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TwinVECTOR

Twinning for Development of World-Class Next Generation Batteries

Project Number: 101078935

Techno-economic modelling & training guideline

Activity: WP5 – Boosting research capacity in techno-economic modelling

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Imprint

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4	KARLSRUHER INSTITUT FUER TECHNOLOGIE	KIT	Germany
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Executive Summary

The objective of deliverable 5.1 is to serve as a techno-economic assessment (TEA) modelling and training guideline. To achieve this, information on conducting TEAs in the context of renewable energy systems and on building models in Python is presented. More specifically, TEAs are defined and common study formats and research questions within them are outlined. In addition, questions such as how to choose the right level of detail for TEAs, how to design an efficient workflow for them, and how to best present TEA results are dealt with. Furthermore, the analyses within TEAs, namely technical and economic assessments, are covered in detail by defining commonly used technical and economic key performance indicators (KPIs). Additionally, concerning economic assessments, topics such as cashflow components, discounting, and sources for economic data are covered. The report also provides guidance on Python coding standards and building TEA models with a coding example.

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1 Introduction

In the following, the project TwinVECTOR is first summarized in Section 1.1. After that, the role of work package (WP) 5 within the project is described (Section 1.2), the purpose and scope of this deliverable is outlined (Section 1.3), and its process of development is specified (Section 1.4). Lastly, references, as well as acronyms and definitions used in the deliverable are stated in Sections 1.5 and 1.6, respectively.

1.1 The project TwinVECTOR – an abstract

The TwinVECTOR project aims to create a center of excellence at the Tomas Bata University in Zlín (TBU), focusing on next generation battery sustainable design, energy business models, and sustainability assessments, with the support of upgraded research and administration unit (RAU). The RAU therefore coordinates the capacity building measures of the partners' activities to emphasise the synergy and the creation of the centre of excellence at TBU. Hence, TBU teams up with excellent institutions: VTT, AIT, KIT, and BAYFOR. The whole spectrum of activities is intended to activate knowledge at TBU, set up knowledge pool and capacity building activities enabling flexible, multidisciplinary project teams to address the topic of the next generation of batteries with the help of life cycle thinking via sustainability assessments. Additionally, advanced battery technologies also need to be assessed via a combination of techno-economic simulation tools, profitability analysis, and business model innovation. The widening country of Czechia, specifically the Zlín region, aims to increase scientific expertise and capacity in these areas and methods. The consortium members will share the expertise so that TBU can boost the research capacity to undertake world-class R&D activities in the energy storage field and bring them to the market. The ability to produce original ideas will be reflected in multiple outcomes expected in the short-term horizon: EU projects submitted in cooperation with excellent partners, scientific papers, conferences, and business agreements. High-impact research is expected long term with technology transfer into practice. The existing research capacity of all members will be strengthened via additional capacity-building activities in partnership with BAYFOR.

1.2 Role of WP5 within the TwinVECTOR project

For a comprehensive assessment of the possible implementation and operation of battery technologies in energy storage systems, it is – among others – necessary to conduct profitability assessments and develop business model (elements), as well as technology scalability studies. The main objective of WP5 is thus to achieve improved excellence, strategic networking, and raised research profile in the TEA of battery technologies across the whole value chain for researchers at TBU.

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Within WP5, knowledge transfer on TEAs, profitability analyses, and business model development will be provided by AIT. Moreover, expertise on fostering innovation through the identification of new research questions and the successful acquisition, execution, and exploitation of research projects will be shared. For those purposes, different teaching activities namely workshops, researcher exchanges, and a summer school are conducted. Moreover, supplementary teaching materials and training guidelines are provided. Examples of topics and methods covered within WP5 include foundations of energy economics, profitability assessments, and marketing options for renewable energy assets, techno-economic models and analytical tools, and business modelling methods.

1.3 Purpose and Scope of the Deliverable

This Deliverable serves as a techno-economic modelling and training guideline for teaching activities within WP5. It provides comprehensive information on the theoretical foundations as well as practical knowledge gained by AIT concerning all aspects of TEAs that are relevant within the context of battery energy storage systems. For that reason, this document may be used by researchers who have no prior knowledge on TEAs to familiarize themselves with this topic.

This document is structured in the following chapters: First, TEAs and their purpose are introduced in Chapter 2. After that, technical assessments and economic assessments are covered in detail in Chapters 3 and 4, respectively. Then, TEA modelling tips and coding standards including a coding example are outlined in Chapter 5. Lastly, the overall progress and current status of this document is detailed in Chapter 6 and conclusions are drawn in Chapter 7.

1.4 Process of Development

The document has been created based on the comprehensive expertise and experience gained by AIT over many years of being active in this field. The general regulative issues of the TwinVECTOR project, written in both the Grant Agreement and the Consortium Agreement have been followed and addressed.

1.5 References

[1] R. A. Brealey, S. C. Myers, and F. Allen, *Principles of corporate finance*. McGraw-Hill, 2020. Accessed: Oct. 18, 2023. [Online]. Available: https://thuvienso.hoasen.edu.vn/handle/123456789/11931

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[3] W. Short, D. J. Packey, and T. Holt, “A manual for the economic evaluation of energy efficiency and renewable energy technologies,” NREL/TP--462-5173, 35391, Mar. 1995. doi: 10.2172/35391.

[4] J. Kapeller, *own illustration*, AIT Austrian Institute of Technology GmbH, 2023.

1.6 Acronyms & Definitions

Table 1: Summary of acronyms and their definitions.

Acronym	Definition
BCR	Benefit-cost ratio
CAPEX	Capital expenditures
CBR	Cost-benefit ratio
CPI	Consumer price index
DoD	Depth of discharge
EoL	End of life
EU	European Union
HICP	Harmonized index of consumer prices
IRR	Internal rate of return
KPI	Key performance indicator
LCOE	Levelized cost of electricity
LCOheat	Levelized cost of heat
LCOH	Levelized cost of hydrogen
LCOS	Levelized cost of storage
LCOx	Levelized cost of energy
LFP	Lithium-iron-phosphate
NPV	Net present value

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OPEX	Operational expenditures
PPA	Power purchase agreement
PV	Photovoltaics
RES	Renewable energy sources
ROI	Return on investment
SoC	State of charge
SoH	State of health
TEA	Techno-economic assessment
UML	Unified modelling language
WP	Work package

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2 Techno-economic assessments

In this chapter, TEAs are first defined (Section 2.1), then common study formats and corresponding research questions are discussed (Section 2.2), and after that, it is outlined how to arrive at a sensible level of detail during TEAs (Section 2.3). Lastly, it is explained how an efficient workflow within a TEA can be designed (Section 2.4) and how to best present TEA results (Section 2.5).

2.1 Definition, key components, and objectives

TEAs in the context of energy systems refer to a comprehensive evaluation methodology used to analyze the feasibility, cost-effectiveness, and performance of various energy technologies and / or systems. These assessments are crucial for making informed decisions about energy system investments, policy development, and project planning. TEAs combine technical and economic analyses to provide a holistic understanding of energy systems and allow a fair comparison of different alternatives. In addition, they are often supplemented by regulatory, sensitivity, and risk analyses. Key components of TEAs and supplementary analyses to them, especially in the context of energy systems, are the following:

- **Technical assessment**: This aspect involves assessing the technical feasibility and performance of a particular energy technology and / or system. It considers factors such as energy efficiency, reliability, scalability, and compatibility with existing infrastructure. Technical analysis helps to determine whether a technology can meet energy demands and environmental goals. Technical assessments are covered in Chapter 2.5.
- **Economic assessment**: The economic assessment focuses on estimating the overall cost associated with implementing and operating the energy technology and / or system. It encompasses various cost categories, including capital costs (e.g., equipment and installation), operating and maintenance costs, fuel or resource costs, and decommissioning costs. Additionally, it evaluates revenue streams, subsidies, and incentives that may affect the economic viability of the project. Moreover, financial aspects of the energy project, including cash flows, return on investment (ROI), payback periods, and net present value (NPV) are evaluated. This analysis helps to assess the attractiveness of an energy project from an investor's perspective and determines its financial sustainability. More details on economic assessments are given in Chapter 4.
- **Sensitivity analysis**: Sensitivity analysis can be conducted supplementary to TEAs and explores how variations in key input parameters, such as energy prices, investment costs, or government policies, can affect the outcomes of the assessment. It helps to identify the most critical factors influencing the project's feasibility and profitability. A detailed coverage of sensitivity analyses is out of scope of this deliverable, because the deliverable focusses

on TEAs themselves and sensitivity analyses are not an inherent part of TEAs but supplementary to them.

- **Risk assessment**: TEAs may additionally be supplemented by assessing the risks associated with energy projects, including market uncertainties, regulatory changes, technology performance, and financial risks. Understanding these risks allows stakeholders to develop mitigation strategies and make informed decisions. A detailed coverage of risk assessments is out of scope of this deliverable, because the deliverable focusses on TEAs themselves and risk assessments are not an inherent part of TEAs but supplementary to them.
- **Policy and regulatory considerations**: Evaluations consider existing policies, regulations, and incentives that may impact the economic efficiency or feasibility of energy projects may also be conducted supplementary to a TEA. This may include aspects such as subsidies, tax incentives, emissions targets, and renewable energy mandates. A detailed coverage of policy and regulatory considerations is out of scope of this deliverable because the deliverable focusses on TEAs themselves and policy and regulatory considerations are not an inherent part of TEAs but supplementary to them.

In summary, TEAs in the context of energy systems provide a systematic and multidimensional approach to evaluating energy technologies, systems, and projects. They help stakeholders to assess the feasibility, cost-effectiveness, and sustainability of different options, ultimately informing decisions that contribute to a more efficient and sustainable energy future.

2.2 Study formats and research questions

TEAs can address a wide range of research questions and study formats across various domains. In the following, common types of study formats that may be investigated using TEAs are described and corresponding research questions are formulated. These research questions and study formats demonstrate the versatility of TEAs in addressing complex energy-related challenges and providing valuable insights for decision-makers, researchers, and policymakers.

2.2.1 Technology feasibility and viability

For given constraints such as an energy demand that needs to be fulfilled or a grid capacity limit, it is investigated if and how a technology of system component can fulfil these needs. Moreover, the economic viability of technically feasible options is assessed.

- Can a specific technology or system meet energy demands in a given context?

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- Is a proposed energy project technically viable, evaluated based on technical key performance indicators (KPIs)?
- What are the technical and economic barriers to implementing a particular energy technology?

2.2.2 Application & design choices

Fitting system, component, or technology configurations to achieve the highest economic (and technical) benefits in different applications and operation modes are evaluated. This can be used, inter alia, to assess what system, component, or technology sizes are optimal depending on the application. Furthermore, technically and economically feasible operation strategies for given systems or technology configurations can be evaluated. In this way, new and existing business models can be developed or validated based on the most technically and economically feasible use cases.

- What design parameters (e.g., capacity, size, configuration) optimize the performance and cost-effectiveness of a system or technology?
- How do different design choices impact the overall efficiency and economic viability of a technology or system?

2.2.3 Technology comparison

The technical and economic impact of a new system or technology (from a plant or system perspective) in comparison to the current (state of the art) system or technology is investigated. Benefits from the implementation of the new system or technology are assessed. In addition, different system or technology options for a given use case can be compared by benchmarking them to each other or to a dedicated reference case. This helps policymakers or investors to prioritize projects that align with their goals and resource constraints.

- Which technology or energy source offers the most cost-effective and sustainable solution for a specific application?
- How do various energy technologies compare concerning different technical and economic KPIs?

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2.2.4 Future technology projection

The likely applicability of a newly developed or existing system or technology in a future energy system based on corresponding market environment forecasts, cost projections, and competitive technology projections is appraised. Complementary to the base analysis, break-even points can be determined for relevant system variables.

- What are the expected advancements in energy technology and their potential impacts on cost and performance?
- How will changing energy supply and demand patterns in the future affect the cost and performance of the technology?
- How do changes in energy market prices impact the system or technology's economic viability?

2.2.5 Research & development needs

The impact of the variation of single component or sub-system properties and costs on the overall system or technology costs is evaluated with dedicated sensitivity analyses. Based on this assessment, main further research needs and areas for a successful market rollout can be determined. Complementary to the sensitivity analysis, break-even points can be determined for relevant system variables.

- What are the most critical areas for research and development at the component or material level to enhance the performance and cost-effectiveness of a technology?
- What research roadmaps can be developed to achieve specific performance or cost targets for energy components or materials?

2.2.6 Replicability & Scalability

Plants are scaled in size and furthermore modelled at different locations with different users to assess possible rollout in different settings. This may additionally comprise investigations of the plants' operation in different countries and corresponding differing regulatory frameworks and weather / climate conditions.

- Can successful energy projects or technologies be replicated in different geographical regions or contexts?
- How can energy systems be scaled up to meet growing demands without compromising efficiency and economics?

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2.3 Level of detail in TEAs

The level of detail in TEAs can significantly impact the accuracy and reliability of the results. It is crucial to strike the right balance between granularity and complexity, and consistency in input data is paramount for meaningful outcomes.

When deciding on a level of detail concerning technical and economic input data, there are practical limitations to the theoretical optimum, such as data availability and computational power. Even so – at least theoretically – it would be optimal to consider a similar detail for each technical and cost component of a system, though this also depends on the question the TEA is dedicated to answer. For example, certain research questions such as research and development needs of a technology (see Section 2.2.5) require a higher level of detail concerning certain types of data such as the cashflows than other study formats. The following considerations regarding the level of detail and consistency in TEAs should be made, in order to ultimately arrive at a sensible decision concerning the level of detail.

2.3.1 Level of Detail

The following levels of detail may be investigated during TEAs:

1. **Material level:** This level of detail involves considering the specific materials used in the construction of energy technologies or systems. It includes factors like the type of metals, composites, or other materials, their costs, availability, and environmental impacts. Assessing material choices is critical for understanding long-term durability, maintenance, and environmental considerations.
2. **Component level:** At this level, the focus is on individual components within a technology or system. For example, in a solar photovoltaic system, this might include detailed analysis of solar panels, inverters, mounting structures, and wiring. Component-level analysis helps in optimizing design and identifying potential reliability issues.
3. **System level:** This is a broader view that considers the overall energy system, including its integration into the larger energy infrastructure. For instance, in a renewable energy project, it would encompass the entire energy generation, distribution, and storage system. System-level analysis assesses how all components interact and impact each other, taking into account factors like grid integration, energy storage, and load balancing.

2.3.2 Consistency

Consistency in input data is crucial for several reasons:

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1. **Reliability of results:** Inconsistent data can lead to unreliable results and skewed conclusions. Consistency ensures that the analysis is based on a coherent set of assumptions and inputs, enhancing the credibility of the assessment.
2. **Comparability:** Consistent data allows for meaningful comparisons between different technologies or scenarios. It ensures that the assessment results accurately reflect the relative performance and economics of the options under consideration.
3. **Transparency:** Consistency makes the TEA process more transparent and understandable to stakeholders. It enables others to replicate the analysis and verify its accuracy.
4. **Risk mitigation:** Inconsistent data can introduce uncertainty and risk into energy projects. By using consistent data, it becomes easier to identify and manage potential risks and uncertainties.

2.3.3 Questions to answer for sensible level of detail

In order to arrive at a sensible level of detail during a TEA, the following questions should be asked:

1. **Project goals:** What are the specific goals and objectives of the TEA? The level of detail should align with the intended purpose of the assessment, whether it is for project planning, policy development, or investment decisions.
2. **Available data:** What data is readily available? Assess the data sources and their quality to determine the level of detail that can be realistically achieved.
3. **Complexity vs. accuracy:** Consider the trade-off between complexity and accuracy. Increasing the level of detail can provide more precise results but may also require more data and computational resources.
4. **Key decision points:** Identify the critical decision points in the energy project or policy analysis. Focus on higher detail in areas that have the most significant impact on those decisions.
5. **Resource constraints:** Assess the resources available for data collection, analysis, and modeling. In some cases, limitations in time or budget may dictate the level of detail that can be reasonably achieved.
6. **Stakeholder needs:** Consider the needs and preferences of stakeholders. Some stakeholders may require more detailed information, while others may prioritize simplicity and clarity.

In summary, selecting the appropriate level of detail and maintaining consistency in input data are essential aspects of conducting meaningful TEAs. The chosen level of detail should align with the goals of the assessment, data availability, and resource constraints while ensuring that the results accurately inform decision-making processes.

2.4 Designing a workflow for simulation-based techno-economic assessments

To design an efficient workflow for TEAs based on detailed simulations, it makes sense to first consider the level of detail the result should picture. The underlying question is what the TEAs will be used for, and which component or cost factor could have the highest impact, see Chapter 2.3. Moreover, components with a high uncertainty should be modelled in more detail.

After considering the level of detail, the workflow can be separated into four steps, as shown in Figure 1.

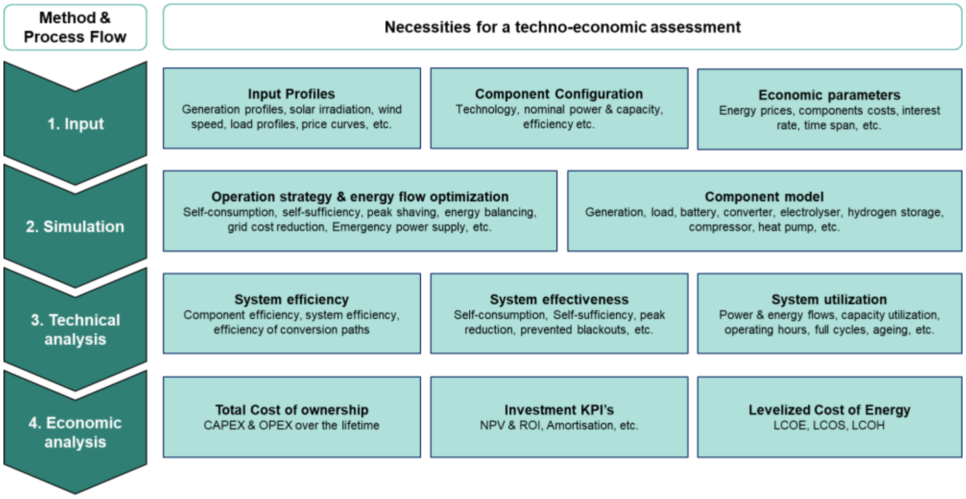

Figure 1 Example design of a TEA. [4]

The first phase, the **input phase,** includes everything that will be required for setting up the simulation model. This mostly starts with the data collection process of various profile data, including load or generation profiles and, if required, solar irradiation and wind speed data. Further, the input phase involves the component configuration, i.e., decisions about which components to include in the system, selection of specific technologies, and determination of component sizes. The third part of the input section focuses on the comprehensive collection of economic parameters. This includes capturing critical information such as energy prices, capital expenditures (CAPEX) and operational expenditures (OPEX) associated with each system component, and a detailed analysis of the

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components lifetime, aging factors, and reinvestment decisions. The interest rate should also be established in this section.

The **simulation phase** should be defined carefully, as the quality of the simulation can highly influence the quality of the techno-economic evaluation. The simulation phase includes the base code model of the components and the system setup. This part should also include technical details of each component such as power, capacity, efficiency curves, and component aging factors. Another crucial part of the simulation phase, however, is the operation strategy of the system and the energy flow decisions. This is the core part which can decide if a system setup is economically profitable or not. As the simulation phase includes a model of all components, including aging factors, it makes sense to simulate the whole system over a longer period of time such as 20 years. This allows to evaluate the aging of different components and therefore identify the reinvestment intervals which have a large impact in the economic assessment.

The **technical analysis** follows the simulation phase, the first technical KPIs of the simulation are evaluated, such as the system efficiency, the system effectiveness, and the system utilisation. The system efficiency measures how well a system converts inputs into desired outputs while minimizing waste or losses. System effectiveness, on the other hand, evaluates how well a system achieves its intended goals or objectives. The system utilization assesses how fully a system's resources or capacity are being used. It looks at whether the system is operating at its maximum potential or if there is room for improvement in resource allocation or productivity. For further details on technical KPIs please have a look in the following Chapter 3. These KPIs allow for the decision, whether the system configuration meets the requirements defined in the input section.

The **economic analysis** is conducted last. Here, it is crucial to differentiate between evaluating single system scenarios or comparing a batch of simulations. The economic assessment includes calculating the total cost of ownership, investment KPIs such as net present value (NPV), return on investment (ROI), and internal rate of return (IRR), but also levelized costs of goods (LCOx). For further information on the KPIs and how these are calculated please see the following Chapter 4.4.

By following this workflow, TEAs can successfully be carried out. If conducted carefully, a TEA will help make decisions about the technical and economic viability of technical projects and innovations.

2.5 Result evaluation & visualization

The result evaluation and visualization are one of the most important parts of the TEA as it is used for communicating the results to outsiders. It is paramount to show the most important technical and economic KPIs, but also background information so the presented data can be interpreted correctly. A more detailed description on technical and economic KPIs and how to calculate them can be found later in Chapters 3 and 4.4.

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As an example, the battery system efficiency is only a sufficient KPI information if the number of full cycles is representative, and the charging/discharging power also covers partial load behaviour. The following section shows a few examples of how results could be evaluated and presented.

2.5.1 Single scenario evaluation

When analyzing single scenarios, the simulation time horizon, included components, system boundaries, and use case should be pointed out. The first step, even before starting to analyse the results, should be to analyse the input data. Especially input profiles should be analysed with regards to data and time consistency (have a lookout for summer/ winter time and time zones in general!). Input profiles should be further analysed on the basis of energy consumption/ generation, but also power values and simultaneousness to other input profiles. Figure 2 shows one possibility of analysing the monthly energy generation of a photovoltaic (PV) power plant. In this graph it can clearly be seen that the PV power plant generates more energy in summer months than in winter.

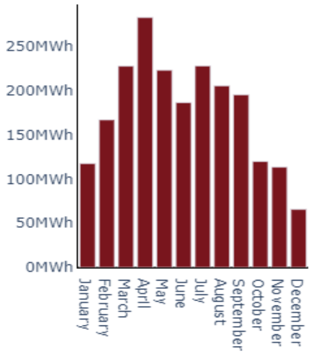

Figure 2 Energy generation analysis per month as a bar chart figure.

Figure 3 shows an additional analysis for input profiles analyzing the power values by month and time of day. Using this graph, it can be seen, that the sun rises later, rises lower, and sets sooner in winter times compared to the summer months. Using hourly boxplot figures, the simultaneousness between generation and load profiles can be compared, maximum power values can be evaluated, and consequently, system component sizes and use cases can be better defined through understanding the profiles in more detail. Further useful plots for analyzing profiles are boxplots by weekday for differentiating workdays from weekends, but also analyzing energy values on a higher granularity.

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Also, this kind of plots cannot only be used for evaluating input profiles but also for evaluating resulting profiles, such as the grid consumption and/or feed-in at the connection point, self-sufficiency, or self-consumption of a power plant.

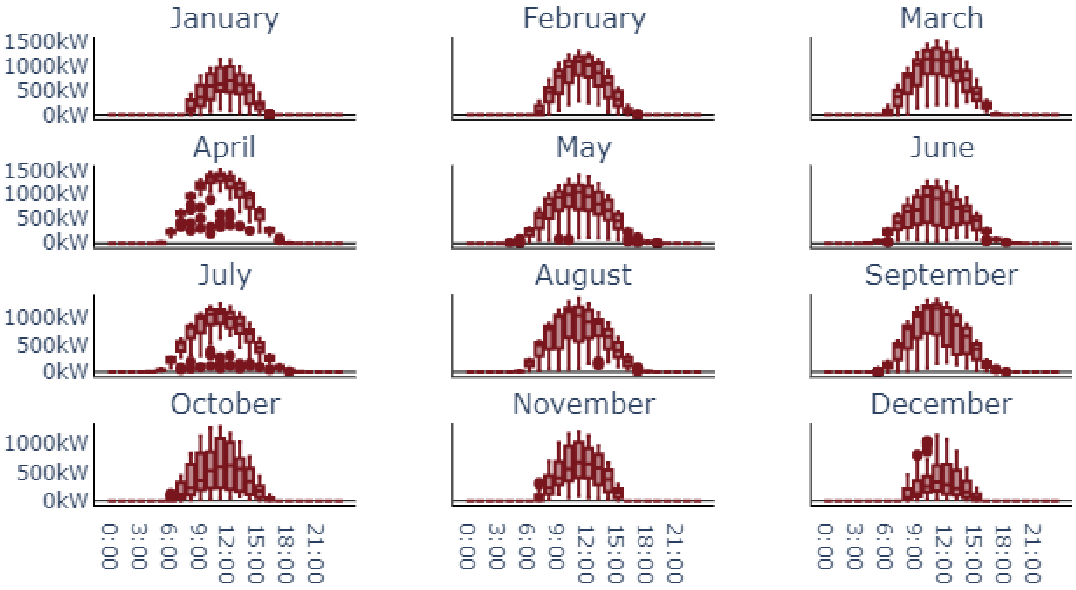

Figure 3 Power generation analysis per month as an hourly box plot figure.

Showing the system operation as line graph can help explaining the operation strategies, boundary condition, and use case, Figure 4 shows an example of how the operation strategy could be presented.

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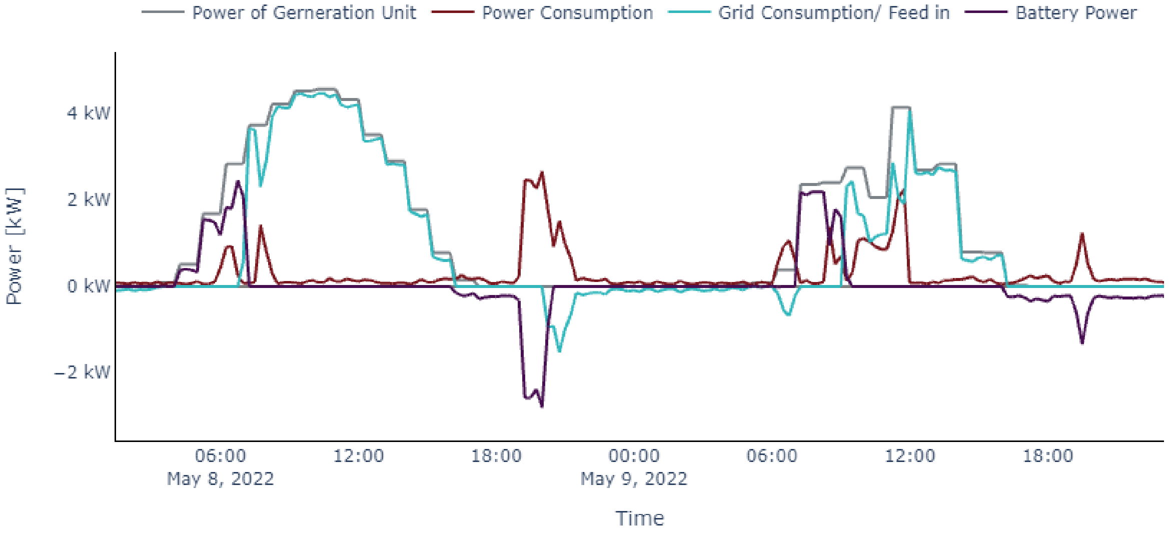

Figure 4 System operation visualization by line graph. [4]

Figure 4 shows the PV power generation, the power consumption, battery operation, and resulting power at the grid connection point. In Figure 4, it is rather easy to identify, that the battery is charging as soon as the PV generation exceeds the current load and discharges when the load is higher than the PV generation, and that any power that cannot be charged is fed into the grid. This graph can also be used for validating the operation strategy.

Adding another line graph, Figure 5, to Figure 4, showing the battery power and state of charge, provides further information of when power is fed into the grid, and at what time it is consuming power from the grid. As an example, comparing Figure 4 and Figure 5, it can be seen easily, that the battery charges until it reaches a state of charge of 100%. Only at this point, the excess PV generation is fed into the grid. For example, on May 8th at 4 pm, the PV generation is lower than the power consumption. At this point, the battery fully supplies the load until the battery is fully discharged, only then the load is covered by the grid connection.

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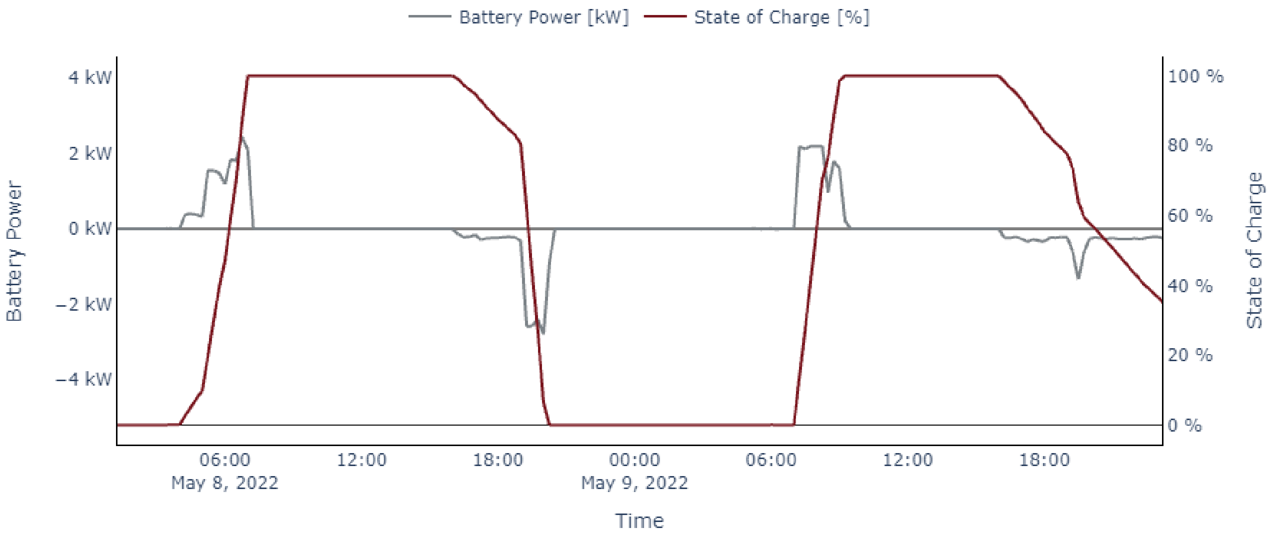

Figure 5 Battery operation visualization by line graph. [4]

The resulting technical KPIs over multiple years could further be presented as a table. Table 2 shows the sum values of three different years at slightly different consumption profiles per year and different weather conditions. As an addition to Table 2, the battery system operation can also be analysed as a table. Table 3 analyzes the battery system operation as percentiles. A percentile is a statistical measure that indicates the relative position of a particular data point within a dataset, representing the percentage of data points that are equal to or lower than it. This analysis shows how often the system is operated in which range. As an example, Table 3 shows that the battery system is operated more often in partial load when discharging than charging, therefore the battery system efficiency for discharging the system is smaller than for charging. This analysis can also help optimizing component sizes to operate less in partial load to increase the system efficiency.

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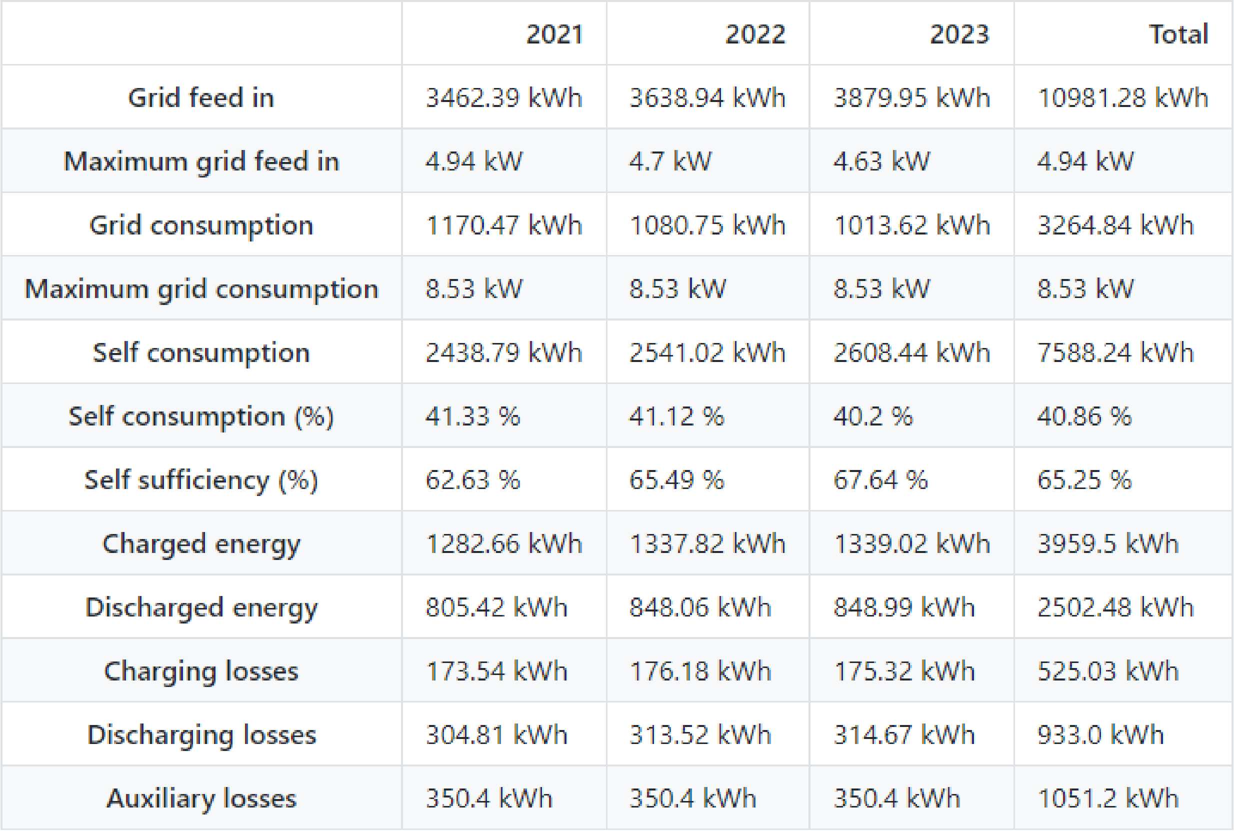
Table 2 Technical KPI summary of a single scenario. [4]



	2021	2022	2023	Total
Grid feed in	3462.39 kWh	3638.94 kWh	3879.95 kWh	10981.28 kWh
Maximum grid feed in	4.94 kW	4.7 kW	4.63 kW	4.94 kW
Grid consumption	1170.47 kWh	1080.75 kWh	1013.62 kWh	3264.84 kWh
Maximum grid consumption	8.53 kW	8.53 kW	8.53 kW	8.53 kW
Self consumption	2438.79 kWh	2541.02 kWh	2608.44 kWh	7588.24 kWh
Self consumption (%)	41.33 %	41.12 %	40.2 %	40.86 %
Self sufficiency (%)	62.63 %	65.49 %	67.64 %	65.25 %
Charged energy	1282.66 kWh	1337.82 kWh	1339.02 kWh	3959.5 kWh
Discharged energy	805.42 kWh	848.06 kWh	848.99 kWh	2502.48 kWh
Charging losses	173.54 kWh	176.18 kWh	175.32 kWh	525.03 kWh
Discharging losses	304.81 kWh	313.52 kWh	314.67 kWh	933.0 kWh
Auxiliary losses	350.4 kWh	350.4 kWh	350.4 kWh	1051.2 kWh

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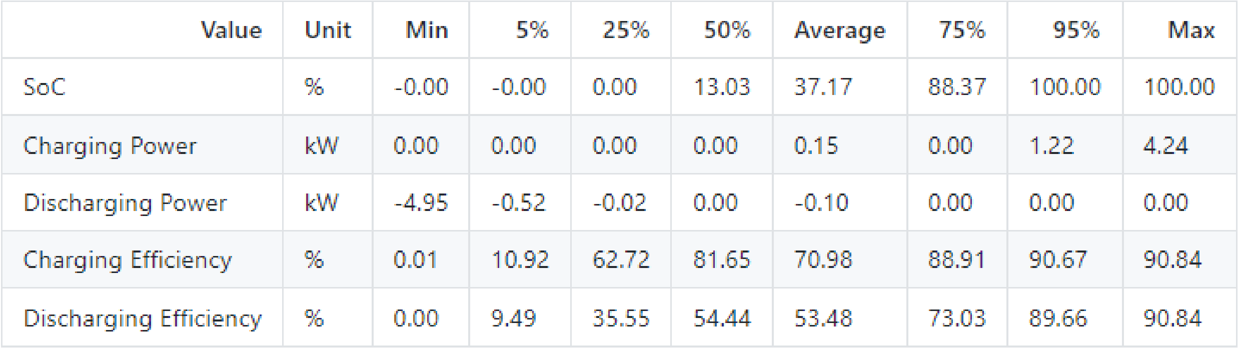
Table 3 Technical KPI summary of battery system as a table.



Value	Unit	Min	5%	25%	50%	Average	75%	95%	Max
SoC	%	-0.00	-0.00	0.00	13.03	37.17	88.37	100.00	100.00
Charging Power	kW	0.00	0.00	0.00	0.00	0.15	0.00	1.22	4.24
Discharging Power	kW	-4.95	-0.52	-0.02	0.00	-0.10	0.00	0.00	0.00
Charging Efficiency	%	0.01	10.92	62.72	81.65	70.98	88.91	90.67	90.84
Discharging Efficiency	%	0.00	9.49	35.55	54.44	53.48	73.03	89.66	90.84

2.5.2 Multiple Scenario evaluation & comparison

In order to compare multiple scenarios, it can make sense to compare a list of scenarios based on different technical as well as economic KPIs. One way of doing so, are so-called heat maps as shown in Figure 6. Figure 6 compares the resulting levelized cost of electricity (LCOE) (for a definition see Section 4.4.6) of multiple battery systems by sorting them on a heat map. The x-axis shows the battery capacity, the y-axis the power, and the z-axis shows the LCOE of a renewable power plant connected to a battery storage as colour code. In this case, the heat map would suggest that a smaller battery storage with less capacity and less power rating would lead to lower energy costs. However, this might not be the only important KPI. Another factor could be self-sufficiency, for example, in order to supply a remote household without grid connection. In that case, the best fitting scenario would be a mixture between low energy costs and high self-sufficiency.

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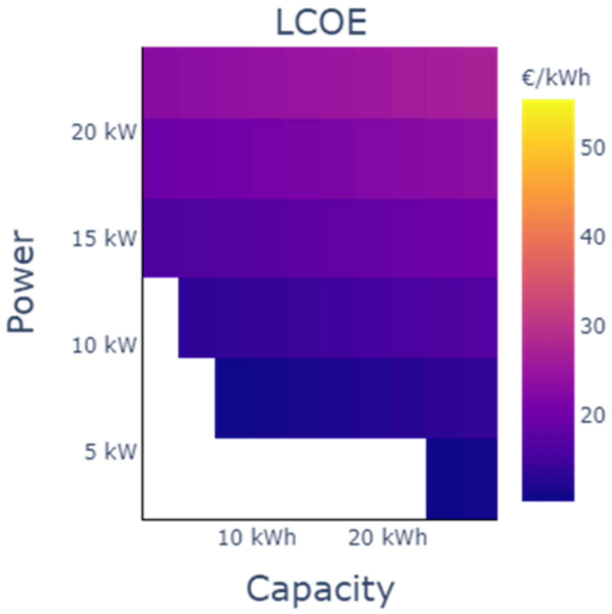

Figure 6 Comparing different scenarios by heatmap graphs, based on selected KPIs. [4]

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3 Technical assessment

The technical assessment part within a TEA is discussed in detail in this section by defining important technical KPIs.

KPIs are quantifiable metrics used to evaluate the performance of a project and / or individual technical assets. KPIs provide a way to measure progress, track achievements, and assess the effectiveness of these projects and technical assets.

3.1 Energy demand

The energy demand is the amount of energy an asset, system, or customer requires over a certain time span. The amount of energy demand may be assessed on a yearly, monthly, weekly or even daily basis. For further input of how the energy demand can be assessed compare Chapter 2.5.

3.2 Energy consumption

The energy consumption defines how much energy the asset, system, or customer actually used during a certain time span. By comparing the energy demand and the energy consumption, the system supply rate may be assessed.

3.3 Supply rate

The supply rate analyzes how much of the energy demand could be supplied and therefore consumed. A system supply rate lower than 100 % means, that the energy demand was not covered, and the asset, system, or customer could not use as much energy as it would have required. This could have a major impact on production and/or operation of the asset, system, or customer.

3.4 Grid consumption, grid feed-in, and energy curtailment

Depending on the system and system boundaries, different energy flows can be evaluated. In case of a grid connection and renewable energy sources (RES) on-site, there might not only be energy consumption from the grid, but also energy feed-in to the grid. Depending on the technical specifications of the system, there might be a power/ energy limit for the grid connection point, leading to power/ energy curtailments.

These values should be analysed separately in order to not only analyze the on balance annual energy flows, but also seasonal grid consumption, grid feed-in, and finally, self-sufficiency of the load, and self-consumption of the RES.

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3.5 Self-sufficiency

The self-sufficiency factor is the amount of energy demand which can be supplied by local RES and storage systems.

$$self - sufficiency = \frac{E_{demand} - E_{grid\ consumption}}{E_{demand}}$$

E_{demand}… Energy demand within the system

$E_{\text{grid consumption}}$… Energy consumption from the grid

Depending in the complexity of the use-case, the formula might differ.

3.6 Self-consumption

The self-consumption is a factor for the amount of energy generation within the system which is also consumed within the system. In-between usage of storage systems is also accounted for.

$$self - consumption = \frac{E_{generation} - E_{grid\ feed-in}}{E_{generation}}$$

$E_{\text{generation}}$… Energy generation within the system

$E_{\text{grid feed-in}}$… Energy feed-in to the grid

Depending in the complexity of the use-case, the formula might differ.

3.7 Efficiency

The efficiency of a system, as well as technical asset, is calculated by defining system boundaries and comparing the energy flow into the system boundaries and the energy output of the boundaries. Therefore, the system boundary has to be chosen carefully, depending on which efficiency shall be evaluated.

$$\eta = \frac{E_{out}}{E_{in}}$$

η… Efficiency

E_{in}… Energy input of the system

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E_{out}… Energy output of the system

Some example system boundaries for battery storage systems are shown in Figure 7:

1. System efficiency including an AC/DC (alternating current / direct current) inverter: AC energy output vs. AC energy input.
2. Battery efficiency: DC energy output vs. DC energy input
3. Battery charging efficiency: Chemically charged energy within the battery vs. the DC energy input
4. Battery discharging efficiency: DC energy output vs. chemically discharged energy within the battery

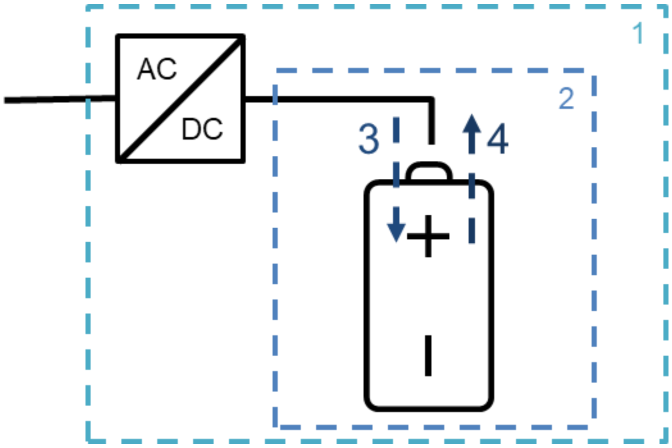

Figure 7 Example of system boundaries for battery storage systems. [4]

3.8 Full cycles

Full charging cycles are used for tracking the battery storage usage and is composed of a complete charging and discharging process. Charging and discharging events which do not fully charge or discharge the battery storage are added together until a full charging cycle is reached.

$$Full\ cycle\ =\ Min\left(\frac{E_{charging}}{E_{nom}};\frac{E_{discharging}}{E_{nom}}\right)$$

E_{nom}… Nominal Capacity

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$E_{charging}$… Energy charged within the battery storage

$E_{discharging}$… Energy discharged within the battery storage

3.9 Operating hours

The operating hours are used for evaluating how a battery system is utilized. The operating hours may be separated into charging and discharging hours. The time period in which the system state is idle or within the dead band of the asset can be evaluated separately.

3.10 State of Health (SoH) and End of Life (EoL)

The State of Health (SoH) is a factor used to evaluate the degree of degradation and tear and should be evaluated separately for each asset. The SoH is influenced by asset-specific aging algorithms. For battery storage systems, for example, this includes cyclic aging and calendar aging, which in turn is influenced by cell temperature, state of charge, and other factors. In addition to the SoH, the end-of-life factor may be used to determine at which point of degradation and tear an asset should be exchanged.

3.11 State of Charge (SoC)

The State of Charge (SoC) is only used for storage systems and indicates how much energy is currently available in the storage system compared to the usable capacity of the storage.

$$SoC = \frac{E_{stored}}{E_{usable}}$$

E_{stored}… Currently stored energy within storage system

E_{usable}… Usable capacity within storage system, considering the nominal capacity, SoH and Depth of discharge.

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4 Economic assessment

In this section, economic assessments and their objectives are defined in Section 4.1 and then cashflow components are explained in Section 4.2. After that, discounting as well as real and nominal cashflows are covered in Section 4.3. Furthermore, economic KPIs are defined (Section 4.4) and sources for economic data are presented (Section 4.5).

4.1 Definition and objectives

The purpose of economic assessments is to appraise the profitability of potential investments with cashflows distributed across various time points. Thus, the valuation of past and future cashflows concerning a reference time point is essential to ascertain their profitability. This assessment involves the summation and discounting of cashflows relative to the reference time point, to which all cashflows are related. This temporal relationship results in a present-day bias, leading to a higher weighting of current cashflows over future ones. Consequently, the mere aggregation of expenses or revenues occurring at different time points is inaccurate. Each revenue or expense stream is defined by its amount and temporal proximity to the present (investment time). Therefore, only cashflows sharing the same time point can be directly aggregated.

Initial investment outlays, denoted as acquisition costs, necessitate upfront expenditure at the project's outset. These costs are thus prefinanced, as their recovery occurs after a duration within the project's timeline. Consequently, the revenues generated during the project must not only cover operational expenses but also contribute to repaying the initial investment, including interest.

4.2 Cashflows components

Profitability assessment of renewable energy investment projects involves evaluating both the costs and revenue components associated with the project to determine its financial viability. In the following, the typical cost and revenue components considered during such assessments are outlined.

4.2.1 Cost Components

1. **Capital Expenditure (CAPEX):** This includes the upfront costs for purchasing and installing renewable energy equipment, such as solar panels, wind turbines, or biomass facilities. It covers the cost of equipment, materials, labor, and engineering services.
2. **Operational Expenditure (OPEX):** OPEX includes ongoing operational costs, including maintenance, labor, insurance, utilities, and other expenses required to keep the renewable

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energy system running smoothly. Since they are one of the most extensive cost components, there is a dedicated Section 4.2.3 on types of costs that fall under OPEX.

3. **Financing Costs:** These encompass interest payments, loan origination fees, and other financial costs associated with borrowing capital to finance the project.
4. **Land and Permitting Costs:** Expenses related to land acquisition or leasing, as well as obtaining permits and licenses required for the construction and operation of the renewable energy facility.
5. **Environmental Compliance Costs:** Costs associated with meeting environmental regulations and compliance, such as emissions monitoring and mitigation measures.
6. **Transmission and Grid Connection Costs:** Expenses related to connecting the renewable energy facility to the grid, including the construction of transmission lines and substations.
7. **Reserve Funds:** Funds set aside for unforeseen events, repairs, and replacements to ensure the long-term sustainability of the project.

4.2.2 Revenue Components

1. **Electricity Sales:** Revenue generated from selling the electricity generated by the renewable energy facility to utilities or other off-takers. This revenue is typically generated through power purchase agreements (PPAs) or feed-in tariffs.
2. **Certificates of origin:** Income from the sale of environmental attributes associated with renewable energy generation. These can be sold separately from the electricity itself and can provide additional revenue.
3. **Feed-in Tariffs (FiTs):** If applicable, revenue generated from government-set tariffs that guarantee a fixed price for renewable energy generation, usually over a specified contract period.
4. **Net Metering or Self-Consumption:** For distributed renewable energy systems like rooftop solar, revenue can be generated by offsetting electricity consumption or selling excess electricity back to the grid.
5. **Ancillary Services:** In some cases, revenue can be earned by providing ancillary services to the grid, such as frequency reserve or grid stability services.
6. **Selling Surplus Energy:** If the renewable energy facility generates more electricity than it consumes or contracts to sell, revenue can be generated by selling the surplus energy to the grid.

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7. **Energy Storage and Ancillary Services:** For projects incorporating energy storage systems, revenue can be earned by providing energy storage services or participating in demand response programs.

The profitability assessment of a renewable energy investment project involves comparing the total revenue generated by these components to the total costs over the project's expected lifespan using different economic KPIs (see Section 4.4). This analysis helps investors and stakeholders to determine whether the project is financially viable.

4.2.3 Operational expenditure (OPEX) components

OPEX for energy system components encompass a wide range of costs associated with the day-to-day operation, maintenance, and management of these components. These costs can vary depending on the type and scale of the energy system, but here are some common types of costs that can fall under OPEX for energy system components:

1. **Fuel Costs:** This includes the cost of purchasing and transporting the fuel required for energy generation, such as biomass.
2. **Maintenance and Repairs:** Regular maintenance and occasional repairs to ensure the reliable operation of equipment like generators, turbines, boilers, and electrical cables.
3. **Labor Costs:** Salaries and wages for personnel involved in operating, monitoring, and maintaining the energy system. This includes operators, technicians, engineers, and support staff.
4. **Utilities:** Costs associated with utilities like electricity, water, and gas needed for the operation of the energy system, including cooling and heating systems.
5. **Insurance:** Premiums for insuring the energy system components against various risks, such as damage, accidents, and natural disasters.
6. **License and Permit Fees:** Costs related to obtaining and renewing licenses, permits, and certifications required for operating the energy system in compliance with regulations.
7. **Environmental Compliance:** Expenses related to emissions monitoring, control, and compliance with environmental regulations, including air and water quality standards.
8. **Testing and Monitoring:** Costs associated with regular testing, monitoring, and data collection to ensure the efficient and safe operation of energy components.
9. **Spare Parts and Consumables:** Costs for maintaining an inventory of spare parts, lubricants, and consumables needed for routine maintenance and unexpected repairs.

10. **Training and Education:** Expenses for training programs and educational resources for personnel to keep them updated on the latest technologies and best practices.
11. **Security:** Costs for implementing security measures to protect the energy system from physical threats, cyberattacks, and unauthorized access.
12. **Software and Data Management:** Expenses related to software licenses, data storage, and data management systems required for monitoring and controlling the energy system.
13. **Transportation and Logistics:** Costs for transporting fuel, equipment, and personnel to and from the energy system's location.
14. **Waste management / disposal costs:** Expenses for proper disposal of waste materials generated during the operation and maintenance of the energy system, including hazardous materials.
15. **Administrative Costs:** Overhead costs associated with administrative functions, such as office space, communication, and administrative staff.
16. **Emergency Response and Safety:** Costs for establishing and maintaining emergency response plans, safety training, and equipment for handling emergencies and accidents.

These are some of the primary types of costs that can fall under OPEX for energy system components. The specific costs will vary depending on the nature of the energy system, whether it is a power plant, storage asset, or another type of energy-related infrastructure.

In practice, however, an estimation of the total OPEX based on a percentage of the CAPEX is often used in profitability assessments due to a lack information on the exact costs for the aforementioned points.

4.2.4 Residual value

The residual value of an asset refers to the estimated monetary value that it is expected to have at the end of its useful life, after it has been depreciated or amortized. It is a critical concept in accounting and financial analysis, as it affects how a company reports the value of its assets on its financial statements and determines depreciation expenses for those assets.

Residual value helps determine the asset's carrying amount on the balance sheet. The carrying amount is the asset's original cost minus its accumulated depreciation. In finance and investment analysis, understanding an asset's residual value can be essential for determining the potential return on investment when buying or selling assets.

Economic factors, such as inflation or changes in technology, can affect an asset's residual value. Rapid technological advancements, for instance, can lead to lower residual values for tech-related

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assets. Moreover, proper maintenance and care of an asset can potentially extend its useful life and impact its residual value.

It's important to note that residual value estimates are subject to change, and companies should periodically review and adjust them if necessary to reflect changing economic conditions or asset performance. Additionally, accounting standards may provide specific guidelines on how to determine and account for residual values.

In TEA in particular, different useful lifetimes than those set by accounting are used in some instances. The reason for that is, that accurate ageing models for technical components exist, thus the useful lifetime can be accurately defined. In addition, this lifetime may differ significantly from the useful lifetime set by accounting standards. Furthermore, this is greatly influenced by the operation strategy.

4.3 Discounting and real vs. nominal cashflows

Discounting of cashflows refers to the process of determining the present value of future cash inflows or outflows by applying a discount rate. This financial concept is used to evaluate the worth of money over time, taking into account the principle that a euro received or paid in the future is worth less than a euro received or paid today. It is important to understand that the discounting factor can consist of different components, such as inflation and financing-related interest, and therefore potentially differs in each time period. The weighted average cost of capital (WACC) or hurdle rate is commonly used for discounting. It is a financial metric that represents the average cost of financing a company's operations, considering the cost of debt, equity, and other sources of capital, weighted according to their respective proportions in the company's capital structure. It is used to assess the minimum rate of return that a company should achieve on its investments to create value for its shareholders. In other words, the WACC is a mixed interest rate used for debt and equity financing. It is defined as follows:

$$WACC = \frac{E}{V} * k_E + \frac{D}{V} * k_D,$$

where E is the equity, D is the debt capital, k is the interest claim on equity/ loan capital, and V is the total capital. [1]

Cashflows occurring at different points in time need to be discounted relative to a reference point in time. Depending on whether inflation is considered in the hurdle rate or not, cashflows are deemed real or nominal. Real cashflows correspond to an actual monetary value related to the reference point in time, while nominal cashflows describe the value of the money at the respective points in time they occur. Hence, the former are adjusted for inflation while the latter are not. [2]

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In order to account for inflation, different inflation indices can be used. For example, there are national consumer price indices (CPIs) which can be used for projects in which cashflows are limited to within one country. Furthermore, there are inflation indices which can be used for international investment projects such as the harmonized index of consumer prices (HICP) which is available on different levels such as national, EU-27, Euro zone, etc. and to include different goods or commodities, like food and energy. Moreover, it should be noted that the European central bank also publishes inflation forecasts for the Euro zone HICP.

4.4 Economic KPIs

In the following, the most commonly evaluated economic KPIs during a TEA are defined and described. In order to obtain comparable results for different options, it is important to evaluate them based on the same indicator.

4.4.1 Net present value (NPV)

The net present value (NPV) is an indicator to evaluate the profitability of investment options and compare them among each other. It calculates the present value of upcoming cash flows that can be earned from an investment project during its lifetime. A positive NPV means that the investment option is profitable for decision makers and a negative NPV means that it would bring losses.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t}, \text{ [NPV]=M. U.,}$$

where t is the time in the desired temporal resolution, most commonly years, T is the considered time span in the desired temporal resolution, r is the hurdle rate, $CF_t = B_t - C_t$, is the cash flow at time t, B_t are the benefits at time t, and C_t are the costs at time t. [2]

4.4.2 Annuity

The annuity method answers the question of how high a constant annuity must be over a time period at a certain interest rate in order to obtain the equivalent present value. Annuity is thus a series of periodic payments made at regular, fixed intervals whereas the length of this interval is called the annuity period.

$$A = C_0 * CRF(r,t), \text{ where } CRF(r,t) = \frac{(1+r)^T - 1}{(1+r)^T * r}, \text{ [A]=M. U.,}$$

where C_0 is the net of initial payments, CRF is the capital recovery factor, T is the time in the desired temporal resolution, and r is the interest rate. [3]

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4.4.3 Return on investment (ROI), benefit-cost (BC), and cost-benefit (CB) ratio

The benefit-cost ratio (BCR) describes the proportion of total benefits to total costs over a project's duration. Conversely, the cost-benefit ratio (CBR) illustrates the inverse relationship. Meanwhile, the return on investment (ROI) characterizes the correlation between net benefits and total costs. These KPIs are mainly used to assess the efficiency of an investment or compare several investment options in a decision-making process. In this context, an investment alternative with a higher ROI or BCR is favourable. Conversely, the investment alternative with the lowest CBR is the most advantageous choice.

$$ROI = \frac{B_{tot}}{C_{tot}} - 1,\ BCR = \frac{B_{tot}}{C_{tot}},\ \ CBR = \frac{C_{tot}}{B_{tot}},$$

where B_{tot} are the expected benefits over the project duration and C_{tot} are the total costs. [3]

4.4.4 Internal rate of return (IRR)

The internal rate of return (IRR) is the discount rate at which the NPV of all cash flows is equal to zero. It is the expected compound annual rate of return that will be earned on a project or investment. Once the IRR is determined, it is typically compared to a company's hurdle rate. The project is deemed profitable if the IRR of the investment project is greater than the hurdle rate of the company.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+IRR)^t} = 0 \rightarrow \text{solve for } IRR,$$

where t is the time in the desired temporal resolution, most commonly years, T is the considered time span in the desired temporal resolution, $CF_t = B_t - C_t$, is the cash flow at time t, B_t are the benefits at time t, and C_t are the costs at time t. [2]

4.4.5 Payback-period / amortization time (static vs. dynamic)

The payback-period or amortization time is the period of time needed for the cumulative benefits from an investment to become equal to the cumulative costs, whereby the static payback period / amortization time does not consider inflation, interest, or price increases while the dynamic one does.

$$t \text{ where } \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \geq 0,$$

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where t is the time in the desired temporal resolution, T is the considered time span in the desired temporal resolution, r is the hurdle rate, B_t are the benefits at time t, and C_t are the costs at time t. [3]

4.4.6 Levelized cost of energy (LCOx)

The levelized cost of energy (LCOx) is defined as the price at which some form of produced energy needs to be sold for the system to break even at the end of its lifetime, whereby the generated energy can be, for example, electricity (LCOE), hydrogen (LCOH), storage (LCOS), or heat (LCOheat). The LCOx accounts for all capital and operating costs of producing the considered energy carrier and therefore enables different production options to be compared on a similar basis. However, it needs to be carefully decided what kind of costs are actually considered within the LCOx calculation since, e.g., the LCOH does usually not include H_2 storage and transport costs which may be required depending upon the application. Moreover, LCOS usually considers only the energy discharged from the device and not the energy charged into it.

In addition, the amount of produced energy is usually discounted in addition to the cashflows to account for the fact that its value changes with time. Moreover, the types of cashflows that are considered in the LCOx are per usual the initial CAPEX and reinvestments, the total OPEX, as well as any residual value of the system that remains at the end of the considered time period. Revenues are usually not considered, for the LCOx is often compared to any revenues accrued by the system in order to evaluate whether it can ever be profitable. However, these issues should be discussed and carefully decided in each individual project.

$$LCOx = \frac{\sum_{t=0}^{T} \frac{CAPEX_t + OPEX_t - residual\ value}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_{x,t}}{(1+r)^t}}, \text{ [LCOx] = M. U./energy unit,}$$

where t is the time in the desired temporal resolution, T is the considered time span in the desired temporal resolution, r is the hurdle rate, $CAPEX_t$ and $OPEX_t$ are the capital and operational expenditures at time t, $residual\ value$ is the residual value at the end of T, and $E_{x,t}$ is the energy produced in each year. [3]

4.4.7 Choosing and comparing economic KPIs

In principle, all economic KPIs have the purpose of aiding investment decisions and being able to compare multiple options using a common metric. Even so, it is highly recommendable to evaluate multiple KPIs within an economic assessment, as they each reveal unique information concerning

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the profitability of each investment alternative. Table 4 summarizes the above-described economic KPIs, as well as information concerning their unit, meaning, and applications.

Table 4 Overview of economic KPIs, their meaning, and applications.

Economic KPI	Unit	Meaning	Applications
NPV	M. U.	Present value of cashflows that can be earned from an investment project during its lifetime	• Information on whether profitability is ever obtained over a project's lifetime • Comparison of different investment options' relative profitability
Annuity	M. U.	Constant share of an investment per time period in order to recover it over the lifetime at a certain interest rate	• Evaluating the economic effect of an investment on a per time period basis • Estimating the residual value of an investment at a point during its lifetime
ROI / BCR / CBR	-	Correlation between total / net benefits and total costs (BCR / ROI) or total costs and total benefits (CBR)	• Efficiency of an investment • Comparison of efficiency of several investment options
IRR	-	Discount rate at which the NPV of all cash flows becomes equal to zero	• Comparison with a company's hurdle rate in order to assess profitability (profitable if IRR greater than hurdle rate)
Payback period/ amortization time	Time unit	Time it takes for the system to break even; dynamic: considering inflation, interest, or price changes; static: not	• Comparison with a component's or system's lifetime (profitable if payback period less than lifetime)

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		considering inflation, interest, or price changes	
LCOx	M. U. per energy unit	Minimum price for each unit of a certain energy carrier for the system to break even	• Comparison with the revenues yielded to evaluate whether profitability can ever be achieved • Assessment of energy production costs • Basis for setting a price for the energy

4.5 Data sources

In the following, examples of the types of price, market, and other data that can be obtained from EU platforms are listed. Please note that the availability and accessibility of these data sources may vary, and some data may require registration or subscription. Additionally, data sources and platforms may change over time, so it is essential to check the latest information from the respective organizations and agencies for the most up-to-date data on EU price and market information.

4.5.1 Energy Market Data

1. **ENTSO-E Transparency Platform**: The European Network of Transmission System Operators for Electricity (ENTSO-E) operates a transparency platform that provides real-time and historical data on electricity market operations, including prices, generation, and consumption data. (ENTSO-E Transparency Platform)
2. **ENTSOG Transparency Platform**: The European Network of Transmission System Operators for Gas (ENTSOG) operates a transparency platform similar to ENTSO-E, offering data on natural gas market operations, including prices, supply, and demand. (ENTSOG Transparency Platform)
3. **ACER (Agency for the Cooperation of Energy Regulators)**: ACER is an EU agency responsible for promoting and facilitating the cooperation of national energy regulators. They provide various reports and publications related to energy market monitoring, including data on electricity and gas market developments, cross-border capacity, and price spreads. (ACER Website)

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4. **European Commission's Directorate-General Energy**: The European Commission's DG Energy provides reports and publications on various aspects of the EU energy market, including electricity and gas prices, energy security, and market integration. (European Commission DG Energy)
5. **Market Exchanges and Operators**: Some energy market exchanges and operators, such as EEX (European Energy Exchange), provide data on energy market prices, trading volumes, and market trends. These sources can be valuable for traders and investors. (EEX Website)
6. **European Energy Exchange (EEX) Market Data Portal**: EEX offers a dedicated market data portal that provides access to electricity, natural gas, emissions, and coal market data for the EU and beyond. (EEX Market Data Portal)
7. **Emissions Trading**: EU Emissions Trading System (EU ETS): Offers data on carbon emissions and trading prices for carbon allowances. (EU ETS information)
8. **Energy Regulators in EU Member States**: National energy regulators in EU member states often publish reports and data related to energy prices, tariffs, and market developments specific to their respective countries.
9. **Environmental Markets**: **Guarantees of Origin (GOOs)**: Association of Issuing Bodies (AIB): Provides information on guarantees of origin for renewable energy sources, including their issuance and trading. (AIB)

4.5.2 Renewable Energy Production

1. **European Environment Agency (EEA)**: The EEA offers comprehensive data on renewable energy production and consumption in the European Union (EU). This data is crucial for tracking the progress of renewable energy integration, assessing environmental impacts, and evaluating the EU's efforts to transition to a sustainable and low-carbon energy system. The EEA provides data in various forms, including:
    - Renewable Energy Production: The EEA offers information on the production of renewable energy from various sources, such as wind, solar, hydroelectric, and biomass. This includes data on:
        - Installed Capacity: Information about the total installed capacity of renewable energy sources in the EU.
        - Energy Generation: Data on the actual energy generated by renewable sources, often measured in gigawatt-hours (GWh) or terawatt-hours (TWh).

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    - Share of Renewables: The percentage of renewable energy in the total energy mix, which indicates progress toward renewable energy targets.
  - Renewable Energy Consumption: The EEA provides data on how much renewable energy is consumed within the EU. This includes:
    - Renewable Energy Share in Final Energy Consumption: This metric shows the percentage of renewable energy used in various sectors, including electricity generation, heating, and transportation.
    - Sectoral Breakdown: Data on renewable energy consumption in specific sectors, helping to assess the growth of renewables in different areas of the economy.
  - Environmental Impact: The EEA also offers information on the environmental impact of renewable energy production, such as emissions reductions and the reduction of greenhouse gases compared to fossil fuels.
  - Trends and Analysis: The agency often publishes reports and analysis on trends in renewable energy production and consumption, highlighting progress and identifying areas for improvement.

These data are valuable for policymakers, researchers, businesses, and the general public, as they contribute to understanding the transition to renewable energy and its environmental benefits. To access this data and stay updated on the EEA's renewable energy publications, you can visit the European Environment Agency's official website. (European Environment Agency (EEA)). On their website, you can explore reports, datasets, and interactive tools that provide insights into renewable energy trends and developments in the EU. Additionally, the EEA collaborates with Eurostat to ensure the availability and accuracy of renewable energy statistics across the EU.

2. **EUROSTAT**: EUROSTAT, the statistical office of the European Union, offers comprehensive energy statistics, including data on energy production, consumption, and prices. They provide detailed information on energy markets and trends within the EU. (EUROSTAT Energy Statistics)

4.5.3 Commodity Market Data

1. **Agricultural Commodities**: The EU Common Agricultural Policy (CAP) offers data on agricultural commodity prices. (CAP information)
2. **Oil and Gas Prices**: The International Energy Agency (IEA) and Eurostat provide information on oil and gas prices. (IEA and EUROSTAT Energy Statistics)

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4.5.4 Consumer Price Index (CPI)

Inflation Data: Eurostat publishes the Harmonized Index of Consumer Prices (HICP), which tracks inflation and consumer price indices across EU member states.

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5 Modelling in techno-economic assessments

This chapter contains coding standards and tips for producing readable and reusable code for techno-economic evaluations. Section 5.1 includes general tips on how to effectively model TEA, how to setup models, and how to use version control systems and code versioning. Further, Section 5.2 contains a short example of how a system component could be set up within a TEA.

5.1 General coding standards

For TEA, the components should be modelled in a kind of steady state simulation. More specifically, it is assumed that during one timestep (which usually is 1 hour or 15 minutes), the power flows are constant. This is an efficient way to model such systems over large periods of time. In contrast, one could use a dynamic modelling approach, where all power flows are constantly changing. This would be usually done by describing the system with differential equations. However, solving these differential equations over such long periods of time is usually much more computationally expensive. Moreover, things like transient processes, which would be captured only by a dynamic simulation, are considered to not have a large enough effect on the overall profitability of the system, so that it is not necessary to consider them in the simulation.

When designing and using components, there is always a trade-off between accuracy and efficiency: A very accurate model, especially if it consists of many calculations that are related to physical details, takes a long time to simulate compared to a model that only works with an efficiency curve. Note that such simulations always have many simplified assumptions (for example, that the solar irradiation is constant in one timestep, or that the load profile will be the same as in a previous year) and one should therefore consider if using lots of resources (both human and computational) on building a very accurate model is worth it. However, it can be beneficial to create components with different levels of detail in order to have better understanding of the costs and revenues.

5.1.1 Coding standards & requirements for python

Programming is not just about making code work; it is also about creating code that is easy to understand, modify, extend, and reuse. Keeping this in mind will not only make the long-time development easier, but it also greatly benefits collaborators, whether they are team members or future maintainers of the codebase. The following points outline the most essential principles for writing high-quality and maintainable Python code.

Reusability: Write modular and reusable code. Break your code into functions and classes that can be used in various parts of your project or in other projects. If you find yourself writing scripts that consist of many (>20) lines inside the same function or in the main scope, consider breaking up the code into multiple functions. Avoid duplicating code and redundant code. If you find yourself writing the same code in multiple places, consider refactoring it into a reusable function or method.

Comments and documentation: Include comments to explain non-obvious parts of your code. Provide docstrings for functions and classes following the PEP 257 (Python Enhancement Proposal 257) recommendations. Documentation should describe the purpose, parameters, and return values of functions and methods.

Readability: Ensure that your code is easy to read and understand by others. Use consistent, meaningful, and descriptive naming conventions, maintain a clear structure, and avoid overly complex expressions. Use blank lines to separate logical sections of code. Avoid excessive spaces at the ends of lines. Make sure your code is visually clean and readable, this makes your code self-documenting and easier for others to understand.

PEP 8 Compliance: Follow the guidelines outlined in PEP 8 (Python Enhancement Proposal 8) for code style. This includes using consistent indentation (usually 4 spaces), following naming conventions (e.g., variable names in lowercase_with_underscores), and adhering to formatting rules.

Avoid hardcoded constants: Instead of using hardcoded constants, define constants with meaningful names. This enhances code readability and makes it easier to maintain.

Testing and testability: Write tests for your code to ensure it functions correctly. Test different parts of your code separately (so called unit tests) and test different possible ways of using your code. Think of scenarios where your code might fail and test those. Do not only verify that your code runs, but also that it produces the correct results (for example by using assert statements). Code that is designed with testing in mind is often more modular and reusable.

Consistent import style: Follow a consistent style for importing modules. Use absolute or relative imports consistently throughout your project. Group imports in the following order: standard library, third-party packages, and your project's modules.

5.1.2 Version Control systems

When writing software, it is recommended to use a Version Control system (VCS). A VCS can be used to very conveniently track the changes made to your software, such that you can always go back to an older version after making changes that you later want to revert. This is especially useful when multiple people work on the same project. The most widely used VCS is git, and most modern IDEs (integrated development environment, for example Visual Studio Code, PyCharm) have supported integration for git.

5.1.3 Versioning

In order to keep track of different versions, the project can further have specific semantic versions for different release dates. Each release gets a new semantic version, this ensures system stability when the code evolves but still needs to be used in an older version for a different project. Most python packages use semantic versioning, which means that they have a version number of the form A.B.C, which is increased (more or less diligently) based on the following rules:

- When the first number, A, is increased, (for example, 1.2.3 -> 2.0.0) it is called a *major release*. In a major release, everything is allowed. It oftentimes comes with many new features and oftentimes even breaking changes. This means that code that uses an older version might no longer be functioning after updating the package.
- When the second number, B, is increased, (for example, 1.2.3 -> 1.3.0) it is called a *minor release*. A minor release is ideally always backward compatible, such that users do not need to change anything in their code. However, minor releases often include new features.
- When the third number, C, is increased, (for example, 1.2.3 -> 1.2.4) it is called a *patch*. According to the rules of semantic versioning, patches are only used to fix existing bugs and not to include new functionality.

It is not necessary to use semantic versioning when writing code that is only used for a limited amount of time, or by few people. However, when writing software libraries that are intended to be used by many people, it is necessary to know these rules, in order to give the users a sense of how much is changing in a new release.

5.2 Coding Example: LFP Battery

The following chapter will give an example on which parameters could be part of the simulation and how the code of a technical component could look like. An LFP Battery was chosen as an example.

As suggested in Chapter 5.1.1, code should be written in a reusable way. One way to do so is creating class types. A class is like a blueprint or template that defines the structure and behaviour of objects. It specifies the properties (attributes) and actions (methods) that objects of that class will have. An object is a specific instance created from a class, with its own unique data, such as capacity and power rating, and the ability to perform the actions defined in the class, storing energy.

Figure 8 shows the UML of a class (named BatteryLFP) which inherits features from a parent class (named Storage). This means, that the BatteryLFP will have the same properties and methods as Storage but can have extra features such as a specific ageing function which only applies to LFP batteries. In this case, the storage is defined as an object with power and capacity which is defined

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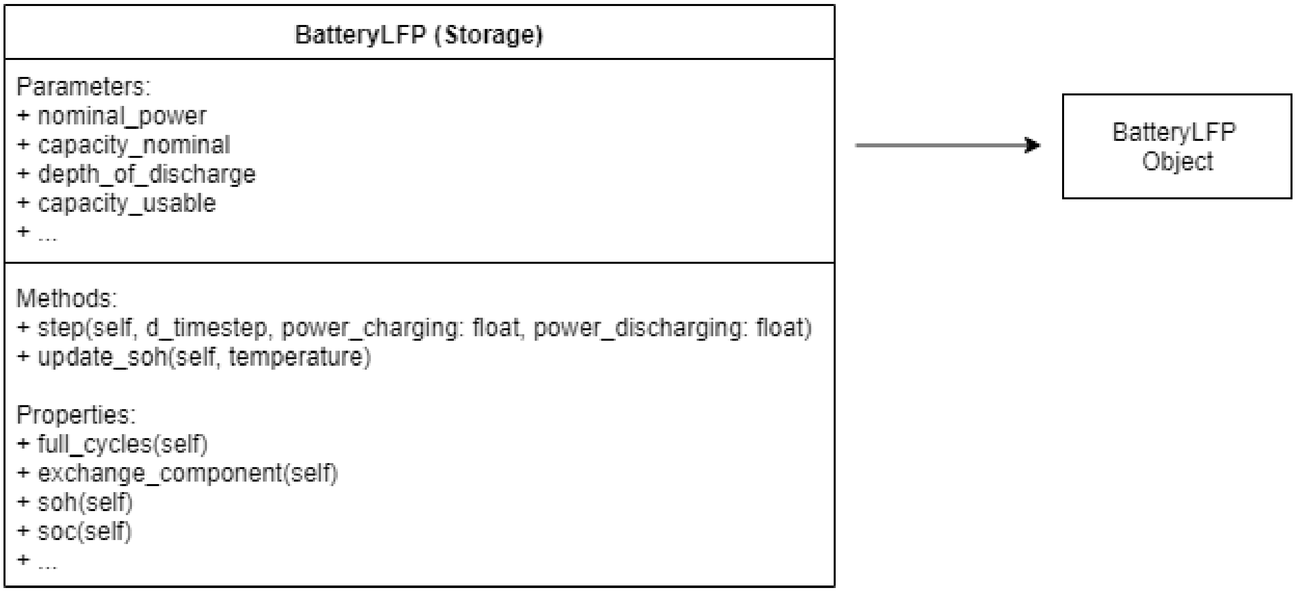
to store energy with a specific charging and discharging efficiency. A Storage could be a LFP battery, as in this example, but also a different type of battery or even a hydrogen or heat storage.



BatteryLFP (Storage)

Parameters:
+ nominal_power
+ capacity_nominal
+ depth_of_discharge
+ capacity_usable
+ ...

Methods:
+ step(self, d_timestep, power_charging: float, power_discharging: float)
+ update_soh(self, temperature)

Properties:
+ full_cycles(self)
+ exchange_component(self)
+ soh(self)
+ soc(self)
+ ...

BatteryLFP Object

Figure 8 UML diagram of the Battery class.

In addition to the parameters listed in the UML diagram, there can be further parameters defined, some of these parameters are listed in Table 5. Depending on the depth of simulation, different parameters should be considered. However, for standard techno-economic evaluations the following parameters in Table 5 should be sufficient.

Table 5 Parameter table for LFP batteries.

	Parameter	Unit	Definition
User Attri	Nominal Capacity *capacity_nominal*	Energy unit	Chemical/ physical energy capacity within storage system.

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	Parameter	Unit	Definition
	Depth of Discharge (DoD) *depth_of_discharge*		Minimum chemical/ physical required energy stored within the storage system in ratio to the nominal capacity
	State of Health (SoH)		Degree of degradation and tear
	End of Life (EoL) *end_of_life*		The end of life defines the SoH, at which the component shall be exchanged
	Usable capacity *capacity_usable*	Energy unit	Amount of capacity which can actually be used within the storage system. $E_{usable} = (1 - DoD) * (E_{nominal} * SoH)$
	Time duration by timestep *d_timestep*	h	As all components are power based, it is necessary to enter the time duration per time step, so that the energy value behind each time step can be calculated
	Nominal power *power_nominal*	Power Unit	Nominal power rating of the battery storage
	State of Charge (SoC) at the initial time step *soc_init*		Relative amount of stored energy in comparison to the usable capacity in the initial time step
Constant Attributes	Auxiliary power *auxiliary_power*	Power Unit	Amount of power required for auxiliaries to the storage, such as the battery management system. Default Value = None
	Capacity cell *capacity_cell*	Energy Unit	Rated energy capacity per Cell
	Efficiency *efficiency*		Battery Efficiency, separately for charging and discharging operations Default Value = 0.9808

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	Parameter	Unit	Definition
	Stated cycle life *stated_cycle_life*		Stated cycle life with which the battery ageing algorithm is initialized Default Value = 5000
	Stated end of life *stated_end_of_life*		Stated end of life with which the battery ageing algorithm is initialized Default Value = 0.8
State Attributes	Charging cycles *cycles_charged*		Sum of energy charged divided by the usable capacity $cycles_{charged} = \sum_{t=1}^{n} \frac{P_{charged} * dt}{E_{usable}(t)}$
	Discharging cycles *cycles_discharged*		Sum of energy discharged divided by the usable capacity $cycles_{discharged} = \sum_{t=1}^{n} \frac{P_{discharged} * dt}{E_{usable}(t)}$
	Full charging cycles *full_cycles*		$full\ cycles = min(cycles_{charged}, cycles_{discharged})$
	Energy flow external *energy_flow_external*	Energy Unit	Energy flow outside the storage, not considering the storage efficiency.
	Energy flow internal *energy_flow_internal*	Energy Unit	Chemically stored energy flow inside the storage, considering the storage efficiency
	Energy stored within battery *energy_stored*	Energy Unit	Currently stored energy within the storage $E = SoC * E_{usable}$ $E = \sum E_{charged} - \sum E_{dischaged}$

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	Parameter	Unit	Definition
	Exchange Components *exchange_components*	Bool	Tracks the SoH and EoL of the storage and marks if the storage is exchanged within a time step. 0 = False… Storage is not exchanged 1 = True Storage EoL was reached, and storage is exchanged
	Operating hours *operating_hours*	h	Sum of house the storage was in operation
	State of Charge (SoC)		Relative amount of stored energy in comparison to the usable capacity $SoC = \frac{\sum E_{charged} - \sum E_{dischaged}}{E_{usable}}$
	Storage power	Power Unit	Power flow inside the storage, considering the storage efficiency, correlated to Energy flow internal.
	Storage power external	Power Unit	Power flow outside the storage, not considering the storage efficiency, correlated to Energy flow external.

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6 Overall progress and Current status

This is the finished version 3 of deliverable 5.1, which has been reviewed.

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7 Conclusion

TEAs In the context of energy systems combine technical and economic analyses to provide a holistic understanding of energy systems and allow a fair comparison of different alternatives. They provide a systematic and multidimensional approach to evaluating energy technologies, systems, and projects and thus help stakeholders assess the feasibility, cost-effectiveness, and sustainability of different options, ultimately informing decisions that contribute to a more efficient and sustainable energy future.

This report provides comprehensive information on all TEA aspects and analyses relevant in the context of renewable energy systems and thus serves as TEA training guideline. Moreover, coding standards and a coding example are supplied, thereby providing a solid foundation on modelling within TEAs.

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Project Coordinator:

Dr. Viera Pechancova
Univerzita Tomase Bati ve Zline
University Institute
Nam. T. G. Masaryka 5555
CZ- ZLIN 760 01
E-Mail: pechancova@utb.cz

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