

# How to increase revenues in utility-scale solar-battery systems?

## White Paper

# Executive Summary

What to expect from this [white paper](#)?

Dear reader,

in this white paper we examine the opportunities to increase the profitability of utility-scale [solar-battery systems](#) by stacking revenues from multiple sources, such as energy sales, capacity payments, and grid services.

Installing batteries at solar power plants can help to increase the penetration of renewables as they can flatten the infeed profile to match the actual demand of the grid. They can even help to [improve grid resilience](#) by providing ancillary services.

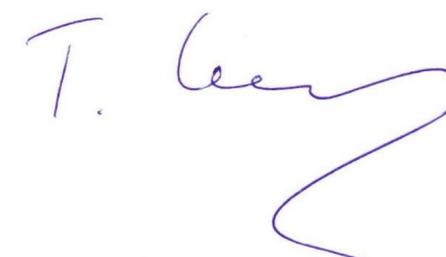
Furthermore, they can help to [increase revenues](#) by wholesale arbitrage. However, this requires an optimization of the storage dispatch to coordinate all these activities.

We present an [optimized dispatch](#) of the system that can generate additional revenue streams beyond traditional energy sales, helping to increase project profitability and reduce investment risks.

This kind of [revenue stacking](#) can also provide grid operators with additional resources to help balance the grid and maintain grid stability, which can improve reliability and reduce the need for expensive grid upgrades. Overall, revenue-stacking can help to make renewable energy projects more attractive to investors and support the growth of the renewable energy industry.

Have a nice read.

Best regards,



Thomas Kalitzky | Managing Director | Qantic GmbH





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# Global storage technology outlook: battery energy storage systems are gaining momentum

### The Americas region

This region is accounting for 18.54% of global volume with a cumulative installed capacity of 3.6 GW by the US in 2021.

Germany is a key country for BESS deployment with a total installed capacity of 2.9 GW and a market value of \$1.37 bn.

### APAC region

Asia-Pacific is the largest market for BESS with a cumulative installed capacity share of 56.11% by 2021.



### EMEA region

Up to 25.35% of the global cumulative installed capacity were built in Europe, Africa and Middle East by 2021.

Global BESS market volume and value till 2026

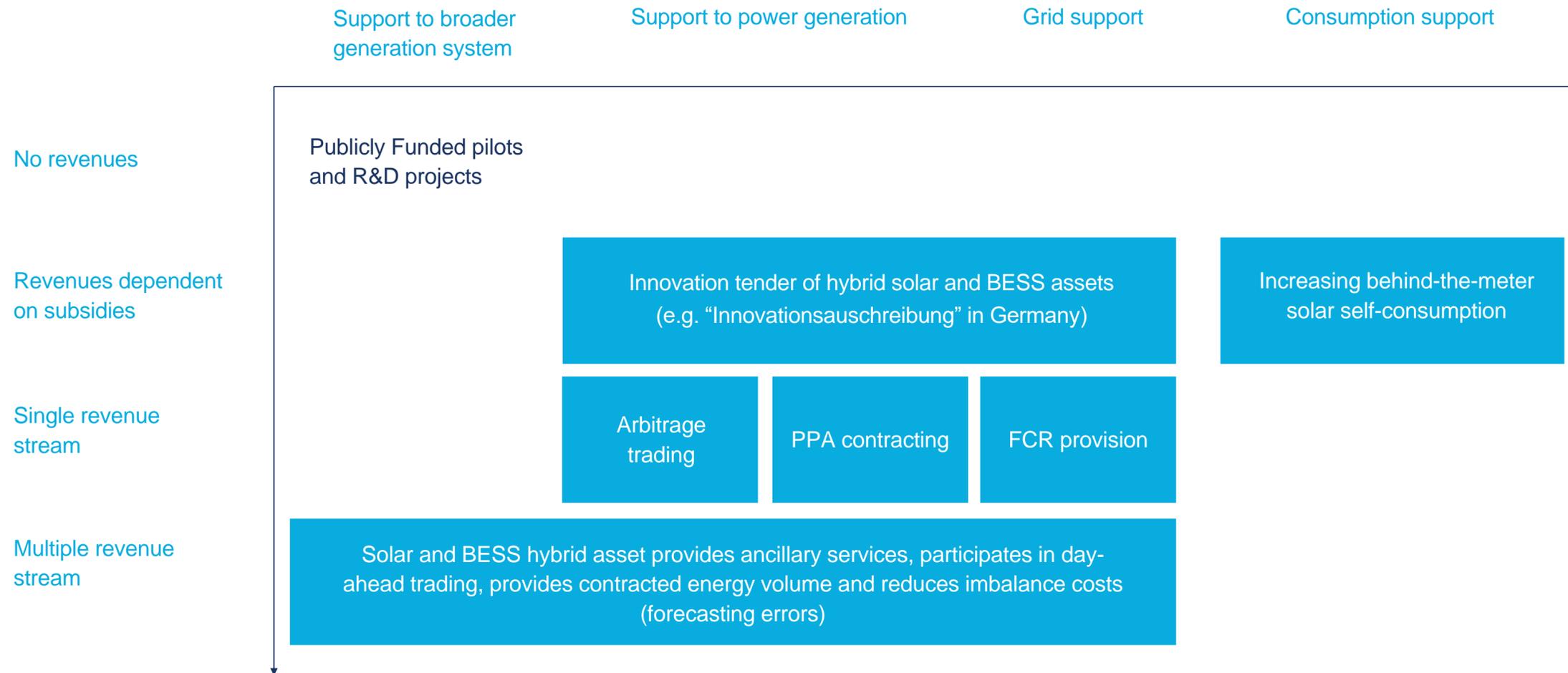


[GlobalData Outlook for Battery Energy Storage 2022]



# Revenue stacking for solar-battery applications in Germany: Finding the right time for the right market

How to increase revenues in utility-scale solar-battery systems?



**+** Our algorithm performs a dynamic capacity scheduling that allows "revenue stacking" via maximizing different revenue streams.

[Roland Berger Focus – Business models in energy storage]



# What parameters need to be considered?

Day-ahead electricity prices

FCR provision prices

PPA energy prices

Infeed-Limits

Solar production forecast

## Solar Battery Optimization



Battery and converter efficiency

Max. charge and discharge power (SoC-dependant)

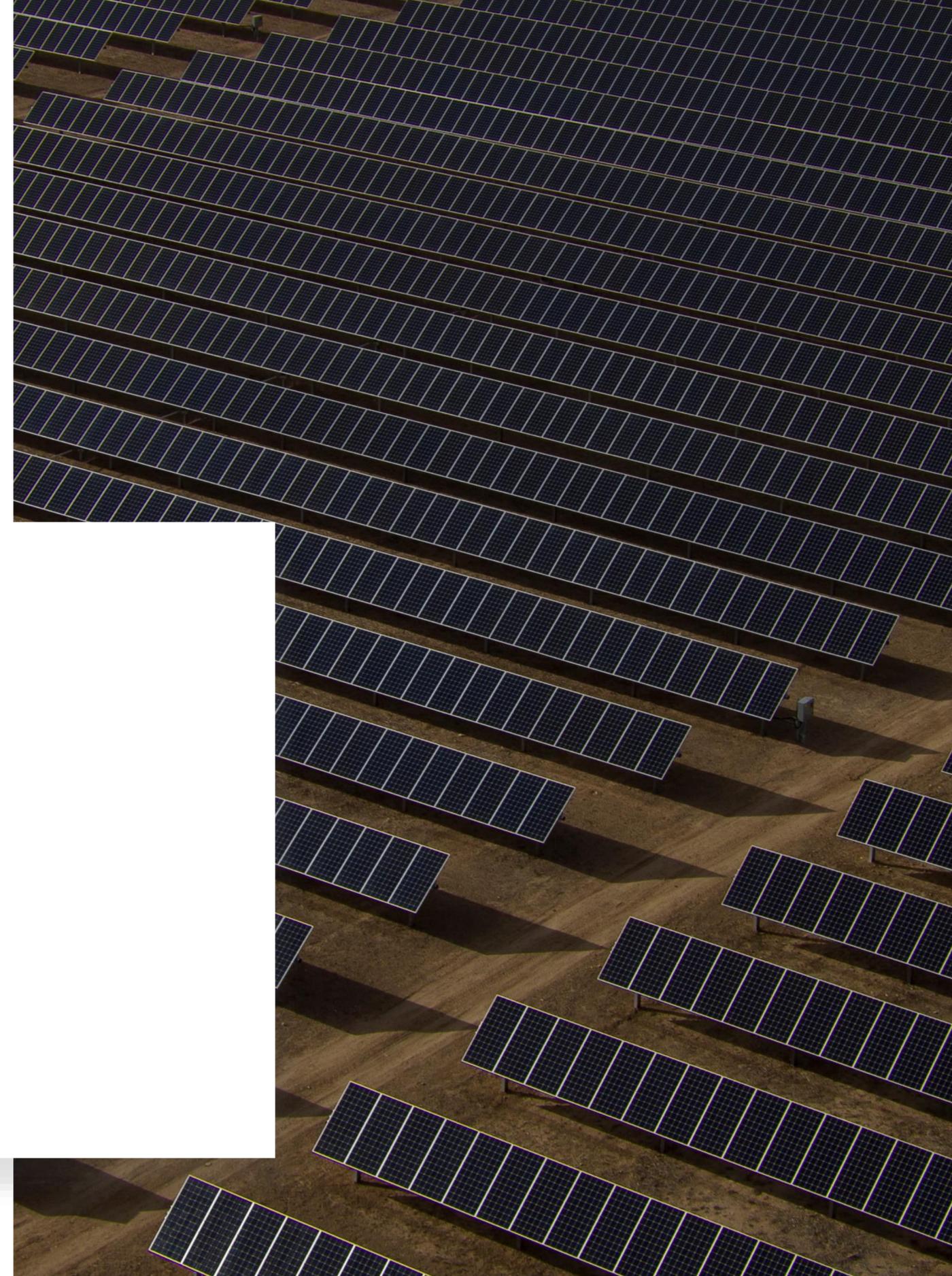
Calendaric aging (SoC-dependant)

Cycle aging (DoD-dependant)

Capacity degradation

Optimal dynamic dispatching and marketing to maximize revenue of solar + storage hybrid asset

# Case study: Utility-scale solar and storage combination in Brandenburg



## Project description

A typical solar battery system consists of solar panels, inverters and batteries.

The solar panels capture sunlight and convert it into direct current (DC) electricity, which is then sent to the inverter. The inverter converts the DC electricity into alternating current (AC) electricity. In our case, the DC from the panels can be directly stored in the battery. **The battery uses the same inverters as the PV to discharge to the grid.**

This design approach can already save initial investments as opposed to traditional designs where PV and battery have their own dedicated inverter.

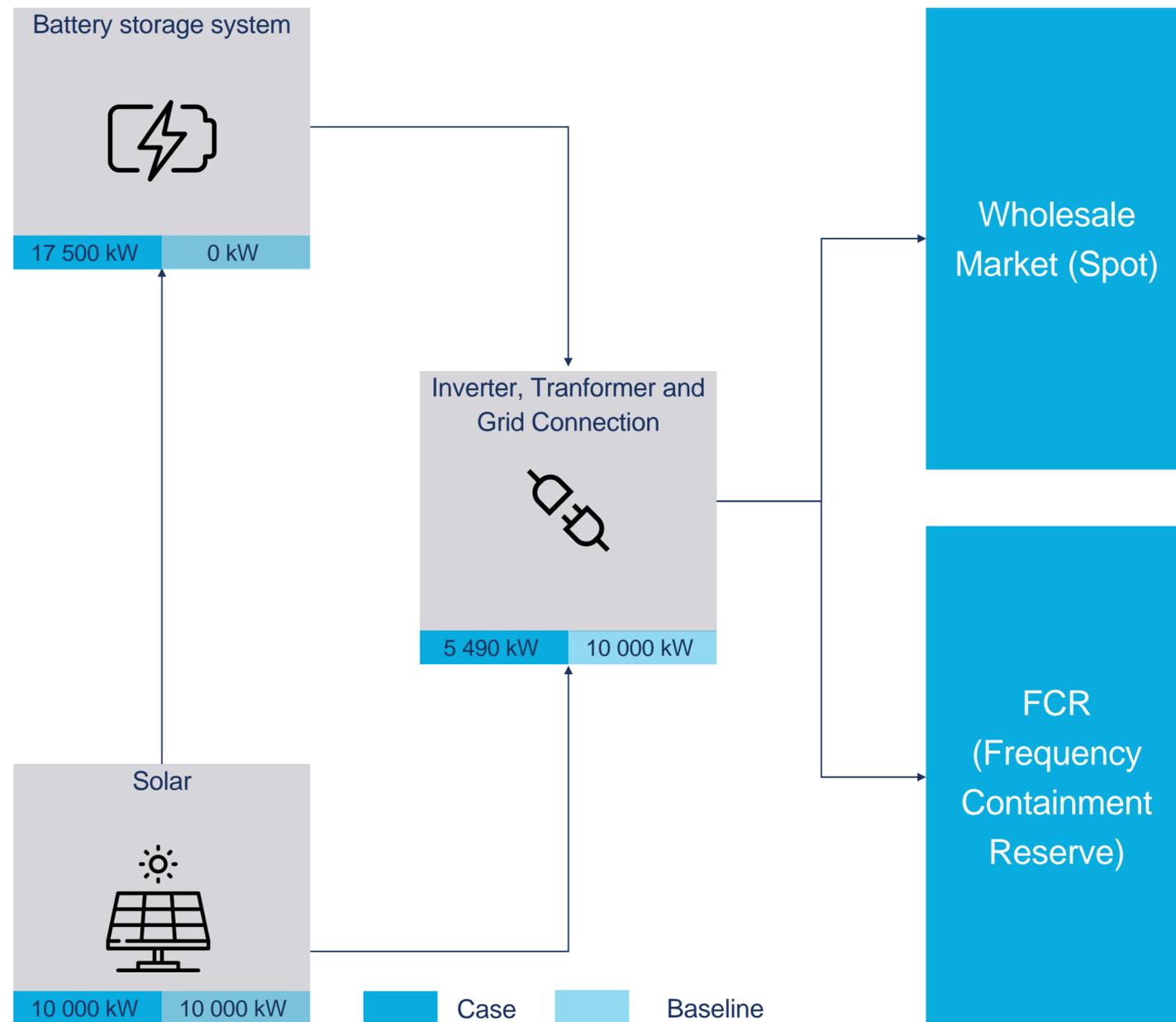
## System design

The system consists of a **17.5 MWh / 17.5MW lithium battery storage system** and a **10 MWp PV power plant**.

Both installation share an **inverter capacity and grid connection (incl. transformer) of 5,49 MW**. Mind that the capacity is lower than the PV peak power.

Although, the shared low capacity inverter reduces CAPEX it poses the challenge to operate the battery in a way that uses most of the **excess energy** that would occur in times when the PV generation hits the maximum inverter capacity.

# A multi-use approach to stack revenues



## Cost assumptions:

- PV: 700 EUR/kWp
- Inverters and Transformers: 150 EUR/kW
- Battery: 300 EUR/kW (excl. converter)
- Side specific irradiation
- Average maintenance costs

## Project parameters

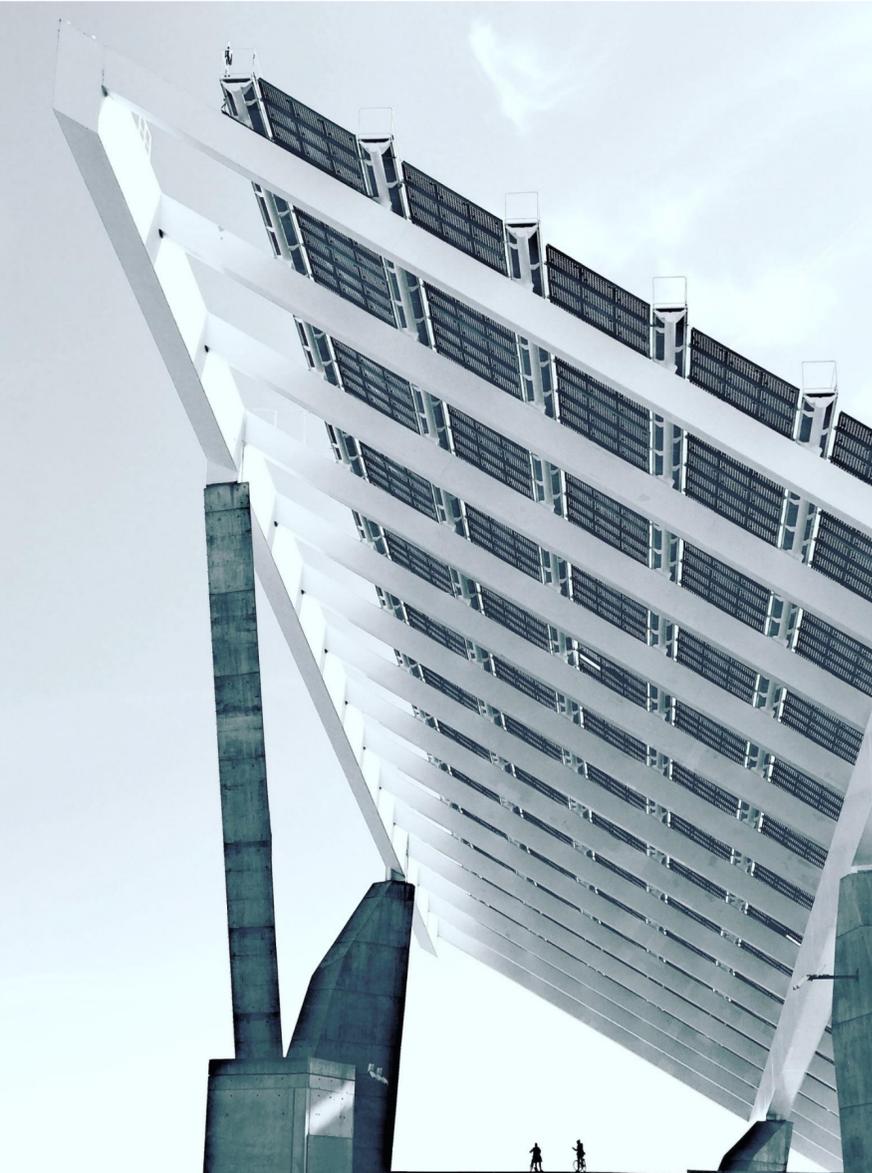
- Lifetime of 25 years
- Interest rate (WACC) 7%
- Inflation rate 3%
- Wholesale prices and FCR energy prices from 2021 (inflated throughout project lifetime)
- Typical battery degradation

## We need to coordinate three different applications

- + Increasing revenues through **market arbitrage**. Selling and feeding energy to the grid when prices are high and charging the battery at low prices.
- + Achieve additional revenues through providing capacity in the **FCR** market. However, we need to consider that this capacity will be no longer available for other applications.
- + Reserving storage capacity to charge **excess of solar power**. However, we want to use as much free capacity as possible to generate revenues from other applications.

We compare the aforementioned system design of the solar battery plant with a baseline configuration which consists of a solar-only system without any storage. The baseline system also varies from our solar-battery configuration as we assume an inverter and transformer capacity of 10,000 kW at the grid access point which matches the peak production of the PV.

The baseline system has a net present value (NPV) of -1,075,365 EUR which means it cannot meet our target WACC of 7 % p.a.



## 39.9 Million EUR

Net Present Value (NPV) of the Solar-Battery-System



## 4.5 Million EUR

Additional Investment



## ~ 3 years

Payback on the battery investment

The design approach of shared inverter and grid connection infrastructure for the battery and PV at reduced capacity of 5,490 kW already leads to **cost reductions of about 675,000 EUR of initial invest**. However, the total initial invest increases as we also need an investment of about 5,250,000 for the batteries

As the costs saving from the reduced inverter and transformer capacities will no help to make our project profitability, we also need to consider the additional benefits of the installed battery.

Firstly, the battery helps us to perform a **time-shifting** of the infeed which allows us to generate **arbitrage** by shifting the market sell to hours of high prices, whereas we try to charge the battery in low priced hours.

Secondly, this time shifting also helps us to efficiently manage the reduced capacity of the grid access (undersized inverter and transformer). We try to charge most of the excess energy of the PV that exceeds the market capacity as a kind of **peak-shaving**. For this purposes the battery needs to have enough free capacity to accommodate the excess energy.

Thirdly, we want to use the storage to act as **FCR** and generate revenues. In order to do this, we need to hold a certain state of charge so that we can charge and discharge according to the FCR commands of the grid operator. i.e. if we sell the whole capacity of our battery as FCR we need to hold a SoC of about 50% to allow for the required positive and negative reserve.

All three activities influence each other and need to be considered in the optimization. **Our optimization leads to an attractive NPV of the project.**

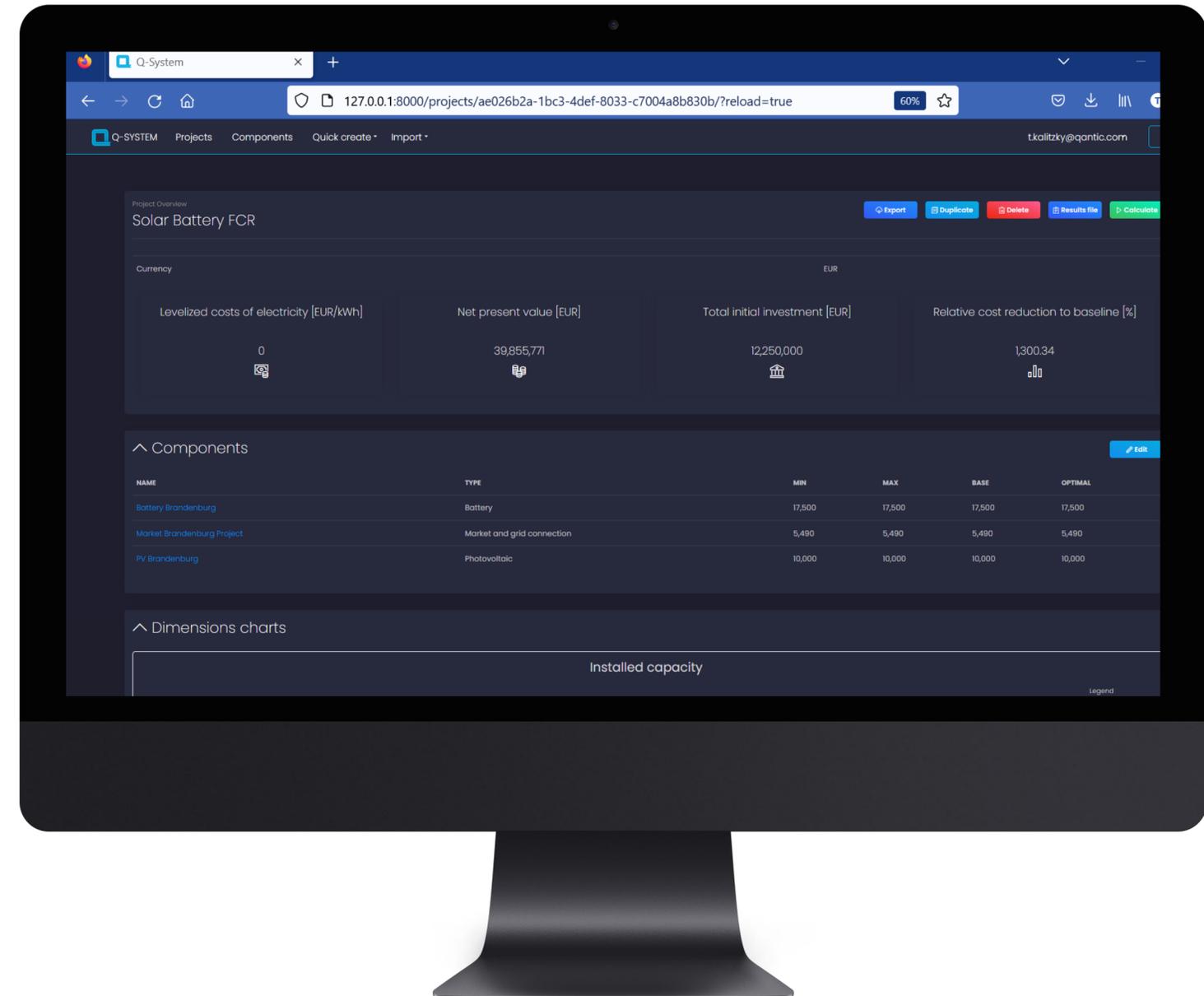
# We used our energy system design tool “Q-System” to calculate the results

Configure component's behaviour and costs

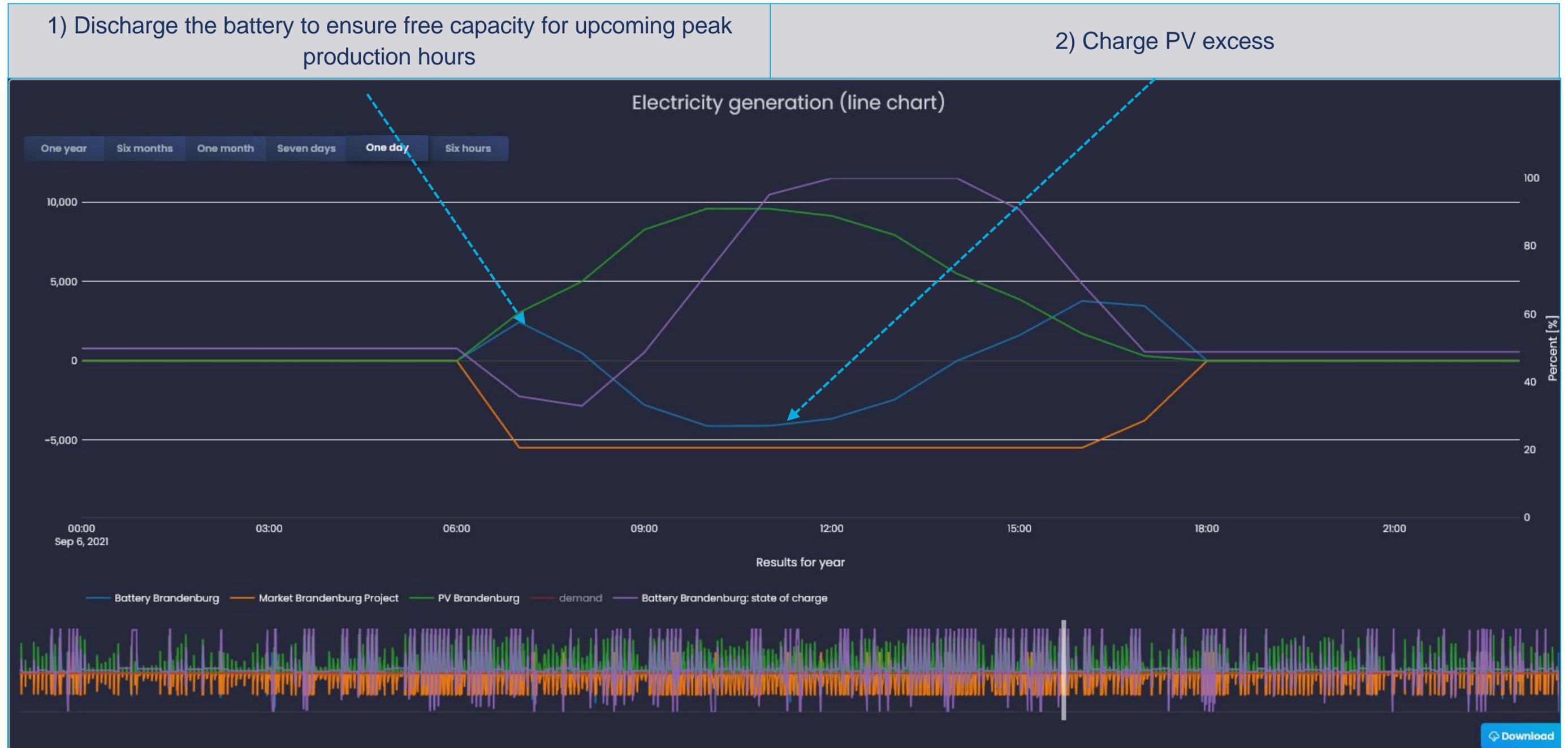
Consider side specific restrictions (e.g. solar irradiation)

Enter market price assumptions

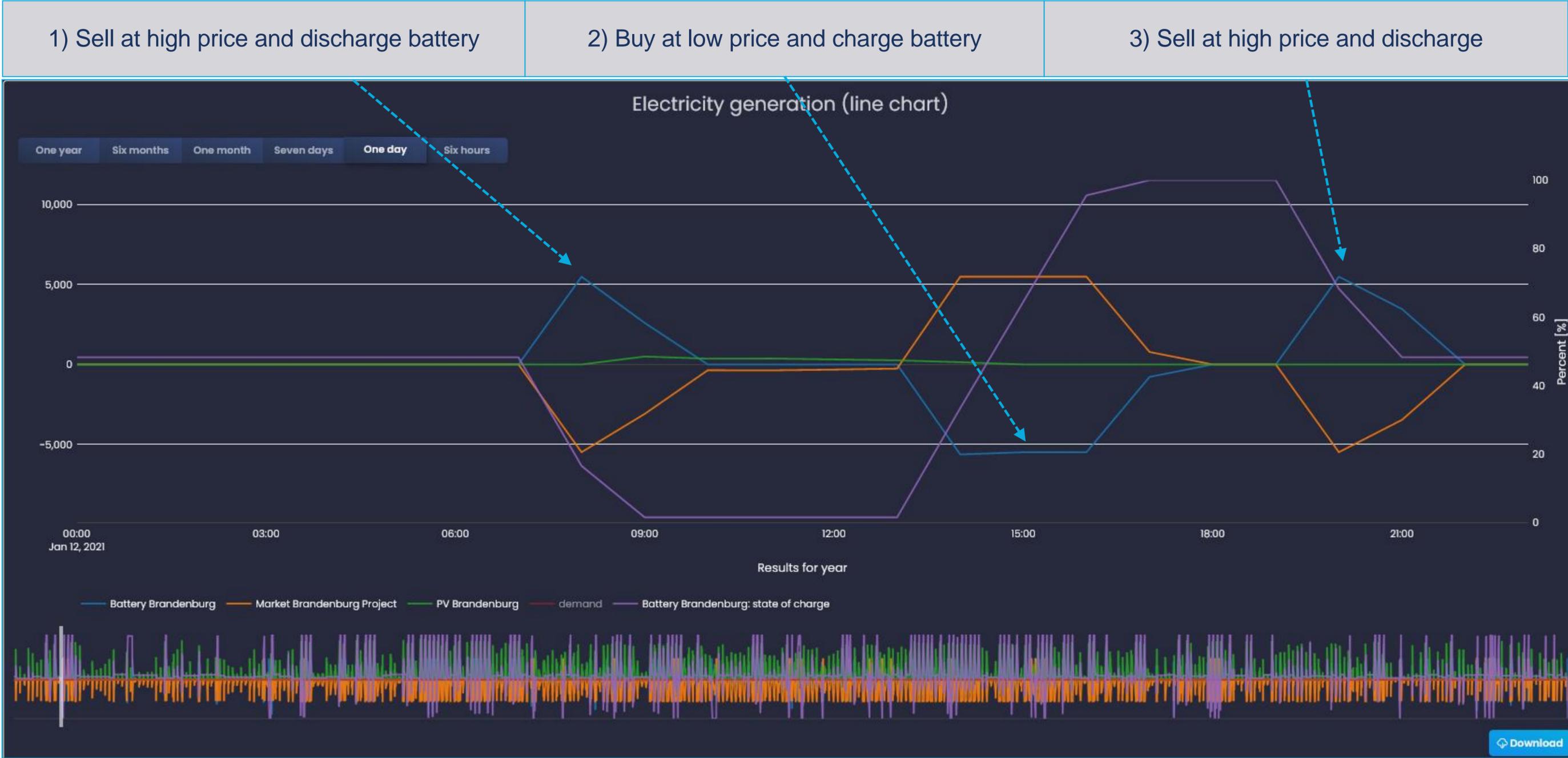
Simulate system dispatch and calculate economics



# Q-System results – A) PV peak shaving in high production hours



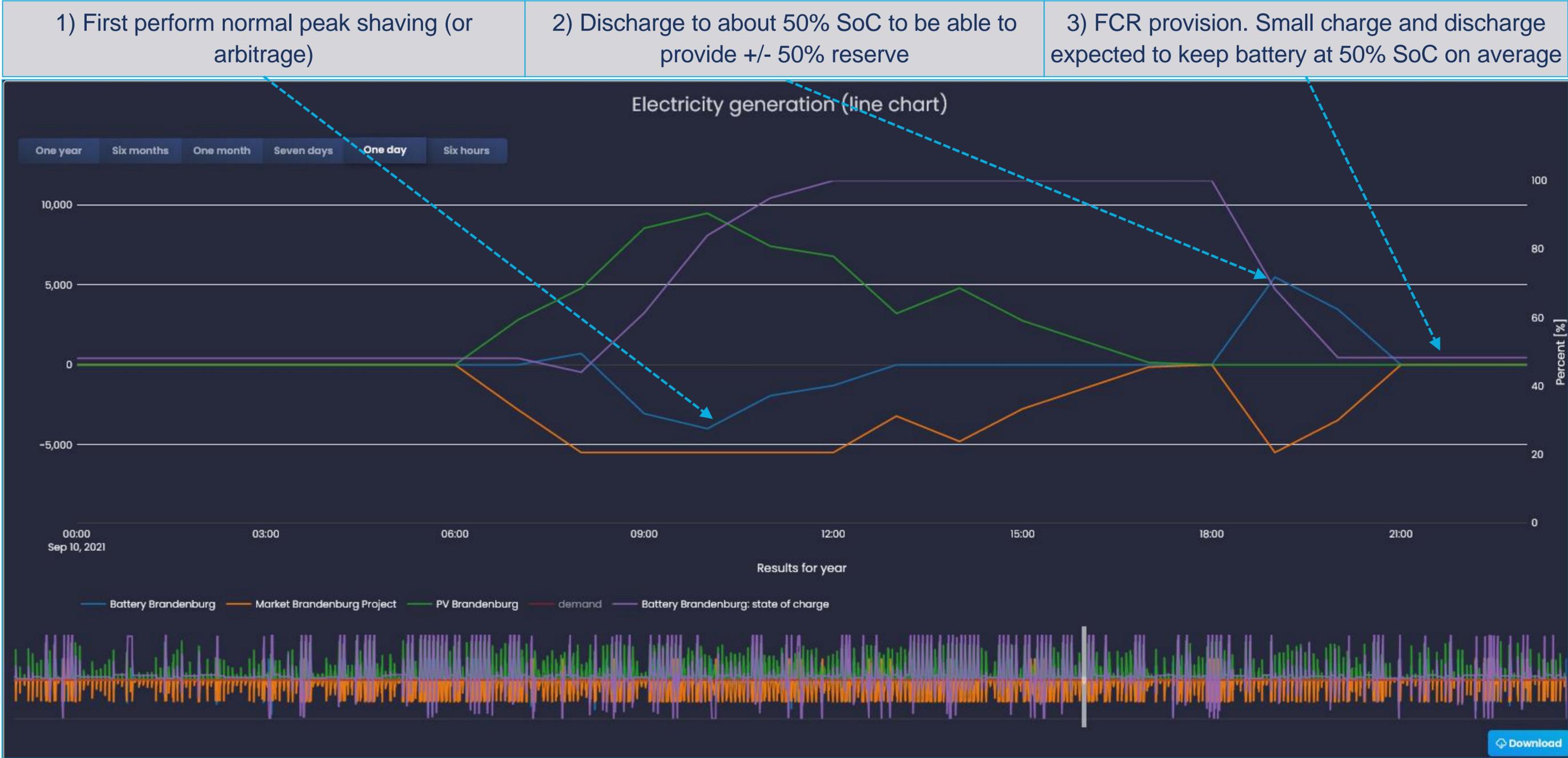
# Q-System results – B) Market arbitrage from price spreads



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# Q-System results – C) Optimal FCR marketing of capacity



How to increase revenues in utility-scale solar-battery systems?



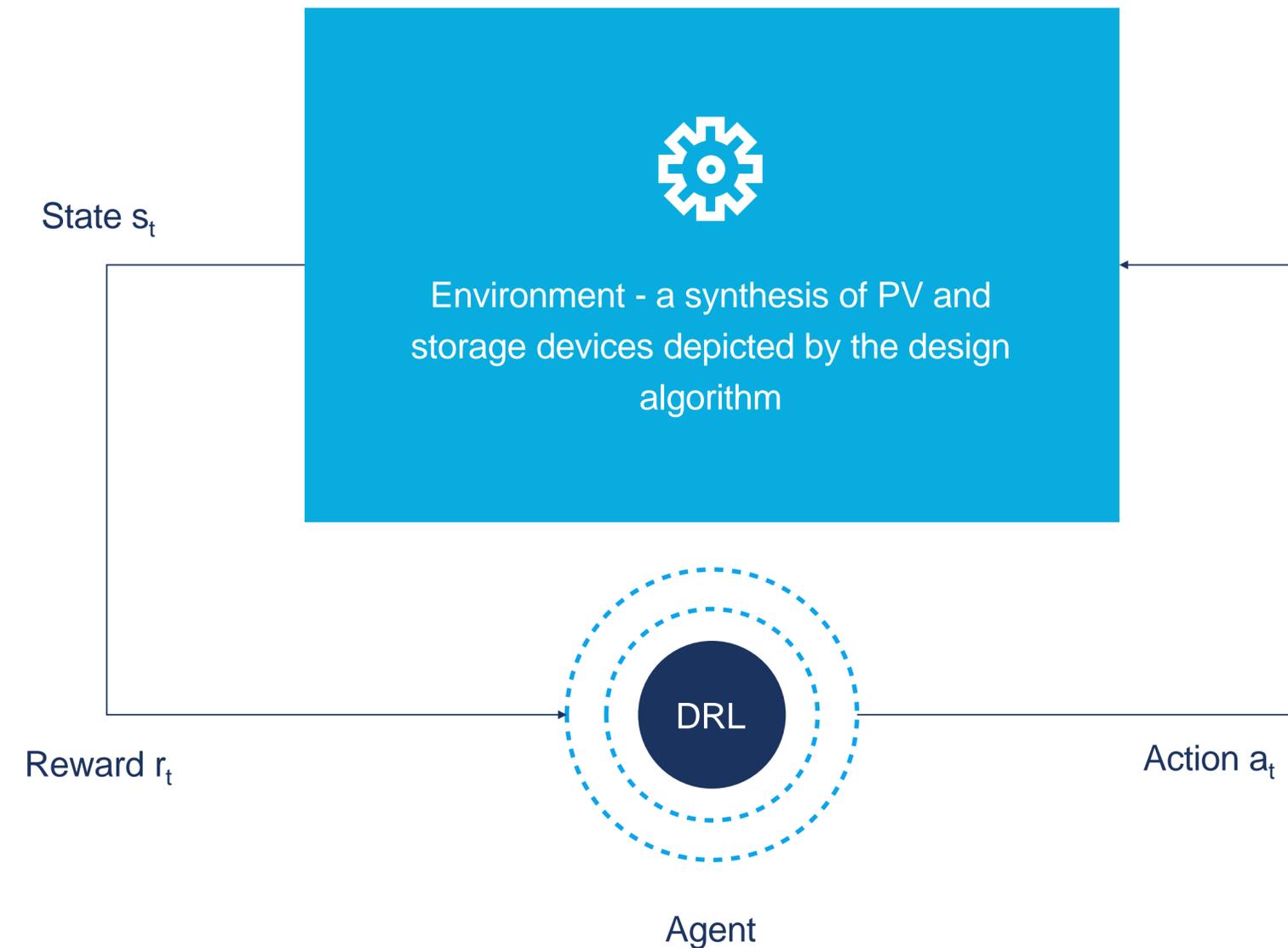
# How does Deep Reinforcement Learning work?

Applications in the field of Deep Reinforcement Learning (DRL) are a subfield of Machine Learning techniques and comes under the discipline of Artificial Intelligence.

In DRL, an Artificial Neuronal Network is trained to guide through the decisions of a so-called **agent**. Then, the agent takes actions on an **environment** (e.g. power assets within microgrids) in order to **maximise or minimise a cumulative reward**.

The change of **state  $s_t$**  is conceived as a sequential decision process (as Markov Decision Process). The  $s_t$  (e.g. state of charge of a storage device) can be changed by **actions  $a_t$**  that are pre-defined in advance (e.g. charge battery). Furthermore, a metric is introduced to evaluate the quality of respective actions and the resulting states as a **reward function  $r_t$** .

During a **training**, the algorithm learns by interacting with the environment to choose the actions that maximise the reward respectively. The trained model can then be used in simulation or operation of the system.



# System simulation starts with choosing an appropriate economic dispatch strategy: AI enables high quality optimization

Heuristics & Rule Based Methods	Deterministic Optimization	Stochastic Optimization	Deep Reinforcement Learning
<b>Rule of Thumb like Approach</b>	<b>Simplified System under Perfect Foresight</b>	<b>Simplified System under Uncertainty</b>	<b>Detailed System under Uncertainty</b>
<p>Straight forward approaches to control power systems by following a set of easy implementable rules.</p> <ul style="list-style-type: none"> <li>➤ Easy to implement</li> <li>➤ High calculation speed</li> <li>➤ But, suboptimal results</li> </ul>	<p>Full optimization of the power system control, e.g. Mixed-Integer Linear Programming or Dynamic Programming.</p> <ul style="list-style-type: none"> <li>➤ Representation of system can be challenging</li> <li>➤ Neglecting uncertainty</li> </ul>	<p>Same as deterministic optimization but using scenarios to represent uncertainties, e.g. Stochastic Dynamic Programming approaches.</p> <ul style="list-style-type: none"> <li>➤ Theoretically optimal</li> <li>➤ Usually needs simplifications</li> <li>➤ Low calculation speed</li> </ul>	<p>Stochastic optimization using AI with a freely chosen simulation model of the system.</p> <ul style="list-style-type: none"> <li>➤ Lowest restrictions in the representation of the power system, detailed modelling is possible</li> <li>➤ Very good coverage of stochastic aspects</li> <li>➤ High calculation speed (of trained model)</li> </ul>

The accuracy of results ...  ... is expected to increase

Definition: The **Economic Dispatch** is the procedure by which an operator selects which of its generators produces at what time to meet electricity demand. It also considers the charge and discharge from batteries

 = Method investigated in this study

**+** AI can yield benefits, if power systems exceed a certain level of complexity, when computation speed is crucial or large amount of input data have to be processed (e.g. measurements or forecasts).



# Why do we need software tools to design battery storage systems?



## Improving decisions

Investing in power assets is cost-intensive. Therefore, a well informed decision that involves most of the available data is crucial. Software products help to guide the process of extracting value from this data.



## Estimation of performance

Considering comprehensive data, software helps us to compute information quickly for the use in day-to-day business and condense information to give a full picture of the estimated project performance.



## Comparing options

Comparing results gives us an idea of different options. Software products help to better understand the systems sensitivity toward changes in the assumptions or future requirements.



## Dealing with uncertainty

A look into the future is always uncertain – therefore comprehensive energy models lower risk using a methodology rather than gut feeling and help to develop robust business models.

Providing accuracy in  
arbitrage trading and  
revenue stacking

Percent of theoretical maximum

> 95 %

Real-time optimization  
possible with pretrained  
models

Computation speed

~ 20 ms

Tenders successful in  
around 20 minutes,  
reduce workload

Workload

~ 20 min

Project managers can  
work simultaneously on  
tenders

Productivity increased

10+ Users

AI outperforms  
numerical models used in  
standard software

... and there are even more benefits of  
our AI-based applications

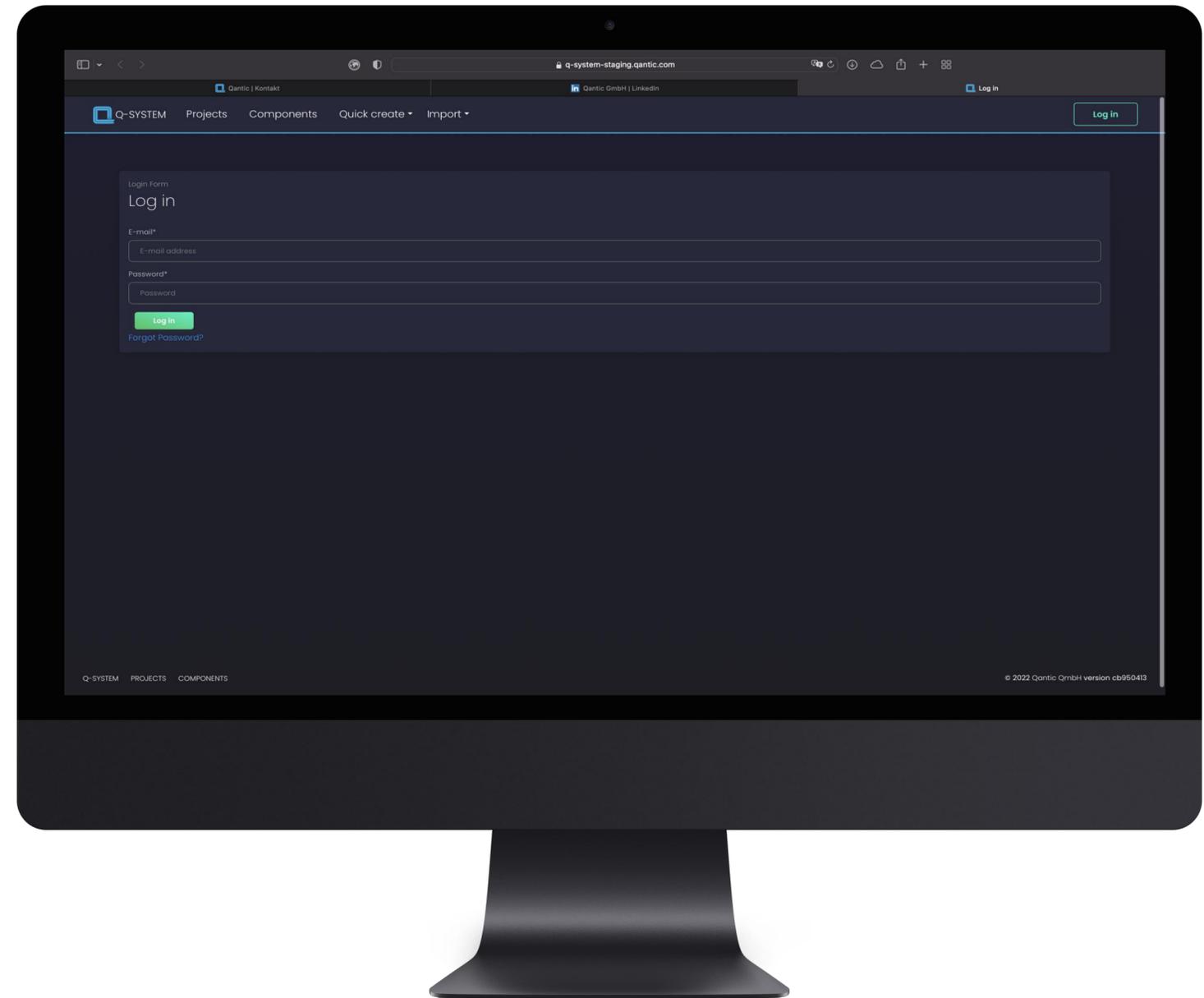
In our [Live Demo](#) we share an introduction of basic functionalities of our Q-System SaaS application. Based on your interest we showcase applications for on-grid and off-grid applications.



# Q-System: Microgrid Design Software

A comprehensive SaaS application to design your microgrid project – [feel free to reach out to us and improve your project with artificial intelligence.](#)

[Click here](#) & schedule a  
**Live Demo.**





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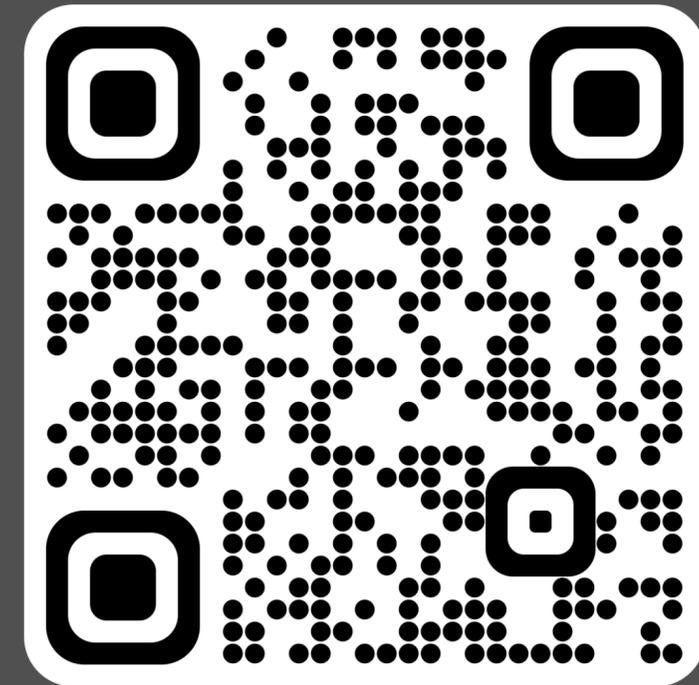
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