Early Screening Tool for the Business Case of Energy Storage

Finding the financially responsible energy storage solution

Master Thesis

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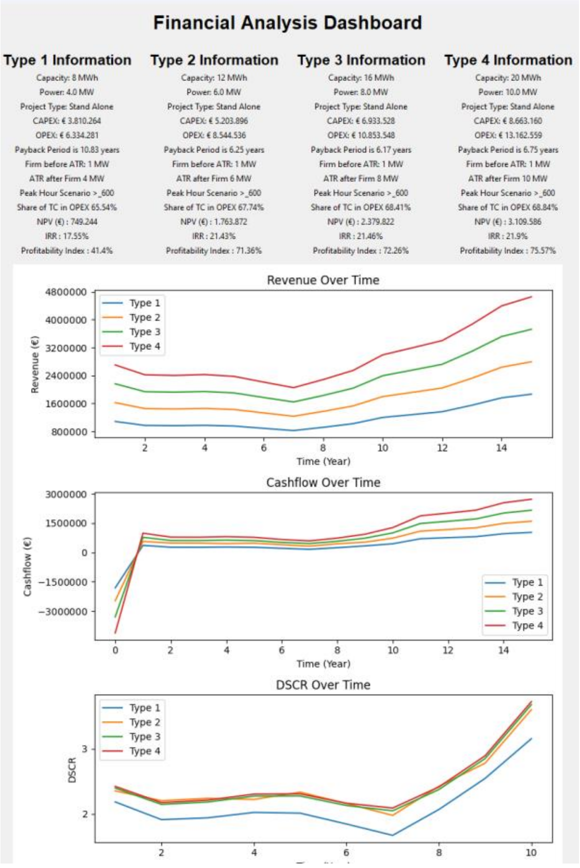
EXECUTIVE SUMMARY

To achieve the government's decarbonisation goals, the source of electrical energy production needs to be replaced by renewable alternatives. The downside of renewable energy sources is that their production is uncertain. That is why more companies are interested in applying grid-size energy storage. Like many competitors, Pure Energie must integrate battery storage systems into its energy portfolio to balance its current production. The business case for battery systems is complicated and impacted by many variables like: “types of energy storage systems, sources of energy, methods of earning money through trading, depreciation, and transport costs”. Therefore, we aim to develop an automated business case tool that can calculate the financial viability of multiple battery systems and compare the associated financial ratios within the project parameters. This enables responsible parties within Pure Energie to speed up the initial scanning process. Moreover, the tool indicates what battery sizes are profitable given the parameters of the intended project.

We systematically divided the project into four phases, each with a specific goal, to ensure the quality and validity of the research. The first phase involved gathering theoretical knowledge and relevant industry standards. In the second phase, we conducted a comprehensive analysis of the current business case to identify the required functionalities and features. These were then automated and validated using Python. The third phase saw the addition of the revenue model of the trading division of Pure Energie to the automated business case, enabling the tool to compare multiple battery sizes based on net present value, internal rate of return and the profitability index. Within this phase, the tool was tested and validated by colleagues, verifying the outputs to ensure reasonableness and coherence. Finally, in the fourth phase, we subjected the tool to a sensitivity analysis and wrote a guide to ensure that the tool can be used after this project is completed.

We aim to develop a tool that can automatically compare multiple battery energy storage systems based on financial ratios within the parameters of the given project. The results are different for every project; the example we use to represent the tool's functionality is a stylised case study performed with the tool. Where we compared four battery systems of different sizes to determine their viability. The output of this case study is represented in Figure 1.



Financial Analysis Dashboard

Type 1 Information
Capacity: 8 MWh
Power: 4.0 MW
Project Type: Stand Alone
CAPEX: € 3.810.264
OPEX: € 6.334.281
Payback Period is 10.83 years
Firm before ATR: 1 MW
ATR after Firm 4 MW
Peak Hour Scenario >_600
Share of TC in OPEX 65.54%
NPV (€) : 749.244
IRR : 17.55%
Profitability Index : 41.4%

Type 2 Information
Capacity: 12 MWh
Power: 6.0 MW
Project Type: Stand Alone
CAPEX: € 5.203.896
OPEX: € 8.544.536
Payback Period is 6.25 years
Firm before ATR: 1 MW
ATR after Firm 6 MW
Peak Hour Scenario >_600
Share of TC in OPEX 67.74%
NPV (€) : 1.763.872
IRR : 21.43%
Profitability Index : 71.36%

Type 3 Information
Capacity: 16 MWh
Power: 8.0 MW
Project Type: Stand Alone
CAPEX: € 6.933.528
OPEX: € 10.853.548
Payback Period is 6.17 years
Firm before ATR: 1 MW
ATR after Firm 8 MW
Peak Hour Scenario >_600
Share of TC in OPEX 68.41%
NPV (€) : 2.379.822
IRR : 21.46%
Profitability Index : 72.26%

Type 4 Information
Capacity: 20 MWh
Power: 10.0 MW
Project Type: Stand Alone
CAPEX: € 8.663.160
OPEX: € 13.162.559
Payback Period is 6.75 years
Firm before ATR: 1 MW
ATR after Firm 10 MW
Peak Hour Scenario >_600
Share of TC in OPEX 68.84%
NPV (€) : 3.109.586
IRR : 21.9%
Profitability Index : 75.57%

Figure 1 Financial dashboard.

The tool's functionality can be displayed using this financial analysis dashboard, and the four different battery systems with capacities from 8 to 20 MWh are compared within the same project parameters. This analysis clarified that all four types have a positive NPV, meaning that value will be added to the company given the chosen discount factor. With this dashboard, we are showcasing the strengths of representing data of multiple battery systems. Project developers can make decisions based on all relevant data in one dashboard and can change input parameters and data for their specific use case.

We performed a local sensitivity analysis on one battery project using the one-at-a-time method. The parameters studied were (Contract Ratio, Revenue Change, Capex Change, Transport Cost, Discount Rate, and Indexation). We present the visualisation of this analysis in Figure 2.

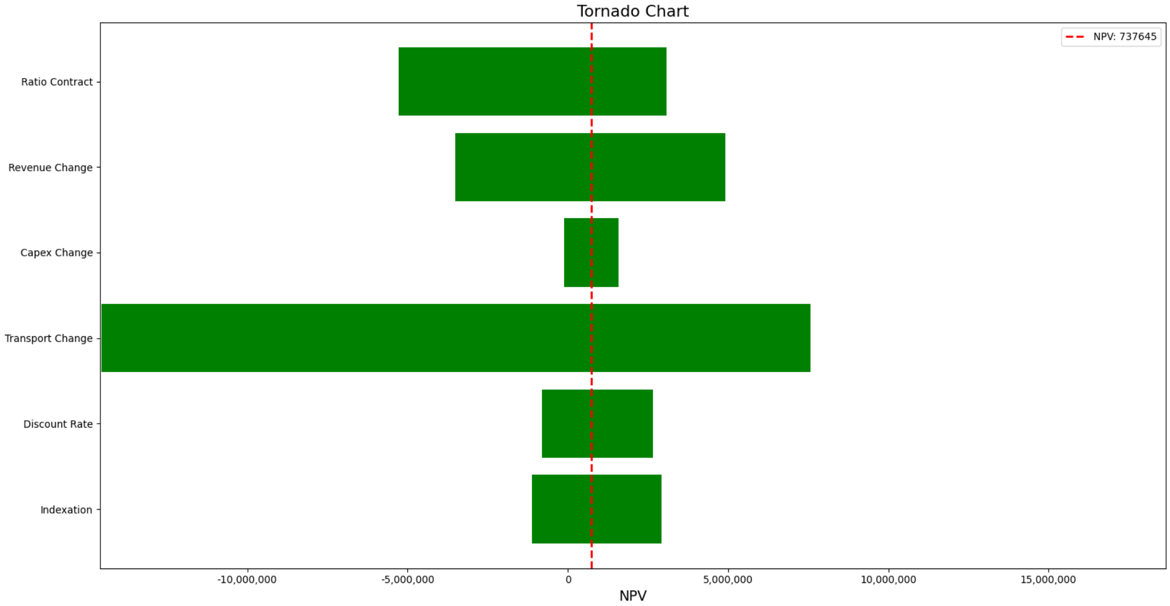


Figure 2 Tornado sensitivity chart.

One of the key findings from the sensitivity analysis is that the transport costs have the largest impact on the NPV and the IRR. This was something that Pure Energie already suspected and can now be confirmed with the results of the sensitivity analysis. Another significant sensitivity within the business case is the Revenue. Currently, the tool only uses the imbalance market as trading strategy. This limits the revenue; by only utilising one market. Since a company cannot change the transport costs, it should, therefore, look at other options to make the business case profitable, and revenue stacking is one of these options. Utilising multiple markets cannot be applied without limit; the battery system still has mechanical boundaries that will bottleneck the revenue potential. Other methods of reducing costs or optimising battery usage must be applied to make more battery systems financially viable.

To conclude, our tool can analyse multiple battery capacities within the same project parameters. This achieves the objective set at the start of the project and can help Pure Energie enhance its workflow. However, some recommendations remain. One of the tool`s limitations is that it cannot predict how transport costs will be optimised during the battery's actual use phase; it, therefore, presumes a worst-case scenario for transport costs. An excellent addition to the tool would be a forecasting model trained on historical data to predict the level of power peaks set during a battery's lifetime, this can help to predict transport costs more accurately.

Another limitation is that the tool only uses the imbalance market to generate a revenue forecast. In further applying the revenue model, a more extensive revenue forecasting method can better represent the revenue capabilities of battery energy systems while utilising different trading methods. Stacking revenue options might help with the profitability of the battery systems.

Keywords: Energy, Battery, Python, Business case, Trading, Li-ion

GLOSSARY

Term	**Definition**[1]
Net Present value	It is the difference between the present value of cash inflows and the present value of cash outflows discounted over a period of time.
Internal Rate of Return	Is the discount rate that makes the net present value of all cash flows equal to zero.
Profitability index	The ratio between the present value of future discounted cash flows and the initial amount invested into the project.
Debt Service Coverage Ratio	Ratio that measures the firm's available cash flow to pay the current debt obligations.
EBT	Are the earnings before the deduction of tax.
EBIT	It is the measurement of the operational revenue of a company before the deduction of interest and tax.
EBITDA	It is the earnings before interest, tax, and depreciation.
Operational Expenditure	The operational expenditures of a project.
Capital Expenditure	The capital expenditures of a project.
Free Cash Flows	The capital that is left over after the operational, capital, and tax expenditures are paid.
Roundtrip Efficiency	The roundtrip efficiency gives a ratio of the total storage output to the total storage input. The roundtrip efficiency of batteries can be broken down into two efficiencies: the first being the voltaic efficiency and the second the Coulombic efficiency (or Faraday efficiency) (Wang et al., 2021).
C-Rate	C-rate is the discharge current at which a battery can be drained. This means that with a discharge rate of 1C, the entire battery can be charged or discharged within 1 hour. (Choi and Lim, 2002; Ning et al., 2003)
SOC	“the inverse of the depth of discharge and is defined as the amount of electrical charge stored in the battery at time t, Q(t), to nominal electrical charge” (Tribioli and Bella, 2022).

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[1] Source: https://www.investopedia.com/financial-term-dictionary unless mentioned otherwise.

NOMENCLATURE

Abbreviation	Definition
aFFR	Automatic frequency restoration
BESS	Battery energy storage systems
BOP	Balance of Plant
BRP	Balance responsible party
BRP	Balance Responsible party
BSP	Balance service provider
BSP	Balance service provider
CSV	Comma separated values
DOD	Depth of discharge
DSCR	Debt service coverage ratio
EHV	Extra high voltage
ES	Energy supplier
FCF	Free cash flow
FCR	Frequency containment reserve
GA	Grid Administrator
GSES	Grid-size energy storage
GVO	Guarantee of origin
HV	High voltage
IRR	Internal rate of return
ISC	Internal short circuit
KWh	Kilowatt-hour
LAB	Lead acid battery
LIB	Lithium-Ion battery
LV	Low voltage
NPV	Net present value
mFFR	Manual frequency restoration
MV	Medium voltage
MW	Megawatt
MWh	Megawatt hour
OAT	One at a time
PI	Profitability index
RNA	Regional Administrator
RUL	Remaining-useful-life
SEI	Solid electrolyte interface
SEI	Sold electrolyte interface
SOC	State of charge
TRO	Transmission system operator
TSO	Transmission system operator

Variables	Definition
T	The expected years for which a project will be carried out are as follows:
t	A year within time, t = 0 (year 0).
N	Total number of charges from the grid.
X_n	nth value of the tariff reduction
r	Discount factor

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INTRODUCTION

In 2016, the European Commission signed the Paris Climate Accords on behalf of the Netherlands (Righart, 2017). Within this binding agreement, the goal was to limit global warming well below 2 degrees Celsius above pre-industrial levels (Rayner and Jordan, 2016). In 2019, the Dutch parliament agreed on their own climate accord, which aimed to reduce carbon emissions by 49% by the year 2030; this was later changed to 55% following the European Green Deal, with a penultimate aim to reduce carbon emissions by 95% in 2050 compared to the levels emitted in 1990 (Rijksoverheid, n.d.). Reducing carbon emissions has effects on the means of electricity production. Fossil-fuelled power plants need to be replaced by renewable energy sources to achieve the goals set by the government. In the Netherlands, these renewable sources come in the form of wind, solar, nuclear and biomass (Scheepers et al., 2022). The downside of renewable energy production is that these sources have uncertainty in their production. Here, nuclear power does not have this limitation; the wind and sun can only produce energy when the weather conditions are correct. At the same time, traditional energy production sources like coal and gas can be up or downscaled in a relatively short timeframe. Renewable energy sources are reliant on the season and time of day. This sometimes causes the electricity net to be unbalanced. There are peak moments when renewable energy sources produce too much electricity; whenever these moments arise, there is too much electricity to comply with demand. Moreover, there are also moments when these renewable energy sources do not produce enough electricity. To solve this issue, spinning reserves can be utilised to balance the system. These reserves can generate electricity at precisely the same frequency as the power grid frequency (Garche et al., 2013). Spinning reserves include gas turbines, steam turbines, hydroelectric plants, diesel generators, battery energy storage systems (BESS), and flywheel energy storage (Kirby, 2007). Where active spinning reserves can constantly add to the energy grid, other reserves can drain and fill it whenever there is demand for this.

Pure Energie is currently working on developing its strategy for energy storage. Pure Energie aims to implement energy storage to provide green and renewable energy even when little solar or wind energy is produced (Energie, n.d.). In the current business case for energy storage, many obstacles must be tackled before a widescale energy storage application is possible. Applying energy storage, like BESS, can help stabilise the energy mix and provide the peak shaving ability that the current renewable technology lacks. Battery energy storage systems are already being deployed on a grid-scale; examples of these so-called Grid Size Energy Storage Systems (GSES) are Gambit Energy Storage[2] and Victora Big Battery Project[3]. Both projects are used to ensure power reliability. One of the significant complications in BESS's development is the business case and the many variables that impact the system's CAPEX, OPEX, and revenue. Moreover, these variables change for every location where new storage projects are developed. For Pure Energie, two types of projects can become interesting when developing its energy portfolio. These project types are individual battery systems that exist independently and co-development projects where a battery system will be placed near a wind or solar park. However, to investigate whether or not such a project can become financially viable, Pure Energie needs to determine what BESS can be utilised within the set parameters of a project.

Currently, no tool within Pure Energie can be used to take into account all the parameters for a project, perform a financial calculation for multiple battery systems of different sizes, and compare which BESS would be the best fit for that project. Here, best would indicate the project's financial viability, which is measured at Pure Energie using Net Present Value (NPV) and Internal Rate of Return (IRR). With the output of this tool, the user should be able to answer the question: “What is the optimal size selection for a Battery Energy Storage System based on financial metrics, such as the NPV and IRR, within the parameters of a given project?“ and compare available battery sizes with their given CAPEX, OPEX and a potential revenue stream that could be accumulated through the utilisation of the BESS within the boundaries of the project. Pure Energie could then use the output of such a tool to perform a deeper investigation. Moreover, perform a detailed business case analysis with updated pricing and fewer assumptions that the model needs to assess possible BESS within the set parameters efficiently.

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[2] https://www.gambit-energystorage.com/

[3] https://victorianbigbattery.com.au/

Thesis Organisation

In Chapter 1, we introduce the thesis by providing an overview of the problem statement and objectives. This chapter serves as a roadmap for the reader, outlining the structure and content of the document. Chapter 2 delves into the intricacies of the Dutch energy markets, offering essential context for understanding the subsequent chapters. In Chapter 3, we describe the energy storage application for Pure Energie. Following this, in Chapter 4, we describe the workings of the tool. Chapter 5 describes the validation and sensitivity analysis methodology. Chapter 6 presents case studies and sensitivity results, followed by a comprehensive discussion in Chapter 7. Chapter 8 presents our findings. Finally, in Chapter 9, we conclude the thesis, providing recommendations for further research and practical applications.

1. RESEARCH METHODOLOGY

Our objective is to develop a tool that can assist Pure Energie in decision-making and the development of Battery Energy Storage Systems, facilitating the identification of financially responsible energy storage solutions. We employ the Managerial Problem-Solving Method (MPSM) to guide our research process. The MPSM framework, detailed in Appendix 11.1, serves as a structured approach to problem analysis and research question formulation. Subsequently, we describe our research design, outlining the methodology employed. A comprehensive review of the state-of-the-art literature in the field is conducted to inform our research direction and contribute to existing knowledge.

1.1 Problem Analysis

A situational overview of the problem was needed to gain deeper insights and find the core problem. To find the core problem, we created a problem cluster that is illustrated in Figure 3 (Heerkens and Van Winden, 2021). The arrows in the problem cluster affect one segment; for example, “Battery” affects “CAPEX/OPEX”, which, on its terms, affects the “Business case”.

The core problem for Pure Energie is known as an action problem (Heerkens and Van Winden, 2021). Pure Energie does not have a tool that can compare multiple battery energy storage systems with different capacities within the same project circumstances and determine the best possible option. Where best would indicate the project's financial viability, measured at Pure Energie using Net Present Value (NPV) and Internal Rate of Return (IRR). In the problem cluster in Figure 3 all the arrows flow towards the business case. However, the business case is not the core problem; the core problem is not being able to calculate the financial ratios of multiple battery energy storage systems under changing variables and compare these within the same project parameters.

Starting at the top, Pure Energie must add energy storage to its energy portfolio. These batteries need to be financed. This financing is only possible when the business case is profitable. When Pure Energie wants to determine whether the business case is profitable, it needs to investigate the total revenue and total cost. To model these two variables, Pure Energie needs a tool that can analyse all critical variables to test the scenarios. Moreover, Pure Energie must investigate under what conditions a BESS can become profitable within the project parameters.

Although the core problem stems from an action problem, it is combined with a knowledge problem because more knowledge is needed about the effect of changing the system parameters and an action problem because there is no model to analyse these parameters. A combination of both is necessary to solve Pure Energie's problem.

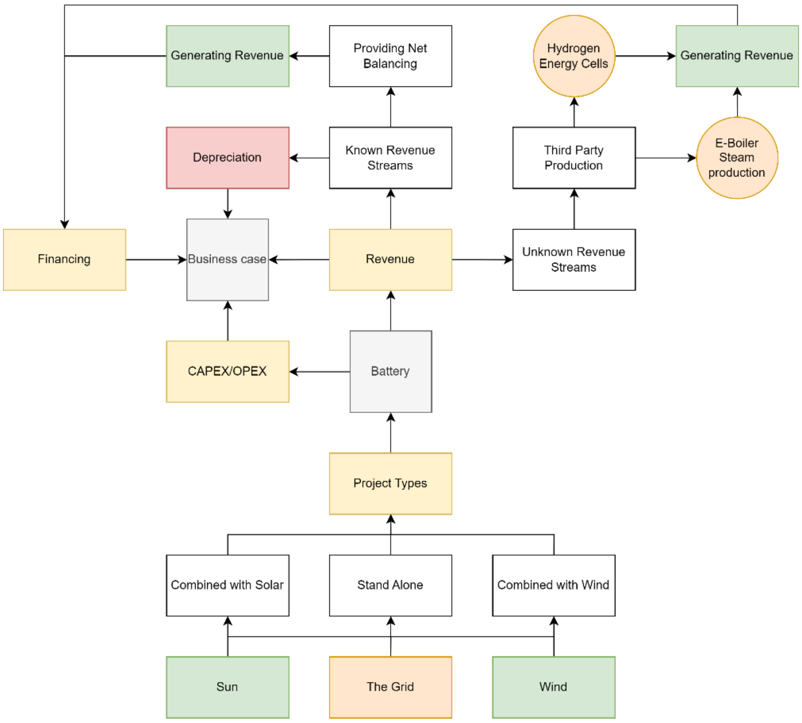

Figure 3 Problem cluster.

1.1.1 Research Questions

We address the following questions, guiding the investigation into battery energy storage systems. This section is divided into four research questions with their sub-research questions. These questions are essential to guide the research and help fill the knowledge gap with state-of-the-art literature.

> "develop a tool that can automatically compare multiple battery energy storage systems based on financial ratios within the parameters of the given project."

Research Questions:

RQ 1: What types of Battery Energy Storage Systems are currently available on the market?

a) Which types of batteries can be used for grid-size applications?
b) Which parameters affect the theoretical lifetime of a battery?

RQ 2: How does the Dutch electricity system function, what are the intricacies of transport costs, and how do their characteristics impact the profitability?

a) What is the 600h norm, and what are the effects on the transport costs?
b) How does the ATR85 reduction tariff work, and what are the effects on the transport costs?
c) Where does the revenue potential for grid-size batteries lie?
d) Which components are essential for the CAPEX of a BESS?
e) Which components are essential for the OPEX of a BESS?

RQ 3: What is the optimal size selection for a Battery Energy Storage System based on financial metrics, such as the NPV and IRR, within the parameters of a given project?

a) Within the parameters of a case, what is the optimal size of a Battery Energy Storage System?

RQ 4: How do potential vulnerabilities within the business case of battery energy storage projects interact with future fluctuations of prices and other financial metrics?

a) Which parameters within the OPEX significantly impact the operational cost?
b) How do changing financial metrics like the inflation or discount rate affect the NPV and IRR?

1.2 Research Design

Pure Energie wants to develop battery projects to expand its energy portfolio further. Therefore, Pure Energie must first decide what battery systems suit their needs whenever they want to develop such a project. Different energy sources are available for their battery as input depending on whether the project is co-developed or standalone. To improve this decision process and, above all, facilitate a comparison between different battery configurations within the same project parameters, they need a tool to help them with this process.

We aim to develop a tool that can compare multiple battery energy storage systems based on financial ratios within the parameters of the given project. Moreover, this facilitates the need for Pure Energie to compare multiple battery configurations within the same project based on their financial viability. The overall approach can be described in four phases, and within these phases, data gathering, programming and validation will occur. In the first phase, we gather information about the energy sector and the variables that impact the financial viability of the battery storage project. All these variables will be researched in detail within the literature review, where state-of-the-art literature is considered, combined with information from Pure Energie and the energy sector. In the second phase, we start with the first programming; the base of this project is an automated business case. This automated business case will take inputs for the CAPEX, OPEX and revenue through a CSV file and calculate the financial ratios that, in a later stage, can be used to compare with similar projects. In the third phase, we further develop the tool to accept inputs from the trading model that Pure Energie employs, which is developed exclusively for revenue prediction when fed with battery system details and energy profiles dependent on the project. With this addition, the output of the trading model could be used to change the revenue within the business case whenever the battery configuration changes. In this phase, the first automated comparisons will be performed. In the fourth and final phase, we complete the tool and can start to perform case studies, conduct a sensitivity analysis and find answers to the main research questions.

1.2.1 Rationale for Research Design

The rationale behind every phase is explained in Table 1. It represents a more detailed reason behind the four phases and explains why they are separate.

Table 1 The rationale behind the four research phases.

Phase 1	Phase 2
Understanding the complexities of the Dutch energy grid is needed to integrate variables like transport costs into the model. Moreover, having a clear view of what is essential for a BESS project and understanding why certain costs exist helps build a valid business case.	Since the business case is the tool's core, a separate phase is needed to develop a working model. This model can then be validated with an already-used business case to check if outputs are comparable and where possible differences lie before implementing Phase 3.
Phase 3	**Phase 4**
Pure Energie's trading algorithm is very complex. A better understanding of its in and output needs to be gathered. The model itself will be seen as a black box. Once this understanding is gained, the knowledge gained can be implemented to further develop the tool from Phase 2. The tool is validated once more with an already working business case, and further testing is applied.	In Phase 4, all phases come together. A sensitivity analysis will be applied to better understand the business case uncertainties and the effects of variables. The information gathered in Phase 4 can be used to write the results, discussion, and recommendations. At the end of Phase 4, we will write an instruction manual to inform users on how to work with our tool.

1.2.2 Visualisation of Research Design

Figure 4 provides a systematic diagram that gives a more detailed description of the development process, which is broadly described in the phases in Section 1.2.

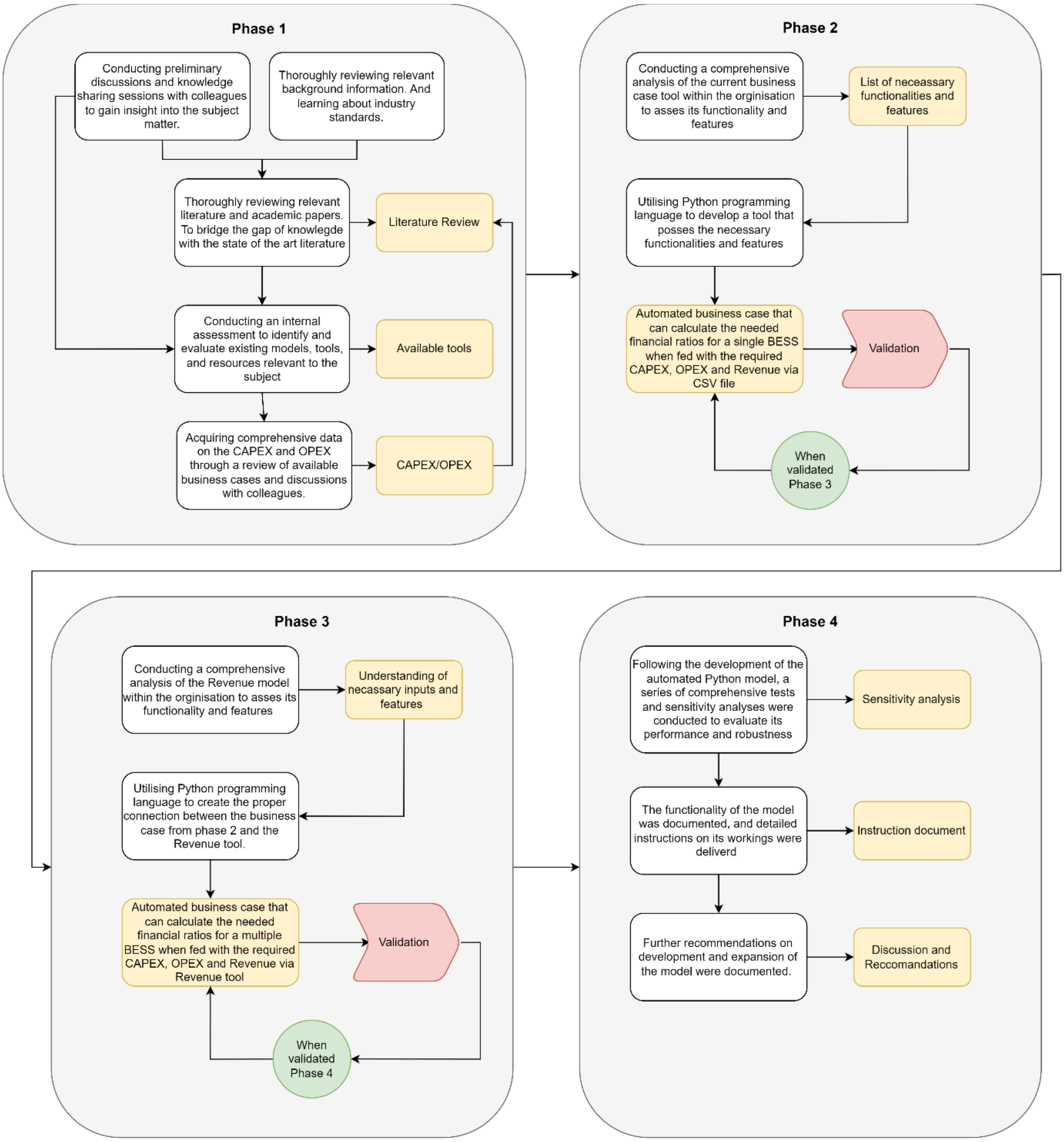

Figure 4 Visualisation of the four research phases.

1.2.3 Data Collection Methods

Data collection is the backbone of a calculation tool; without the necessary data, the tool cannot perform its task. Data can be categorised into various types based on their nature and characteristics. For this report, only quantitative data was collected using mixed methods. The tool has four data categories, each with a separate dataset. For the second phase of this research, these datasets will be imported through a comma-separated values (CSV) file and collected through the means described in Table 2.

Table 2 Data collection methods, including source and confidentiality.

Dataset	Method	Source	Confidentiality (Yes/No)
CAPEX			
Purchasing	Case-study	Pure Energie	Yes
Software/Hardware for control	Case-study	Pure Energie	Yes
Land	Case-study	Pure Energie	Yes
R&D costs	Case-study	Pure Energie	Yes
OPEX			
Grid operating costs	Document Analysis	Grid Operators	No
ATR85	Document Analysis	ACM	No
Asset management costs	Case-study	Pure Energie	Yes
Land lease and local taxes	Case-study/ Document Analysis	Pure Energie/ Municipalities	Yes/ No
Depreciation	Calculation	Pure Energie	No
Revenue			
Revenue of Battery	Case-study	Pure Energie	Yes
Financial			
Equity/Debt	Case-study	Pure Energie	Yes
Depreciation and Interest	Case-study	Pure Energie	Yes
Tax Rate	Document Analysis	Government	No
Indexation	Document Analysis	Pure Energie	No

In Phase 3, we require the data to be more adaptable; here, we make some assumptions that can be described as “rules of thumb” or practical guidelines derived from the experience and observations of the storage department within Pure Energie rather than supplier-provided data. This is also mentioned in the limitations section of the Section 1.2.5.

A description of these assumptions and specific data points where these assumptions are used are described in Table 3 and Table 4. The methodology behind the assumptions made in the CAPEX is based on economies of scale, where developing more significant projects decreases the price per operationalised unit (for this project, €/MWh) (Goolsbee et al., 2019). The battery industry is undergoing significant development, meaning that these values are ever-changing, and practical guidelines are the industry standard for a pre-scanning tool. Pure Energie will provide these values; therefore, this rapport will not mention the exact values. The values are based on real-world price data and experience gathered by the storage department within Pure Energie. Since the values are confidential, the data will not be available for the reader of this report and will be depicted as N/A.

Table 3 CAPEX price assumptions.

Subset	Description
CAPEX	The cost price for the data within this subset of data has been operationalised towards €/MWh, meaning that the battery's capacity determines the total cost price of a selected data point.
Battery CAPEX	N/A
BOP	N/A
Control Hardware	N/A
CPS	N/A
Cables	N/A
Switch	N/A
Amenities	N/A
Purchasing of land	N/A
Landscape integration	N/A
Grid connection	N/A
Development cost	N/A
Financing and DD cost	N/A
Interest cost during development	N/A
Development fee	N/A
Car insurance	N/A
Leges	N/A

Table 4 OPEX price assumptions.

Subset	Description
OPEX	The cost price for the data within this subset of data has been operationalised towards €/MWh, meaning that the battery's capacity determines the total cost price of a selected data point.
O&M and warranty	N/A
Technical asset management	N/A
Commercial asset management	N/A
Project administration costs	N/A
Accounting costs	N/A
insurance	N/A
Resident compensation	N/A
Additional payment former landowner	N/A
WOZ value as % of CAPEX	N/A

1.2.4 Data Gathering

The data needed for this project were gathered from different case studies within Pure Energie. First, the data must be separated into different datasets to prepare for use within the tool. These datasets are mentioned in Table 2. The data was already operationalised to the correct format (€/MWh) and needed no further modifications. Since Pure Energie previously gathered the data and validated it, no additional data validation has been performed. The cost price data are based on invoices from manufacturers, so these are assumed to be correct. Cost price data of GSES can only be gathered from manufacturers and are not available on the internet. We found cost indications by Bielewski et al. (2022). Here, an indication is mentioned for the purchasing price of an entire grid-size battery system; the report indicates that the cost of grid-size storage is 350.000 €/MWh for the whole system as of 2021. This seems to be in the same order of magnitude as the data provided by Pure Energie. Outside of the network operating costs, which we collected from the net operator's websites (the dataset can be found in Appendix 11.2), all the OPEX, CAPEX, and Revenue data is proprietary or company-specific and will differ among competitors.

1.2.5 Limitations

This research project has certain limitations due to the restriction of time and resources to ensure that this research can be completed within the given time. The limitations and restrictions that are relevant to this research project are:

- As mentioned in Section 1.2.3, specific values are assumed to make the tool dynamic. This means the tool can only be used as an indication, not an actual result. Although the tool can be used with the correct values, this will not be done during this research because of a lack of real-world pricing data.
- Although delivered by Pure Energie and outside the scope of this research, the revenue model used within the tool does not use dynamic trading and only an algorithm for the imbalance market.
- Markets like FCR, aFFR, mFFR and Gopacs will not be included in this tool.
- Third-party storage options like hydrogen or e-boilers are outside the scope of this research and are excluded from the tool.
- Subsidies from the Dutch government are outside the scope of this research.
- Indexation is added through a flat rate.

1.3 Literature Review

The literature on batteries is extensive. Using the search engine Scopus.com and only searching the term “battery” and limiting this term to the subject area “energy”, we found more than 133 thousand articles. Moreover, these articles were written with over 71 thousand hits within the last five years. Most of these articles are about lithium-ion batteries, essential for many industries. The automotive industry is one of the driving forces for battery research, followed by storage for industry and grid balancing. Appropriate articles were searched through by filtering on most cited papers, and interesting articles were selected from there based on titles. The abstracts were read in this first selection round, and whenever the information was relevant to this paper, the article was further assessed and cited within the literature review.

1.3.1 Types of Batteries

Batteries are mature energy storage devices with high energy densities and voltages (Koohi-Fayegh and Rosen, 2020). There are several types of batteries with different chemicals; these are: “Lithium-ion (Li-ion), sodium-sulphur (NaS), nickel-cadmium (NiCd), lead acid (Pb-acid), Lead carbon batteries, zebra batteries (Na-$NiCl_2$), and flow batteries” (Koohi-Fayegh and Rosen, 2020). However, there is a big difference between the physics behind every battery type, which can be found in cell voltage, capacity, cycle life, losses and energy density (Nitta et al., 2015). “The trade-off for battery development is between power and energy; batteries can be utilised for either high power or high energy, but not both” (MIT, 2008).

Chemistry of a Battery

A battery is a device that converts electrical energy into chemical energy; this conversion is reversible. Electrochemical energy storage is realised by electron and ion exchange. A battery comprises an anode and cathode, a separator and an electrolyte (Liu, 2010). The anode is the negative pole and a suitable reducing agent (electron donor), and the cathode is the positive pole, a suitable acceptor. The separating agent is called an electrolyte, which is used to separate the anode from the cathode physically and is applied as a pure ionic conductor. In practice, a porous, electrically insulating material containing the electrolyte is placed between the anode and cathode (Winter and Brodd, 2004). Whenever the anode and the cathode touch directly, the battery will be shorted and release all the energy stored inside it as heat.

1.3.2 Battery Life

The number of cycles that are optimal for a battery earnings model depends heavily on the effect a cycle has on the battery capacity. Every cycle a battery performs, it degrades slightly. Batteries that are bought from a manufacturer have a specific guarantee. This guarantee tells the battery buyer that the capacity will not drop below a certain threshold when used within specifications. This threshold is called “remaining useful life (RUL)” and is crucial for the battery's use and safety. Pure Energie states batteries are difficult to insure below 60% of RUL and can become dangerous. From an operational risk point of view, the battery cells should be replaced at or before this point. According to Zhang and Lee (2011), batteries below certain thresholds have an increased chance of thermal runaway. To decrease the risk of overheating and possible thermal runaway problems, electrochemical reactions (new materials) need to be developed (Liu et al., 2018). Several parameters affect the health of a battery, and these parameters are mentioned in the literature. (Severson et al., 2019; Wang et al., 2011; Zakeri and Syri, 2015) describe the effect of cycles (Ameli and Ameli, 2021); describe the impact of the depth of discharge; (Chombo and Laoonual, 2020) describe the safety measures and temperature, and Liu et al. (2018); (Nitta et al., 2015) describe the effect of materials used within the battery's cathode and anode.

The number of battery cycles is limited; every material used within the battery has a different effect on the number of cycles a battery can do. A cycle can be described as fully charging and discharging the battery. To develop more knowledge about battery life and the earlier-mentioned parameters' effects on it, we dive further into the literature in the coming subchapters to gain knowledge from the state-of-the-art literature.

Effect of Depth of Discharge on Battery Life

Depth of Discharge (DOD) is defined as: “the amount of charge removed from the battery at a given state (Q) related to the total amount of charge that can be stored inside the battery” (Waag and Sauer, 2009). Batteries mostly come with a graph from the manufacturer that shows the cycle life of a battery related to the DOD. The DOD impacts the number of cycles a battery can physically perform and, thereby, reach the end of life sooner. A study by Wang et al. (2011) researched the effect of the DOD on the end-of-life of a $LiFePO_4$ battery. Here, the author found that cells cycled at DODs greater than 50% were shown to reach the defined end of life sooner than cells cycled at DODs (<50%) (Wang et al., 2011). This was explicitly found for $LiFePO_4$, but a similar effect can also be found in studies by Omar (2014) and Watanabe et al. (2014), where a different battery chemistry was used. Here, the test was performed on $LiAl_yNi$-x-yCo_xO_2, and there was a significantly faster capacity deterioration between 0-100% DOD and 10-70% DOD. All these papers found a correlation between the faster degradation of batteries and the DOD. However, there is a difference in the extent of the effect and what type of chemicals are used inside the battery. For every battery, the effect will be different, but there is a correlation between the degradation of the battery when used at higher DOD each cycle.

Effect of Temperature on Battery Life

Batteries generate heat; under normal conditions, this heat generation comes from the charge transfer, where the ohmic heating process occurs, and resistance within the electrode and electrolytes hinders the transportation of charges and creates heat or the exothermic chemical reaction in the battery (Xiao and Choe, 2013; Zhang, 2011). The temperature of a battery is very important for its health and efficiency. The acceptable temperature region for Lithium Ion Batteries (LIB) is (-20 - 60 °C) (Ji et al., 2013). Pesaran et al. (2013) showed that the optimal temperature range for LIBs is (15 – 35 °C). The performance of LIBs degrades at temperatures below 0°C (Jaguemont et al., 2016; Jow et al., 2018). The performance degradation of LIBs at low temperatures can be attributed to several causes (Ma et al., 2018). The low temperature affects the properties of electrolytes. The electrolyte's viscosity increases with decreasing temperatures, reducing the ionic conductivity (Ma et al., 2018). Operating under high temperatures also affects the performance of a battery. The effects of operating under high temperatures are ageing and thermal runaway. Ageing is divided into cycle and calendar ageing, while ageing affects the battery's performance and reduces the battery's lifetime (Ecker et al., 2014; Zavalis et al., 2013). Thermal runaway may happen when batteries are manufactured defectively or mishandled (Ma et al., 2018).

Cathode and Anode Material

As mentioned in Section 1.3.1, battery development has one significant trade-off: capacity and power. The materials used for the cathode or anode of the battery significantly affect the electrical properties of the battery. Capacity is the volume of electrical energy stored within the battery. Furthermore, power is the electricity a battery can charge or discharge. However, there is another crucial aspect that has not been mentioned before. The materials used for high-capacity batteries are primarily heavy metals that are difficult to recycle or are in short supply and are primarily found in foreign countries. This creates supply chain risk, which is one of the reasons why developing different cathode/anode materials is currently being investigated.

Conventional high-storage batteries are made with LIB; LIB is employed because of its high energy density, high coulombic efficiency and low self-discharge features (Kim, 2019). Conventional LIB cannot offer high charge capacities (>200 mA/h/g^{-1}). Therefore, research has shifted towards high energy density technologies such as Li-Rich, Ni-Rich, Li-sulphur, Li-Air, organic electrodes, and solid-state batteries (Kim, 2019).

The next-generation battery technology, sulphur, is a promising candidate for cathode material. The theoretical energy density achieved with sulphur is ten times higher than the current transition metal oxides (Kim, 2019). Another promising development is Li-air batteries, where the cathode is a carbon matrix with a catalyst (Kim, 2019). The practical energy density can reach 1700 Wh/kg^{-1} (Girishkumar et al., 2010). The last promising development from recent years is solid-state batteries; these can be divided into three categories: inorganic solid-electrolytes, solid polymer electrolytes and thin film electrolytes (Chen et al., 2016). Moreover, new developments are moving away from lithium and using Na-ion technology, as they are widely regarded as an alternative to LIB (Duffner et al., 2021) and currently only commercially available in China.

Effect of Battery Charging Cycles per Day

Manufacturers determine the number of cycles a battery can utilise until it is unsafe to use. The number of cycles is often related to the DOD, affecting the battery's performance. When all the parameters are known, the optimal daily cycles can be determined; there is an optimal number of daily cycles with DOD. The earnings potential is determined by the number of cycles it goes through; every cycle generates revenue but also deteriorates the battery's health. Since the battery can only be insured for a specific amount of time, the battery can only be used within this time period. It should be operated to its full potential to earn enough revenue. The initial investment of the BESS is sizeable; therefore, it must be cycled as often as possible to earn enough revenue to pay for the initial investment. However, to optimise the use of the battery, it is also essential that the spread between buying and selling the electricity is big enough to cover the costs. According to an internal report of Pure Energie, the most significant potential for the energy storage business case lies within the first couple of years. The market will be saturated with more batteries in the coming 10-15 years. This will decrease the potential revenue that energy storage systems can create. The trading division determines the strategy for optimising daily cycles within Pure Energie. The trading division made an algorithm that optimises the cycles, using the total cycles until the depreciation of the battery is deployed and the optimal trading potential using their trading algorithms.

1.3.3 Current State of Development (Grid Size Energy Storage)

According to Zhu (2022), there are still many discrepancies between the literature and the reality of BESS or grid-size energy storage (GSES). To become practically and economically viable, researchers should direct their attention to reliable safety, battery cost and preparation processes. The main focus in literature lies on electrochemical performance, whereas these performance levels are impossible in real-world scenarios (Zhu, 2022). Moreover, the cost and risk associated with these performance levels could be more realistic for practical application. Zhu (2022): “LIBs may still be the mainstream batteries for the GSES field in the coming 10-20 years”. One example of a GSES is the Hornsdale Power Reserve in Australia[4]; LIB systems from TESLA are used here.

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[4] https://hornsdalepowerreserve.com.au/

1.4 Interim Conclusions

In the interim conclusion, a summary of the required theoretical knowledge will be given to fill the literature gap with the state-of-the-art literature researched in the literature review. The state-of-the-art literature is driven by the automotive industry, where size and charging speed are important. Therefore, a substantial part of the literature is focused on developing improved battery chemistries with greater energy density and better available resources, which decreases supply chain risks and pollution by heavy metals. However, size and charging speed are less critical for grid balancing. For grid balancing, storage capacity and high cycle life are essential. Furthermore, there is still a gap between theoretical research and real-world application.

Which types of batteries can be used for grid-size applications?

Two types of battery chemistries are used for grid-size applications: lead-acid and lithium-ion batteries. Working cases of this are Hornsdale Power Reserve, Gambit Energy Storage and Victora Big Battery. In all of these cases, LIBs are applied as battery chemistries. Lead-acid can be used for grid-size storage because of its relatively low costs. The downside of Lead-acid is its lower lifetime compared to lithium-ion batteries, which are more expensive but have a longer lifespan and higher energy density. Although the physical size of the battery system is not as important, higher energy densities are still preferred for grid-size applications.

Which parameters affect the theoretical lifetime of a battery?

Battery decay falls into two categories: active decay and inactive decay. With active decay, the number of cycles a battery goes through affects its remaining useful life. Every battery has a certain number of cycles it can go through, affecting its theoretical lifetime. The second category would be inactive decay, which happens when the battery is not used; although not as relevant within LIB, it decreases the battery's RUL. Depth of Discharge has also been found to decrease the battery's theoretical lifetime; however, this is coupled with the number of cycles; whenever a battery is discharged, the depth at which this happens causes the battery to deteriorate sooner. Significant decreases in cycle life were found whenever the DOD was above 50%. c-rate is the speed at which the battery charges and discharges, which affects the deterioration of the battery.Temperature is another critical factor that impacts the lifetime of a battery; because of the resistance within the material, the battery generates heat; this process is called ohmic heating. That is why battery systems are equipped with cooling systems to keep the battery cells within the system at an optimal temperature range for that given battery cell. The optimal temperature range for the performance of LIBs was between 15 and 30 degrees Celsius. There are known cases of thermal runways with LIB BESS systems, which is why cooling and safety systems are essential.

Finally, the materials used are probably the most significant factor in the theoretical lifetime of the battery. Batteries made with lead-acid chemistry have significantly shorter cycle lives than LIB batteries, which makes it challenging to use them for trading since there are many cycles involved.

2. CONTEXT ANALYSIS

Within the context analysis, we investigate the Dutch energy sector and answer the second research question: “How does the Dutch electricity system function, what are the intricacies of transport costs, and how do their characteristics impact profitability?” With the knowledge gained in this chapter, the business case tool of Phase 2 can be developed. With a deeper understanding of the transport costs, the vulnerabilities of this parameter can be explored. The primary source of information within this chapter is the TSO TenneT website.

2.1 Energy Sector

Since the 1990s, Europe has been liberalising the energy market, which has affected the energy production generation sector most (CPB, 2006) . According to Deloitte (2015), the Dutch electricity market has been open to competition since 2002, first only for industrial consumers and then, since 2004, also for public consumers. With this, the production of electricity was open to the free market. Historically, the Netherlands has been an exporter of natural gas, which can be extracted in the province of Groningen and the North Sea. The Netherlands has been exporting and using this natural gas for energy production. In 2012, 41% of the energy consumption within the Netherlands was produced with natural gas, only beaten by petroleum at 42% (Deloitte, 2015).

As mentioned in the introduction, the European Commission signed the Paris Climate Accords on behalf of the Netherlands in 2016 (Righart, 2017). This meant that the energy mix needed to change drastically to comply with these accords and realise the goals set. As of 2016, the share of renewable energy within the Netherlands was only 6%, according to the report “Hernieuwbare energie in Nederland 2016” (CBS, 2017). Changing the energy mix to a more significant share of renewable energy severely affects the grid's stability. Renewable energy, in the form of wind and solar energy, depends on the time of day and weather conditions. While electricity production through wind is less dependent on the time of day, its production can be inconsistent because the weather conditions must be met for optimal production. In 2023, 48% of electricity was generated from renewable sources in the Netherlands (CBS, 2024). Energy production through renewable sources causes peaks in the grid. Energy storage, like batteries, can help stabilise the energy mix and provide the peak shaving ability that the current renewable technology lacks. Another application for energy storage is in ancillary services for TenneT, such as Frequency Containment Reserve (FCR) and automatic or manual Frequency Restoration Reserve (aFRR/mFRR).

The business case for energy storage is very complicated because of the many variables that affect its viability. These variables are types of energy storage systems, sources of energy, methods of earning money through trading, subsidies, depreciation, and transport costs. However, complications are not the only risks in a business case. The market will become more saturated with energy storage in the coming years. According to an internal report of Pure Energie, the saturation of energy storage systems will decrease the revenue potential of specific trading methods. Several different energy storage systems are available to achieve Pure Energie's goal. However, even in the application of battery packs, there are significant differences in how the battery packs can be applied to earn money. The options mentioned above, FCR, aFFR, mFFR, peak shaving and unbalanced market, are different applications of trading electricity that can generate revenue utilising batteries. Furthermore, e-boilers, PEM fuel cells, alkaline fuel cells, and other applications of electricity could be utilised to discharge the battery and create income to change the revenue for the business case. Information about the depreciation of these energy systems is still very scarce, and the subsidies given by the Dutch government are complicated and heavily dependent on the political climate. Combining all these reasons makes setting up a business case for energy storage complex and intriguing.

2.1.1 Dutch Energy Market

In the long-term market, with forwards and futures, electricity is sold between 4 years and one month before delivery. Futures are standardised long-term contracts; however, forwards are bilateral or traded and are not standardised. Long-term agreements are essential for producers and end-users who want to cover their expenses for the long term and be assured that their price is known. On the day-ahead market, parties can buy or sell electricity for the next 24 hours of the coming day. The electricity is sold in blocks of 1 hour and is released at midnight. At this point, the intersection of supply and demand determines the price and volume for each hour. The clearing price of that day best reflects that day's energy price. The hourly price from this market is called the “electricity price.” Whenever the day-ahead market is cleared, the intraday market will open. In this intraday market, it is continuously possible to trade electricity. Whenever a buy-bid corresponds to a sell-bid, the transaction is closed. There are multiple parties responsible within the Dutch energy market, these are (TenneT, 2022b):

1. Transmission System Operator – TSO.
2. Balance responsible party – BRP.
3. Balance service provider – BSP.

Day-Ahead: All BRPs send electricity programming for a day of action, and the TSO checks if supply and demand are zero-sum.

Day of Action: BRPs follow the programming; whenever there is a power imbalance, the TSO tries to solve it within 15 minutes.

Day-After: After a day of action, the financial clearing starts at 10:00; in this phase, the imbalance is cleared and determined per BRP.

2.1.2 Trading Options Within the Dutch Energy Sector

There are multiple options for battery energy storage systems to earn revenue with their stored energy. The first option is to buy energy at a low cost and sell the electricity for a higher price later using the buy-low, sell-high strategy. The spread of electricity between buying and selling will be a possible profit. However, there are some losses within the battery, meaning there is a discrepancy between the volumes bought and sold. Other options for trading electricity are frequency regulating markets. These markets are FCR, aFFR, and mFFR (TenneT, 2022a). FCR is the Frequency Containment Reserve; TSOs must maintain the reference frequency within the grid. FCRs balance reactive instruments, short-term (30 seconds) means to level out the frequency deviations. These frequency imbalances stem from the differences between supply and demand. FCR trading is currently limited to (1 - 25 MW for at least 4 hours), meaning the minimal capacity a battery needs is 4MWh (TenneT, 2022a). Whenever the frequency deviations hold on for extended periods (30 - 300 seconds), the Automatic Frequency Reserves (aFFR) replaces the FCR. Whenever the frequency deviations hold on for extended periods (5 - 12,5 minutes), the Manual Frequency Reserve (mFFR) replaces the aFFR. mFFR trading is currently limited to 1 - 9999 MW for at least 15 minutes, and the price resolution is in (Euro/MWh) (TenneT, 2022a). The last possible trading method is the imbalance market. Whenever electricity is traded from an Energy Supplier (ES), they hold a position for their portfolio. However, when not all positions are cleared, they are traded against the imbalance price. This is the final clearing price of the market and can be either high or low, depending on supply and demand. Whenever the volume of energy is high, the price of the imbalance market will be low. However, when there is a specific need for electricity and thus high demand, the price of the imbalance market can spike. This is currently one of the best markets in which to earn revenue for BESS systems.

2.2 Transport Costs

The Dutch Energy grid is maintained and developed by TenneT TSO. TenneT has a natural monopoly because the development and maintenance costs are too high for multiple companies to compete in this industry (Goolsbee et al., 2019). However, the Dutch government restricts TenneT's profits through strict ACM regulations (Autoriteit Consumenten & Markt). Moreover, the maintenance and development of the Dutch Energy Grid transport costs are paid. Multiple parties within the Dutch electricity grid pay transport costs. TenneT maintains and develops extra high voltage (EHV) and high voltage (HV) in the Netherlands. Then, locally, the medium voltage (MV) and low voltage (LV) are being maintained by Regional Net Administrators (RNA). The RNA pays transport costs to the TSO, and the ES that needs the energy grid pays accordingly to the party that maintains and develops the required electricity grids (EHV, HV, MV, LV) see Figure 5 .

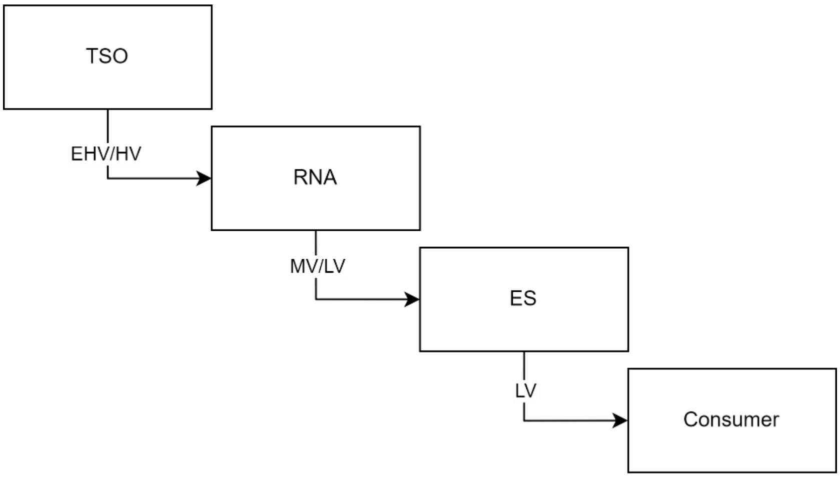


Figure 5 The dropdown of energy transmission within the Dutch energy grid.

The transport costs depend on multiple parts: standing charge, kW contract, kW max monthly, kW contract yearly (max 600 hours), and kW contract weekly (max 600 hours), where some of these costs are fixed, and others are variable (ENEXIS, 2024). Moreover, every TSO/RNA/ES has different prices for these parts (see Appendix 11.2). The variable part of the transport costs is based on the total transported kWh, kW contract and the monthly maximal measured transport power. No extra variable costs are counted for delivering energy to the grid.

The Standing Charge is the charge every user pays independent of their use; it covers administrative tasks, periodic connection fees, and maintenance and development of the grid. kW contract is the amount of power the customer expects to be average at any moment of the year; the price the customer pays depends on the current and power level needed (see Table 5). For every category, the customer pays a different price for standing charge (€/Year), contracted power (€/kW/Year), maximal power (€/kW/Month), blind use (€/kVArh), kWh nominal use (€/kWh), and kWh low use (€/kWh). Transport costs are paid after usage, meaning that the user of the grid can still optimise its usage during the year of operation. However, this cannot be known for a business case, so applying a worst-case scenario where max costs are calculated is reasonable.

Table 5 Energy categories within the Dutch energy market (ENEXIS, 2024).

Category	Contract Power	Current
LS	≤ 50 kW	≤ 1 kV
MS/LS	50 - 125 kW	1 - 20 kV
MS-D	125 - 1500 kW or ≥ 1500 kW	1 - 20 kV
MS-T	≥ 1500 kW	1 - 20 kV
HS/MS	≥ 1500 kW	
TS	≥ 1500 kW	30 - 50 kV

2.2.1 Explanation of the 600 hours norm

There is a separate category for consumers who do not expect to need high power all the time. This category is called the 600-hour norm. Within the 600-hour norm, consumers can set higher than 1.5 MW peaks without needing to be in a more expensive transport category. Whenever these peaks stay below 600 hours yearly, the consumer only pays a more expensive tariff for the peak hours. Whenever you actively trade to stay below the 600h norm, you set one peak moment, and with this peak, you decide how much electricity you can charge from the grid. For example, a battery with a grid connection of 20 MW can utilise the grid for 20 multiplied by 600h, so 12000 MWh of volume. When you go above the 12000 MWh of electricity charged, you will be settled for the >600h tariff. Battery energy systems that only take energy behind the meter, meaning it only load energy from their production or within a closed system; the 600-hour norm is not essential. However, this norm becomes very important for batteries using the grid to charge their reserves. Going above the 600-hour norm will give the consumer more flexibility since they are not limited and can charge from the grid whenever necessary. This, however, means that this consumer will pay for a higher power contract that will be more expensive. Whenever the spread of electricity prices is thin, paying for a more expensive contract can deter profitability. Moreover, when a customer determines he will stay under the 600-hour norm, this means that he can only use 600 hours of peak power, is limited to his production, and, with this, cannot trade freely. There are four scenarios for BESS with a capacity of >1.5 MW. These are drawn in Figure 6.

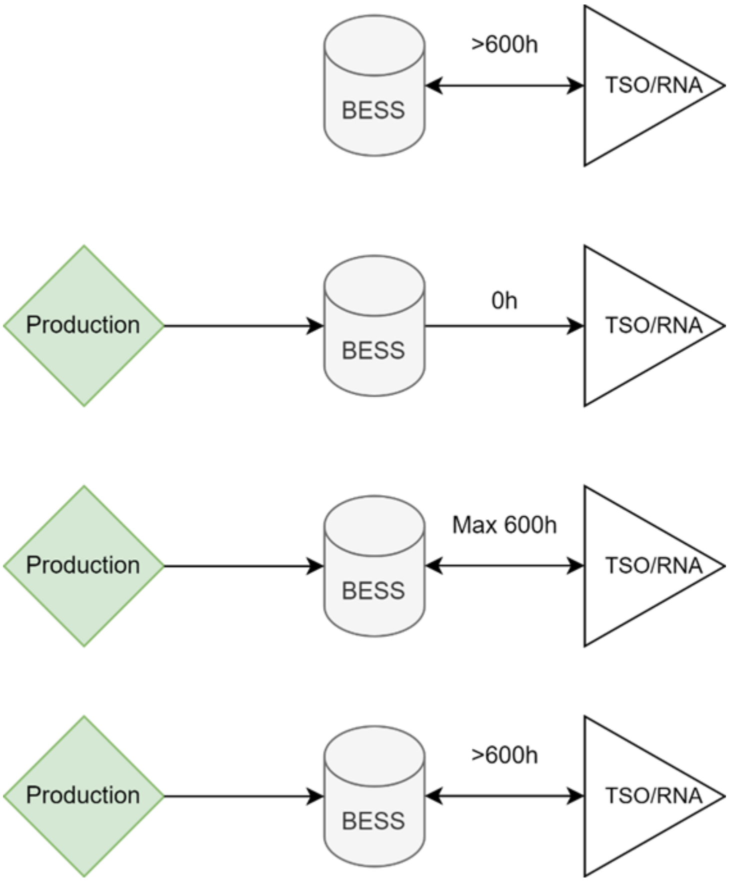


Figure 6 Option for end-user within the 600-hour norm.

In Scenarios 1 and 4, the consumer has to contract a peak power above 1.5 MW. In Scenario 2, the customer will not use the grid to charge the battery and will only pay for contract costs since he still needs to discharge his electricity. In Scenario 3, the customer will use the particular contract where the maximal 600 hours will be above 1.5 MW, and the rest of the electricity will come from its production or below the peak power of 1.5 MW. Transport costs currently influence the strategy and business case of a BESS. The 600-hour norm directs the options for trading and determines flexibility.

2.2.2 ATR85 TenneT

The grid administrators (GA) need to reduce congestion within the grid. Congestion arises whenever there is too much electricity going through the grid. The GA need more companies who can offload this electricity to reduce congestion. One example of an off-taker is a BESS. However, significant transport costs are associated with offloading energy from the grid, which makes it financially unfeasible to utilise a battery to unload the grid whenever there is no real incentive or compensation.

To compensate the battery owners, the TSO TenneT made a proposal that could benefit both parties. This proposal is called ATR85. There will be two types of contracts for off-takers, the first one being ATO “Aansluit-en Transport Overeenkomst” and the second one being ATR “Alternatief Transport Recht”. An off-taker contracts a peak power and connection capacity (or Firm capacity “*Firm* is the name for peak power that a company contracted using ATO”) within the ATO. This is also true for the newly proposed ATR85 (so-called non-firm “*non-firm* is the name for peak power that a company contracted using ATR85”), but here, the off-taker is limited to 85% availability of the connection; whenever the TSO decides to cut off the connection because of congestion, the off-taker cannot use the connection. The cut-off time will be known at 9:30 the day ahead. To compensate the off-taker for this, the transport costs will be reduced, the kW contract will be costless, and the kW max will get a reduced tariff, which will depend on the timeframe of usage. As of this moment, ATR85 has not been entirely accepted by the ACM, so it can still be changed. The current reduction proposal from TenneT can be seen in Figure 7.

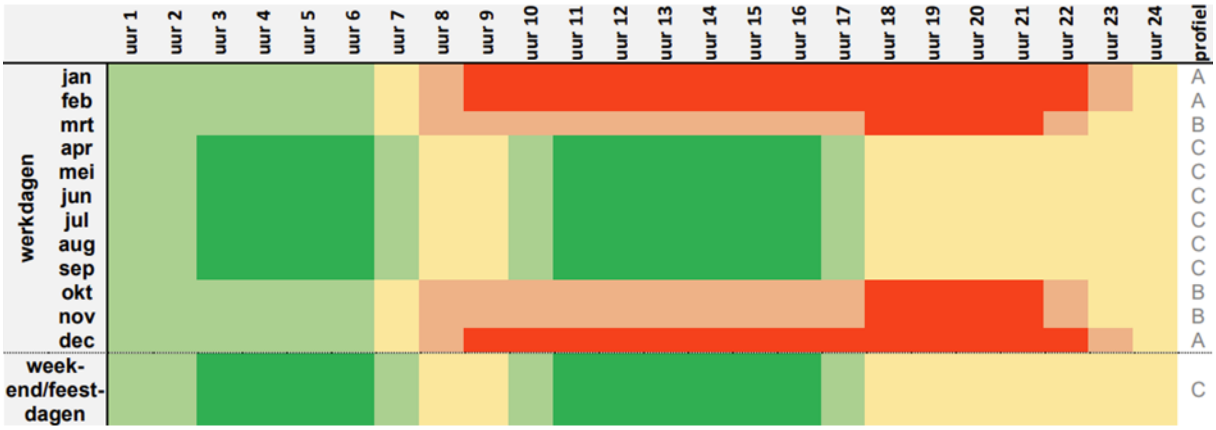


Figure 7 Proposal TenneT (Nederland, 2023).

Whenever electricity is offloaded from the grid, the kW max cost price will be multiplied by the weight factor in Table 6. According to a report from Netbeheer Nederland, depending on the trading strategies used, the total reduction of transport costs can amount to 50-60% (Nederland, 2023). This proposal is specific to the TSO TenneT; the current proposal of the RNAs is the same for the kW contract and a reduction of 10% of the kW max for the entire year, according to a source from Pure Energie. A combination of ATO and ATR will probably be applied for most projects where a smaller amount of kW peak will be contracted through ATO and the rest through ATR. Optimisation between the two can become very important for the BESS business case.

Table 6 Legend accompanying Proposal TenneT.

Colour	Weight Factor	Reduction
Dark Red	1.0	0%
Light Red	0.9	10%
Yellow	0.8	20%
Light Green	0.7	30%
Dark Green	0.6	40%

2.3 Summary of Costs for a Battery Energy Storage System

The BESS's costs (see Table 7) are divided into two categories: capital expenditures (CAPEX) that need financing and operational expenditures (OPEX) required during its operation.

Table 7 Summarised cost of BESS.

CAPEX	OPEX
Purchasing • Battery CAPEX • Balance of plant (BOP) Software/Hardware for control • Control hardware • Consumer power station • Cables • Switch • Permanent Amenities Land • Purchasing of land • Landscape integration • Grid connection CAPEX R&D costs • Development cost • Financing and DD cost • Interest cost during development • Development fee • Car insurance • Leges	Grid operating costs • Fixed tariff • kW contract (<600 hrs) • kW max week (<600 hrs) • kW contract (>600 hrs) • kW max month (>600 hrs) Asset management costs • BESS O&M and warranty • Technical asset management • Commercial asset management • Project administration costs • Accounting costs • Insurance • Unexpected Costs Land lease and local taxes • Residents compensation • Land Lease • OZB user Tax • OZB owner Tax

2.4 Interim Conclusions

Three components—CAPEX, OPEX, and Revenue—affect the profitability of a Battery Energy Storage System. The capacity and roundtrip efficiency of the chosen battery system also affect profitability.

What is the 600h norm, and what are the effects on the transport costs?

The 600h norm is a particular contract form in which the user can decide whether to use the connection for above or below 600h while utilising a peak power of above 1.5MW. Whenever the user contracts >600h, he pays for kW Max Month, meaning a monthly peak power; this does not have to be the same every month. Another contract form is <600h; here, the user can set a peak above 1.5MW for less than 600 hours while paying a lower tariff. This bottlenecks the user in trading possibilities. However, when the user has his own production, this might be enough not to be bottlenecked in revenue and pay a lower tariff. Examples of possible contract forms are depicted in Figure 6.

How does the ATR85 reduction tariff work, and what are the effects on the transport costs?

ATR85 is a separate contract that TenneT is developing; here, the end-user can contract a peak power above their Firm's current peak power for a reduced tariff; this reduction depends on the time of day and month of the year. The matrix that is provided with this reduction tariff can be seen in Figure 7. The contract costs will also be reduced to 0 due to the ATR85. For this, the user of the connection will not be able to make use of the connection for the entire year. 15% of the year, the users will only be able to use the FIRM they contracted. When and if the connection is unavailable, it is known as 9:30, the day ahead of the cut-off. ATR can reduce the transport cost by almost 50-60% if used optimally and specifically within the less expensive hours.

Where does the revenue potential for grid-size batteries lie?

Revenue can be obtained from different trading options: FCR, aFFR, mFFR and imbalance trading. Depending on the battery's capacity, a method or multiple methods can be chosen. When the battery is used to balance the grid, there is an added service fee; however, when the battery is only used within imbalance trading, the revenue will only consist of the spread between buying and selling the electricity within the imbalance market. Revenue stacking can be utilised if the battery's capacity is sufficiently large; this has the largest potential since opportunities can be had from multiple markets.

Which components are essential for the CAPEX of a BESS?

The Capex or capital expenditure includes all components mentioned in Table 7.

Which components are essential for the OPEX of a BESS?

The OPEX or operational expenditure consists of grid operating costs, asset management costs, land lease, local taxes (Table 7). Within the OPEX, transport costs are one of the most influential costs linked to where the energy is transported from; transport costs are applied whenever the energy is transported from the grid into the battery. Optimising transport costs can become one of the major factors of profitability in the business case.

3. APPLICATION OF BATTERY ENERGY STORAGE SYSTEM

The battery energy storage system must be filled with energy to produce revenue. For Pure Energie, there are three possible sources of energy distribution towards the BESS. These three sources of electrical energy are windmills, solar panels and the grid (see Figure 8). The energy source depends on the project type that Pure Energie wants to pursue. The two project types are stand-alone and co-development. Within a standalone project, the BESS will be the project's primary focus and, as the name suggests, will be a standalone. The BESS will be built at a chosen location and connected to the grid. The second type of project is called co-development; here, the BESS is coupled with a wind or solar project. This project can be an existing or new one where the battery is an additional asset. Both project types have advantages and disadvantages, but the foremost benefit of a co-development project is that certain costs can be shared between the assets. This cost-sharing can be essential in financing a BESS project because of the shared capital and operational expenditure, regardless of the type of project the BESS will be a part of. Moreover, not using the grid to fill the battery can significantly reduce transport costs. Not having to pull peak power from the grid because of your own production reduces the need for expensive ATO/ATR contracts. The source of its energy will determine its possible revenue, and the purchasing strategy dictates whether the battery will be filled. The revenue simulation will be performed using a model that the trading division of Pure Energie made, which includes the trading strategy. The revenue this model predicts depends on the battery's size, project type, energy production profile, and net capacity. Essential variables like charging capacity, round trip efficiency, and daily cycles are utilised in the revenue model.

The capacity of the BESS determines which trading method can be applied; as mentioned in the limitations of this report, only imbalance will be considered. However, the tool can be extended in the future with the possibility of utilising other trading methods. According to an internal report of Pure Energie, five possible profitable trading methods exist that can become profitable. These are FCR, aFFR, mFFR, GOPACS and passive imbalance trading. When utilising multiple markets, revenue stacking can be applied; with revenue stacking, you trade on the most profitable markets available at any given moment and compile all revenue generated from these different markets together. Not being limited to only one trading market, possibly generating more revenue together and at least having more potential since you can utilise the peaks of multiple markets, at least as long as these markets are not saturated.

The battery can also be used as a buffer; whenever the price of electricity is low or negative, it can be temporarily stored and sold for a higher price later. Subsequently, the use case scenario also affects the battery's lifetime. A battery's lifetime is determined by its number of charging cycles. The battery's capacity deteriorates over time, meaning that the capacity decreases after a certain number of cycles. The trading division of Pure Energie has determined the optimal number of cycles. This maximises the revenue that the battery can produce, considering the degradation.

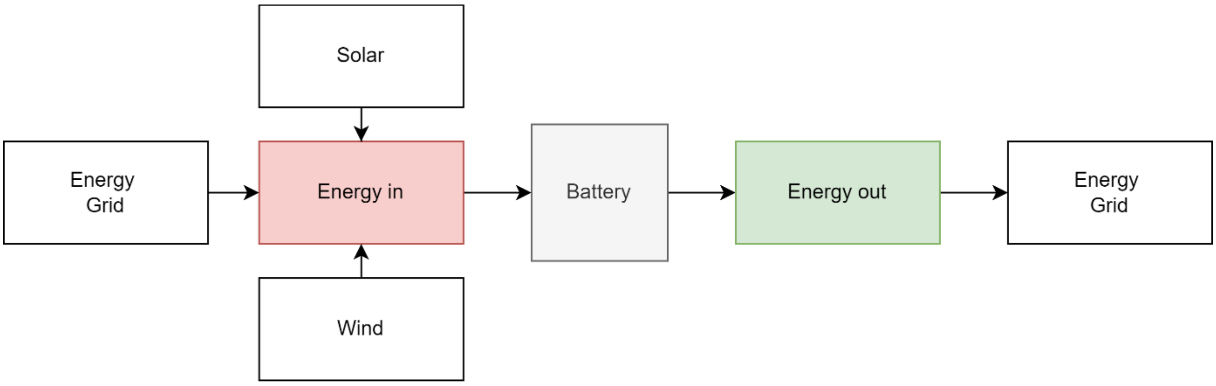


Figure 8 Simplified energy scheme.

3.1 Current Process Within Pure Energie

Pure Energie has a dedicated department responsible for developing battery projects. This does not mean that this is the only department responsible for batteries; it engages in BESS projects and investigates their financial feasibility. For this, the department requires input from other departments within Pure Energie to fill in essential parameters for the business case. Whenever a battery project is possible, the storage department investigates which battery system could become profitable for this given project. Several tools are used to perform different analyses of a BESS business case. These tools all work independently and are written in different coding programs. This makes using the tools within each other challenging and requires much manual work. The utilisation of multiple programs can be very sensitive to errors. The available models are:

- **Revenue model:** This model (written in Python) forecasts revenue. For this paper, the model itself is perceived as a black box. The only usage of this model within the paper is the input and output utilised within the tool. Pure Energie currently uses this model to forecast the battery revenue of multiple projects.
- **Business case:** Pure Energie uses a business case within Excel that can be filled with inputs to determine the cashflows over time and calculate the NPV and IRR as an output. This model must be filled in by hand, can only determine the NPV and IRR of one battery system at a time, requires prepared revenue data, and uses many assumptions.

In the procedure that Pure Energie currently uses, a possible BESS with a specific capacity is chosen, and the system's CAPEX and OPEX are used to calculate its potential profitability. In most cases, revenue will be determined by forecasting values from a rapport that Pure Energie has bought from a third party. The current process of Pure Energie uses the trial-and-error strategy, where the chosen system capacity is not random but chosen through a deterministic process where many assumptions are made. It is, therefore, sensitive to errors, time-consuming, and delivers uncertain results. Whenever a potential BESS that fits the project and can become profitable is found, the next step can be taken to develop the project further. In the project's further development, independent firms' revenue analysis will be conducted to get independent information about possible revenue. This can only be done when the system capacity is known. Accompanying this, accurate pricing data for the battery system will be requested from a manufacturer. This can then be applied within the business case to get a more detailed net present value and internal rate of return that the project will generate. Whenever a potentially profitable business case is developed by the storage department, the process can continue and incorporate other departments within Pure Energie.

3.2 Financial Analysis

Financial analysis is mandatory for projects that require investments from either internal or external sources. A rigorous financial analysis must occur before these investments are approved. Net present value (NPV) and internal rate of return (IRR) are financial metrics commonly utilised in financial analysis. Whenever cashflows are involved, the time value of money is an important concept. The time value of money is the concept that money now is worth more than money in the future because the money now can be invested into something to increase in value. There is a particular opportunity cost of capital (Brealey et al., 2020). The NPV accounts for this by discounting future cash flows to their current value using the discount rate, where the discount rate is commonly interpreted as the required rate of return (Brealey et al., 2020). Discounting cashflows ensures that all cash flows are considered on equal terms. Financial ratios can be used as decision criteria to determine if an investment is worth taking; financial ratios like the NPV or IRR can be one of these criteria. Whenever the NPV is positive, the investment project will generate an expected value; how much it needs to generate can be a secondary criterion. The same can be said for the IRR; whenever this value is above a certain threshold, it can be enough for a company to approve an investment.

However, risks are associated with only looking at one financial ratio (Brealey et al., 2020). The IRR can complement the NPV by providing insight into the project's rate of return. Unlike the NPV, which only looks at the cash flow, the IRR compares the project's profitability relative to its capital expenditure. According to Brealey et al. (2020), there are four pitfalls when only looking at the IRR when investing in projects. With this, the biggest pitfall is mutually exclusive projects; when only looking at the IRR, there is no vision of the cashflows, and a project with a lower IRR could be a better investment; combining it with NPV can introduce better insight. Since IRR can still be positive with a negative NPV. The financial ratios can also be used to compare with other projects; the IRR can generate a value that can be compared to other investments and can also be used to compare the performance of similar projects. This can help prioritise projects based on their potential impact on the company. However, applying a robust sensitivity analysis to these financial ratios is essential. The NPV and IRR can be very sensitive to slight changes in the business case. Changes to discount factors have a significant impact on the outcome. Adding sensitivity analysis to the financial ratios can mitigate the risks associated with the investment and add depth to the financial analysis. Within this paper, the chosen financial analysis is a business case study. The output of the business case should be a value that the financial department can use to raise the funds needed to finance the BESS project. Financial ratios can help compare projects and see their investment potential for Pure Energie. A consistent comparison with the same financial ratios is needed to determine the most viable option when comparing different BESS systems. In addition to the NPV and IRR, the profitability index (PI) could be used; here, the total investment is divided by the discounted free cash flow, giving a fraction as output. This can give better insight into the actual value of the investment, taking out the assumption that capital can be gathered without a limit. Moreover, going back to the BESS, building a more extensive system will hypothetically yield a higher NPV but also require more capital expenditure. Utilising the profitability index can make that ratio more visible because the fraction will decrease even when the NPV rises if the cashflows do not increase significantly.

Another addition to the business case is the DSCR (Debt Service Coverage Ratio); this ratio is used for financing and determines the ratio between available cash and obligations that need to be paid. With this, an estimate can be made with the forecasted cashflows in how well the lender can pay back its obligations with his possible investment. A DSCR of above 1 indicates that the company can pay back its debt service cost; there is no industry standard, but two or above is considered very strong since the company can cover its debt twice. Since the battery industry is still new and seen as risky with uncertain cash flows, showing that the DSCR is above a specific value can help secure investment against lower interest rates. In the future, if proven true and successful, it might be able to lower the Debt/Equity ratio for investments into battery systems, making it easier to develop a new project since less internal investment is required.

4. Business Case Tool

The developed business case tool can swiftly compare multiple battery business cases within the same project parameters. Moreover, these business cases are compared based on financial ratios. This tool produces a dashboard where the results can be presented. We have developed the tool in Python, and it can work with multiple data inputs, such as a CSV file. It also uses a revenue model for this thesis to forecast revenue with the given battery capacity provided by Pure Energie. This chapter explains how the tool works and the methodology used for calculations.

4.1 Programming

In Figure 9 the interconnection between different parts of the model is shown, and in the sections after this, a more profound explanation will be given about each individual part. The tool is divided into four sections that take data and perform the necessary actions so that these can be used within the last section, financial values.

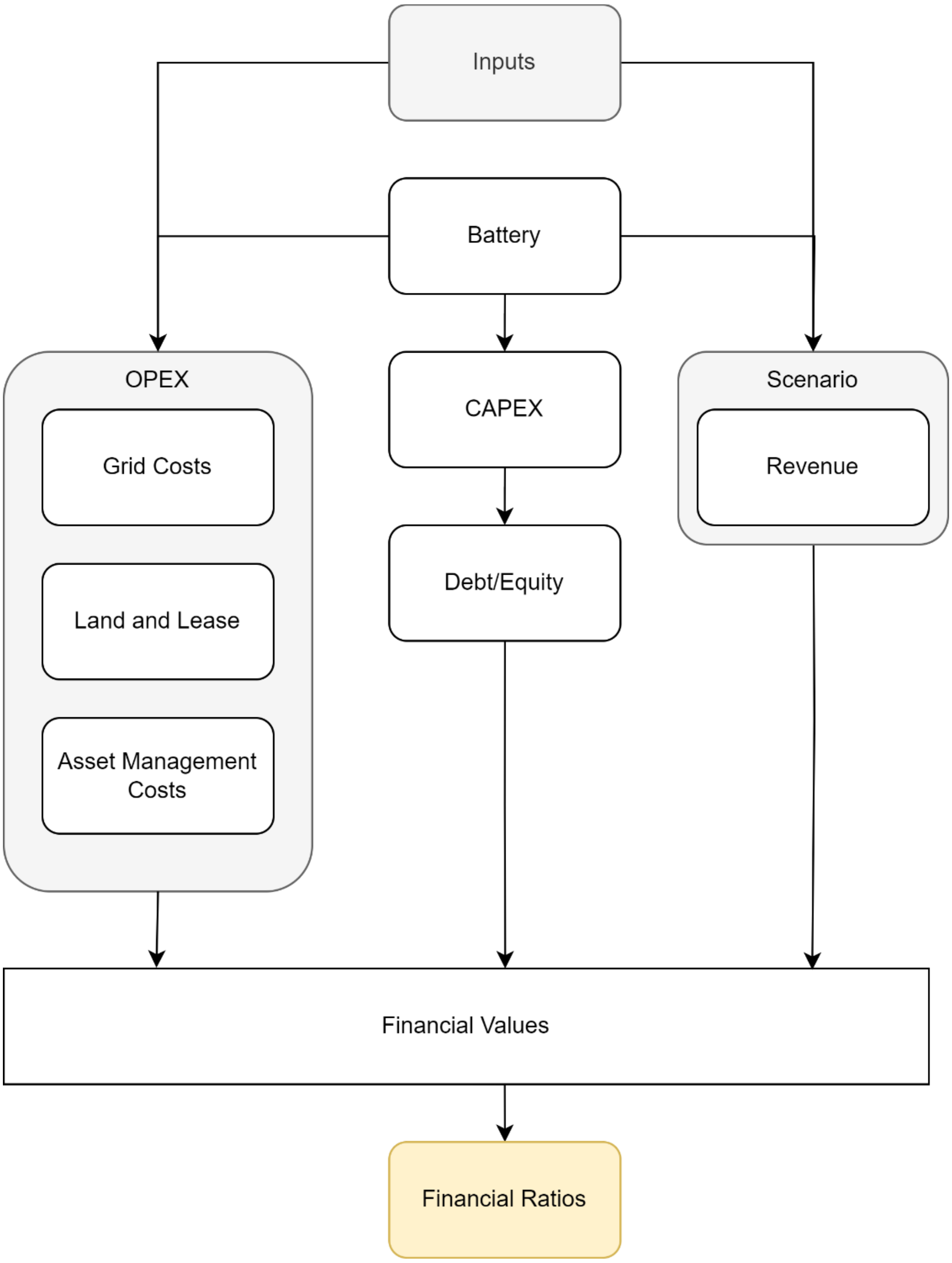


Figure 9 Block Scheme business case tool.

4.2 Separate Blocks

As mentioned, the tool works with different blocks that handle their own dataset; in addition to the necessary variables, the primary input component is the battery type. The battery type is a class within the tool with variables that are specific to that battery system. An example of this is given in Table 8. A class makes it possible to compare multiple battery types; the variables are roundtrip efficiency, max capacity, c-rate, project type, and grid connection (Firm and Non-Firm). Formulas used within the tool are mainly gathered from the case study of the business case model in Phase 1 of this project. They might be divergent from the usual formula found in the state-of-the-art literature. The calculation done within the tool follows a time path dependent on the project's length. This is indicated within the formulas through (T). Where (t) stands for the year in time, (T) stands for the expected years that the project will be carried out, and (t = x) is a particular year within the project.

Table 8 Example of a Battery Type.

Variable	Type X
Round Trip Efficiency	0.9
Max Capacity	8 MWh
Charging Rate	0.5
Project Type	Stand Alone
Firm Connection	2 MW
Non-Firm Connection	2 MW

4.2.1 Revenue

Although Pure Energie provides the Revenue model, it is essential to explain its workings and outputs briefly. The revenue model of Pure Energie forecasts the revenue that a possible battery system can produce within a period. Within the context of this research, it uses only the imbalance market and determines the revenue the battery could have produced in the selected period using historical data. For this, it uses price data of the APX (renamed EPEX), energy production data from Pure Energie (if the project type calls for it) and specific strategy profiles. The model can be used to produce all kinds of data; however, the business case tool only utilises the revenue, the status, and the grid volume of electricity. These outputs are then used within the tool; here, two manipulations happen: a scenario is added that gives a representable decay or growth of the revenue this incorporates the potential market change and degradation of the battery system, and secondly, an indexation is added to consider the inflation over time. The scenario used for revenue decay is chosen from a report specially made for Pure Energie. These scenarios are determined for different charging rates, and the tool applies the correct scenario based on the c-rate that is selected with the battery. Although the Revenue is calculated by the revenue model, this scenario adds a factor per year through the expected time of the project, which is calculated with Formula 1. Currently, inflation is added through a flat rate, but a variable rate can be added in future versions. For Pure Energie, this tool uses Pure Energie's own revenue model as input for the revenue; this is not a necessary feature as the tool can also work with the input of a single value or CSV file with generated revenue data. Revenue at (t = 1) is the revenue produced by the model, and revenue when (t > 1) includes the mentioned correction from within the tool.

$$Revenue\ (t) = Predicted\ Revenue(t=1) \times \frac{Scenario\ Revenue\ (t=1)}{Scenario\ Revenue\ (t)}. \tag{1}$$

4.2.2 CAPEX

The CAPEX is calculated using the values mentioned in Table 3. These are then multiplied by the battery system's capacity. As presented in Formula 2, all the separate parts are combined to produce the total CAPEX as output. A separate calculation is performed for the total investment for the BESS, which includes the Battery and the BOP. This is later needed for the sensitivity analysis.

$$\begin{aligned} Total\ Capex = {} & Bess\ Capex + Bess\ Control + CPS + Permanent\ Amenities \\ & + Landscape\ Intergration + Grid\ Connection\ Cost \\ & + Development\ Costs + Financing\ Costs + Interest\ Cost \\ & + Car\ Insurence + Leges. \end{aligned} \tag{2}$$

4.2.3 OPEX

The OPEX is divided into three modules, each containing its intricacies; the parts are later summed together to determine the total OPEX. Where CAPEX only has one value as its output, the OPEX has an entire array as its output since the OPEX is different every year and must be indexed with the inflation rate. For a business case, it is also essential to be able to see all the cashflows and not just one value for the entire project. The Total OPEX is calculated by Formula 3.

$$Total\ OPEX\ (t) = Grid\ Costs\ (t) + Asset\ Management\ Costs\ (t) + Land\ and\ Taxes\ (t). \tag{3}$$

Grid Costs

The grid connection costs are complicated to calculate and depend on many variables that change the network costs. It starts with selecting the network supplier, which is dependent on the location of the project; every network supplier has its own cost price; after calculating the scenario of (up or below) 600 hours, determine what network costs are associated with the connection, and finally, the latest addition to the network costs, which is called ATR85, this determines what reduction on the network costs are added as explained in the literature review. In Figure 10 , a flowchart represents the decisions made within the code to calculate the correct network costs.

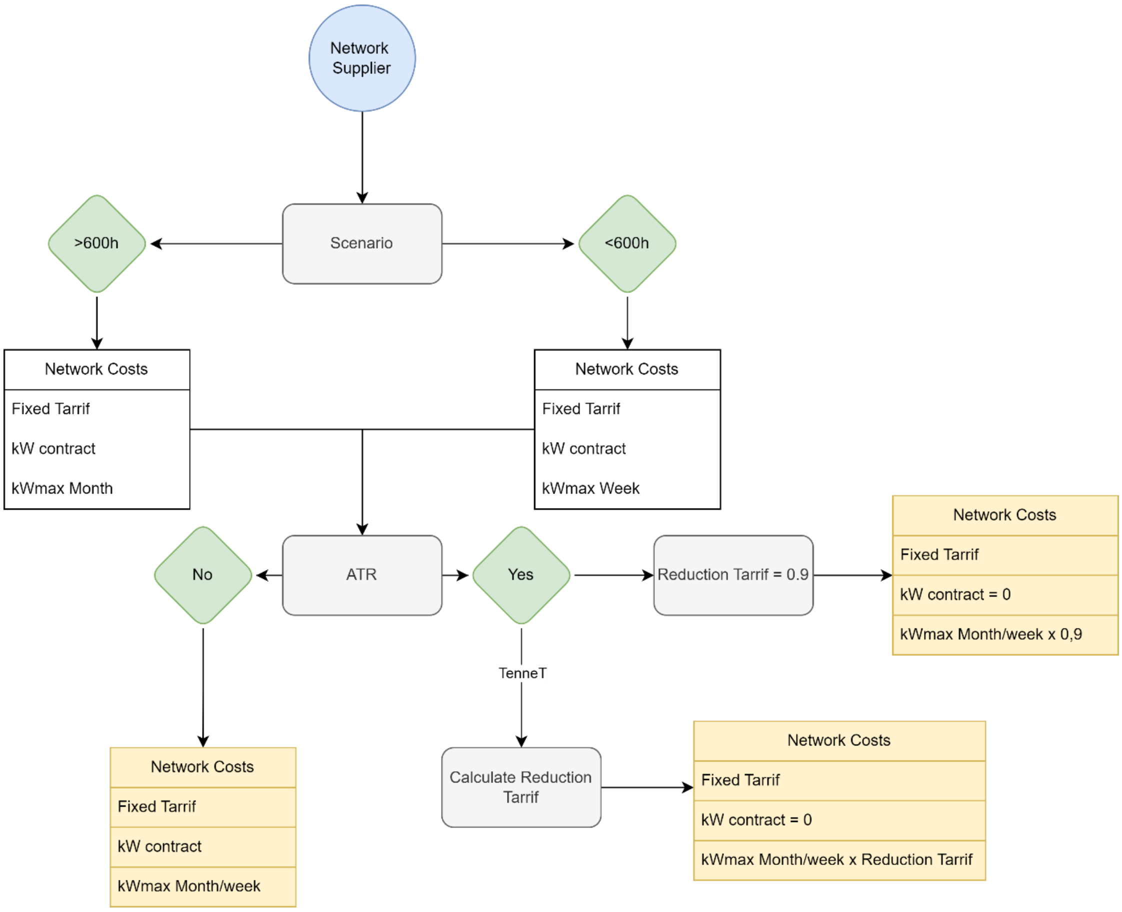


Figure 10 Calculation for the transport costs.

The decisions made within the code for the ATR reduction tariff are depicted in Figure 11; whenever the revenue model forecasts the revenue the battery could produce in a year, it also determines when a specific state change happens within the simulated battery whenever the battery charges from the grid, the code of calculated reduction tariff determines the correct reduction tariff for that time. As explained in Section 2.2.2, TenneT has specific reduction tariffs that are different for every hour of the day and month. The code extracts the time data that is coupled with the state change to determine when this state change happened. Using these values, it now can use the hour value as the y-axis coordinate and the month as the x-axis coordinate. This extracts the correct reduction tariff from the matrix in Appendix 11.3 (value X_n) and starts a counter (N). The total expected tariff reduction is calculated with

Formula 4, and this decision also considers what type of project is being forecasted. Co-development projects require an extra step since the charging can also be from your own production, and this is not taxed with network costs. (A more detailed explanation can be found in Section 2.2.2)

$$E(Reduction) = \frac{1}{N}\sum_{n=1}^{N} X_n \tag{4}$$

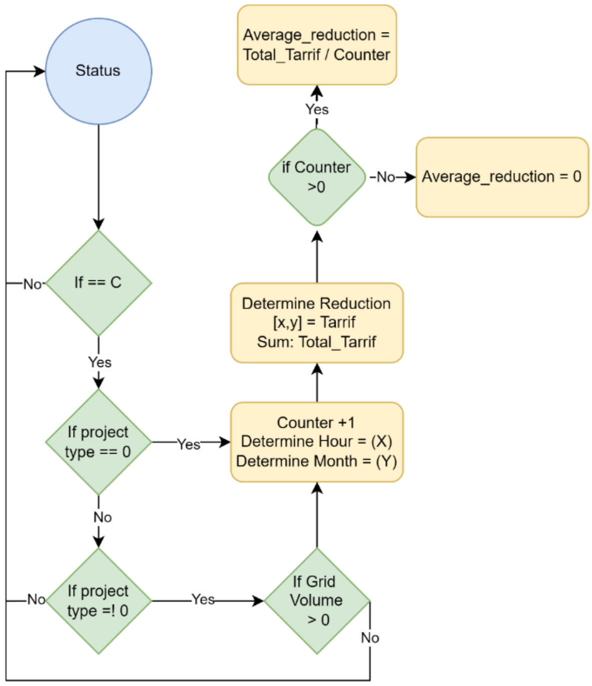


Figure 11 Calculation of Reduction Tariff.

Since there are multiple scenarios with grid costs, there are multiple formulas for determining the total grid costs. Table 9 gives all possible scenarios with their correct formula. Here, the formula stands for the Grid Costs per year. There are some minor altercations dependent on the network supplier; these are not mentioned in Table 9. These alternations do not change the calculations for the different scenarios but add some complexity. In the formula, Firm (MW) stands for the grid connection within the ATO, and ATR (MW) stands for the grid connection within the ATR.

Table 9 Grid cost Formulas for different scenarios.

Scenario:	**Formula :**	
>600	$Fixed\ Tariff + (kW\ Contract \times Firm \times 1000) + (kW\ Monthly \times 12 \times Firm \times 1000).$	(5)
<600	$Fixed\ Tariff + (kW\ Contract\ \times Firm \times 1000) + (kW\ Weekly \times 52 \times Firm \times 1000).$	(6)
>600&ATR	$Fixed\ Tariff + (kW\ Contract \times Firm \times 1000) + (kW\ Monthly \times 12 \times Firm \times 1000) + (kW\ Monthly \times 12 \times ATR \times 1000 \times Reduction\ Tarrif).$	(7)
<600&ATR	$Fixed\ Tariff + (kW\ Contract\ \times Firm \times 1000) + (kW\ Weekly \times 52 \times Firm \times 1000) + (kW\ Weekly \times 52 \times ATR \times 1000 \times Reduction\ Tariff).$	(8)

Asset Management Costs

Asset management costs are calculated using the values of Table 4 multiplied by the battery capacity. Since these values are also needed for cash flow analysis, they are indexed at the same flat rate as the other OPEX items. Then, an additional cost category is added for “unexpected costs”; Pure-Energie uses this to manage some unexpected risks associated with asset management costs. It is currently set at a flat rate and can be changed when needed. The asset management costs are calculated using Formula 9.

$$\begin{aligned} &Asset\ Management\ cost\ (t) \\ &\qquad = Bess\ Warranty\ (t) + Technical\ Asset\ Management\ (t) \\ &\qquad + Project\ Administration\ (t) + Accounting\ Costs\ (t) \\ &\qquad + Insurance\ Costs\ (t) + Unexpected\ Costs (t). \end{aligned} \tag{9}$$

Land and Taxes

For land and taxes, a couple of values need to be calculated. The first value that is being calculated is the WOZ value of the battery; WOZ stands for “waardering onroerende zaken”, or valuation of immovable property in English. An appraiser of the local authority typically determines this value. However, an estimation is made for the simulation based on the total investment into the battery. As seen in Formula 10, this is then multiplied with the variable WOZ. The operator of the model can choose this variable; it is currently set at 50%, as provided by Pure Energie. During the project, the WOZ value depreciates over time using the calculation in Formula 11.

$$WOZ\ value = Capex\ Battery\ \times WOZ. \tag{10}$$

$$WOZ\ value\ (t) = WOZ\ value\ (t) - \frac{WOZ\ value\ (t=0)}{Depreciation\ period}. \tag{11}$$

The WOZ value is then used to calculate the OZB “Onroerendezaakbelasting” value or Property tax in English. The OZB values for every municipality are different; there is an OZB owner tax and an OZB user tax, both of which apply to the battery. The percentage applied per category can be found on the municipality's website. The OZB value at a specific period in time can be calculated using Formula 12.

$$OZB\ value\ (t) = WOZ\ value\ (t) \times (\ OZB\ Owner + OZB\ User). \tag{12}$$

Lastly, the land lease costs and compensation for the local residents are calculated by multiplying the battery capacity with the value from Table 4 these are yearly costs. The total land and local lease costs are calculated using Formula 13.

$$Land\ and\ Taxes\ (t) = \ \ OZB\ value\ (t) + Lease\ costs\ (t) + compensation\ (t). \tag{13}$$

4.2.4 Debt and Equity

Debt and Equity are calculated using a couple of formulas. The tool's inputs are “Percentage of Debt” and “Percentage of Equity.” Summed together, they must be 1. The Debt and Equity at the start of the project are calculated using Formulas 14 and 15.

$$Debt\ (t=0) = Total\ Capex\ \times Percentage\ of\ Debt. \tag{14}$$

$$Equity\ (t=0) = Total\ Capex\ \times Percentage\ of\ Equity. \tag{15}$$

The Debt will be repaid during the project through yearly payments. It is financed through a secondary party, and interest must be paid on it. The total debt at a time can be calculated using Formulas 16-19.

$$Repayment = \frac{Debt\ (t=0)}{Financing\ Period}. \tag{16}$$

$$Debt\ (t) = Debt\ (t-1) - Repayment. \tag{17}$$

$$Interest\ Costs\ (t) = \frac{Debt\ (t-1) + Debt\ (t)}{2} \times Interest\ Rate. \tag{18}$$

$$Total\ Debt\ (t) = Debt(t) + Interest\ cost\ (t). \tag{19}$$

4.2.5 Financial Values

We used two different financial libraries within Python to calculate the NPV and IRR. These packages contain formulas for determining financial ratios. Cashflows are an essential aspect of the financial dashboard. Several financial calculations must be performed to transform the revenue and costs into the free cash flow (FCF). First, the EBITDA (Earnings Before Tax Depreciation and Amortisation) must be calculated; this is performed with Formula 20. After this, the EBIT (Earnings Before Interest and Tax) is calculated using Formula 22. Here, the Financial depreciation is subtracted from the EBITDA; this is a bookkeeping tactic to smear out the total equity paid over several years. There is no actual cash flow since the equity was already paid at the start of the project. After that, the EBT (Earnings Before Tax) is calculated using Formula 23, followed by the Net Income calculated with Formula 25. There are two different Corporate Tax brackets in the Netherlands, so depending on the value of EBT, a high or low tax bracket is paid (low tax rate of 19% and above €200.000 25.8% (pwc, 2024)).

Finally, the FCF can be calculated using Formula 26, where the financial depreciation is added again (since there is no actual cash flow), and the debt repayment (see Formula 16) is subtracted.

$$EBITDA\ (t) = Revenue(t) - Total\ OPEX(t). \tag{20}$$

$$Finacial\ depreciation\ (t) = \frac{Total\ Capex}{Financing\ Period}. \tag{21}$$

$$EBIT(t) = EBITDA(t) - Financial\ Depreciation(t). \tag{22}$$

$$EBT(t) = EBIT(t) - Interst\ Costs(t). \tag{23}$$

$$Corperate\ Tax(t) = EBT(t) \times Corperate\ tax\ rate\ \left(\frac{high}{low}\right). \tag{24}$$

$$Net\ income\ (t) = EBT(t) - Corperate\ Tax(t). \tag{25}$$

$$Free\ Cash\ Flow(t) = Net\ Income(t) + Financial\ Deprication(t) -\ Repayment(t). \tag{26}$$

The NPV is calculated by the NumPy Finance library function “npf.npv”, which takes as input the discounting rate, equity value for (t = 0), and free cash flow for every (t > 0). Then, it uses Formula 27 to calculate the value of the NPV (Gitman, 2000).

$$NPV = \sum_{t=0}^{T-1} \frac{Free\ Cash\ Flow(t)}{(1 + Discount\ rate)^t}. \tag{27}$$

The Pyxirr library calculates the IRR using the function “pyxirr.irr”, which takes as input the same cashflows as the NPV, equity as a value for (t = 0), and free cash flow for every (t > 0). Then, it uses Formula 28, setting the Formula equal to zero and calculating the IRR, solving for the polynomial (Gitman, 2000). The polynomial can have multiple outcomes whenever there are multiple negative cashflows. This package only returns the value that is closest to the expected discount factor, this helps with guiding the answer whenever there are multiple negative cashflows. Whenever the IRR of a project is negative, the tool will set it to 0% since there is no use in representing a negative IRR value. IRR can only be below the discount factor whenever the NPV < 0.

$$0 = \sum_{t=0}^{T} \frac{Free\ Cash\ Flow(t)}{(1 + IRR)^t}. \tag{28}$$

The PI is calculated using the discounted free cash flows, which are discounted using Formula 29 and then divided by the equity (see Formula 30).

$$Discounted_{Cashflow}(t) = \frac{Free\ Cash\ Flow(t)}{(1 + Discount\ rate)^{t}}. \tag{29}$$

$$PI = \frac{\sum_{t=1}^{T} \frac{Free\ Cash\ Flow(t)}{(1 + Discount\ rate)^{t}}}{-Equity}. \tag{30}$$

Finally, the DSCR is calculated using the EBITDA minus corporate tax and divided by the Debt plus interest cost (see Formula 31). Since the debt is paid after this period, the DSCR can only be calculated during the project's financing period.

$$DSCR\ (t) = \frac{EBITDA\ (t) - Corperate\ tax(t)}{Repaymen(t)}. \tag{31}$$

4.3 Additional Scenarios

We added some extra functionality to the tool, although it was initially only meant for sensitivity analysis. It can also be utilised to add more scenario variability to the business case. Three additions can be used to change uncertain aspects within the business case: Capex, Revenue and Transport Ratio (see Table 10). Capex makes it possible to change the CAPEX costs of the battery whenever the sensitivity value is different from 0, which changes the value of the battery capex. Where negative values reduce the CAPEX, positive values cause the CAPEX of the battery to grow. The second addition is revenue, which works like the CAPEX sensitivity and changes the revenue generated by the revenue model according to the chosen sensitivity value. Filling in 1 for sensitivity value will double the revenue; this works with negative values as well, and using -0.5 will half the revenue. The last sensitivity will change the value that is used for “ATO FIRM”, and it will override the hardcoded value for ATO within the battery type and will utilise the newly chosen value; this can be utilised to change the ratio between “firm” and “non-firm” connection and find an optimal value for the chosen battery project.

Table 10 Effect of sensitivity on the tool output.

Sensitivity type	Input Range	Effect
Capex	-1 > & <∞	Value < 0: Decreases the CAPEX of the battery system. Value > 0: Increases the CAPEX of the battery system.
Revenue	-1 > & <∞	Value < 0: Decreases the Revenue of the battery system. Value > 0: Increases the Revenue of the battery system.
Transport Ratio	0 > & < ATR	Changes in the Value of ATO: Increasing the ATO value will increase transport costs since there is no reduction within the ATO contract. Decreasing the value will decrease transport costs.

4.4 Output

We want to use the tool's output to introduce the results; within the output, we will show the tool's capabilities and highlight important features that can be utilised to perform the financial analysis that the tool is used for. We will showcase these features in the form of a case where four potential battery capacities will be compared within the same project parameters. A description of the project parameters is a stand-alone project in the Enschede area. The location is essential for the “network provider” and certain location-specific taxes. Input variables will remain the same and will not be changed (see Table 11). The flexible values are explained in

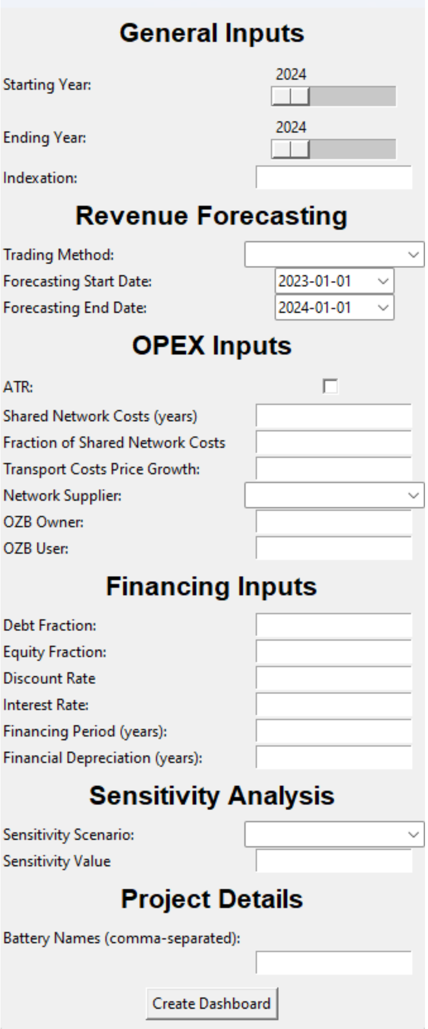
Table 12. Hardcoded values that belong to the battery cannot be changed from within the input screen.

Table 11 Explanation of variables within the model.

Variable :	Explanation:
General Inputs	
Starting Year	The starting year is the year the project generates value for the first time. Based on this value, the correct starting year of the revenue scenario is chosen.
Ending Year	The ending year is the last year the project generates value. The difference between the starting year and the ending year determines the expected project years.
Indexation	The flat rate that is chosen for inflation correction.
Revenue Forecasting	
Trading Method	The trading strategies chosen to forecast the revenue.
Start Date	The trading strategy can forecast revenue for a period of time (max one year). The start date indicates the start date of that period.
End Date	The trading strategy can forecast revenue for a period of time (max one year). The end date indicates the end date of that period.
OPEX inputs	
Shared Network Costs (years)	Whenever a project is shared, part of the network costs are shared with a secondary party. This value determines how many years the costs are shared.
Fraction of Shared Network Costs	Whenever network costs are shared with a secondary party, this value determines the share that the other party pays.
Price Growth	The price growth ads a presumed price increase for the transport costs. This will be added exponentially every year to the project.
OZB Owner	This is the OZB owner (non-residential) value of the specified municipality where the project will be built.
OZB User	This is the OZB user value of the specified municipality where the project will be built.
Financing Inputs	
Debt Percentage	This is the percentage of the total investment recognised as debt by the user.
Equity Percentage	This is the percentage of the total investment recognised as equity by the user.
Discount Rate	The applied financial discount rate.
Interest Rate	The applied financial interest rate for borrowing money.
Financing Period	Period of time that the user of the model recognises as a financing period.
Financial Depreciation	Period of time that the user of the model recognises as the period in which the project will be financially depreciated.

Table 12 Explanation of variables within the model 2.

Variable:	**Explanation:**	**Possible values**
Network Supplier	There are multiple network suppliers within the Netherlands, depending on where or what kind of installation is needed. The input can change.	“Tennet”, “Enexis (HS/MS)”, “Enexis (MS-D)”, “Liander (HS/MS)”, “Stedin (HS+TS/MS)”
ATR	ATR can be switched on or off depending on the type of contract.	“True” or “False”
Sensitivity Scenario	For the sensitivity analysis, several scenarios were added that could change aspects of the business case.	“none” “Revenue” “Capex” “Contract”
Expected Revenue	A revenue expectation can be added depending on the expected future scenario. This changes the generated revenue to reflect the increase or decrease within the selected scenario.	N/A



General Inputs

Starting Year: 2024

Ending Year: 2024

Indexation:

Revenue Forecasting

Trading Method:

Forecasting Start Date: 2023-01-01

Forecasting End Date: 2024-01-01

OPEX Inputs

ATR: ☐

Shared Network Costs (years)

Fraction of Shared Network Costs

Transport Costs Price Growth:

Network Supplier:

OZB Owner:

OZB User:

Financing Inputs

Debt Fraction:

Equity Fraction:

Discount Rate

Interest Rate:

Financing Period (years):

Financial Depreciation (years):

Sensitivity Analysis

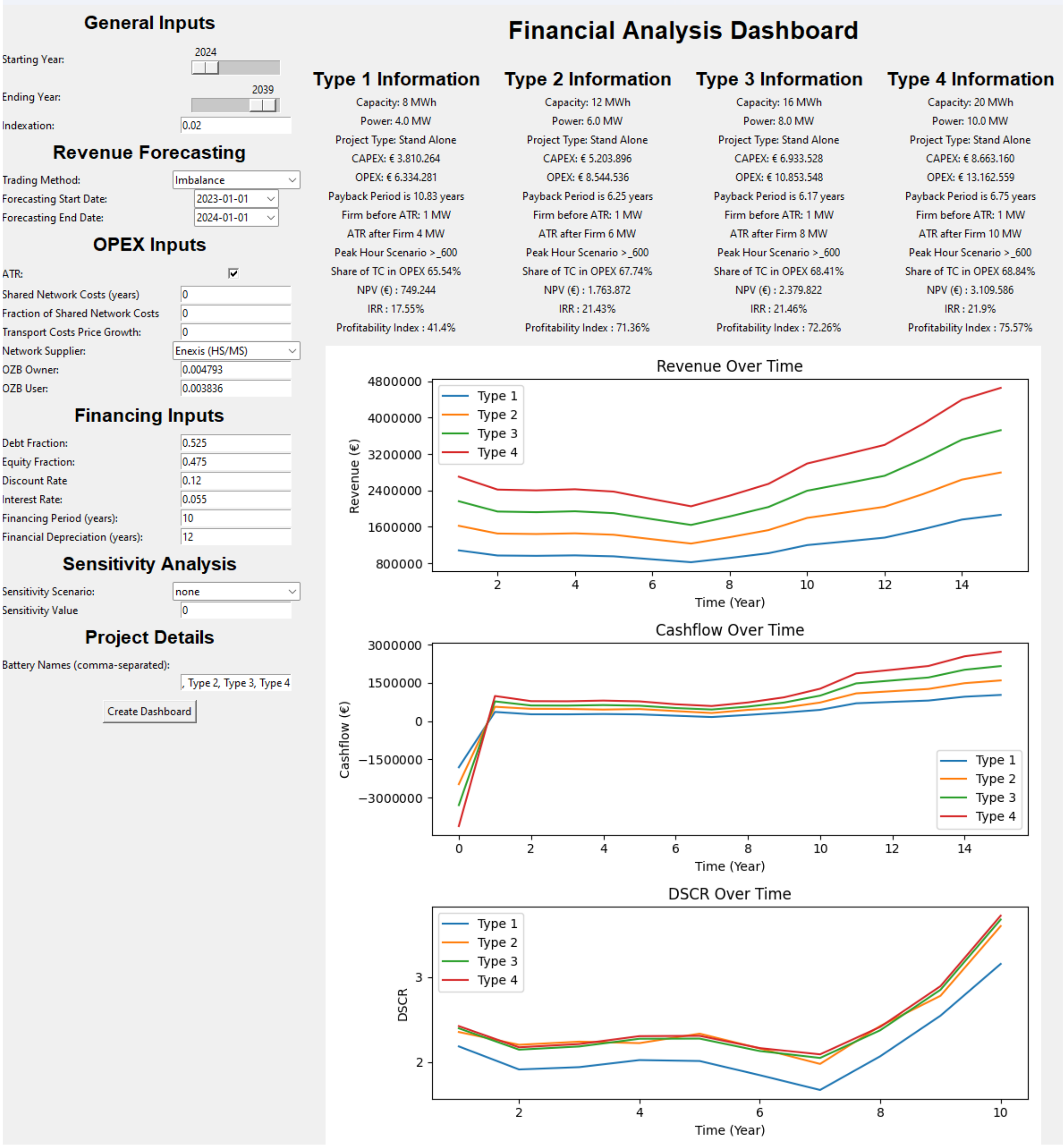
Sensitivity Scenario:

Sensitivity Value

Project Details

Battery Names (comma-separated):

Figure 12 Input Screen for the Tool.



General Inputs

Starting Year: 2024
Ending Year: 2039
Indexation: 0.02

Revenue Forecasting

Trading Method: Imbalance
Forecasting Start Date: 2023-01-01
Forecasting End Date: 2024-01-01

OPEX Inputs

ATR: ☑
Shared Network Costs (years) 0
Fraction of Shared Network Costs 0
Transport Costs Price Growth: 0
Network Supplier: Enexis (HS/MS)
OZB Owner: 0.004793
OZB User: 0.003836

Financing Inputs

Debt Fraction: 0.525
Equity Fraction: 0.475
Discount Rate 0.12
Interest Rate: 0.055
Financing Period (years): 10
Financial Depreciation (years): 12

Sensitivity Analysis

Sensitivity Scenario: none
Sensitivity Value 0

Project Details

Battery Names (comma-separated): , Type 2, Type 3, Type 4

Financial Analysis Dashboard

Type 1 Information

Capacity: 8 MWh
Power: 4.0 MW
Project Type: Stand Alone
CAPEX: € 3.810.264
OPEX: € 6.334.281
Payback Period is 10.83 years
Firm before ATR: 1 MW
ATR after Firm 4 MW
Peak Hour Scenario >_600
Share of TC in OPEX 65.54%
NPV (€) : 749.244
IRR : 17.55%
Profitability Index : 41.4%

Type 2 Information

Capacity: 12 MWh
Power: 6.0 MW
Project Type: Stand Alone
CAPEX: € 5.203.896
OPEX: € 8.544.536
Payback Period is 6.25 years
Firm before ATR: 1 MW
ATR after Firm 6 MW
Peak Hour Scenario >_600
Share of TC in OPEX 67.74%
NPV (€) : 1.763.872
IRR : 21.43%
Profitability Index : 71.36%

Type 3 Information

Capacity: 16 MWh
Power: 8.0 MW
Project Type: Stand Alone
CAPEX: € 6.933.528
OPEX: € 10.853.548
Payback Period is 6.17 years
Firm before ATR: 1 MW
ATR after Firm 8 MW
Peak Hour Scenario >_600
Share of TC in OPEX 68.41%
NPV (€) : 2.379.822
IRR : 21.46%
Profitability Index : 72.26%

Type 4 Information

Capacity: 20 MWh
Power: 10.0 MW
Project Type: Stand Alone
CAPEX: € 8.663.160
OPEX: € 13.162.559
Payback Period is 6.75 years
Firm before ATR: 1 MW
ATR after Firm 10 MW
Peak Hour Scenario >_600
Share of TC in OPEX 68.84%
NPV (€) : 3.109.586
IRR : 21.9%
Profitability Index : 75.57%

Figure 13 Example of a case study for GSES in Enschede.

5. Validation and Sensitivity Analysis

In this section, we describe our approach to validating the tool to verify the outputs and to ensure reasonableness and coherence. This involves testing procedures to compare its outputs under various conditions. Additionally, we outline our strategy for analysing the tool's sensitivity, which entails assessing its responsiveness to changes in input parameters and external factors. Addressing the fourth research question, "How do potential vulnerabilities within the business case of battery energy storage projects interact with future fluctuations of prices and other financial metrics?" necessitates applying sensitivity analysis. This analytical approach enables us to identify critical factors influencing the viability of battery energy storage projects and their susceptibility to future uncertainties.

5.1 Validity and Reliability

In Phase 3 of this project, the tool's validity was measured by an independently chosen participant who fell within the validation criteria specified in Table 14. Several tests of validity were applied to the tool. These tests are described in Table 13. A report of the validity test can be found in Appendix 11.6, which is discussed in Chapter 7 .

To test the model's reliability, it was subjected to a Test-Retest reliability test. The tool was tasked with calculating the same battery system twice using the same project specification. Since the input parameters were all the same, there should not be a noticeable difference between the calculations.

Table 13 Validity Measures.

Type	Meaning	Application
Face validity	Face validity concerns whether the tool in question does what it is supposed to do (Gillen, 2009).	The application of face validity in this research concerns the tool's function: Does it calculate the correct financial ratios within the correct parameters?
Content validity	Content validity concerns whether the tool encompasses all the relevant aspects of the constructs it is supposed to measure (Roebianto et al., 2023).	The application of content validity in this research concerns the tool's content: Does the tool encompass all the relevant values for CAPEX, OPEX and revenue, and does the tool use the appropriate calculations for the needed financial ratios?
Criterion-related validity	Criterion-related validity tests whether a tool's output is comparable to that of a previously validated tool (George et al., 2003).	The application of criterion-related validity in this research concerns the calculated financial ratios' values and whether these are comparable to the previously validated business case that Pure Energie already uses.

Even when the tool is deemed valid and reliable, a risk remains that needs to be acknowledged and addressed. This risk was the tool’s user; human error when inputting values could cause the tool to produce incorrect values. The only way to reduce the risk of misinterpreting the values produced by the tool with wrong inputs was by inserting guiding values and warning messages whenever a value fell outside the margin. An instruction manual was also made as part of the deliverables; within this manual, clear instructions were written on how to operate, update and change the tool. Moreover, clear instructions were also written about the input values and the range in which these input values can be chosen.

5.1.1 Description of Participant Recruitment

Within the development process, multiple validation points ensure that the tool developed has all the necessary features and that the financial ratios produced are comparable to the current business case. A matrix (see Table 14) was developed with the required skills and experience to validate the tool.

Table 14 Validation Recruitment Criteria.

Recruitment Criteria:	**Description:**
Theoretical background knowledge	• The participant is under employment of an energy-producing company, and has previously worked with a business case for battery storage systems. • The participant knows the 600-hour norm employed by the TSO and understands its implications for the OPEX. • The participant knows the necessary assumptions for the CAPEX of a BESS. • The participant is aware of the ART85 and understands the effect of Firm and Non-Firm connections on transport costs.
Technical expertise	• The participant has prior experience with Python programming language.

5.2 Sensitivity Analysis

A sensitivity analysis will be performed to understand the tool's workings and the variables' effect on the output. For this sensitivity analysis, certain variables were identified that, according to the earlier sensitivity analysis of Pure Energie, had the largest impact on the business case. Other variables were chosen because of the risk they might pose to the viability of the business case. The range of possible values chosen for these variables is depicted in Table 15. Moreover, according to the collected data, a range will be around the base scenario ($\mathbf{x_0}$). The methodology used for the sensitivity analysis is a local sensitivity analysis where one variable at a time (OAT) will be tested and its impact on (value for NPV and IRR, $\mathbf{y_0}$). The impact of certain variables can be assessed in Chapter 6, where the results are presented in the form of a tornado diagram. The interpretation of the sensitivity analysis is discussed in Chapter 7. Furthermore, implications that resulted from this are discussed in Chapter 8.

Table 15 Variables for sensitivity analysis.

Variable	Explanation	Range
Indexation	Indexation is used to compensate for inflation. Using a flat rate can be misleading since the inflation will not be the same during the project.	[0%, 1%, **2%**, 3%, 4%]
Discount Rate	The discount rate is needed to calculate the NPV and determine the discounted cash flows within the business case. A change in the discount range could affect the financial ratio, making investments suddenly unwise.	[10%, 11%, **12%**, 13%, 14%]
Revenue	The market will become more saturated in the coming years, and the range of possible revenue will become thinner. That is why it is vital to investigate how much this affects the viability of the business case.	[-10%, -5%, **0%**, 5%, 10%]
Transport costs	Transport costs can grow or decline every year. As a company, you have no control over this factor. That is why it is vital to research how sensitive the output is to changes in this variable from a financial risk standpoint.	[-10%, -5%, **0%**, 5%, 10%]
Capex Battery	Battery prices can grow and decline depending on resource availability, development, and the geopolitical climate. Certain supply chain risks can also affect the viability of the business case.	[-10%, -5%, **0%**, 5%, 10%]
Spread between ATO and ATR	One of the most pressing problems with the business case is transport costs; the spread between contract values can become interesting to investigate for the transport costs.	$[\frac{1}{30}, \frac{3}{28}, \boldsymbol{\frac{5}{26}}, \frac{10}{21}, \frac{15}{16}]$

5.2.1 Impact Analysis

Impact analysis can help determine which factor impacts the tool most. Although irrelevant to this tool, impact analysis can assist in removing less important variables to simplify the tool. The benefit of doing an impact analysis for this project is understanding which variable has the largest impact on the profitability of the business case. Understanding this can make it easier for users to optimise profitability as long as it is a factor that the user can change. Adding to this, it can give insight into the risks that are prominent and add dangers to the investment. An absolute difference between the base scenario ($\mathbf{y_0}$) and the simulated scenarios gives a fair representation of the change in variables' impact on the output. We assume that the model is linear by approximation in Figure 14 this claim is supported by the model's calculation of the NPV for 12 different battery systems, all within the same project parameters and subject to the same revenue altercation. (It is important to mention that this is a stylised result, meaning no factual conclusions can be drawn from it.) Assuming that the tool is linear allows us to use a local sensitivity analysis (Reed et al., 2022).

Presentation

We first present the sensitivity analysis data in a tornado diagram; this diagram can be used to present the spread between the worst-and best-case scenarios with an expected scenario as an indication. The tornado diagram presents the spread of outcomes for every variable. With this, visual analysis can occur, where the biggest spread between the base scenario ($\mathbf{y_0}$) can be compared with the lowest and highest values. Based on the width of the spread, the biggest impact on the business case can also be found. However, this only compares the values visually. We will analyse the absolute values to determine the biggest change within the chosen variables.

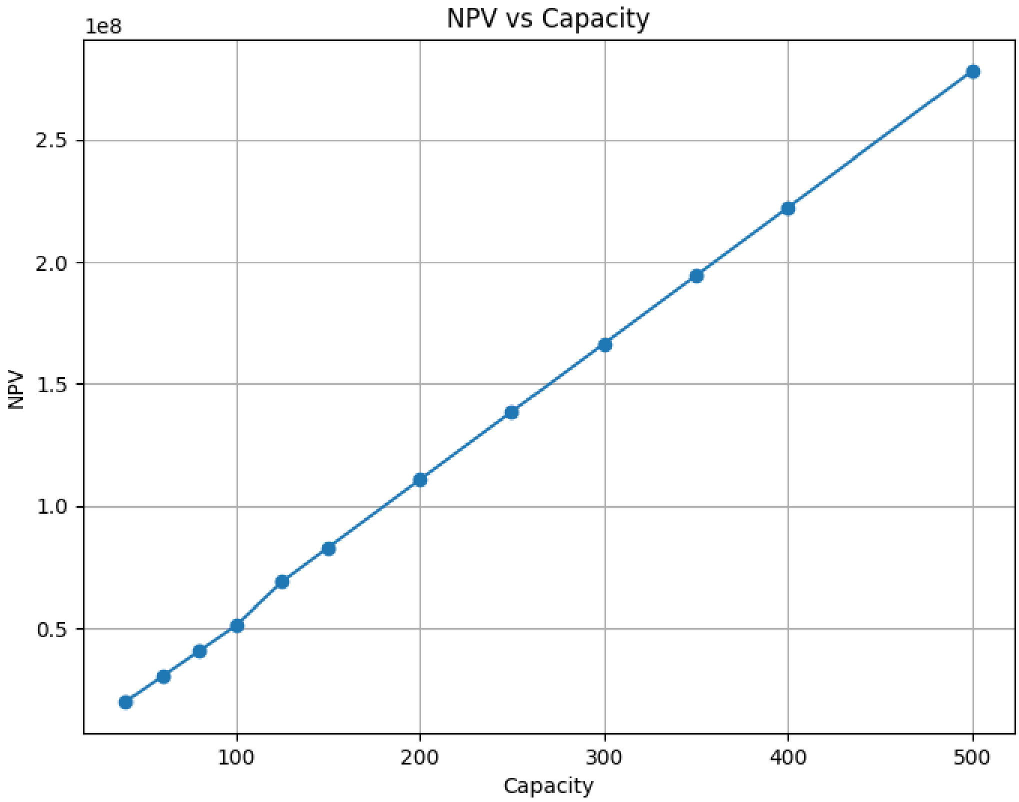


Figure 14 NPV against Capacity within a stylised scenario.

6. Results

In this chapter, we aim to explore the utility that the tool can provide for the end user. We will report on the tool's output in this analysis and show the results of the validation and sensitivity analysis.

6.1 Analysis of Output Case Study

We analysed four battery systems using the same project parameters. For this, we used the tool's functionality to compare battery capacities [8, 12, 16, 20] MWh. The tool has three central output values: NPV, IRR and PI. The output of the financial ratios for this case study is placed in Table 16. It is important to mention that this is a case study of a possible scenario. No factual conclusion can be drawn from it. It is merely shown to showcase the functionality of the tool and where it can be used. All inputs can be found in Figure 13, and a scenario is added to change the revenue over time.

Table 16 Output Case study Financial Values.

Capacity	8 MWh	12 MWh	16 MWh	20 MWh
NPV	€749.244	€1.763.872	€2.379.822	€3.109.586
IRR	17.55%	21.43%	21.46%	21.9%
PI	41.4%	71.36%	72.26%	75.57%

In this case, all systems have a positive net present value. This is a valuable insight for the end user since they know what configurations are possible. Whenever options are possible, deeper analysis can take place. Investigate whether bigger capacities would be better if the investment can be made. Sensitivity analysis can be applied to the configuration with a positive NPV to determine the sensitivity of the business case and the variables that pose risks during the project.

Another valuable insight the tool gives is the revenue over time, as seen in Figure 15 all revenue lines follow the same scenario but produce different revenue curves; smaller batteries can produce less revenue, as the figure shows.

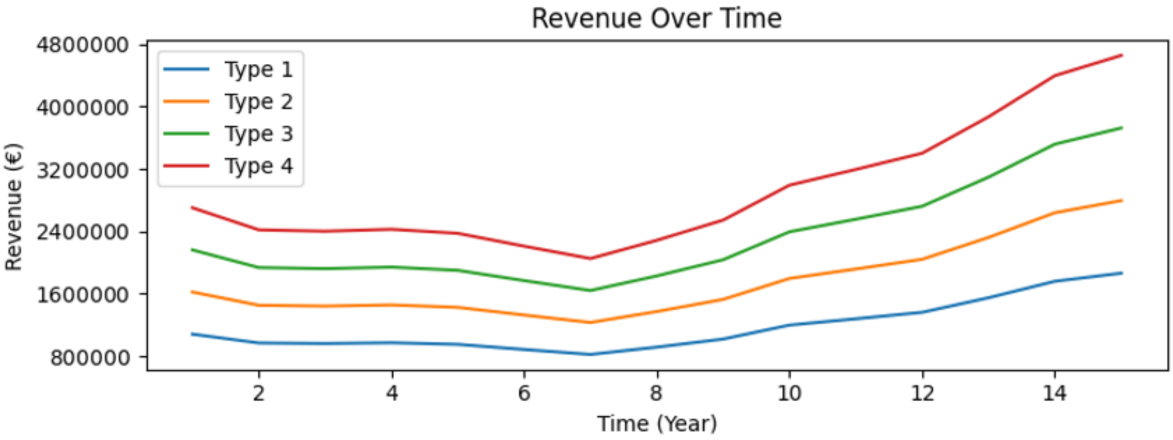


Figure 15 Revenue graph from the case study.

Valuable information like the total CAPEX can give insight into how much investment is needed for a battery project. Information about the percentage of transport costs gives insight into how significant this factor is within the business case. This can also indicate the effect of applying ATR since the percentage should be lower when ATR is applied. Transport costs are perceived as one of the biggest problems within the business case; to validate this, the transport costs will be researched within the sensitivity analysis. However, knowing how much of the total OPEX is transport costs can give valuable information when optimising these costs while comparing the same battery system instead of multiple sizes.

The financial dashboard's second graph shows the free cash flows, where the initial investment is shown in year 0. After the first year, the revenue dips, as seen in Figure 15. Moreover, until year 10, the debt for investing needs to be paid, including interest costs; we also see a spike in revenue after year 10, which creates an upward motion in the free cash flow. This can be seen in Figure 16.

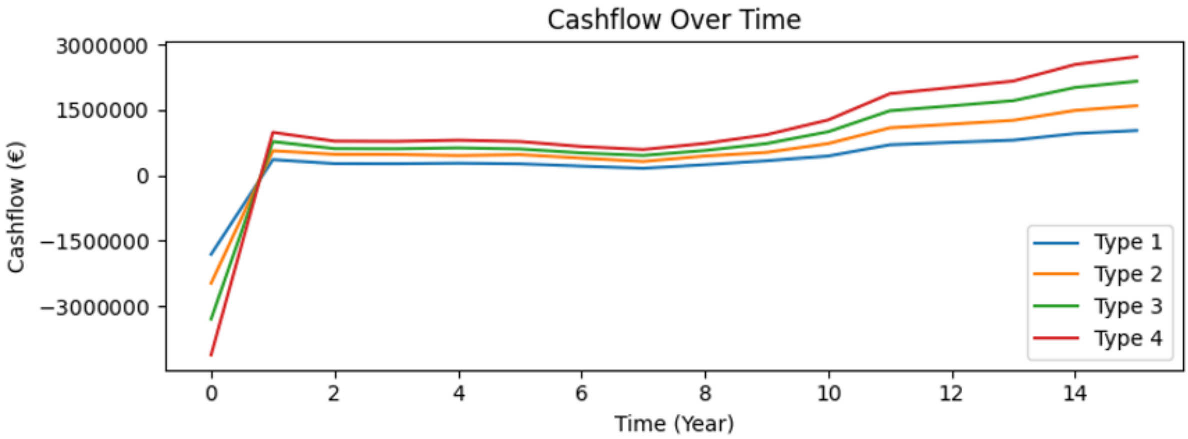


Figure 16 Cashflow graph from the case study.

The last graph on the financial dashboard depicts the DSCR over the financing period. Within this period, the ratio is calculated to give the user insight into how well the potential project can pay for its debt. The bank uses the DSCR to determine how well the lender can pay off its debt. The DSCR for this case study is depicted in Figure 17 here, all battery systems perform well above 1 DSCR, meaning that debt obligations can be met during the project's time.

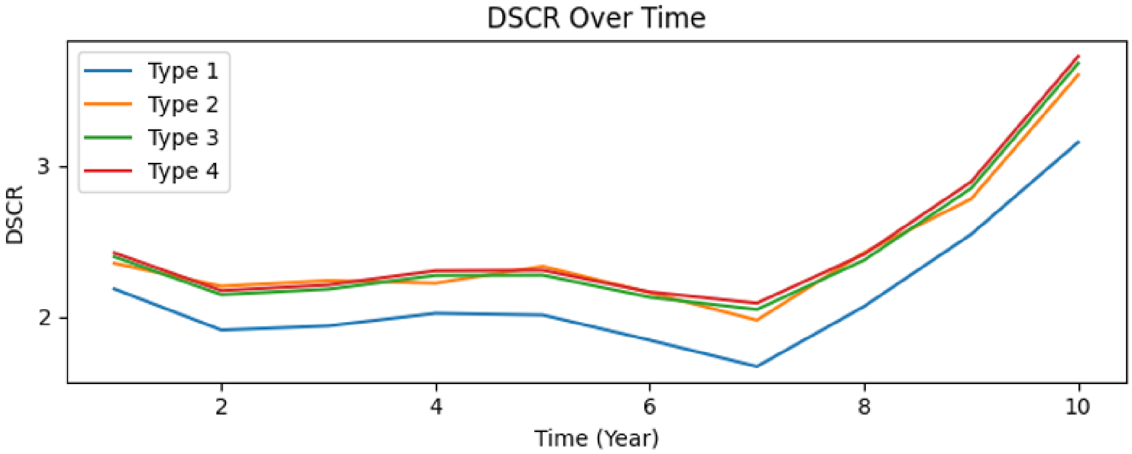


Figure 17 DSCR graph from the case study.

6.2 Validation and Testing

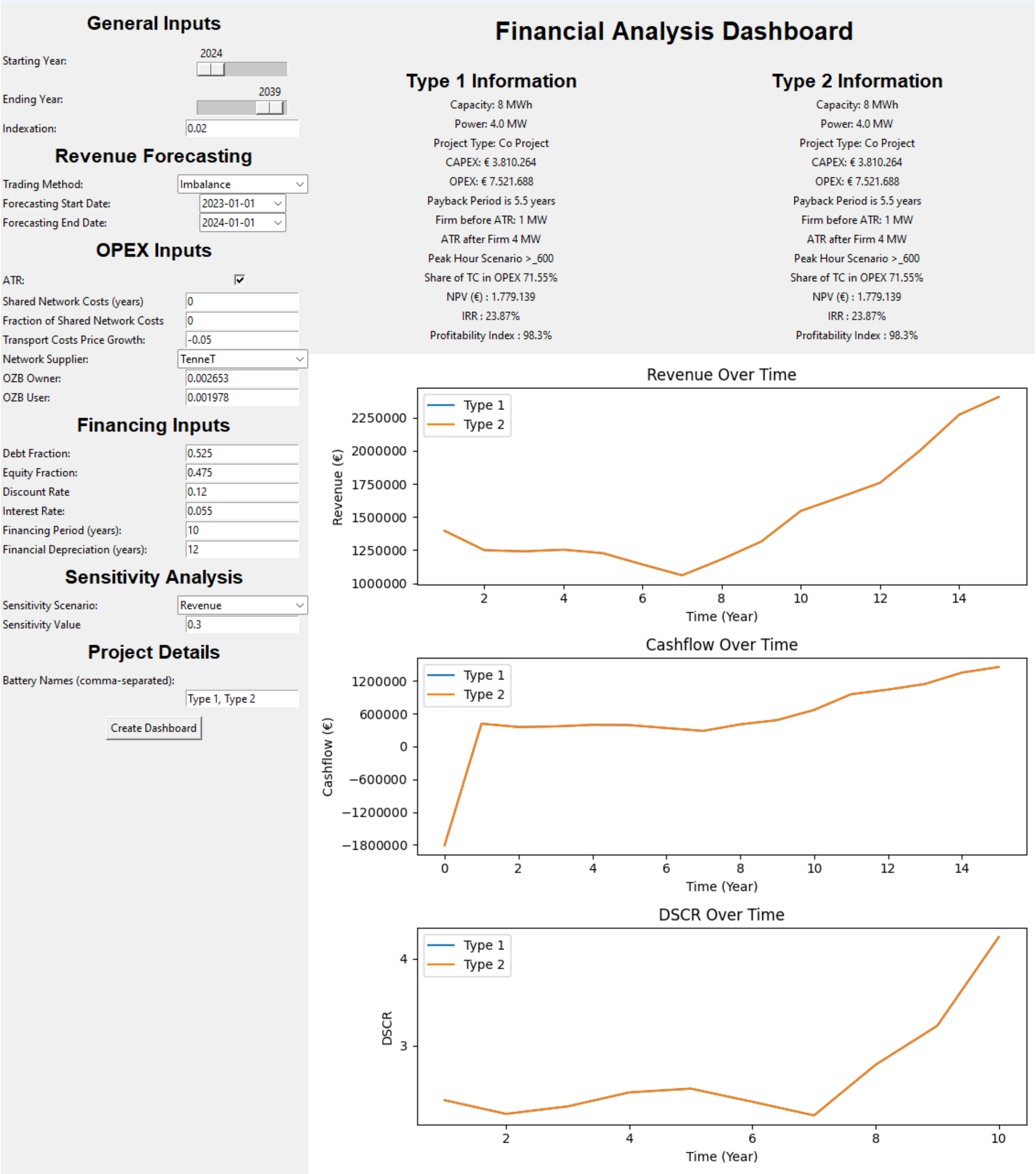
We validated the tool in the second and third phases of the tool's development. As mentioned in the methodology, the tool was validated on three different criteria: “Face Validity”, “Content Validity” and “Criterion Validity”. We performed the validation in the second phase, where we compared the first version of the tool with a business case that Pure Energie is currently using to determine the profitability of a new project. The results of this validation are presented in Table 17. Specifically, chosen colleagues from Pure Energie validated and tested the tool in the project's third phase. They performed a validation mostly on criterion validity, where they compared the tool's output against an already validated business case and tested the model for significant problems. To ensure that content validity was also checked, a meeting was held with the financial controller to check if the formulas used within the tool were correctly applied. For testing criterion validity, they used the tool to perform case studies; the results are presented in Table 18 (The entire report can be found in the Appendix 11.6). To test the reliability of the model, Test-Retest was applied; the result of this can be found in Figure 18.

Table 17 Summarised Validation Tool (Phase 2 of the project).

Criteria	**Description**	**Result**
Face Validity	Does it calculate the correct financial ratios within the correct parameters?	The tool provides the user with an output of the NPV and IRR.
Content Validity	Does the tool encompass all the relevant values for CAPEX, OPEX and revenue, and does the tool use the appropriate calculations for the needed financial ratios?	The tool uses Python to read the given CSV files. When comparing the inputs to the tool for CAPEX, OPEX, and Revenue, it uses the same values as the business case it is compared with.
Criterion Validity	The application of criterion-related validity in this research concerns the calculated financial ratios' values and whether these are comparable to the previously validated business case that Pure Energie already uses.	Since all the inputs of the CAPEX, OPEX and Revenue were the same as mentioned in "content validity", the output should be the same. Results from Criterion Validity show that the NPV and IRR gave the same value. This result shows that the used formulas are applied correctly.

Table 18 Summarised Validation Tool (Phase 3 of the project).

Criteria	Results
Face Validity	"The model does what it should: the financial factors of batteries with different power/capacity within the same project can be compared to each other."
Content Validity	"The tool uses the appropriate Formulas for the financial calculations performed within the tool."
Criterion validity	This validity test compared two possible systems for Hazeldonk. These two systems have capacities of 8 and 16 MWh, both with a c-rate of 0.5. The profitability of these systems is calculated with both the Excel model and the new tool. The results from this comparison show that within both Tools, the 8MWh system is the better choice for this project. It is worth noting that there was a difference in absolute values for the IRR.
	This validity test compared two possible systems for Eeltinkveld. These two systems have capacities of 10 and 20 MWh, with a c-rate of 0.5 and 0.25. For both the Excel model and the new tool, the battery with a c-rate of 0.5 performed better. When looking at absolute values of the NPV, the new tool gives a more positive NPV than the Excel model.
	For Both Hazeldonk and Eeltinkveld, wind co-location would be more successful than Solar co-location. However, it is impossible to compare the absolute values of the new tool with the Excel model. The same conclusions can be drawn from both. The new tool is more efficient and easier to use. To compare both models on absolute values, a new business case needs to be made where both use the same revenue as input.



General Inputs

Starting Year: 2024

Ending Year: 2039

Indexation: 0.02

Revenue Forecasting

Trading Method: Imbalance

Forecasting Start Date: 2023-01-01

Forecasting End Date: 2024-01-01

OPEX Inputs

ATR: ☑

Shared Network Costs (years): 0

Fraction of Shared Network Costs: 0

Transport Costs Price Growth: -0.05

Network Supplier: TenneT

OZB Owner: 0.002653

OZB User: 0.001978

Financing Inputs

Debt Fraction: 0.525

Equity Fraction: 0.475

Discount Rate: 0.12

Interest Rate: 0.055

Financing Period (years): 10

Financial Depreciation (years): 12

Sensitivity Analysis

Sensitivity Scenario: Revenue

Sensitivity Value: 0.3

Project Details

Battery Names (comma-separated): Type 1, Type 2

Financial Analysis Dashboard

Type 1 Information

Capacity: 8 MWh
Power: 4.0 MW
Project Type: Co Project
CAPEX: € 3.810.264
OPEX: € 7.521.688
Payback Period is 5.5 years
Firm before ATR: 1 MW
ATR after Firm 4 MW
Peak Hour Scenario >_600
Share of TC in OPEX 71.55%
NPV (€) : 1.779.139
IRR : 23.87%
Profitability Index : 98.3%

Type 2 Information

Capacity: 8 MWh
Power: 4.0 MW
Project Type: Co Project
CAPEX: € 3.810.264
OPEX: € 7.521.688
Payback Period is 5.5 years
Firm before ATR: 1 MW
ATR after Firm 4 MW
Peak Hour Scenario >_600
Share of TC in OPEX 71.55%
NPV (€) : 1.779.139
IRR : 23.87%
Profitability Index : 98.3%

Figure 18 The output of the Test-Retest.

6.3 Sensitivity Analysis

As mentioned in the methodologies, we investigated the sensitivity of the business case. For this, we used a local analysis utilising the on-at-the-time method. For six specifically chosen variables, a range of inputs was tested against the base value. The range in which these variables are tested is depicted in Table 19. The effect of the changing variables on the net present value and internal rate of return was chosen as the output variables to visualise the effect of the changing variables on the net present value. A tornado diagram was made for both output variables (see Figure 19 and Figure 20), to determine which variable impacted the NPV and IRR most. (The base inputs are depicted in Appendix 11.4)

Table 19 Changing Input Values.

Input	Min		Base		Max
Indexation	0%	1%	2%	3%	4%
Discount Rate	10%	11%	12%	13%	14%
Revenue	-10%	-5%	0%	5%	10%
Transport costs	-10%	-5%	0%	5%	10%
Capex Battery	-10%	-5%	0%	5%	10%
Spread between ATO and ATR	1/30	3/28	5/26	10/21	15/16

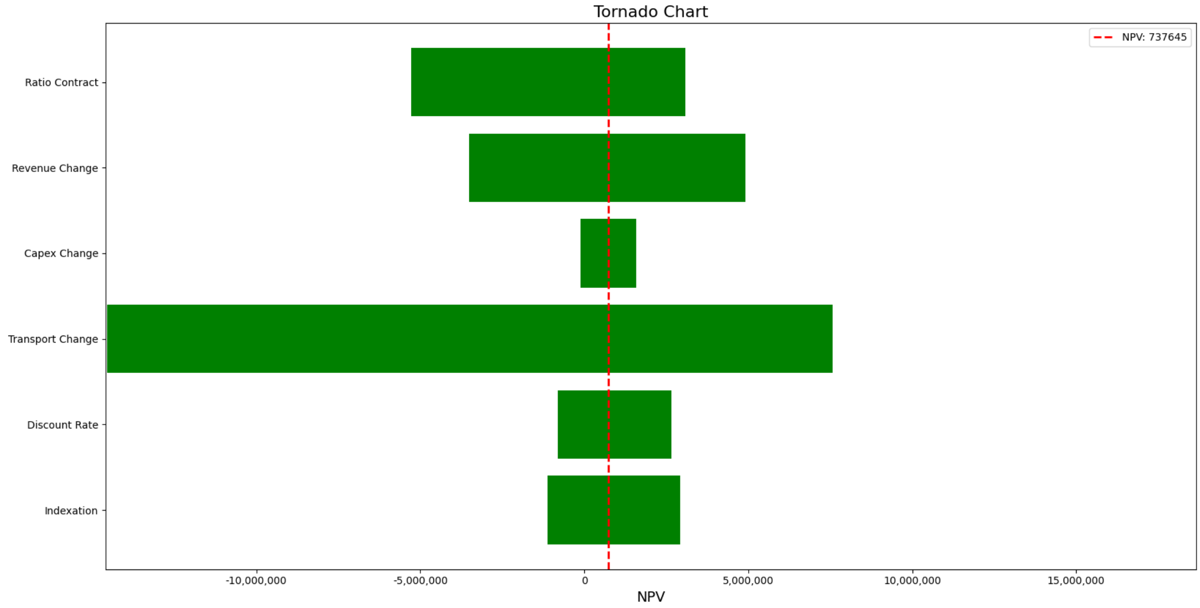


Figure 19 Tornado Diagram NPV.

From the tornado diagram in Figure 19 we can conclude that the biggest impact is seen in Transport Change; from this, we may conclude that transport costs have the biggest impact on the NPV of the chosen six variables tested with the OAT method. To give a more detailed view of every variable's change compared to the base situation, we also provide the absolute change of NPV when changing one variable compared to the base situation. From this, we gain insight into which parameter changes had the most significant impact on the outcome. The results from the absolute differences are presented in Table 20, where the most significant value is marked in bold.

Table 20 Absolute change compared to the base value (NPV).

Indexation	€1.854.714	€959.785	0	€1.043.793	**€2.179.345**
Discount Rate	**€1.918.966**	€907.333	0	€815.599	€1.550.371
Revenue	**€4.247.832**	€2.088.748	0	€2.090.638	€4.166.975
Transport costs	€6.836.778	€4.034.947	0	€6.034.754	**€15.287.491**
Capex Battery	**€848.160**	€424.080	0	€424.080	**€848.160**
Spread between ATO and ATR	€2.339.423	€1.173.763	0	€2.967.464	**€6.024.129**

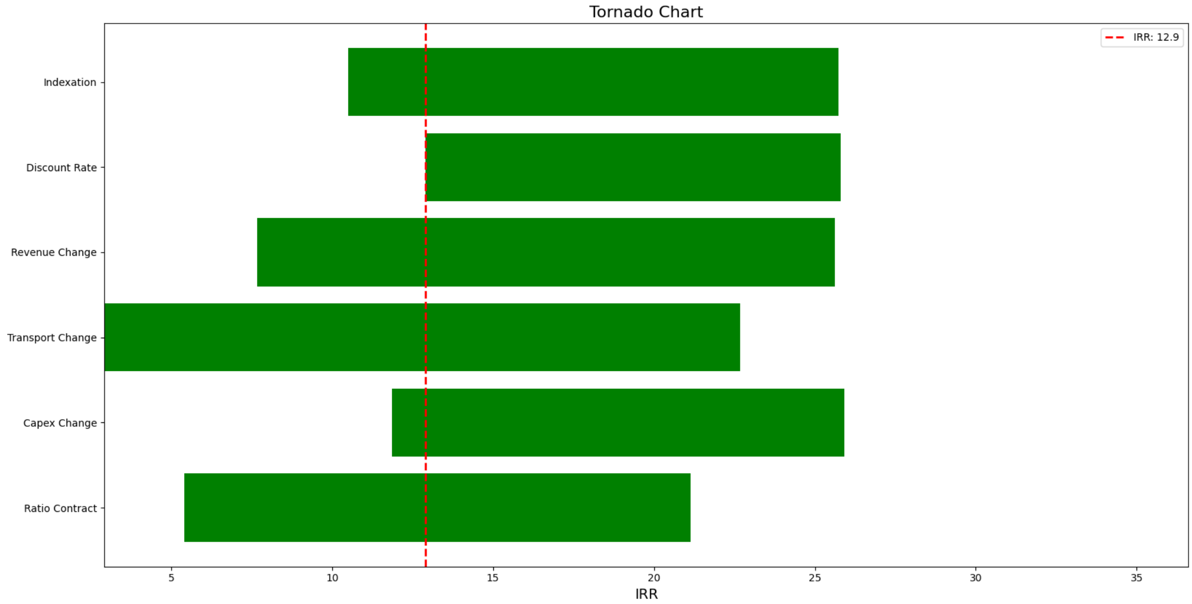


Figure 20 Tornado Diagram IRR.

From the Tornado Diagram in Figure 20 we can conclude that the biggest impact is seen in Transport Change; from this, we can conclude that transport costs have the biggest impact on the IRR of the six chosen variables tested with the OAT method. To give a more detailed view of the change every variable had compared to the base situation, we also provide the absolute change of IRR when changing one variable compared to the base situation. From this, we gain insight into what parameter changes had the most significant impact on the outcome. The results from the absolute differences are presented in Table 21, where the largest value is marked in bold.

Table 21 Absolute change compared to the base value (IRR).

Indexation	**2.4%**	1.18%	0%	1.17%	2.33%
Discount Rate	0%	0%	0%	0%	0%
Revenue	**5.23%**	2.56%	0%	2.54%	5.06%
Transport costs	6.68%	4.26%	0%	9.98%	**N/A**
Capex Battery	**1.15%**	0.56%	0%	0.53%	1.03%
Spread between ATO and ATR	2.83%	1.42%	0%	3.65%	**7.49%**

7. Discussion

In this chapter, we discuss our main findings and research questions, and whether the goal of this research has been achieved. The discussion is divided into three parts: Tool, Validation and Sensitivity Analysis, each highlighting and discussing a section of the results. The results from the case itself are not essential to discuss, but some assumptions and tool features will be mentioned.

7.1 Tool

We aim to develop a tool that can automatically compare multiple battery energy storage systems based on financial ratios within the parameters of the given project. As seen in the results, the tool can perform this task and is able to compare multiple battery systems. The tool user can fill in the necessary inputs and produce a financial dashboard that can be used to determine the best system option based on financial parameters. However, the tool does not pick the best option, this decision falls on the user with his preferred criteria. Optimising only the NPV or IRR can result in not picking the optimal system.

Then, answering the third research question, “What is the optimal size selection for a Battery Energy Storage System based on financial metrics, such as the NPV and IRR, within the parameters of a given project?” When we look at our case study, the answer is clear: there is only one battery project that outperforms all the other batteries on every financial ratio, and thus, the project that can add the most shareholder value, given the input parameters. When a company only uses the NPV and is able to finance the initial investment, Type 4 would be the best fit.

The strength of the tool is that the application of this tool does not only have to be comparing multiple battery systems based on their capacity; it can also be utilised to perform analysis on scenarios: what if the prices rise, what if the transport cost will decrease? Additionally, it can be used to optimise not only on capacity but also on grid connection ratio. In the scenario where the business case is not yet viable, and the only option the end-user has is the optimisation of the grid costs since all other variables cannot be changed, the model can be used to perform this analysis and make it visible within a financial dashboard that can be shared with other parties.

7.1.1 Revenue

We used the revenue model of Pure Energie`s trading division to feed the tool with revenue data, this made it possible to calculate the revenue for different size battery systems. This revenue model only utilises the imbalance market. Only trading on the imbalance market is not optimal, according to an internal report of Pure Energie. A more optimal strategy would be to use the method that is mentioned in Chapter 3, this method is called revenue stacking. With revenue stacking, you utilise all the possible trading methods. Applying revenue stacking can boost the battery's revenue since the trading division can now utilise peak opportunities in multiple markets, boosting the battery's potential revenue. Since the current tool does not use this opportunity, the revenue forecasting can be lower than what is possible for the battery system's size, which can give a conservative view of the profitability.

To take into account potential market changes and degradation, the revenue forecasted by the revenue model is adjusted with a scenario. This ensures that the change of revenue through time is not random but founded in revenue forecasting. (The scenario that is currently applied is a scenario gathered from an internal rapport of Pure Energie; it is seen as the mid or most likely scenario for batteries with a c-rate of 0.5.) The tool applies the correct revenue scenario for batteries with different c-rates.

7.1.2 CAPEX

The tool currently applies operationalised values for the CAPEX, meaning that the project's cost price is based on the relative size of the battery. With the data available, this was the only way to compare many different battery sizes.

Another point of discussion is the shared CAPEX; currently, the model does not apply a factor for shared costs. This means the co-development project does not benefit from shared costs, at least not within the CAPEX part. What makes this challenging to add is knowledge about how the project will be seen; even when the project is marked as co-location, this does not mean that the entities are seen as one business case. Therefore, the costs cannot be shared directly without this knowledge. The tool, however, can be used to change the CAPEX of the battery with the sensitivity scenario “CAPEX”. When a negative value is filled in for the sensitivity value, this typically represents a reduction in the CAPEX price but can be used to simulate cost sharing.

7.1.3 OPEX

As seen in the sensitivity analysis and mentioned earlier in the report, transport costs are one of the most influential factors within the business case. A problem with this is that you as a company cannot change these costs. You could apply the optimisation within the contract form; here, multiple options are possible, utilising above or below the 600h norm, especially for co-development projects where most of the charging can be done from their production. Then, how much peak power will you contract with ATO or ATR? Since the ATR rate is reduced, it would be best to contract most of your peak power within that contract form; the downside would be that you are bottlenecked within your trading for 15% of the time. These are complex considerations, but the tool can help optimise these ratios and provide better insights into the effects of changing these variables.

Currently, the tool calculates the worst-case scenario for transport costs. It assumes that the maximal peak will be set within that period, depending on the type of 600h contract. This means that kW Max (week or month) will always have the highest value it can get. This is probably unrealistic in almost every scenario and certainly in co-location projects. Moreover, the upside of utilising your production is not having to pay transport costs when you charge the battery system. This would theoretically mean you will not have to hit the peak power every month/week if you optimise your trading behaviour accordingly. This means that when utilising the battery, the transport costs will be lower certainly for co-development projects, and the tool cannot take this into account since it does not know when or if the peak will be set during the years of utilisation and that is why it calculates the worst-case scenario. This means that the direct benefits of co-projects cannot be seen, at least not within the transport costs.

7.1.4 Output

The NPV and IRR are calculated using a Python library function, which is described in Chapter 5. However, multiple ways of calculating these values exist. The chosen methods are used within the literature, but for example, Excel has a different method of calculating the NPV and IRR, making it challenging to compare business cases.

The discount rate is used to calculate these financial ratios. Typically, this discount rate is calculated using an appropriate method like the CAPM method. The discount rate is an input value that can be changed, but for the case analysis within this paper, 12% was chosen. Pure Energie provided this value. The board of directors within Pure Energie determines this factor for all projects within Pure Energie; they do not mention the method used. Then, the percentage that is taken for interest rate was also provided by Pure Energie and is a changeable factor within the tool. The percentage depends on the rates the lender will charge, the project's risk, and the borrower's creditability, which is different for everyone. The ratio between debt and equity is an assumption of the financial department within Pure Energie that depends on the expected cash flows. There are certain risks with new investments like battery storage, and banks are reluctant to finance these projects, meaning that a more significant share needs to be financed with personal funds compared to investments with less uncertainty in their cashflows. That is why it was also chosen to provide the DSCR over time; this can display how well the project can pay its obligations. On a large scale, battery projects are relatively new, so the long-term viability is not yet known. Therefore, showing the project's prospects is vital for securing financing.

The Profitability index is also shown in the case study; the results show that the NPV might be better for bigger investments, but the PI will not grow significantly. The difference between 12 MW and 20 MW is only 4.21% PI. However, the initial investment is almost 3.4 million more (~56%), and Pure Energie can use this to determine if they really want to invest in more extensive projects or research whether it would be better to build multiple smaller batteries to increase their shareholder value.

A final remark on the output: since IRR should not be negative, the tool changes the output for IRR whenever that value becomes negative. The package used for the IRR calculation picks the value closest to the discount factor; whenever cashflows include multiple negatives, the IRR has multiple solutions. That is why this approach was chosen, which is important to mention. We encountered difficulties with NumPy Finance (NPF), so Pyxirr was chosen to perform the IRR calculations. Within NPF, the value closest to 0 was chosen whenever there were multiple IRRs, and this caused the IRR to be below the discount factor even when the NPV > 0; this is not correct.

7.2 Validation and Testing

We validated and tested multiple tool versions to achieve reliability and validity. The model was validated against an existing business case in the project's second phase and showed no fundamental differences. The second time, it was validated and tested by a secondary party that fell within the selection criteria mentioned in Section 5.1.1.

Some valid remarks about some differences are mentioned in the validation report; most importantly, the way of calculating the NPV and IRR are different; the methods used are not the same and cannot be compared 1 to 1. Another part of the discussion is that the NPV of the compared cases was positive, and the tool's output was negative. The significant difference between the two cases is the revenue used to calculate the results. An external company forecasts the revenues used within the Excel business cases and utilises revenue stacking. This is something the tool currently is not able to do. Therefore, the tool's forecasted revenue is lower, which could explain the negative NPV and IRR.

The overall impression from the validation was that it indicated that the same size of the battery would be a better fit for the project, and that is the most important conclusion from the validity test

7.3 Sensitivity Analysis

We performed a sensitivity analysis, and we assumed that the business case was linear. One of the most significant criteria for the one-at-a-time method is that it does not capture interactions between variables that a global analysis would have caught. Within a linear model, there should be no interactions between variables, so that should not be a problem. We performed a local analysis of variables perceived as influential for the business case. There can always be variables that were not considered, influencing the model's output. However, with the constraint of time and resources, we made a selection in consultation with Pure Energie. We selected the spread of inputs around the base scenario, and no specific methodology was used to select these values.

Discussing the tornado diagram of the NPV, we see the most significant change in transport costs, which was somewhat expected. Transport costs are such a significant share of the total operational expenditure that changing this cost either positively or negatively will impact the NPV. When the OPEX costs rise, the free cash flow will decrease; when the OPEX costs decrease, the free cash flow will increase. This means it will directly impact the NPV when all the other variables are the same. The second and third most influential parameters are revenue and the contract ratio. The reason for this is also quite logical: increasing the revenue directly increases the free cash flow, following the same effect as the costs. Moreover, changing the ratio of FIRM and ATR will increase or decrease the transport costs, which will have the same effect, although not as significant as increasing the transport costs. The absolute values show the same results, although the spread between ATO and ATR is ranked higher than revenue.

Only the outlier of the IRR analysis will be mentioned to prevent repetition. Within the sensitivity analysis of the IRR, the discount rate showed no difference when changed positively or negatively. This can be explained because the range in which the discount value is changed is [10, 11, 12, 13, 14] per cent. This means that within the lower boundary, the NPV will be higher since the discounting factor is lower. And with a higher Discount factor, the NPV will be lower and that is exactly what happens within the results. Every IRR is 12.9, as seen in the output file in Appendix 11.5 . Meaning that there is no absolute change.

The results of the sensitivity analysis can be used as risk indicators, as mentioned in Section 5.2. Here, the risks coupled with the sensitivity variable are mentioned. Since the battery development project takes several years to complete, a lot can happen to the possible revenue and costs. This indicates the importance of an extensive risk analysis and proper risk mitigation strategies.

Another utility of the sensitivity analysis is the opportunity to optimise certain parts of the business case. Not all variables' sensitivities can be utilised as optimisation measures, but the operator can at least tweak revenue and the spread between ATO and ATR from the chosen sensitivity variables.

8. Conclusion

Our aim was to develop a tool that can automatically compare multiple battery energy storage systems based on their financial ratios within the parameters of the given project. With the developed tool, it is possible to compare multiple battery storage systems within the parameters of a given project and find the best fit for the project based on its financial values and ratios. We conclude our research by answering our last two research questions. These questions were designed to guide and shape our research activities and provide us with the necessary information to complete our research goal.

What is the optimal size selection for a Battery Energy Storage System based on financial metrics, such as the NPV and IRR, within the parameters of a given project?

The answer to this research question has already been discussed and depends on the input parameters chosen for a given project. Every project has a different optimal size BESS. For the stylised case, this was 20 MWh, within the chosen range. This does not mean this is the optimal battery capacity for that project, but for the chosen range, it was. However, this showcases the power of the developed tool; from this result, the tool user can choose a new range of batteries, which would technically be possible to develop for that project. Furthermore, investigate if other capacities have more potential. Even for sizes that currently cannot generate a positive NPV, the tool could be used to find a variable configuration that would be possible within the current project parameters.

How do potential vulnerabilities within the business case of battery energy storage projects interact with future fluctuations of prices and other financial metrics?

From the sensitivity analysis, we gained valuable insight into the parameters that most affected the NPV and IRR. Some vulnerabilities are external vulnerabilities that the developer of battery projects cannot control. Future price fluctuations are unpredictable and should be considered when developing a battery project. The Transport costs had the most impact on the NPV and IRR; however, this vulnerability cannot be controlled. Some steering is possible by choosing the optimal ratio between ATO and ATR or contracting a lower power peak. This, however, will impact the revenue directly, which, according to the sensitivity analysis, was also an impactful parameter. Another vulnerability is inflation; although inflation had less impact on the NPV and IRR than the cost prices, indexation is used to correct many variables within the model and be accounted for when deciding if the investment is worthwhile. The last variable tested for its sensitivity is the discounting rate; this directly impacts both the NPV and IRR since it is used to discount the cashflows that are used to determine these financial ratios. It cannot be seen as a direct vulnerability since the project investor chooses it, but it will impact the size of the battery that can become profitable. With the knowledge gained from the sensitivity analysis, project developers can better understand the risks associated with the chosen parameters and consider possible dangers for the future development of battery storage systems.

8.1 Contribution to the body of knowledge

Theoretical contribution

Our addition to the body of knowledge is a tool that can take revenue forecasting and pricing data and perform the necessary calculations to provide the user with a dashboard for cash flow analysis, revenue analysis, and financial ratios for multiple battery capacities within the same project parameters. The tool also allows the user to optimise the ratio between ATO and ATR for the same battery capacity within the project specifications.

A secondary addition is a detailed sensitivity analysis of the grid-size battery business case that includes vulnerabilities for applying grid-size batteries within the Dutch energy grid.

Practical contribution

Our research's practical contribution to the development of battery energy storage is a tool that can take four datasets: battery type, revenue, CAPEX, and OPEX and determine what battery storage solution would be financially possible within the boundaries of a certain project. The tool can be used by operators who understand Python but also by those who have no experience with the programming language since the Input screen is added for ease of use.

9. Recommendations

We divide the recommendations into two parts. In the first part, we recommend the tool and its possible directions if further development is desired. In the second part, we give some recommendations about further research possibilities that were outside the scope of this paper or only possible after the completion of this research.

9.1 Tool Development

We mentioned in the discussion that sharing a project in the CAPEX and OPEX currently does not provide an additional benefit. For further tool development, adding functionalities that can account for cost-sharing between projects for some parts of the CAPEX and maybe even a method of forecasting when a peak load will be set would be interesting. A possible application is using historical trading data and training an algorithm to recognise the patterns and optimise the transport costs that way. When there is a credible base to determine when the peak will and will not be set, the costs can be altered accordingly.

Currently, the sensitivity analysis is performed within a separate Python script that can be utilised with the functions developed for the tool. The current tool has not been developed to perform sensitivity analysis. In addition to the tool, the most essential sensitivity measures could be added to the financial dashboard and calculated for every battery separately. This is not possible with the current code.

In the current version of the tool, a flat rate for indexation is chosen. A forecasting method can be added to include a dynamic expected inflation rate in future models using appropriate methods like the Vasicek model. An accurate estimate of the inflation adds to the accuracy of the tool's output.

9.2 Further Research

As mentioned in the discussion, Revenue stacking could be added to perform a more detailed revenue analysis. This should better represent the possible Revenue that the battery will produce. The model we used in this research did not have this functionality, so adding this would require a model that can forecast multiple markets to enable revenue stacking.

Researching whether it would be better to build multiple smaller batteries instead of only one big battery, in the case study, we saw a slight increase in the profitability index with much more significant investments. Maybe it can be interesting to do more research into this.

Currently, the only applied sensitivity analysis is a local sensitivity analysis. However, it would be interesting to investigate if any interactions between variables are relevant to the model. One of the variables utilised in the model is indexation, which is used within the tool to compensate for costs and revenue for inflation endured during the project. There are slight indications that the indexation could interact with multiple variables. Interesting future research would be to apply a global sensitivity analysis like the SOBOL approach to find these interactions and research the risks for the business case.

Lastly, cleanup costs or breakdown costs are standard practice for projects where a product's RUL is over after the project. They have not been added yet within the current business; for future research, it might be interesting to research this topic and add more accuracy to the value calculation of battery projects.

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11. Appendix

11.1 MPSM

The managerial problem-solving methods by Heerkens and Van Winden (2021) are not just a tool, but a proven and effective approach to tackle the combination of a knowledge problem and an action problem. This research is dedicated to finding the best solution for Pure Energie's problems, and the MPSM is our trusted guide in this journey. To achieve our goal, we will meticulously follow the phases of the MPSM.

Phase 1: ***Defining the problem.***

Section 1.2.2 defines the problem. It combines a knowledge and action problem defined by Heerkens and Van Winden (2021). The knowledge problem can only be solved using the action problem's output.

Phase 2: ***Formulating the problem-solving approach.***

The problem-solving approach has three steps that must be followed, and the 3D model proposed by Heerkens and Van Winden (2021) must be used. These three steps are: “Do, Discover and Decide”. First, theoretical knowledge about the variables mentioned in the problem cluster must be gathered. This, combined with researching business cases for the current BESS project within Pure Energie. The gathered theoretical knowledge can then be transformed into a model that can be used to analyse the profitability of the business case with the given variables. To fully understand the problem, a deeper understanding of the energy market must be developed. This can be researched by combining the state-of-the-art literature reading energy reports and BESS business cases delivered by Pure Energie, followed by research into the state-of-the-art literature on BESS. The focus has been developing 1 model that combines multiple tools to narrow the research down. The model output will be used to investigate the business case further.

Phase 3: ***Analysing the problem.***

Given all the variables in the problem cluster in Figure 1, no model is currently available for Pure Energie to determine if the BESS can become profitable. To decide if this BESS can ever become profitable, a theoretical analysis of all the parameters first needs to be done; when these parameters are researched, their output can be used to build a model to analyse the profitability.

This research analyses under which circumstances BESS deployment becomes profitable for Pure Energie, given their energy production and feeding electricity from the energy grid. To analyse the profitability of the BESS, knowledge about revenue, CAPEX, and OPEX is essential. Moreover, within these variables, some sub-variables affect them. At Pure Energie, knowledge of some of these variables is already available. In the case of revenue, it is known what methods can be used to earn income with the BESS; forecasting models that predict the energy selling prices and production of energy are available. These can be used to determine when the battery will be used. For the cost side, there is knowledge about the cost of purchasing batteries, operational costs, and essential information about transport costs. The information gap can be filled by reviewing the most recent literature about batteries, alternative revenue streams and available models for battery modelling. All the missing theoretical subjects for this research can be found in Figure 21.

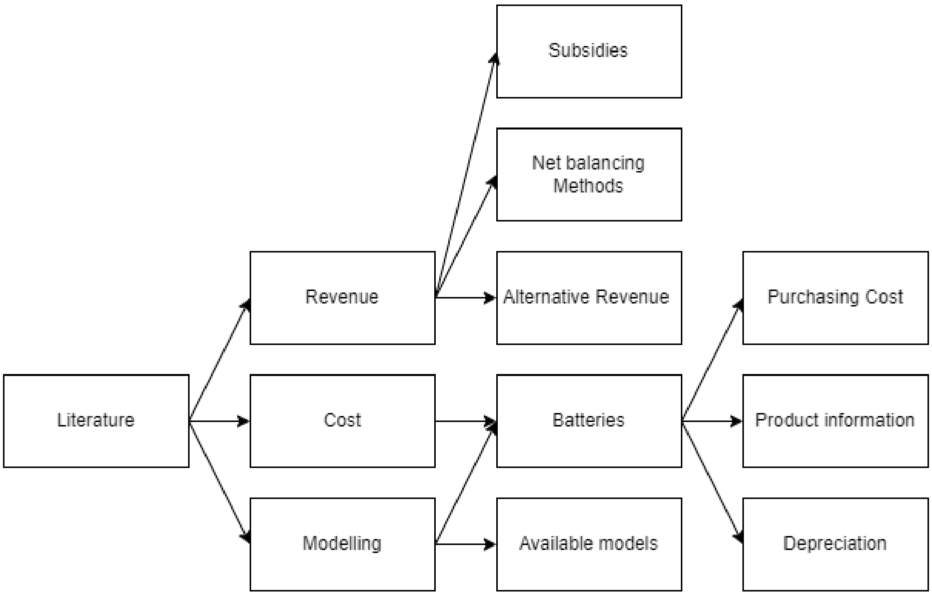


Figure 21 Literature review.

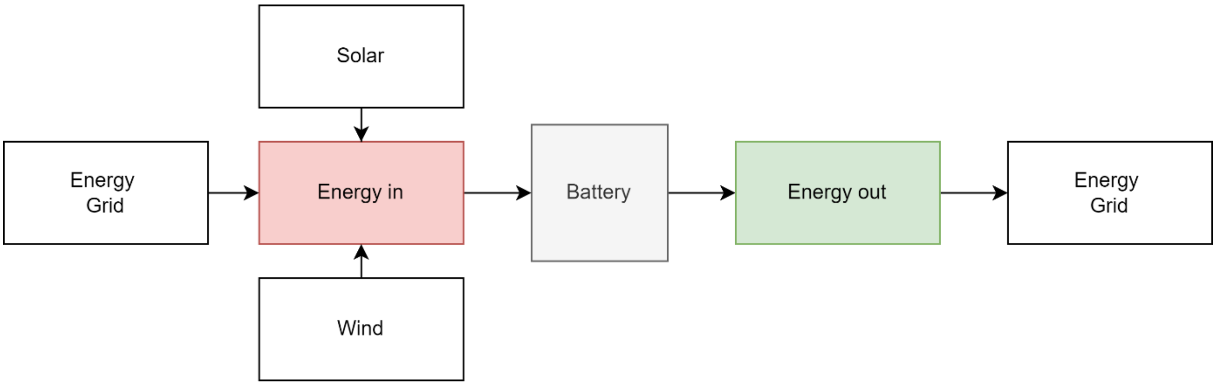


Figure 22 Energy balance.

To simplify the problem further, Figure 22 Illustrates the information needed to analyse the battery's profitability successfully. The energy stream starts with “energy in”; this energy is available from either wind, solar or the energy grid. There is a specific cost for this energy, which will be delivered to the battery. The cost price of energy is ever-changing and can both be positive and negative. The price depends on the market demand and is continuously changing (This ever-changing price can also be affected by the contract that has been closed with the selling party). The battery will also discharge this energy into the grid for a cost price to earn revenue. This charging and discharging cycle becomes profitable when costs are lower than the revenue. However, there are more costs associated with the battery that also need to be researched; the cost of purchase, operational cost, transport cost, and lifetime of the battery are essential components to calculate the total profitability of the battery. The battery is profitable if the total revenue it earns over its lifetime is greater than the total cost of the battery of its lifetime. The theoretical research needs to yield information about all the costs associated with the battery, potential revenue streams for the battery, and forecasting models that can be used to predict the energy price. With this knowledge, a model can be built to analyse the profitability of a battery under different scenarios.

Main Research Question:

What battery type has the best internal rate of return when given the amount and source of electricity production within an electricity-producing company?

Sub Research Questions:

1. What types of batteries are there currently available on the market?
    a. What types of batteries can be used for grid-size applications?
2. What parameters affect the theoretical lifetime of a battery?
3. What affects the profitability of a BESS?
    a. Where does the revenue potential for grid-size batteries lie?
    b. Which components are essential for the CAPEX of a BESS?
    c. Which components are essential for the OPEX of a BESS

Operationalisation

There will be two types of information gathered during the theoretical research phase. These two variables are qualitative and quantitative. Qualitative information can be used to support qualitative information and understand certain aspects of the problem to create a solution. The quantitative information needs to be operationalised to be used inside a tool. Pure Energie works with (Euro/MWh); this is the preferred operationalisation. The potential model from the top down can be seen as a profit model, with a total cost and total revenue stream with, in conclusion, the profit and Internal rate of return in (Euro).

Data gathering

Looking back at Figure 22, data gathering can be grouped into three subjects: energy in (OPEX), Battery (CAPEX), and Energy out (Revenue). The needed data is summarised in Table 22.

Energy In (OPEX) :

The battery must be filled with energy. There are three options for energy distribution (Sun, Wind, Grid). The best source for charging the battery at the time (T=t) must be determined. The price of this energy is volatile and constantly changing under the circumstances. The purchasing strategy will dictate when and if the battery will be filled. The revenue simulation will be performed using a model that the trading division of Pure Energie made, which includes the trading strategy.

The time it takes to charge the battery with the bought electricity and the discharging time must be considered. (If this variable is not used, the battery can be filled more often than physically possible, which would significantly affect the business case.)

Another essential variable is the battery's number of cycles daily. This will affect the battery's deterioration and, with it, the potential cost it will incur over its lifetime.

Battery (CAPEX):

The type of battery determines the use case scenarios (battery capacity can become a variable within the model, which will affect price). Although capacity should become a variable, the battery's capacity determines which trading method can be used. According to a report, five possible profitable trading methods exist. These are FCR, aFFR, mFFR, GOPACS and passive imbalance trading. The availability of these methods is limited to the battery's capacity. The battery can also be used as a buffer; whenever the price of electricity is low or negative, it can be temporarily stored and sold for a higher price. Subsequently, the use case scenario also affects the battery's lifetime. A battery's lifetime is determined by its number of charging cycles. The battery's efficiency will deteriorate over time, meaning the revenue potential will decrease after a certain number of cycles. (Information needed from this is the availability of batteries, the number of cycles these batteries are made for and a deterioration of efficiency after X number of cycles.)

Energy out (Revenue):

For the possible trading methods (if seen as an essential variable for the model), a forecasting tool is necessary to determine the spot prices of the abovementioned trading methods. The stored electrical energy can then be sold for the best available price.

Possible energy allocations:

1. To match demand: Generation power exchanges wholesale “Forward, Day Ahead, Intraday.”
2. To provide frequency stability: Ancillary services frequency control (FCR)
3. To balance out disturbances and forecast deviation: Ancillary services balancing (aFFR/mFFR)
4. To ensure transmission of power from A to B: Ancillary services re-dispatch congestion

This tool requires specific trading strategies to determine when and if the energy gets sold at a particular price. For simplicity, this trigger should be a deterministic value that can be changed within the model as a parameter (this can later be used for the model's sensitivity). Although these methods are all traded with a particular spot price, there is a difference between offering a service and utilising the battery as a buffer for producing electricity. (affects the availability of the battery at time T=t)

Table 22 Data needed for analysis tool.

Energy in/out	Battery
Revenue forecasting model	Type of battery “capacity”
Forecasting energy production wind	Total CAPEX
Forecasting energy production sun	Speed of charging the battery
Total OPEX	Use case of the battery.

Phase 4: *Formulating solutions*.

Since the core problem requires an analysis tool, the solution should be a model that can analyse different scenarios. These scenarios are mentioned in Figure 23.

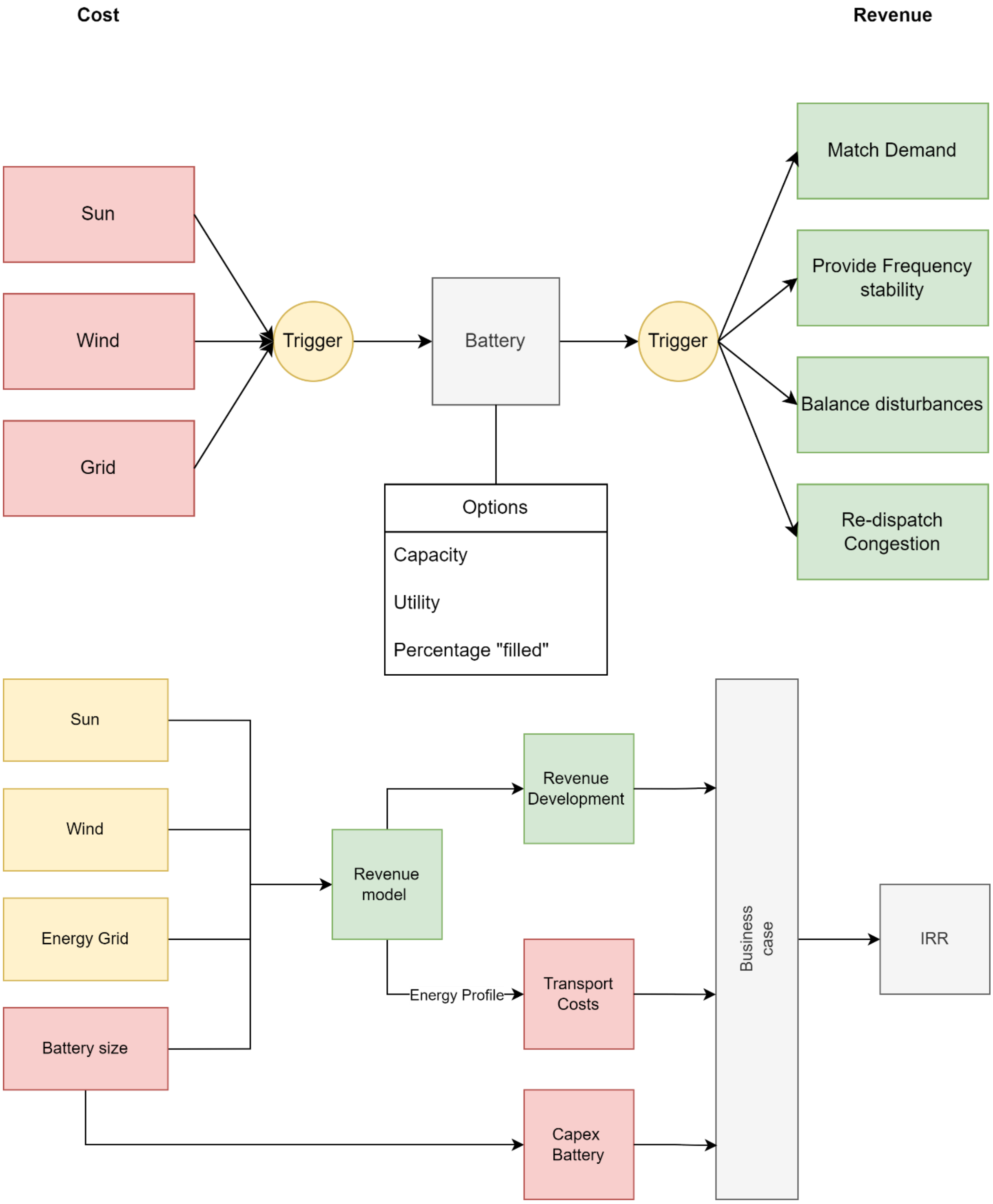


Figure 23 Possible scenarios.

Phase 5: ***Choosing a solution.***

A proper solution can scan all available batteries and determine the IRR; with this information, further, more detailed research can be performed to determine the possible BESS project's actual profitability.

Phase 6: ***Implementing the solution.***

Within this phase, the solution can be developed, tested and improved.

Phase 7: ***Evaluating the solution.***

The model's validity can be measured against Pure Energie's 1 MW 3-hour deep battery business case to determine its performance. Some limitations will be introduced to increase the viability of the research within the limited time.

1. A revenue model from the Pure Energie Trading division will determine the revenue stream within a BESS system.
2. Dynamic trading for selling energy will not be added.
3. Battery will only use the scenario where the unbalanced market is traded.
4. Additional third-party energy takers like e-boilers and hydrogen cells will be kept out of the model.
5. The addition of government subsidies will be kept out of the model.

List of deliverables

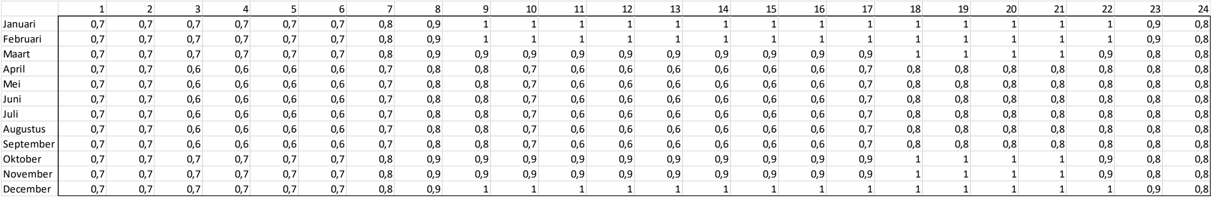
1. Model that can deliver a scan of all available batteries and determine the IRR;
2. An estimate of profitability for BESS within the parameters specified by Pure Energie
3. Recommendation on how to further improve the model.

11.2 Prices of different Net Administrators

Table 23 Prices of the netbeheerders in the Netherlands.

2024	Fixed Tariff	kW Contract >600h	kW Max (Month)	kW Contract <600h	kW Max (Month) <600h	kW Max (week)	kWh component
TenneT	€2760	€84,55	€8,88	€42,27		€2,73	
Enexis (HS/MS)	€2760	€42,78	€4,38	€21,39		€1,51	
Enexis (MS-D)	€441	€30,44	€3,61				€0,03
Liander (HS/MS)	€230	€50,37	€5,81	€25,116		€1,75	
Stedin (HS+TS/MS)	€230	€48,81	€5,42	€24,40	€10		

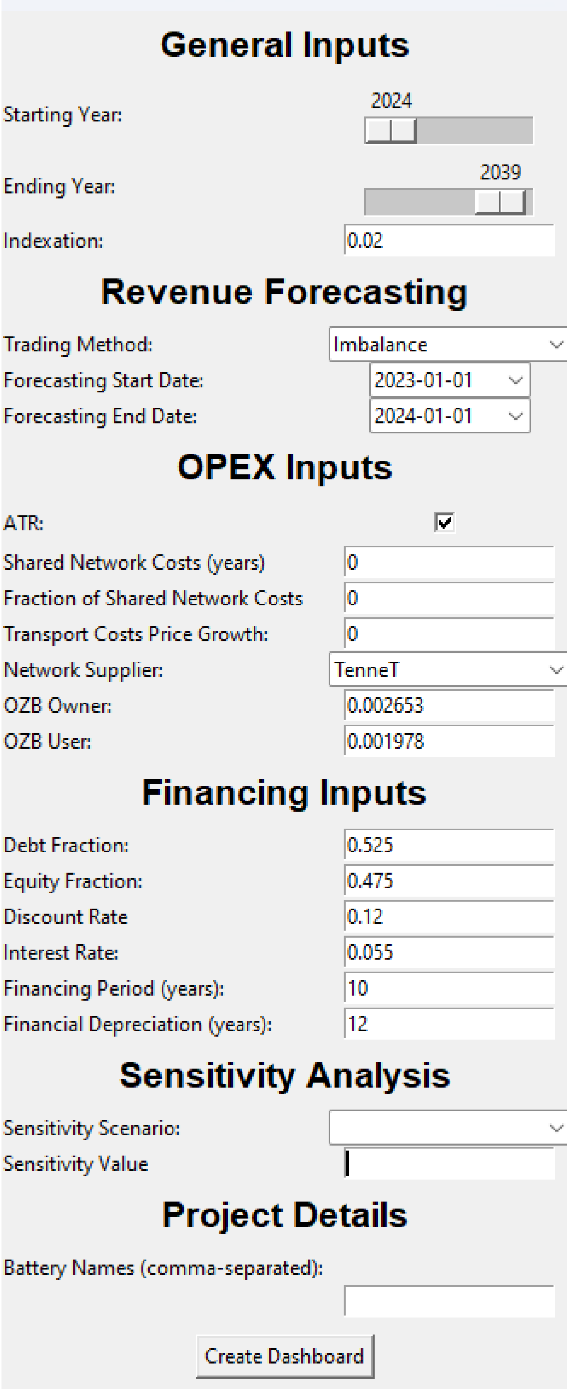
11.3 Reduction Matrix TenneT



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Januari	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,9	0,8
Februari	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,9	0,8
Maart	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	1	1	1	1	0,9	0,8	0,8
April	0,7	0,7	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,7	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Mei	0,7	0,7	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,7	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Juni	0,7	0,7	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,7	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Juli	0,7	0,7	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,7	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Augustus	0,7	0,7	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,7	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8
September	0,7	0,7	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,7	0,6	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Oktober	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	1	1	1	1	0,9	0,8	0,8
November	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	1	1	1	1	0,9	0,8	0,8
December	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,9	0,8

Figure 24 Reduction Matrix TenneT.

11.4 Inputs sensitivity analysis



General Inputs

Starting Year: 2024
Ending Year: 2039
Indexation: 0.02

Revenue Forecasting

Trading Method: Imbalance
Forecasting Start Date: 2023-01-01
Forecasting End Date: 2024-01-01

OPEX Inputs

ATR: ☑
Shared Network Costs (years) 0
Fraction of Shared Network Costs 0
Transport Costs Price Growth: 0
Network Supplier: TenneT
OZB Owner: 0.002653
OZB User: 0.001978

Financing Inputs

Debt Fraction: 0.525
Equity Fraction: 0.475
Discount Rate 0.12
Interest Rate: 0.055
Financing Period (years): 10
Financial Depreciation (years): 12

Sensitivity Analysis

Sensitivity Scenario:
Sensitivity Value

Project Details

Battery Names (comma-separated):

Figure 25 Base values for sensitivity analysis.

11.5 Raw output sensitivity analysis

IRR	-2	-1	0	1	2
Indexation	10,5	11,72	12,9	14,07	15,23
Discount_Rate	12,9	12,9	12,9	12,9	12,9
Revenu	7,67	10,34	12,9	15,44	17,96
Transport_Costs	19,76	17,16	12,9	2,92	0
Capex_Battery	14,85	13,84	12,9	12,02	11,19
Spread_ATR_ATO	15,73	14,32	12,9	9,25	5,41

NPV	-2	-1	0	1	2
Indexation	-1117069	-222140	737645	1781438	29616990
Discount_Rate	2656611	1644978	737645	-77954	-812726
Revenu	-3510186	-1351102	737645	2828283	4904619
Transport_Costs	7574423	4772592	737645	-5297109	-14549846
Capex_Battery	2181034	1462167	737645	13122	-707026
Spread_ATR_ATO	3077068	1911407	737645	-2229818	-5286484

11.6 Validation Rapport

Name(s): Karlijn Wiggers (Business Developer Energy Storage – Pure Energie)
Tool Version: Version 1.1
Validation Type: Criterion Validity
Compared business case: Hazeldonk & Eeltinksveld

General Impression:

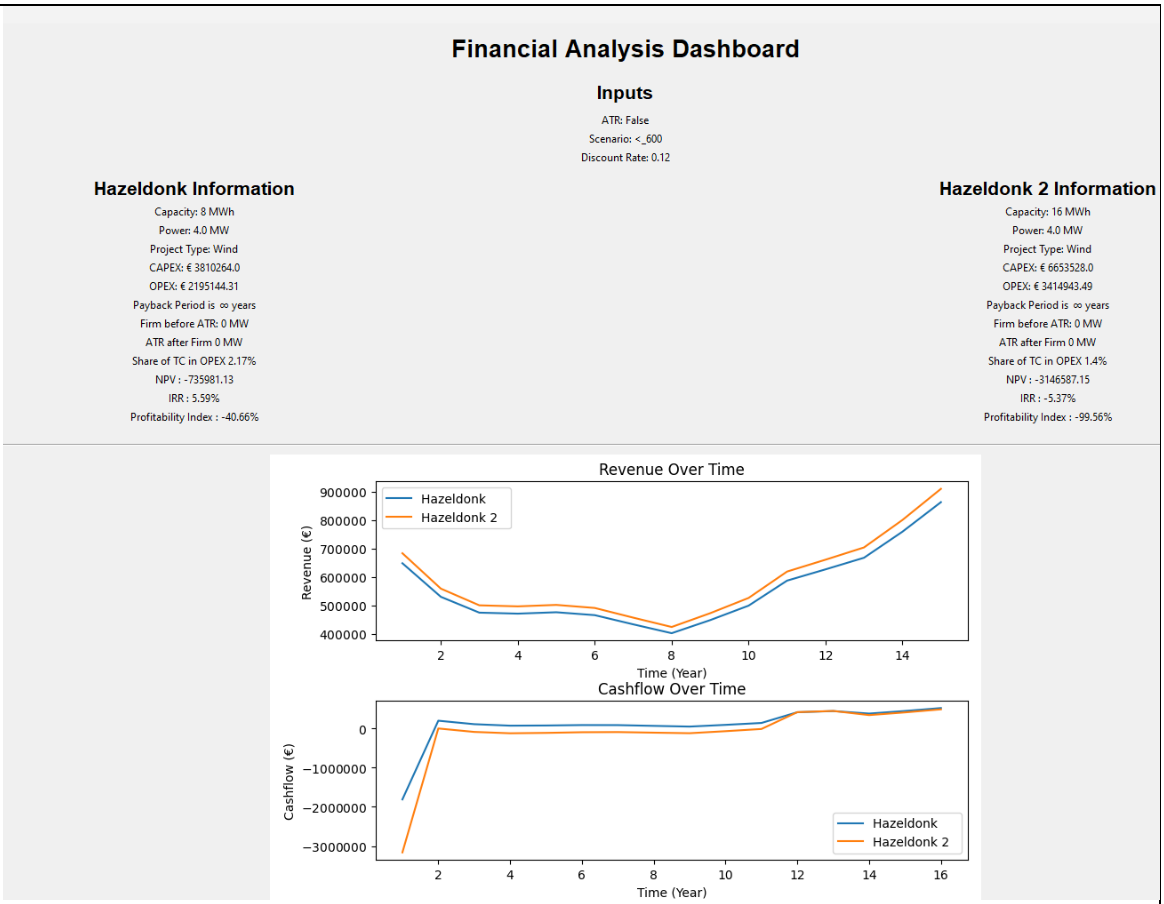
The model does what it should: the financial factors of batteries with different power/capacity within the same project can be compared to each other. To set up a new comparison, it is necessary to change inputs in different code files: add a new battery (Battery3.py), link it to an energy generation file (functions.py) and change some values in both *Results output.py* and *functions.py.* This is a bit convoluted, but still logical due to how the already existing code from the Trading department was constructed. With the addition of a manual on how to use these inputs, it should be clear enough for use. It would also be a valuable addition to have a short explanation on how to interpret the given output. Still, the output is clear enough in itself to draw conclusions on the best size for the battery. Some errors were also still found during the testing, but they were fixed immediately.

Input Comparison

For both Hazeldonk and Eeltinkveld, batteries of 4MW/8MWh and 4MW/16MWh have been run. They are compared to 2 different versions of old business cases. In these BC's, most of the other inputs are different, so it's mostly useful to look at the relative differences between the two batteries.

Output comparison

For Hazeldonk, the new model gives a more positive output for the 8 MWh battery than for 16 MWh (5.59% vs -5.37% IRR). This is also true for the old BC's, which give 1.35% (8) vs 0.17% (16) and -2.76% (8) vs -9.39% (16). The gap between the two types of batteries is different for each model, but it is complicated to pinpoint why, since so many factors play a role. In general, all models lead to the conclusion that 8 MWh works better for this project.



Financial Analysis Dashboard

Inputs

ATR: False
Scenario: <_600
Discount Rate: 0.12

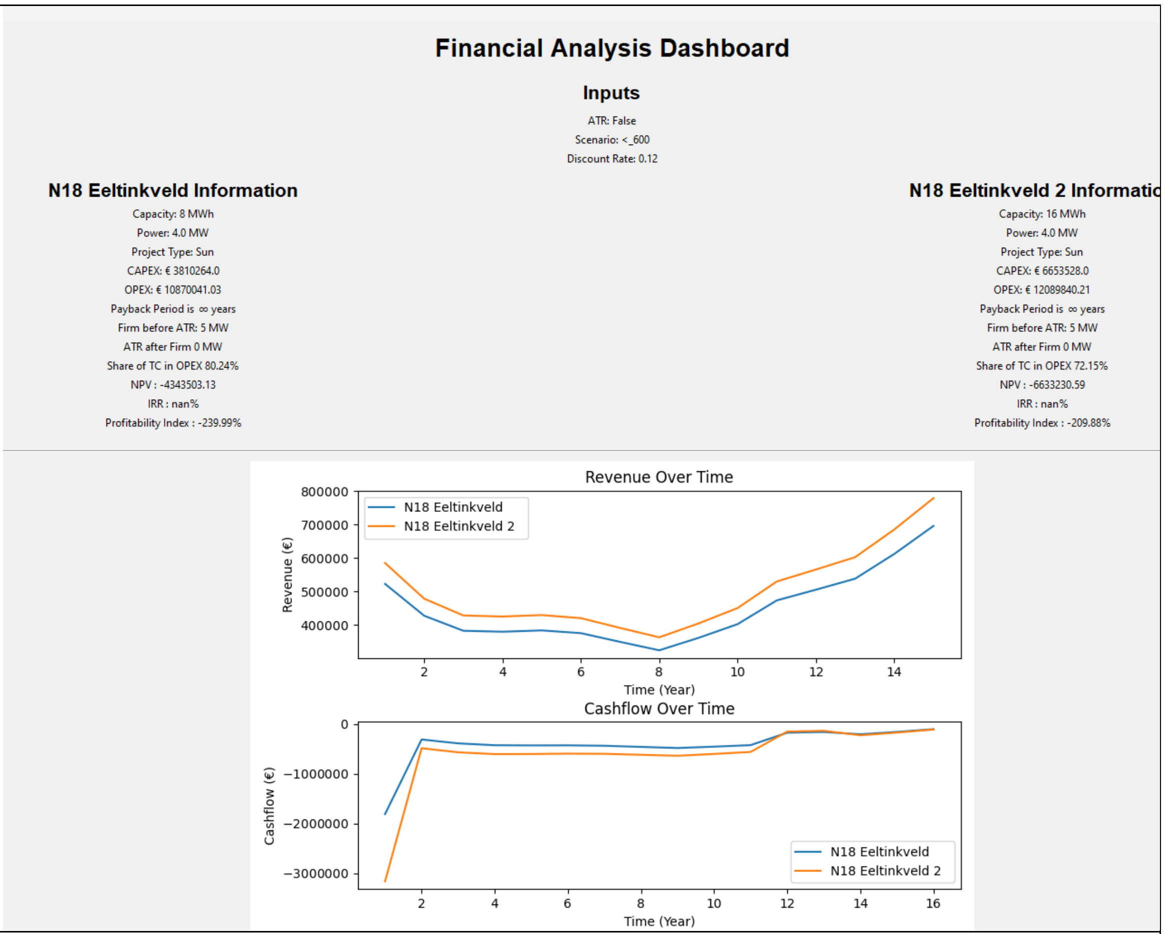
Hazeldonk Information

Capacity: 8 MWh
Power: 4.0 MW
Project Type: Wind
CAPEX: € 3810264.0
OPEX: € 2195144.31
Payback Period is ∞ years
Firm before ATR: 0 MW
ATR after Firm 0 MW
Share of TC in OPEX 2.17%
NPV : -735981.13
IRR : 5.59%
Profitability Index : -40.66%

Hazeldonk 2 Information

Capacity: 16 MWh
Power: 4.0 MW
Project Type: Wind
CAPEX: € 6653528.0
OPEX: € 3414943.49
Payback Period is ∞ years
Firm before ATR: 0 MW
ATR after Firm 0 MW
Share of TC in OPEX 1.4%
NPV : -3146587.15
IRR : -5.37%
Profitability Index : -99.56%

For Eeltinkveld, the comparison is slightly less accurate, since BC's have mostly been made for 5 MW. Still, one old model can be used with 4 MW. The new model doesn't give an IRR for this project, since the project doesn't perform well financially. In an old model 4MW/8MWh gives an 1% IRR and 16 MWh gives -6.12%, so the former performs better. In the other old model 5MW/10MWh gives -18% and the IRR for 5MW/20MWh isn't being calculated due to it being too low. This also gives a more positive outcome for the 2h-battery, but in general isn't profitable at all. When looking at the NPV, the new model also gives a less negative output for the smaller battery.



Financial Analysis Dashboard

Inputs

ATR: False
Scenario: <_600
Discount Rate: 0.12

N18 Eeltinkveld Information

Capacity: 8 MWh
Power: 4.0 MW
Project Type: Sun
CAPEX: € 3810264.0
OPEX: € 10870041.03
Payback Period is ∞ years
Firm before ATR: 5 MW
ATR after Firm 0 MW
Share of TC in OPEX 80.24%
NPV : -4343503.13
IRR : nan%
Profitability Index : -239.99%

N18 Eeltinkveld 2 Informatio

Capacity: 16 MWh
Power: 4.0 MW
Project Type: Sun
CAPEX: € 6653528.0
OPEX: € 12089840.21
Payback Period is ∞ years
Firm before ATR: 5 MW
ATR after Firm 0 MW
Share of TC in OPEX 72.15%
NPV : -6633230.59
IRR : nan%
Profitability Index : -209.88%

It can also be concluded from these two tests that wind co-location would be more successful that solar co-location, which also resulted from the old models. Although it's impossible to compare the performance of the new model based on absolute numbers, the same general conclusions can be drawn as with the old models, only the new model is more efficient. For more reliable absolute numbers, a more detailed BC should be made, but that wasn't the goal of this model.

General Remarks and Comments:

- The model seems to achieve its goal
- Both input and output would benefit greatly from a manual
- The general conclusions from the model seem correct