information Administration; IEEE, Institute of Electrical and Electronics Engineers; MRP, Mean reverting process; NPV, Net present value; NRE, Non-renewable energy; O & M, Operation and maintenance; PDE, Partial differential equations; RD^3, Research, development, demonstration and deployment; RE, Renewable energy; REN21, Renewable Energy Policy Network for the 21st Century; RO, Real option

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results in a number of insights that may be of value in design of RO valuation of RE and of benefit to researchers and the interested public.

The paper is structured as follows. A brief description of the theoretical background follows this introduction part, after which the methodology of the study is described. The presentation and discussion of the results is divided into three subsections covering the topics of research focus and research trends, research design, and use of RO to enable operational flexibility in RE power generation projects. The paper ends by summarizing the key findings. An appendix is included that gives a tabulated summary of the key characteristics of the papers reviewed.

2. Theoretical background

Real options theory acknowledges managerial flexibility to adjust investment projects in the light of a future uncertain and changing environment. This flexibility refers to finding and incorporating real options into investment projects, or in other words, possible managerial actions that can reshape a project to adapt to changing conditions to maintain or enhance its profitability. By analogy with financial options, RO is a right but not an obligation. Hence, an investment project with RO is more valuable than one without, because it includes a capability of change to account for changing factors in order to maximize gains.

Traditional literature differentiates the following types of real options [7]:

1. *The option to defer* investment in order to get more information or to await technological development. This option is synonymous with an option to delay or postpone, or in broader sense, a timing option.
2. *The option to stage* investment to minimize risks. This option refers to breaking down the investment phase into several stages, thus enabling termination of later stages in the case of unfavorable circumstances.
3. *The option to abandon*. This option implies an option to stop or sell the project.
4. *The option to change scale*. This option allows managers to scale back or expand the project.
5. *The option to stop/restart* operations. This option provides flexibility to adapt to changing demand or other conditions.
6. *The option to grow*. This option enables managers to gain more if market conditions or other factors are more favorable than expected.
7. *The option to change inputs/outputs*. This option refers to an ability to change input materials or fuels or output products. A common example is flex-fuel vehicles.

Nowadays, the whole investment project is often treated as one real option [8–11], in which case it is usually termed an option to invest or, analogous to financial options, a call option.

A considerable body of literature is devoted to approaches to modeling and valuing real options, including reputable textbooks [7,12] as well as concise overviews in recent review papers [3,4,6,13]. Therefore, this paper does not present general discussion of development of the methodology from financial to real option valuation, instead, attention is drawn to commonly used techniques found in the reviewed literature. Here five main approaches are identified:

1. *Partial differential equations (PDE)*. Initially used for valuing financial options, the Black-Scholes formula [14] has been adopted for RO valuation. PDE, in general, are applied to formulate specific assumptions or different types of RO [12].
2. *Binomial trees* (or lattices) were initially presented by Cox et al. [15] as a binomial options pricing model. The approach represents a discrete-time model of asset price evolution with two (or more in advanced methods) alternative future outcomes in each step.
3. *Simulation*, in particular Monte Carlo simulation, creates a distribution of project values taking into account all given sources of uncertainty [16]. Monte Carlo simulation could be considered as the easiest way to value RO of complex projects, since it does not require formulation of cash flow through differential equations or trees. However, it appears to be the most computationally expensive approach.
4. *Fuzzy sets based approaches*. In recent years, some modern techniques to value real options have exploited fuzzy set theory, e.g. the pay-off method [17]. Modeling value distribution as fuzzy numbers allows advantages of simulation-based methods to be retained while reducing computational requirements. These methods have, however, not been widely adopted.
5. *Dynamic programming*. In addition to the above listed methods, some researchers use recursive optimization methods such as dynamic programming (DP) [18–20]. The approach allows the optimal timing of the investment to be found and enables different types of RO to be combined with various possible scenarios. The underlying idea behind the method is to compare the value of different investment realization scenarios with a so-called continuation value (the value of waiting and realizing the optimal scenario in future periods) moving backwards from the last period to the initial one. In each step, the value of the scenario is evaluated using one of the above-mentioned methods, e.g. PDE or simulation. As a result, the optimal solution and timing for the investment in an uncertain environment can be defined.

Since flexibility is only valuable in the presence of an uncertain environment, an important part of RO valuation is definition of the sources of uncertainty and modeling of their possible development. Again, a variety of methods can be applied. However, researchers most often utilize stochastic modeling, including geometric Brownian motion (GBM), mean reverting processes (MRP) or binomial trees that are discreet-time approximations of GBM. Some specific types of uncertainty require specific models, for example, uncertainty in technology cost and efficiency is usually modeled with learning curves. The interested reader is encouraged to visit [21] for a study on the fit of the aforementioned types of valuation models with different types of uncertainty.

As can be seen from the discussion above, many different types of RO exist and there are many different approaches to RO valuation, which explains the significant research design variability in the literature.

3. Methodology

This literature review follows the state-of-the-art practice proposed by the Webster and Watson [22] as well as incorporating the strengths of previously-published literature reviews in the field [3,4]. The reviewed papers are analyzed using several parameters, and the results are then presented in a quantitative form.

A three-part paper selection process was used to gather the relevant literature (Fig. 1).

The initial search in the SCOPUS database was limited by the following criteria:

1. A real option approach is used;
2. At least one type of renewable energy technology is evaluated;
3. The language of the article is English.

The following combination of key words was used as a search criterion: “renewable energy” and “real option”. With the language

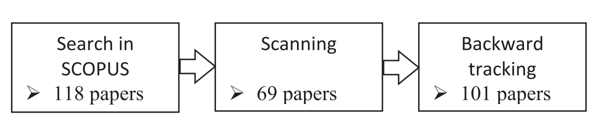

Fig. 1. Literature selection process.