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THE DOCTORAL THESIS EVALUATION REPORT

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Supervisors: prof. Ing. František Freiberg, CSc.
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Opponent: doc. Ing. Tomáš Macák, Ph.D.
Title of the dissertation:

Advanced Valuation of Grid-Scale Batteries Based on Real Options Theory

Syllabus of Review:

1. Achieving the set goal
2. Level of analysis of the current state of knowledge
3. Theoretical and practical contributions
4. Appropriateness of the used methods
5. Correctness of the used methods
6. Demonstration of relevant knowledge
7. Formal level of the thesis
8. Final recommendation

In the introduction to the dissertation assessment, I allow myself a small explanation of the opponent's approach to this thesis. At the end of 2023, I had the opportunity to familiarize myself with the 2023 version of this dissertation. This new version of the 2024 dissertation brings improvements over the previous version. The improvement consists of the inclusion and clarification of notes and the further development and refinement of the content. Thus, this assessment is based on the latest dissertation thesis version and considers any improvements made since the previous assessment.

1. Achieving the set goal

The primary objective of the dissertation is defined in Chapter 6, "Goals," and its wording is as follows: "creation of a real options analysis (ROA) based framework for advanced capital investment valuation of BESS project. Subsequently, three research questions and three hypotheses to answer them are specified.
In my opinion, the main objectives are achieved through Chapter: II. BESS Valuation Framework – Results of the research.

2. Level of analysis of the current state of knowledge

The current state of knowledge of the solved subject is described in enough detail in the first chapter, Theoretical Background, which represents the present state of knowledge. This research provides the necessary information base for the formulation of research questions. Regarding the origin of the used resources, mainly foreign funds are used. Thus, the solution presented in the proposal part of the dissertation thesis uses globally accepted knowledge.
The chosen dissertation topic is highly relevant. For example, in the Web of Science database, there are 370 articles published on the issue of grid-scale energy storage systems and 656 articles on real options analysis over the last five years.

3. Theoretical and practical contributions

The main objective is to create a framework based on ROA analysis for valuing capital investments in BESS (Batteries Energy Storage Systems) projects. This objective is relevant when the importance of renewable energy sources and the need for efficient energy storage is increasing.

This part also specifies three research questions and three hypotheses, which undoubtedly contribute to a deeper understanding of the issue. The main theoretical contribution lies in creating an investment framework and answering these questions, which can provide valuable insights for further research.

The implementation of two practical scenarios through case studies underscores the practical significance of the dissertation thesis. These scenarios could potentially translate the theoretical findings into tangible applications and guide strategic investment decisions in Grid-Scale batteries.

4. Appropriateness of the used methods

The dissertation methodology includes a complex mix of methods suitable for the stated research purposes. By combining qualitative and quantitative approaches, you can provide a balanced analysis that removes subjectivity and numerical oversimplification in a homomorphic investment decision model.

In concrete terms, the multi-criteria decision analysis (MCDA) method is particularly suitable for evaluating complex decision-making scenarios, such as those associated with investment decisions for battery energy storage (BESS). MCDA allows multiple criteria and preferences to be taken into account, which is key when evaluating investment options in renewable energy sources.

On the quantitative side, using ARCH (Autoregressive Conditional Heteroskedasticity) and GARCH (Generalized Autoregressive Conditional Heteroskedasticity) models for volatility analysis is a robust choice. These models are commonly used in financial econometrics to capture the time-varying nature of volatility, which is essential for risk assessment in investment projects. In addition to the above, using Discounted Cash Flow (DCF) methods alongside Real Options Analysis (ROA) provides a comprehensive framework for evaluating investment opportunities. DCF methods help assess the present value of future cash flows, while ROA allows flexibility and uncertainty to be incorporated into investment decisions. The combination of these methods offers a solid foundation for theoretical analysis and practical application in the context of battery storage and electricity sales from renewable sources. Utilizing diverse analytical tools, you can effectively address the complexities associated with the presented research topic and generate valuable insights for stakeholders in the energy industry.

5. Correctness of the used methods

The MILP (Mixed Integer Linear Programming) model to solve the BESS problem represents a robust approach with a theoretical contribution. The MILP model can provide a comprehensive and optimized solution for constraint problems, crucial for investment decisions in battery energy storage.

Regarding hypothesis testing, the author has relied on literature reviews and case studies instead of traditional statistical significance level testing. This approach can be relevant, primarily if the hypotheses are related to causal relationships and are not easy

to test using conventional statistical methods. Causal verification can provide a deeper understanding of the relationships between premises and hypotheses and can be considered a more robust approach than statistical verification alone. A thorough analysis of causal relationships can yield valuable insights and confirm the validity of these hypotheses.

From my point of view, the author has chosen adequate and relevant methods that correspond to the specific needs and nature of multidisciplinary research.

6. Demonstration of relevant knowledge

In the level research part of the dissertation, the doctoral student demonstrated extensive knowledge in systems engineering, financial management, real options theory, and corporate management, which he then applied by designing his own models for investment evaluation.
Due to these capacities, it was possible to create a dissertation that provides a clear theoretical overlap in addition to practical use.

7. Formal level of the thesis

The dissertation is carefully prepared in content and form and meets the requirements for doctoral theses. The author also uses understandable and cultured language and complies with the citation standard. All figures and tables are properly numbered.

8. Final recommendation

The author creatively approached framework design for efficiency in the investment and trading activities within the battery energy storage system (BESS) and created work with a high level of expertise in the proposed solution.

In conclusion, it is possible to summarize the evaluation report.

Dissertation "Advanced Valuation of Grid-Scale Batteries Based on Real Options Theory" I have studied. I recommend its defense before the Dissertation Commission at the Faculty of Mechanical Engineering at CTU in Prague. After its successful mastering, I recommend granting a Doctorate (PhD).

In terms of the formulation of the results achieved dissertation has two questions:

1. What is your opinion on the practical applicability of your grid-scale ROA-based battery investment framework and methodology in the actual industry? What are the main advantages and limitations of this approach?

2. Can you clarify how you identified and evaluated the causal relationships between the various variables in your MILP model? How did you ensure that these relationships were relevant and correctly captured for valuing investments in the BESS project?

In Prague, 16/04/2024

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