

MOTIVATION

Battery energy storage systems (BESS) offer satisfactory parameters of storage; however, high initial capital cost has been restricting more significant spread of the technology. The effect of high capital cost is worsened by the inadequate valuation processes used for this type of investment. BESS projects are implemented under high uncertainty, stemming mainly from high volatility of energy prices. At the same time, management typically possesses flexibility when it comes to the scope and timing of BESS projects. Real options analysis (ROA) recognizes both uncertainty and flexibility inherent in these types of projects, and offers an enhanced method of valuation. This dissertation recognizes importance of both the discounted cash flow (DCF) and ROA methods, and develops a valuation framework covering both approaches, designated specifically for BESS projects.

GOALS

The main goal of this dissertation is the **creation of an ROA-based framework for advanced capital investment valuation of BESS projects.**

To meet this goal, the following sub-goals are considered:

- Create an optimization program for a dispatch of BESS to maximize the NPV of the investment, which can then be used as one of the inputs for ROA.
- Consider popular ROA methods in the proposed valuation framework and provide a method for selecting the suitable method for valuation of a BESS project, based on specific valuation requirements.
- Verify functionality of the created framework through its application to a real-world business case.

METHODS OF RESEARCH

The dissertation employs both qualitative and quantitative data. The qualitative secondary data was collected in the form of literature review. Quantitative primary data came from the Energy Exchange of Austria (EXAA), which is used as the source for day-ahead prices of electricity. The main research methods of the present study are a literature review, experiment, and case study.

In the experiment, causation between project value as a dependent variable and independent variables, such as battery parameters or electricity prices, are examined. The literature review provides an overview of the existing methods and gaps in the research field, analyzing and synthesizing the collected scholarship in the context of the present study.

Case study methodology is used not only to demonstrate the functionality of the proposed valuation framework with real-world data, but also to help answer the defined research questions.

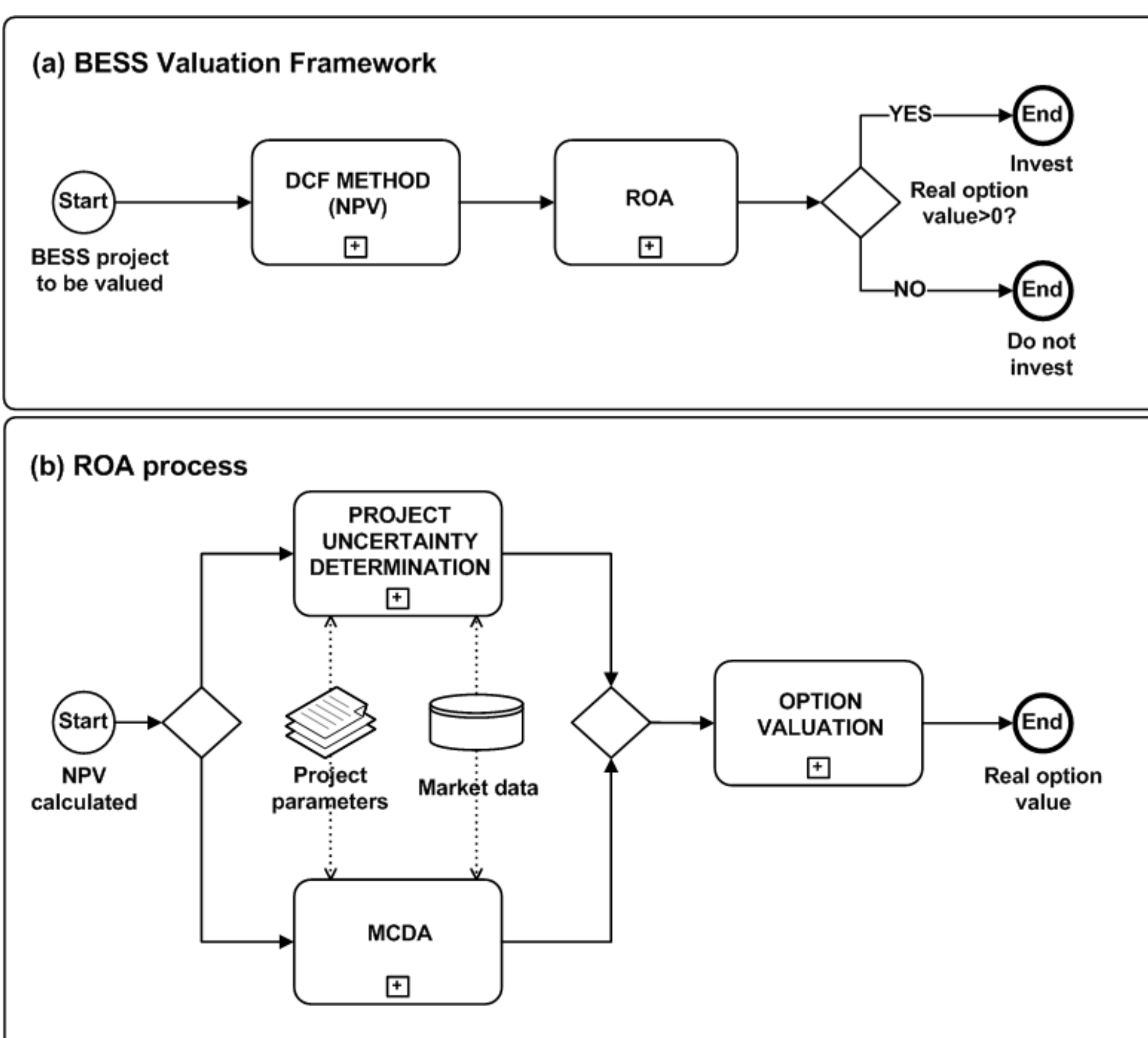


Fig. 1. BESS Valuation Framework: (a) High-level view of the valuation framework; (b) ROA process in detail.

RESULTS

DCF process – BESS dispatch problem

- After the introduction of the battery degradation process the mixed-integer linear programming (MILP) model has substantially improved financial expectations from the investment.
- NPV of the investment improved from -86566 EUR in Scenario 1 to -15635 EUR in Scenario 2 - compare Fig. 2 with Fig. 3. The results are presented in Table 1.

ROA – MCDA

- Using the multi-criteria decision analysis (MCDA), the group of five experts selected the Cox-Ross-Rubinstein model (CRRM) as the most preferred method, followed by the Monte-Carlo simulation (MCS) and the Black-Scholes model (BSM).

ROA – CRRM

- A total of 1000 simulations using MCS were performed to generate the expected future realizations of the electricity price.
- Ten (10) out of the 1000 simulations performed are plotted in Fig. 4.
- The resulting cash flows are plotted in Fig. 5.
- The decision tree in Fig. 6 shows that it is not optimal to call the real option prior to its termination date.
- The created valuation framework proved to value the BESS project.

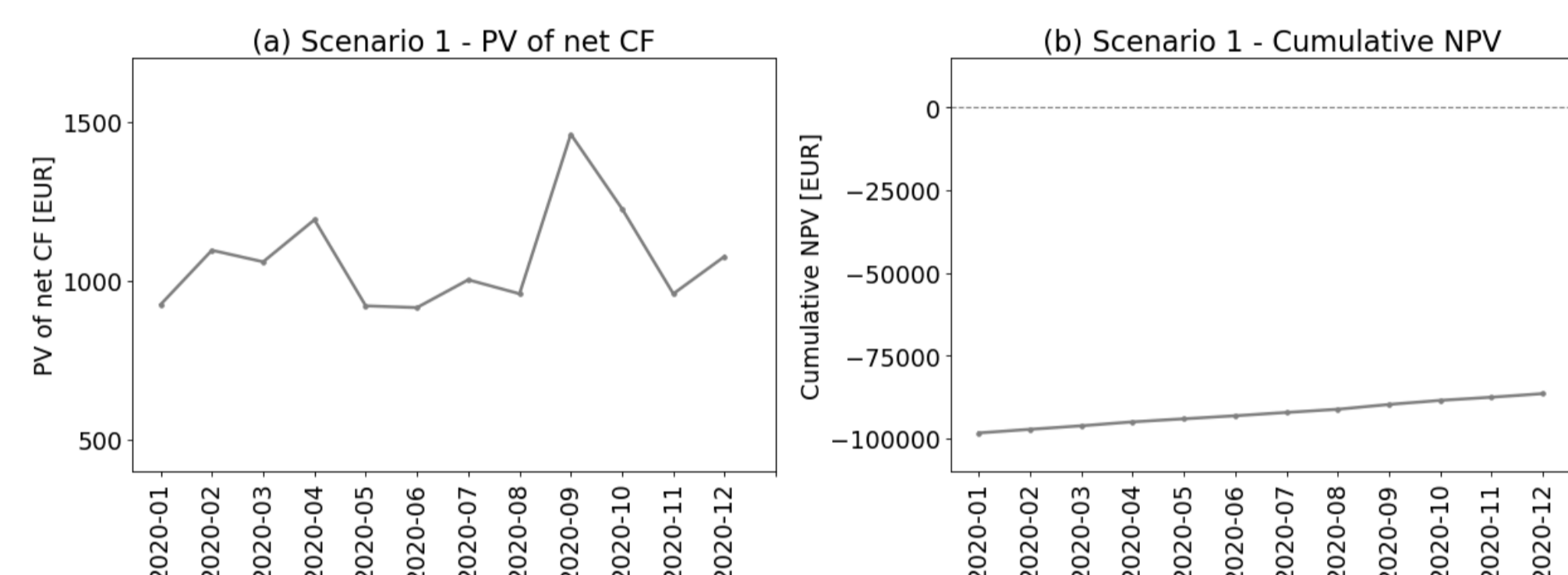


Fig. 2. Scenario 1 – Discounted net cashflow and cumulative NPV from a BESS dispatch ignoring the battery degradation process in the dispatch model.

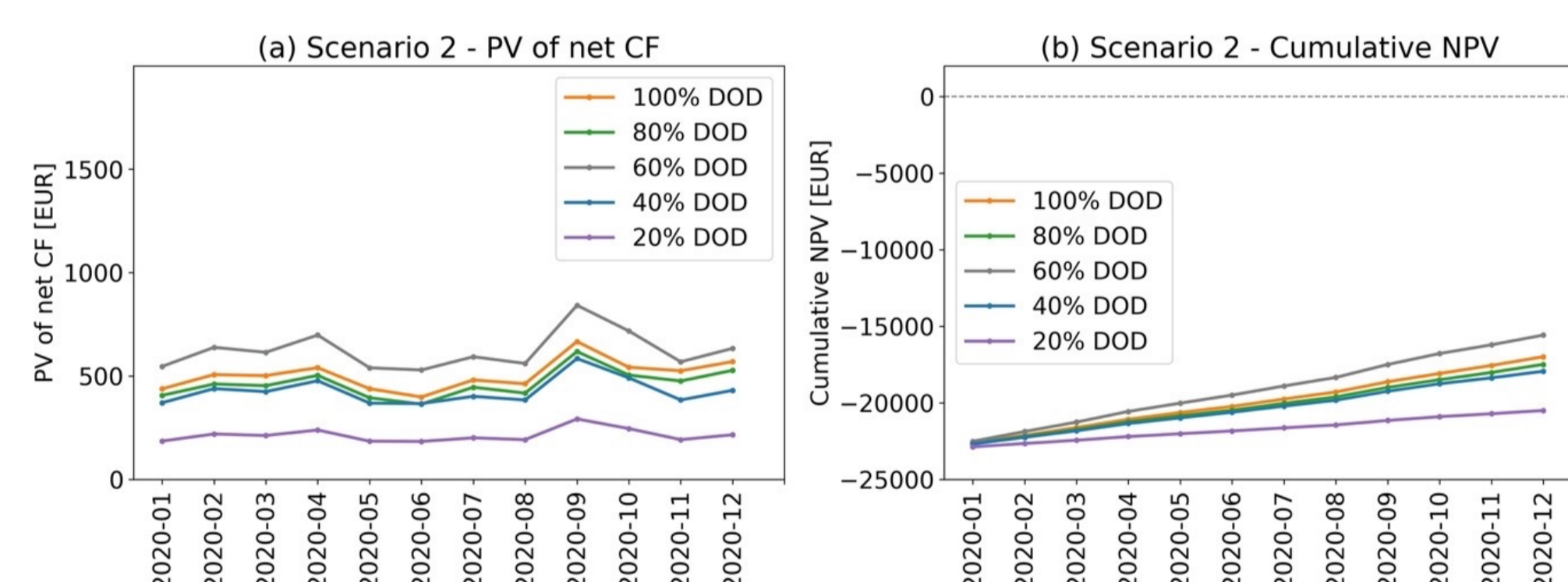


Fig. 3. Scenario 2 – Discounted net cashflow and cumulative NPV from a BESS dispatch respecting the battery degradation process in the dispatch model. Sensitivity of the dispatch model to DOD.

	Scenario 1	Scenario 2
Accumulation [MWh]	806	402
Generation [MWh]	774	387
Sum of net CF [EUR]	12794	7480
NoC(T)	748	626
NoC(T)/CL	0.288	0.062
T/RL	0.067	0.067
NPV [EUR]	-86566	-15635

Table 1. Comparison of BESS dispatch between Scenario 1 and Scenario 2.

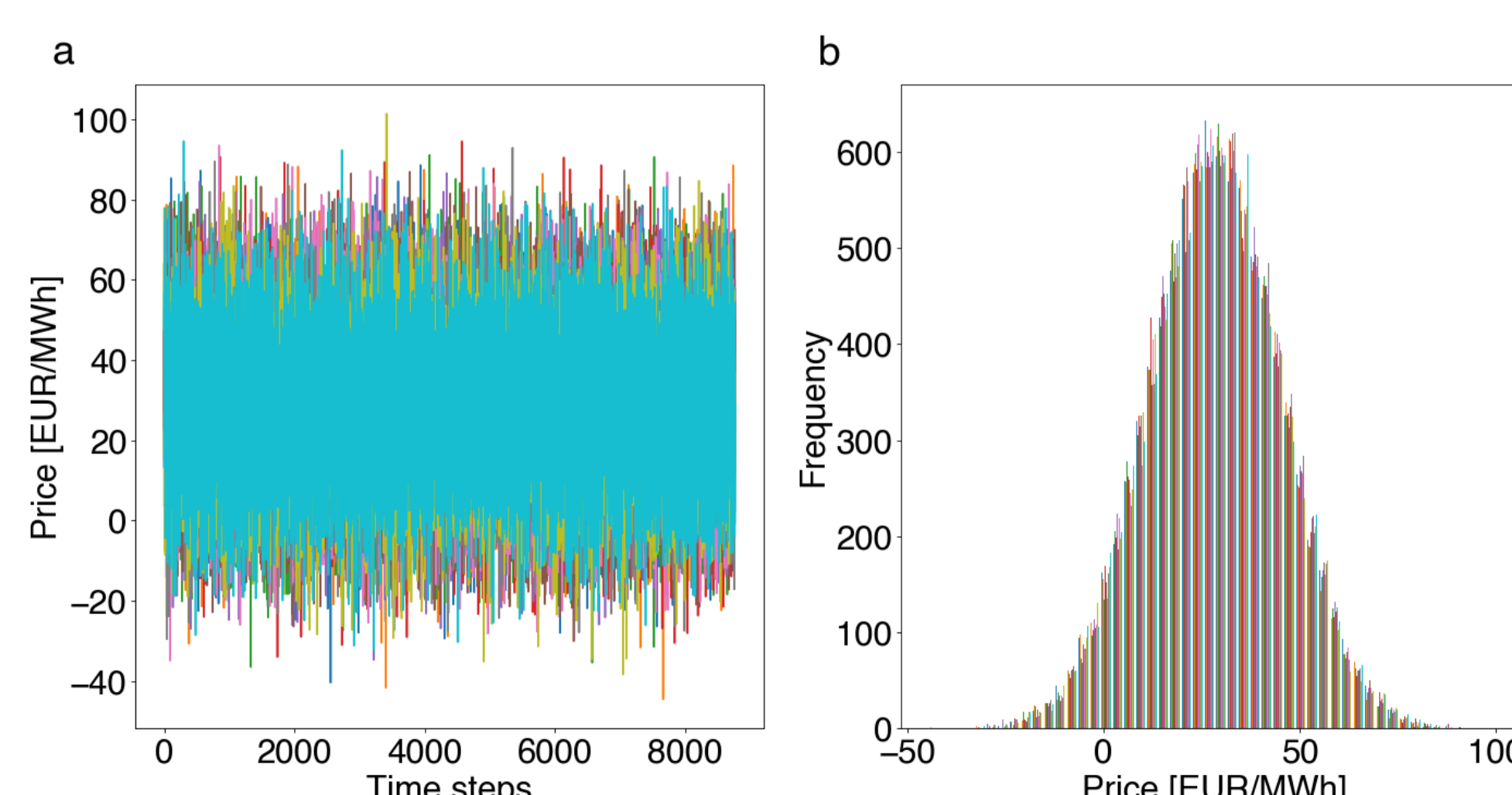


Fig. 4. Simulations (totaling 1000) of the day-ahead price based on MRM: (a) Price plot of 10 simulations; (b) Histogram of 10 simulations.

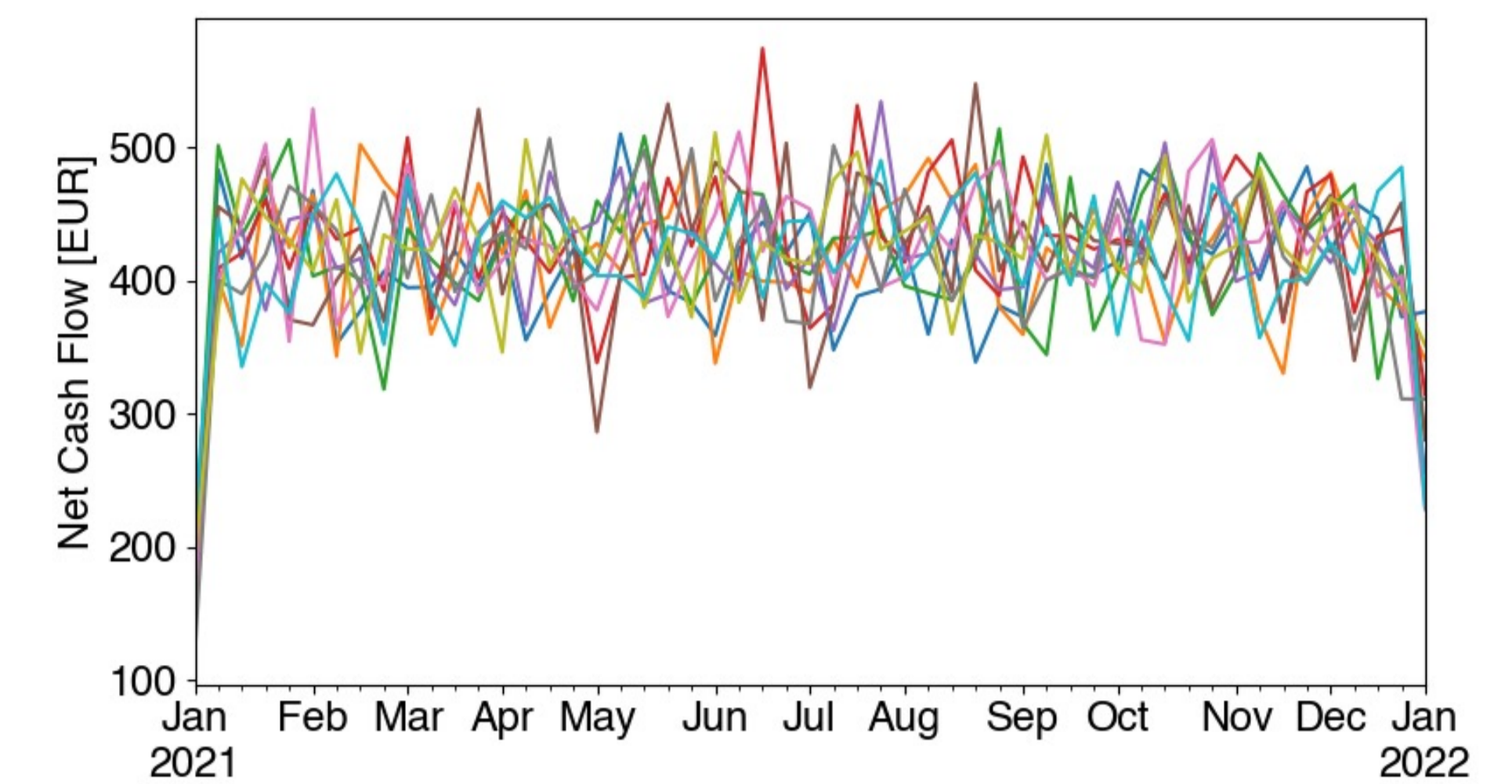


Fig. 5. Scenario 3 – Net Cash Flow of 10 out of the 1000 simulations.

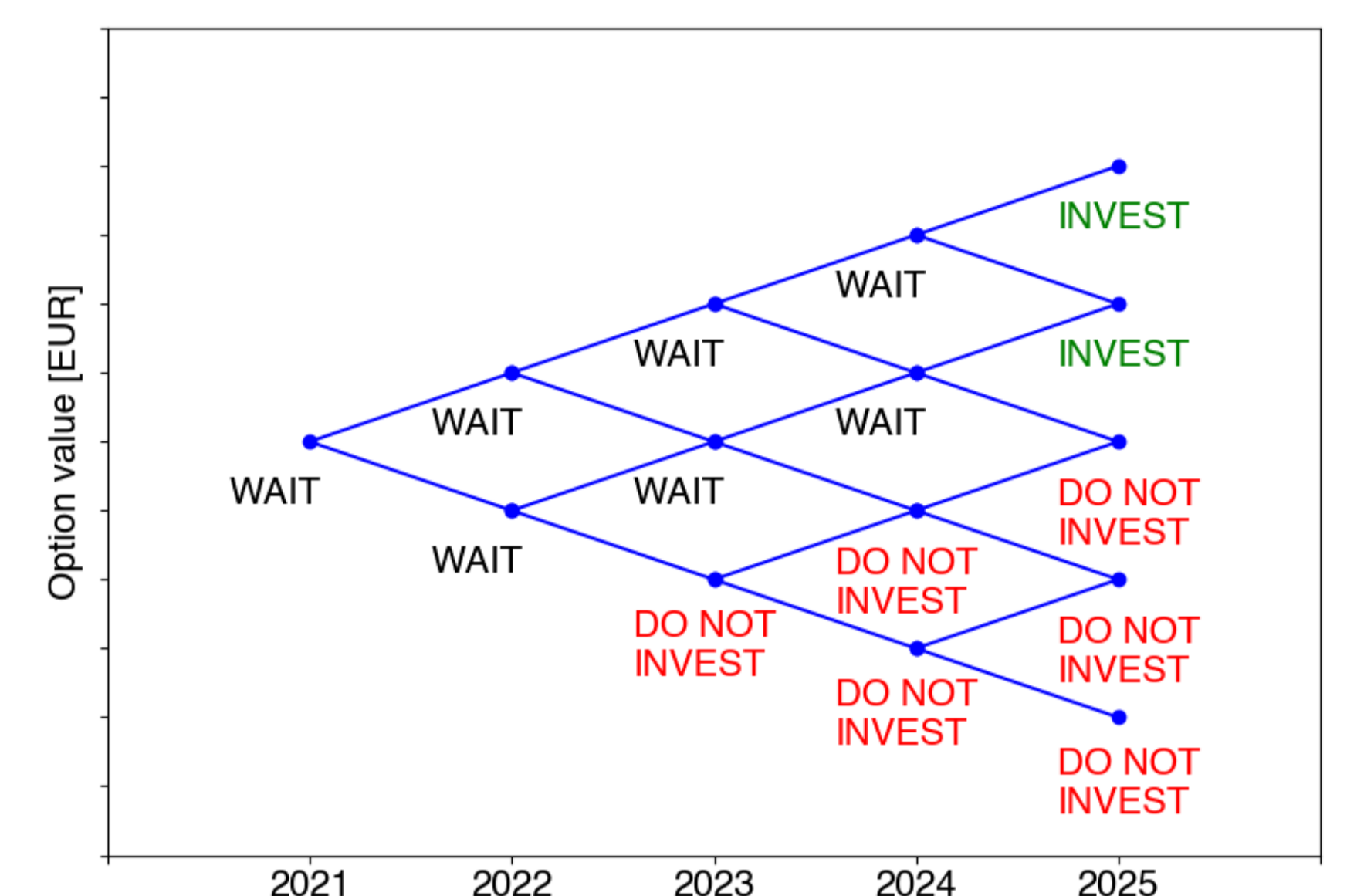


Fig. 6. Scenario 3 – Decision on the investment.

CONCLUSIONS

In the dissertation, the ROA-based framework for advanced capital investment valuation of BESS projects has been created. The program for dispatch of a BESS was defined with two versions of the MILP model, where the initial MILP maximizing net cash flow of a project was extended with a battery-degradation process in the second, more advanced, MILP. The extended version of the model was subsequently used as an input for ROA in the case study. MCDA was proposed as a suitable selection method for ROA model. Eight assessment criteria were determined, based on the in-depth literature review. The case study confirmed that the proposed valuation framework is functional and that it can be used to value a BESS project considering the battery degradation process, and the inherent uncertainty of the project.

PUBLICATIONS

Hurta, A., Žilka, M., & Freiberg, F. (2022). Impact of the splitting of the German–Austrian electricity bidding zone on investment in a grid-scale battery energy storage system deployed for price arbitrage with gray and green power in Austrian and German day-ahead power markets. *Energy Reports*, 8, 12045-12062. <https://doi.org/10.1016/j.egyvr.2022.09.045>. Share of the author Adam Hurta is 60%. WoS Journal Impact Factor 2021: 4.937; Scopus CiteScore 2022: 5.6.

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