Combined Prospective Economic and Environmental Assessment of Energy Technologies Using the Example of Hybrid Battery Storage Systems

Clemens Willenbrock, Patrick Draheim, Henning Wigger, Camilo Gomez, Urte Brand, Thomas Vogt

German Aerospace Center (DLR), Institute of Networked Energy Systems, Carl-von-Ossietzky-Str. 15, 26129 Oldenburg, patrick.draheim@dlr.de, +49 441 99906 157

I Motivation and goal

The assessment of energy technologies is becoming more demanding:

- Increasing relevance of the environmental dimension and environmental life cycle assessments (LCA)
- Higher complexity (e.g. sector coupling, decentralized renewables)
- Prospective consideration of future costs, revenues and market developments
- Extensive life cycle costing (LCC) and identification of cost drivers

Whereas several established frameworks dealing with LCA exist (e.g. Brightway2), there is a lack of standardized economic assessment frameworks.

Thus, an economic assessment model is developed, including LCC, capital budgeting, sensitivity and prospectivity methods, enabling an integrated economic and environmental analysis.

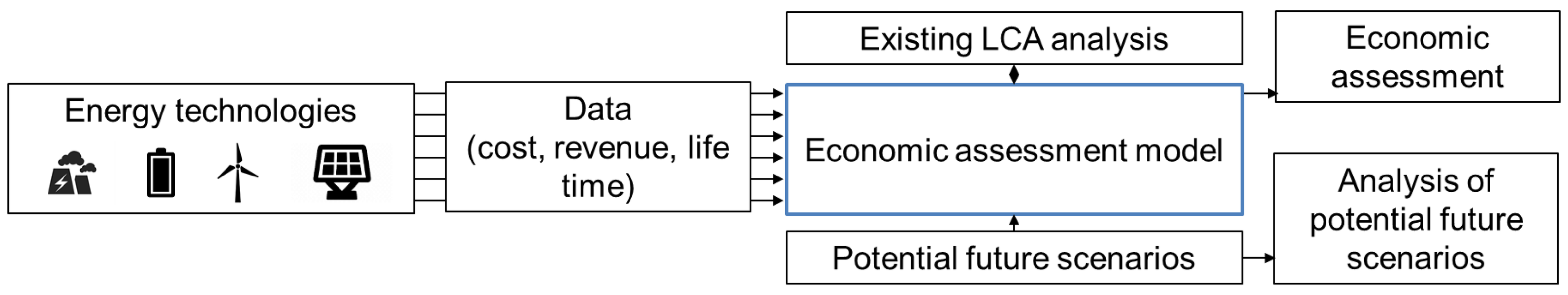

Fig. 1: Structure, components and relationships of a combined economic and environmental assessment [own source]

II Economic assessment

In order to systematically record the costs and revenues and their changes over time, a LCC approach is used for the object breakdown, gathering and storing data. This LCC method divides the object considered into three dimensions:

- The different life cycle phases (installation, operation, end-of-life etc.)
- The components of the object (e.g. battery, electric boiler, inverters)
- The different cost types (personnel, material, tax etc.)

Based on the LCC data, capital budgeting indicators are used for the economic assessment, e.g.:

- Net present value (NPV)
- Internal rate of return (IRR)
- Levelized cost of energy (LCOE)
- Levelized cost of storage (LCOS)

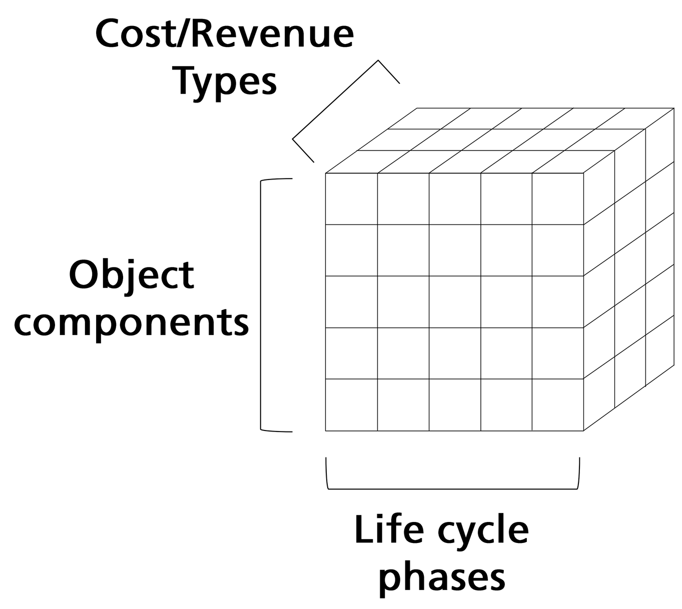

Fig. 2: Cost element concept according to DIN 60300-3-3 with the dimensions 'phase', 'component' and 'cost type' [based on 1]

III Energy technologies

In order to enable a feasible general assessment model, the term "energy technologies" needs to be narrowed down.

Looking at the "life cycle of energy" depicted in Fig. 3, the model focuses only on technologies within the first two phases: 'generation and transformation' and 'storage'.

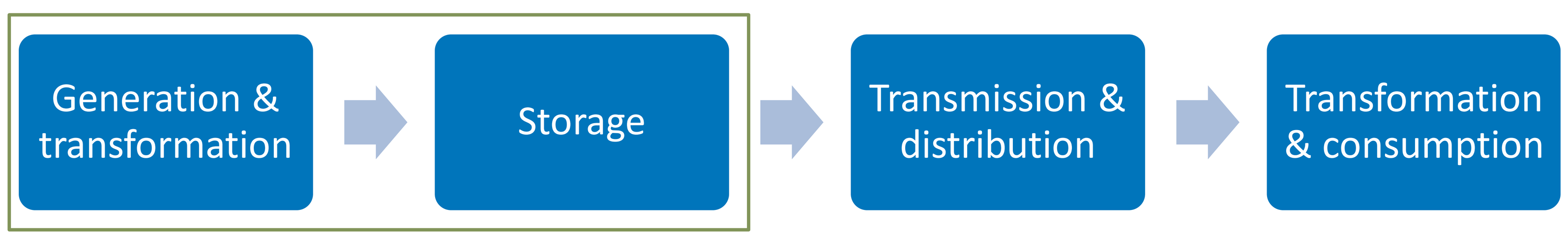

Fig. 3: "Life cycle of energy" and the phases of the technologies considered in the model [based on 2]

IV Economic assessment model

The assessment model works in three steps:

IV.1 Definition of the LCC breakdown structure

Based on the DIN 60300-3-3, six phases are defined across all applications (conception, development, manufacturing, installation, operation, end-of-life). For the product breakdown structure the top two levels are generally defined as shown in Fig. 4, whereas the lower levels can be defined according to the energy technology assessed.

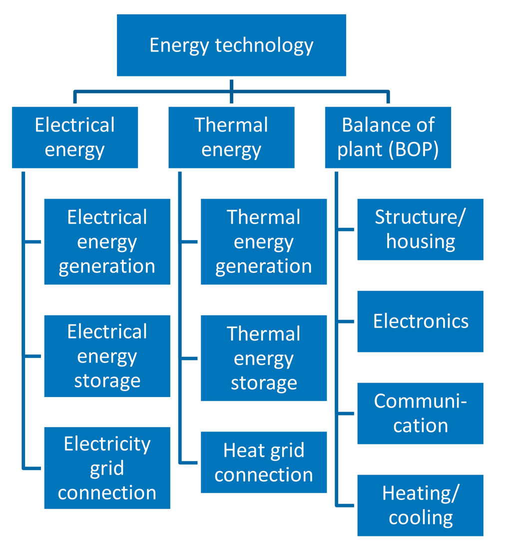

Fig. 4: General product breakdown structure for energy technologies [own source]

IV.2 Data input into the individual data structure for the energy technology

Next, the actual cost and revenue data as well as information on the assumed lifetime and interest rate need to be gathered. This information is provided to the model in the structure established in the previous step.

IV.3 Evaluations, visualisations and prospective analysis

Once the structure is set and all data is allocated, the model can be used to assess the economic capital budgeting methods and deliver the results.

V Application example: hybrid battery storage

In order to demonstrate the model, a existing hybrid battery storage system (HyReK) is used. This system consists of a lithium battery storage coupled with an electric boiler and supporting electronics such as a power inverter, and is integrated in the electricity grid and local district heating grid. The system can flexibly deliver frequency containment reserve and benefits from lower battery costs due to the electric boiler.

According to the three steps of the model, the hybrid battery storage technology is modelled in terms of its LCC breakdown structure. Where possible, real world data is inserted into the model, and missing data are scientifically estimated.

VI Results

First, the costs can be evaluated and visualized aggregated by the product breakdown structure as can be seen in Fig. 5. This enables easy and simple analyses of cost drivers and optimization potentials. The level of detail can be adapted by changing the amount of layers of the breakdown structure analysed.

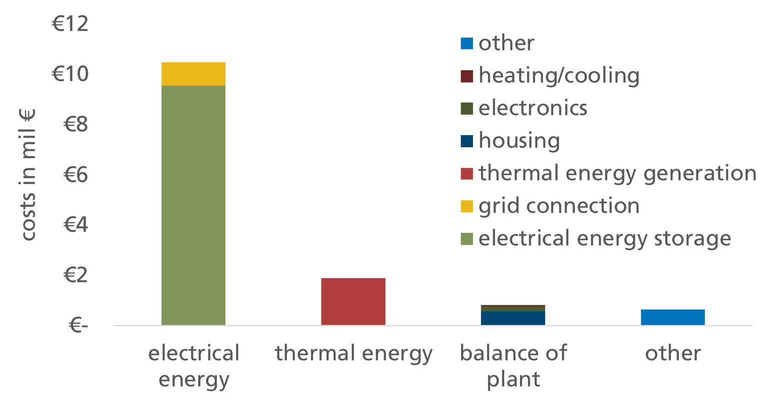

Fig. 5: Discounted component costs determined in the economic assessment [own source]

To assess the economic value of the energy technology, revenue data can be included and evaluated together with the cost data for example by cost/revenue type (Fig. 6) or time (Fig. 7).

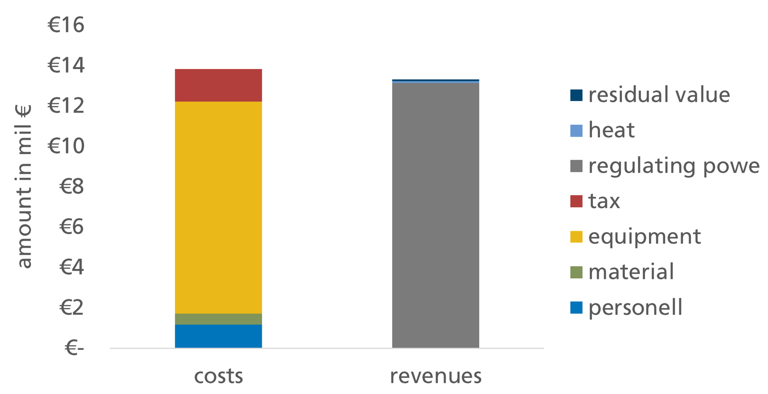

Fig. 6: Discounted costs and revenues by type [own source]

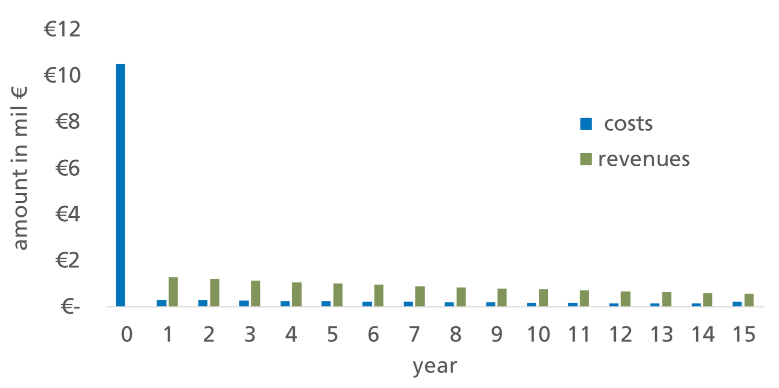

Fig. 7: Discounted costs and revenues by year [own source]

Finally, the data can be used to conduct sensitivity analyses to evaluate the impacts of future developments or uncertainties. In Fig. 8, the impact of changes in battery cell costs on the NPV was evaluated, showing a break even point at a battery cost reduction of approx. 12%. Also the economic and environmental assessments can be connected to conduct combined assessments, including results from other works for example through an eco-efficiency analysis of different operating strategies of the HyReK in Fig. 9.

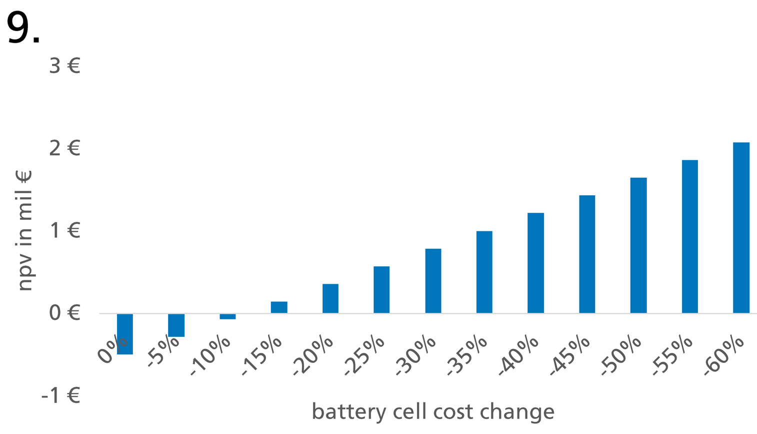

Fig. 8: Sensitivity analysis: Impact of battery cell cost reduction on total NPV [own source]

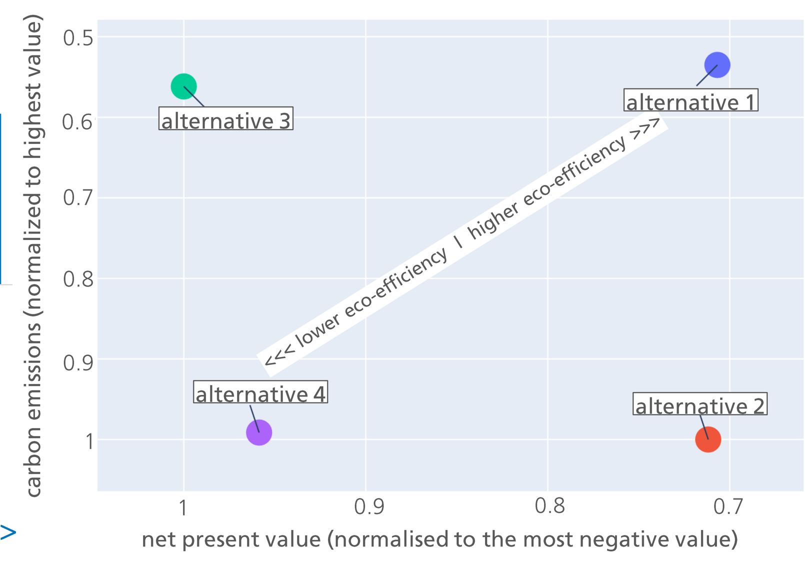

Fig. 9: Eco-efficiency of different operating strategies of the HyReK related to NPV [own source and 3]

VII Conclusion and outlook

To obtain a holistic view on energy technologies both economic and environmental aspects need to be assessed with a structured and standardized approach.

The presented model delivers reliable results and poses a first step towards integrated economic and environmental assessment modelling of energy technologies. Upcoming steps include:

- Further prospectivity analyses (e.g. Monte Carlo)
- Additional methods of combining economic and environmental assessment results

Acknowledgement

This work has been funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) under the grant no. 03ET6147C and is part of the project "HyReK 2.0 – Hybrid Regulating Power Station".

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

LCM 2021

[1] DIN 60300-3-3, 2005: Zuverlässigkeitsmanagement
[2] Subramanian, A. et al. (2018) Modeling and Simulation of Energy Systems: A Review. Processes, 6 (12). doi: 10.3390/pr6120238
[3] Besner, R. (2021) Vergleich einer statischen und dynamischen Ökobilanzierung eines Hybridregelkraftwerks unter Berücksichtigung verschiedener Betriebsstrategien. Masterarbeit, Hochschule für Technik und Wirtschaft Berlin.