

Review on Dissertation

Czech Technical University in Prague

Faculty of Mechanical Engineering, Department of Management and Economics

Ph.D. Programme	Mechanical Engineering
Student	Ing. Adam Hurta
Dissertation	Advanced Valuation of Grid-Scale Batteries on Real Options Theory
Supervisor	prof. Ing. František Freiberg, CSc.
Reviewer	prof. Ing. Marek Zinecker, Ph.D.
Workplace	Brno University of Technology, Faculty of Business and Management

This Ph.D. thesis review evaluates the timeliness of the topic idea, the definition and fulfilment of the research objectives, the theoretical background, the methodology, and the research results with emphasis on their contributions to the development of the scientific field and practice. An integral part of the evaluation is the formal and linguistic level of the thesis as well as its structure.

Timeliness of the topic idea

Current developments in the energy sector are taking place in the context of deregulation processes, the development of renewable energy sources, and the development of battery energy storage systems (BESS). The efficiency of investment in BESS technology is heavily burdened by high initial capital expenditure. In addition, projects are associated with a high degree of uncertainty that arises from the high level of volatility of energy prices and the problem of timing of investment. Therefore, traditional discounted cash flow-based valuation methods for investment projects appear inadequate in the BESS field. The importance of the issue on how to assess performance of BESS projects can be documented by the growing attention given to the topic in the international academic community. For the period 2020 to 2024 alone, a Google Scholar search for "battery energy storage and efficiency assessment" yields almost 17,000 publications (search conducted in June 2024). In this context, I consider the chosen topic of the Ph.D. thesis, which is focused on developing BESS valuation models, to be highly promising in terms of the potential to extend the current level of knowledge.

Theoretical background

The author relies on an extensive literature review including mainly scientific monographs and highly cited articles indexed in the Web of Science and Scopus databases. A total of 148 sources are cited in the reference list. This guarantees that the current level of knowledge is based on up-to-date and relevant literature. I consider the theoretical background of the Ph.D. thesis (Section I) to be appropriately structured and consistent in terms of the defined research objectives.

Chapter 1 provides an introduction to the BESS technology and its importance in the context of current developments (e.g., carbon neutrality in the EU, geopolitical issues, price arbitrage, and price predictions). In Chapter 2, a wide variety of studies focused on the optimal dispatch of BESS combined with the discounted cash flow (DCF) method is emphasized.

Chapter 3 deals with assessing the suitability of real option valuation methods (ROA) to BESS projects. The author discusses in detail the main theories of financial options, their different types, and then the main valuation techniques represented by partial differential equations (PDEs), lattices, dynamic programming (DP), and simulations. Finally, the most popular ROA methods are analysed in sub-Chapter 3.2.1, in particular, BSM, CRRM and MSC.

From a methodological point of view, I appreciated the inclusion of chapter 4, "Review of the literature on ROA applied to BESS projects", synthesising the current state on knowledge of ROA applied to grid-scale batteries. Similarly, inclusion of Chapter 5 facilitates orientation in multiple criteria decision analysis (MCDA) methods, which can be used to standardize the ROA method selection process.

In individual chapters, the author demonstrates his ability to work with relevant academic sources related to the subject of research. Hence, the literature review represents a convincing basis for determining the status quo of research and defining its subsequent issues, key objectives and sub-objectives with the highest degree of quality. I will allow myself only one minor recommendation for future scientific work of the Ph.D. candidate: At the end of the literature review, I would welcome the inclusion of a subsection, diagram or table synthesising the current state of knowledge and clearly delineating the research gap.

Ph.D. thesis objectives and methodology

The main research objective of the Ph.D. thesis is as follows: "Creation of an ROA-based framework for advanced capital investment valuation of BESS projects" (see page 39). Subsequently, properly-structured sub-objectives supporting the fulfilment of the main objective are set. The research hypotheses (page 40) are based on a comprehensive review of the literature (Section I).

In Chapter 6.5 (page 42), the structure of Section II is described. This supports the orientation in the direction of the research and its design.

The author used a wide range of research methods (content analysis, experiment, and case study approach) that support the achievement of defined research objectives. Both qualitative and quantitative data were used. The source of quantitative data was the Energy Exchange of Austria (EXAA). Here, I would like to point out that, unlike the author who refers to this data as primary data, I am of the opinion that data gained from databases are of secondary nature.

The "BESS Valuation Framework" and "ROA process" schemes (page 44) showing the obvious weaknesses of DCF methods, as well as the contribution of the ROA approach should be appreciated. The complementarity of ROA and DCF for the valuation of BESS projects is well

documented in Fig. 4.

I am convinced that the author has demonstrated his ability to link the research objective with the methods used. He works systematically, and the methods applied are appropriately used.

Fulfilment of the research objectives

The Ph.D. thesis results, i.e. the fulfilment of the research objectives and answering of the research questions, are presented and discussed in Chapters 7 to 11.

Chapter 8 deals with the BESS dispatch problem, which is solved with the MILP (mixed-integer linear programming) model developed by Hurta *et al.* (2022). Before formulating the model, a set of assumptions is defined (page 46). Two scenarios are considered: Scenario 1 (MILP model without battery degradation process) and Scenario 2 (MILP model with battery degradation process). In Chapter 9, components critical for ROA applied to BESS projects are discussed, more specifically, the price and volatility of the asset. In the following Chapter 10, a set of eight assessment criteria is defined to select a suitable ROA valuation method for projects in the energy sector. The selection of the criteria is appropriate and justified with reference to relevant sources.

The author used a real-world case study to verify the proposed valuation framework shown in Fig. 4. This methodological approach has proven to be a powerful tool that can demonstrate the practical value of the proposed methodology. Based on the calculations provided by the author, the decision to invest in the BESS project is rejected in Scenario 1 (BESS dispatch ignoring the battery degradation process), while in the case of Scenario 2, when the battery degradation process has been considered, the MILP model has significantly improved financial assessment of the investment. Finally, the research results from Scenario 2 were used in Scenario 3 to calculate the value of waiting and determine the optimal timing of the investment. In this context, the volatility of the project cash flow had to be determined before the CRRM was designed. The resulting lattice for the underlying asset, the lattice for the determination of the option value, and the investment recommendation for the lattice are visualised in Figs. 19, 20 and 21.

In Section III, the author takes a position on the achievement of the research objectives and research questions and evaluates the validity of the formulated hypotheses.

After studying the individual parts of the dissertation, I can conclude that the submitted Ph.D. thesis provides answers to all formulated research questions, the objectives of the thesis are gradually fulfilled in the scope of Chapters 7 to 11, and the verification of the research hypotheses is discussed in Subchapter 12.3. One recommendation may be needed here to address the issue to explicitly include discussion of research results and their limitations in Section III, referring appropriately to previous studies representing the basis for the comparison of the achieved results in future scientific works of the author.

Contributions to the development of the scientific field and practice

The results of the Ph.D. thesis contribute significantly to our understanding of ROA-based frameworks for advanced capital investment valuation of BESS projects, which can be used by both researchers and practitioners.

Presentation and language

The Ph.D. thesis meets high standards in terms of structure and language used. It is written in a coherent and academic formal style. Citing primary and secondary sources of information is appropriate.

Questions

The author suggests that an intriguing avenue for follow-up research could represent the analysis of BESS projects under the existence of the interconnected European electricity market. In the discussion, could the Ph.D. candidate highlight the importance of this stream of research in the light of the current geopolitical and economic developments? What would be the main assumptions for solving this research problem?

Conclusion

In the submitted Ph.D. thesis, the author has demonstrated the ability to conduct independently in scientific research, i.e., in particular the ability to think critically and to apply a scientific approach. The main research objective has been achieved. The results presented contribute to a better understanding of ROA-based frameworks for advanced capital investment valuation of BESS projects.

On the basis of the above, I conclude that the Ph.D. thesis meets the requirements of Section 47(4) of Act No. 111/1998 Coll., on Universities, as amended.

The candidate has demonstrated his creative abilities in the relevant research area. I recommend the dissertation for defence.

Brno, 6 June 2024

prof. Ing. Marek Zinecker, Ph.D.