Final report - REALISE

1. Project details

Project title	REALISE – Renewable Energy Analytics for Lifetime Investment and Systems Engineering
File no.	
Name of the funding scheme	EUDP
Project managing company / institution	Vattenfall
CVR number (central business register)	31597544
Project partners	Vattenfall Aegir Insight DTU - Wind and Energy Systems Energy Cluster Denmark
Submission date	22 July 2025

2. Summary

Project summary:

- **The purpose of the project**

An integrated software solution has been developed which can optimize and evaluate hybrid energy parks with wind, solar, electrical batteries and electrolyzers participating in the PPA, spot-, intra-day-, balancing, and hydrogen markets. This can be done on project and portfolio level in Europe and has been tested on concrete Vattenfall cases.

- **Results, conclusions and perspective**

The key project results were:

- A surrogate for the Balmorel energy system model which is a useful tool for energy, wind, and control systems engineering allowing for the efficient sampling of realistic stochastic electricity price timeseries in an aggressive decarbonization scenario.
- An optimization methodology for the operation and sizing of hybrid power plants. A python-based open-source software platform (HyDesign) was further developed and used for design and operation

of utility-scale hybrid power plants. HyDesign can now optimize or evaluate for either minimizing levelized cost of electricity (LCoE) or maximizing net present value over the capital expenditures (NPV/CAPEX).
- Specifications, requirements and framework for business case evaluation of RE parks were established.
- Aegir Integrate, a techno-commercial decision support tool for fast-investment analysis of hybrid power plants which enables rapid early-stage project & portfolio assessment was developed.
- The tools were demonstrated and validated on three specific cases provided by Vattenfall.

The capabilities developed in REALISE for Aegir Integrate will join Aegir's data-intelligence-software product portfolio. Vattenfall will implement learnings in internal tools.

Having both an open-access tool (HyDesign) and a commercially available tool (Aegir Integrate) to model hybrid power plants in Denmark and abroad will accelerate deployment of the very complex energy projects that hybrid power plants are.

Projektresumé:

- **Formålet med projektet**

Der er udviklet en integreret softwareløsning, som kan optimere og evaluere hybridenergiparker med vind, sol, elektriske batterier og elektrolyse, der deltager i PPA-, spot-, intra-day-, balance- og brintmarkederne. Dette kan gøres på projekt- og porteføljeniveau i Europa og er blevet testet på konkrete Vattenfall-cases.

- **Resultater, konklusioner og perspektiv**

De vigtigste projektresultater var:

- En surrogat for Balmorel energisystemmodellen, som er et nyttigt værktøj til energi-, vind- og kontrolsystemer, der muliggør effektiv sampling af realistiske tidsserier for stokastiske elpriser i et aggressivt dekarboniseringsscenarie.
- En optimeringsmetodologi til drift og dimensionering af hybridkraftværker. En python-baseret open source-softwareplatform (HyDesign) blev videreudviklet og brugt til design og drift af hybridkraftværker i forsyningsskala. HyDesign kan nu optimere eller evaluere for enten at minimere Levelised Cost of Energy (LCoE) eller maksimere nutidsværdien over kapitaludgifterne (NPV/CAPEX).
- Specifikationer, krav og rammer for business case-evaluering af VE-parker blev etableret.
- Aegir Integrate, et teknisk-kommercielt beslutningsstøtteværktøj til hurtig investeringsanalyse af hybridkraftværker, som muliggør hurtig projekt- og porteføljevurdering i en tidlig fase, blev udviklet.
- Værktøjerne blev demonstreret og valideret på tre specifikke cases leveret af Vattenfall.

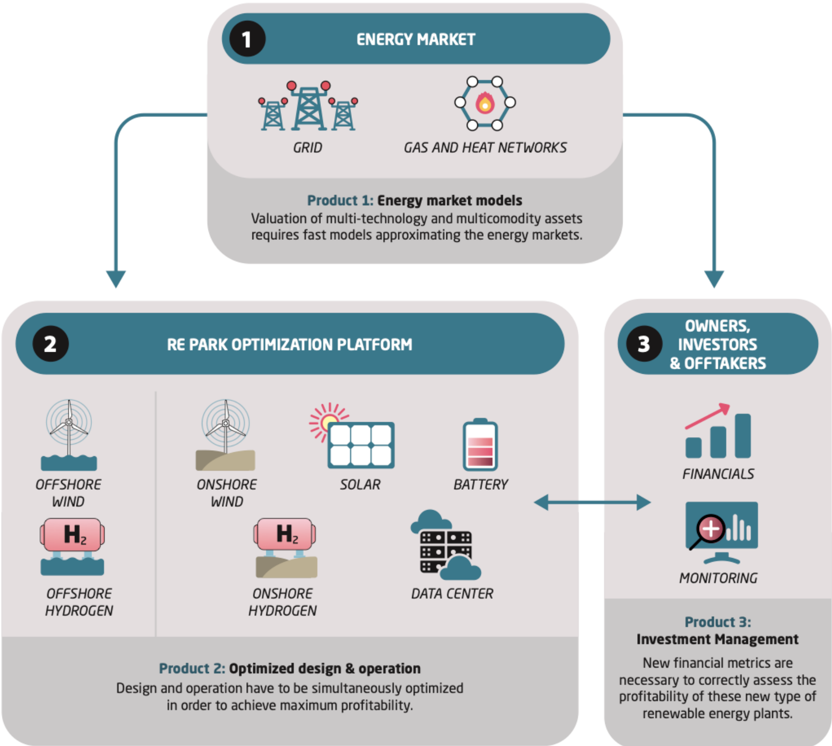
Funktionerne udviklet i REALISE til Aegir Integrate vil blive en del af Aegirs produktportefølje for data-intelligens-software. Vattenfall vil implementere læring i interne værktøjer.

At have både et open-access-værktøj (HyDesign) og et kommercielt tilgængeligt værktøj (Aegir Integrate) til at modellere hybridkraftværker i Danmark og i udlandet vil accelerere udbredelsen af de meget komplekse energiprojekter, som hybridkraftværker er.

3. Project objectives

The project has delivered an analytics software suite for the design and valuation of multi-technology renewable energy assets, also known as Renewable Energy Parks. Future wind and solar farms will provide green power not only to the grid but also to electrolysers delivering green hydrogen and heat to gas and heat networks, to energy storage units delivering constant green electricity to the grid, and to data centers providing IT solutions to its customers. REALISE has provided key innovative solutions within energy system modelling, simultaneous optimization of design and operation, and advanced financial engineering, which are critical to successfully develop hybrid renewable energy parks. The value of REALISE has been demonstrated and validated through use on concrete cases for Vattenfall in optimizing and designing hybrid renewable energy parks.

REALISE has delivered 3 core Innovation Products, as shown in the figure below. Vattenfall has incorporated the learnings from these innovation products in their internal tools, Aegir Insight has incorporated them in their tools; Aegir Integrate and DTU has incorporated them in their publicly available tools Hydesign and Topfarm.



4. Project implementation

The project was coordinated through scheduled monthly coordination meetings where the WP leaders always participated and the researchers and developers who were currently actively worked on the project participated. This was supported by smaller ad-hoc online meetings and workshops as needed and half to full day meetings between the project participants every quarter to half year, depending on the needs of the project. This was an effective way to carry out the project.

None of the identified technical risks was encountered during the project. But a variation of “Risk 3: RE Park constituent technology costs remain high or increase (i.e. storage and P2X) making RE Park solutions uncompetitive” has been encountered to a degree which was not expected. Global events has significantly increased the cost of multiple parts of a renewable energy park, but has at the same time over the longer term increased political focus on becoming less dependent on foreign produced energy. Here it has been key for the project to have participation of Vattenfall not to rely solely on public sources for costs which has not changed as rapidly.

In addition the Danish tender which the consortium had planned to use as a case for the tools was cancelled. In practice this has limited effect on the project as other cases were identified. The complexity of the project, combined with various personal circumstances required that the project was prolonged slightly to achieve the ambitious goals.

While it was not surprising in that it was the entire thought behind putting the consortium together, the project really harvested the fruits of bringing together the modelling expertise from a leading university, a key energy company and a quick start-up

5. Project results

5.1 Project Scope and Assumptions

Note: we put considerations regarding scope here when writing the WP sections below. Then if it turns out they fit better in the individual WP’s then we move it there.

5.2 WP2 Energy System Scenarios and Modelling

In WP2, energy system scenarios were created for the REALISE project, with focus on electricity spot price development towards 2050. These scenarios provide information to the other WPs about future electricity prices, to be used in the optimal planning and operation of hybrid power plants.

A highly electrified main scenario towards 2050 was considered, with investment optimisation carried out for scenario years 2025, 2035 and 2045. In addition, a number of sub-scenarios, where some of the key inputs are varied, were created. The full set of 30+ energy systems scenarios was then used to create a surrogate model for future electricity price time series, allowing efficient assessment of expected electricity price variation as different input variables are modified.

The Balmorel energy system model was used to analyse the development of the European energy systems towards 2050, with the CorRES tool used to model the VRE generation time series. Investment costs of VRE and other technologies and CO_2 tax and gas price developments towards 2050 were varied in the different scenarios to understand how these variations impact electricity prices and other scenario outputs. An example output for two of the 30+ scenarios can be seen in Figure 1, where the projected electricity price distributions for the Swedish bidding zones towards 2050 are shown. The plots on the left show the projected prices in a normal-gas-price scenario (price level before the Ukraine war) and the plots on the right in a high-gas-price scenario (10x gas price). It can be seen that the 2025 electricity prices are much higher when gas prices are high (especially in Southern Sweden, i.e., SE3 and SE4), but towards 2050 the mean price differences between the scenarios decrease (as VRE generation replaces gas fired generation). However, the price variability remains high for all scenario years when the gas price is high, as gas generation is still needed on some hours of the year (seen as a spikes in the price duration curves). An overview of the scenario results is provided in[1], with more detailed in REALISE deliverable D2.2.

The Balmorel energy system model is costly to run, requiring about two days to evaluate a scenario using three 128 GB computational nodes on the DTU supercomputer. This motivated the development of a high-dimensional surrogate for a fast-to-evaluate approximation of the full model. The surrogate uses a multiple-output support vector regression (MSVR) model to approximate region-year-specific variable renewable energy capacities and electricity price timeseries. The MSVR surrogate was selected because it is capable of efficiently handling high-dimensional outputs with limited computational resources.

This surrogate was used to perform a detailed analysis of the electricity prices forecasted across Europe by Balmorel[1]. In particular, the sensitivity of region-year-specific electricity price percentiles was quantified with respect to uncertainty in the future projected costs of different technologies. This study compared linear and nonlinear MSVR kernels, concluding that the electricity prices predicted by Balmorel showed significant nonlinearities with respect to the cost of natural gas, and that a linear kernel model is not suitable to capture these dynamics, even after nonlinear preprocessing of the training data. Large natural gas OPEX/CAPEX costs lead to the early construction of transmission lines, lowering the bulk cost of electricity prices in all region-years. Despite this added transmission capacity, larger natural gas costs leads to larger peak electricity prices, due to the nature of reserve-orientated gas power plants.

The surrogate developed in this work is a useful tool for energy, wind, and control systems engineering by allowing for the efficient sampling of realistic stochastic electricity price timeseries given an aggressive decarbonization scenario. This can be useful for assessing the impacts of energy policies, feasibility of proposed power plants, and viability of different control strategies. These applications often necessitate hundreds or thousands of energy systems model evaluations to characterize uncertainty in forecasted electricity prices, which would be computationally prohibitive without the developed surrogate.

The data provided from WP2 about future electricity price projections has helped the other WPs to include a view of future revenues to their analyses, and has thus met the objectives of the WP. The surrogate model has greatly increased the understanding of how different inputs impact the future electricity prices, and has provided an easy-to-use tool for the end users to project prices towards 2050 under different assumptions. In addition to electricity prices, the scenarios provide information on how much VRE technologies are expected to be installed in different European countries (see D2.2 for details), providing an estimate of wind and solar market sizes. Preliminary H2 and balancing market price projections were also provided for one of the scenarios, to enable assessment of hybrid power plant revenues beyond electricity spot markets.

[1] J. Quick, et al., “Surrogate-Based Modeling and Sensitivity Analysis of Future European Electricity Spot Market Prices”, Electric Power Systems Research, vol. 234, September 2024 (https://doi.org/10.1016/j.epsr.2024.110675).

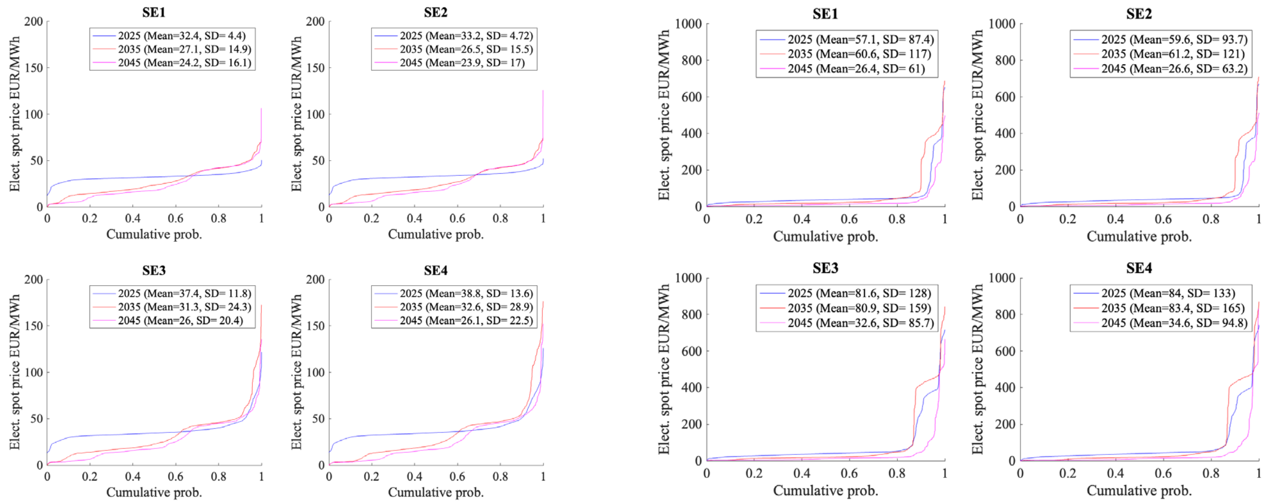


Figure 1. Electricity price durations curves for the Swedish regions in the main scenario (the 4 subplots on the left) and in a high-gas-price scenario (the 4 subplots on the right). SD = standard deviation. Taken from the REALISE deliverable D2.2.

5.3 WP3: Optimization of RE Park Design and Optimization

In WP3, the optimization methodology for the operation and sizing of hybrid power plants (HPPs) comprising wind, solar, battery and power-to-hydrogen is developed. A python-based open-source software platform– HyDesign [3.1], is further developed and used for design and operation of utility-scale hybrid power plants. This tool can perform sizing optimization of HPP or evaluation of a specific plant design with a user-specified objective function, i.e., minimize levelized cost of electricity (LCoE) or maximize net present value over the capital expenditures (NPV/CAPEX).

Methodology: A sizing methodology for the design of utility-scale grid-constrained HPPs that maximize the net present values over the capital expenditures, including turbine selection (in terms of rated power, specific power and hub height), a wake losses surrogate, simplified photo-voltaic panel degradation, an internal energy management system operation optimization, and battery degradation is developed, which is a nested-optimization problem: with an outer sizing optimization and an internal operation optimization. The problem of outer sizing optimization is solved using a new parallel “efficient global optimization” algorithm. This new algorithm is a surrogate-based optimization method that ensures a minimal number of model evaluations but ensures a global scope in the optimization. To tackle the non-linear and multi-disciplinary nature of optimization problems, it is necessary to have an efficient computing platform. This is why the implementation in OpenMDAO framework and demonstration in HyDesign tool [3.1], [3.2] were carried out. The data for weather and future electricity price projections has been used from WP2. The cost assumptions for different technologies were provided by Vattenfall and some of the parameters are referred from the DEA.

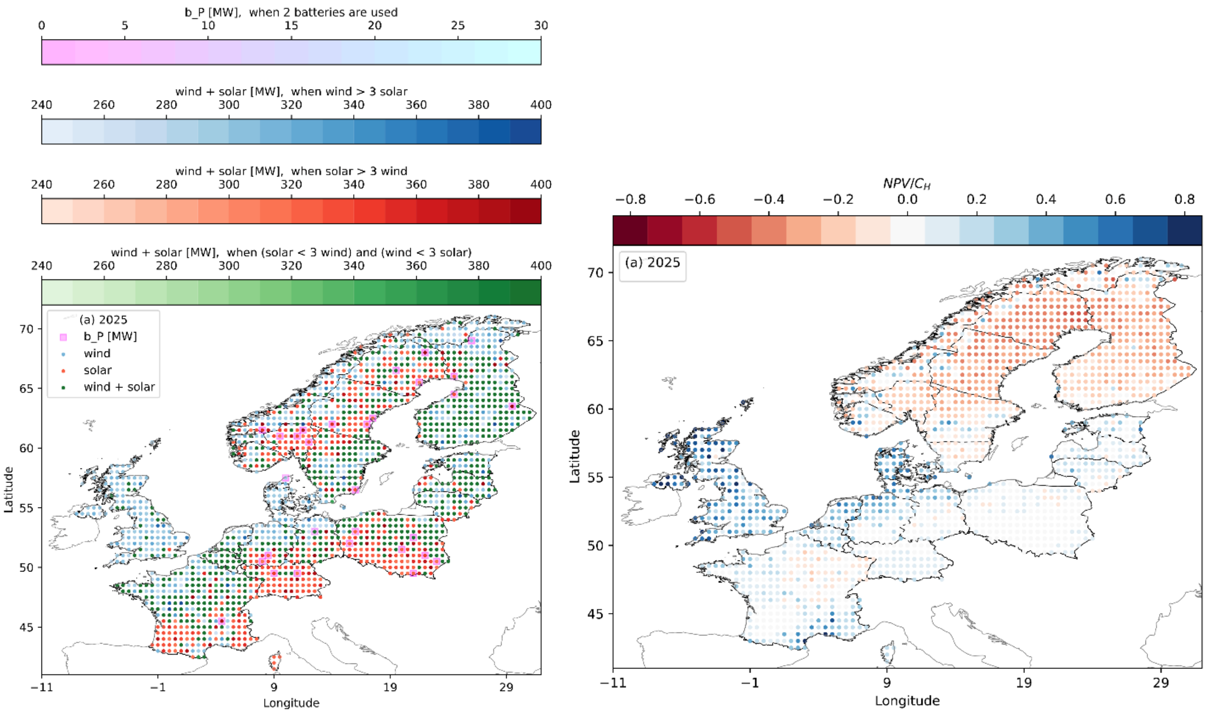
Case studies: Various case studies have been performed to assess the profitability and feasibility of HPP across the different locations.

Hybrid renewable power plants behind a single grid connection and sharing electrical infrastructure costs across different generations and storing technologies can provide additional value to the owners and society in comparison to individual technology plants. The hybrid sizing algorithm is applied for a peak power plant use case at different locations in India where renewable energy auctions impose a monetary penalty when energy is not supplied at peak hours. It has been observed that battery storage is installed only on NPV/CAPEX based designs. Wind turbine selection on this site prioritizes cheaper turbines with a lower hub height and lower rated power. The number of batteries replaced changes at the different sites, ranging between two or three units over the lifetime. A significant oversizing of the generation in comparison to the grid connection occurs on all NPV/CAPEX-based designs [3.2]. Whereas LCoE-based designs are a single technology with no batteries, as shown in Table 3.1.

Table 3.1. HPP sizing optimization results in the example sites with respect NPV/CAPEX and LCoE.

Site		Denmark West		Denmark East		Germany NW	
Design objective		LCoE	NPV/CAPEX	LCoE	NPV/CAPEX	LCoE	NPV/CAPEX
Plant design							
Grid capacity	MW	300	300	300	300	300	300
Wind plant size	MW	260	325	156	260	260	325
PV plant size	MW	400	400	400	400	400	320
Battery power capacity	MW	0	150	0	0	0	33
Battery energy capacity	MWh	0	300	0	0	0	99
Number of batteries	-	0	2	0	0	0	2
Outputs							
NPV/CAPEX	-	0.63	0.65	0.66	0.71	0.63	0.68
NPV	M€	290	356	214	333	303	383
LCoE	€/MWh	36.4	37.1	33.5	33.8	37.9	37.9
Total CAPEX	M€	458	552	323	479	479	560
Total OPEX	M€	6	7	4	6	6	7
Total curtailment	GWh	450	928	92	704	237	556
Grid utilization factor	-	0.42	0.5	0.33	0.47	0.42	0.5

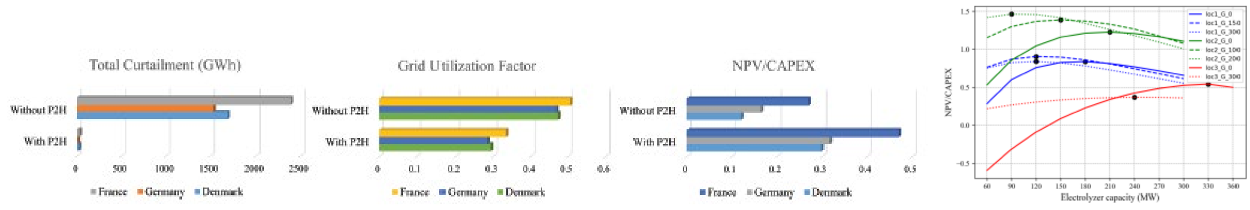
Although a detailed analysis is beyond the scope of this report however, it is interesting to see that the design principle of profitability (NPV/CAPEX) performs better than minimizing cost (LCoE) although it has more cost and curtailment but still the NPV/CAPEX based design manages to produce more profit per unit of investment. Sizing optimization has been run on a grid over northern Europe to produce maps of the profitability and HPP potential in Northern Europe. This study shows that there is no value for battery energy storage on HPPs that rely uniquely on the spot market to produce revenues as shown in Fig. 3.1. The wind capacity ratio to total hybrid can be predicted by the use of the mean wind speed and the correlation between wind speed and spot price, while the overplanting level can be predicted using the solar capacity ratio [3.3].



(a) (b)

Fig 3.1. (a) Map of optimal wind, solar, total hybrid capacity, and power capacity of battery for 2025 spot prices, (b) Map of NPV/CAPEX for 2025 spot prices.

Note that the above results show the profitability only considering spot market participation. In this project, profitability analysis with participation in other markets, especially to balancing market and Hydrogen (H2) markets, are also performed. Combining Power-to-Hydrogen (P2H) technology within HPP reduces the fluctuation from non-dispatchable production and reduces the amount of curtailment in the system similar to storage devices [3.4]. Case studies performed at various sites in Europe show notable improvement in the techno-economic benefits of HPP with P2H as shown in Fig. 3.2. Also, the analysis has been done to identify the financial improvements in HPP operations producing hydrogen with or without grid connection for a few offshore and onshore locations in Europe to identify the value of asking for a grid-connection [3.5].



(a) (b)

Fig. 3.2. (a) Evaluation of HPP with and without P2H for three locations in Europe, (b) NPV/CAPEX variation with the capacity of electrolyzer for different locations and grid capacity.

Reference papers:

[3.1] https://topfarm.pages.windenergy.dtu.dk/hydesign/
[3.2] https://wes.copernicus.org/articles/9/759/2024/
[3.3] https://ieeexplore.ieee.org/document/10365102
[3.4] https://ieeexplore.ieee.org/document/10365063
[3.5] "Evaluation of Grid-Connected and Off-Grid Operations of Hybrid Power Plant with P2H Integration", 8th Hybrid Power Plants & Systems Workshop, Azores, Portugal, 2024.
[3.6] "Hybridization of Wind Farms Using Hybrid Power Plant Sizing Optimization", 8th Hybrid Power Plants & Systems Workshop, Azores, Portugal, 2024.

5.4 WP4: Financial Analysis and Valuation of RE parks

In WP4, the specifications, requirements and framework for business case evaluation of RE parks were established.

Task 4.2 focused on development of methodology and framework for techno-economic assessment of RE parks. It involved conducting a theoretical review of economic metrics and methods used for techno-economic evaluation of energy projects to determine appropriate metrics for energy systems analysis in REALISE. The metrics were classified into two categories: profitability indicators and cost indicators.

- The Net Present Value (NPV) was chosen as the appropriate profitability metric since it accounts for both the cost and revenue side of the project and can include all possible incoming or outgoing cash flow with varying periods.
- The levelized cost metrics levelized cost of energy (LCOE) and levelized cost of hydrogen (LCOH) were chosen as the appropriate metrics for representing the cost side.

Task 4.3 involved identifying and defining different cost structures and multiple revenue streams and assessment of critical elements with uncertainty due to technical complexity arising from multiple technologies involved. This formed the foundation and was adapted for preliminary screening and identification of opportunities for HPPs at a global scale.

The cost structure has been split into: project development expenditures (DevEx), capital expenditures (CapEx), operation & maintenance expenditures (OpEx) and taxation. The cost shares according to plant items were reviewed & calibrated with respect to Danish Energy Agency Technology Data Catalogue and industry standards.

RE parks have potential for multiple revenue streams due to generation of a variety of products. Typical products which can be used for sales & increase profitability include electricity, heat, hydrogen and synthetic fuels.

An overview of available revenue streams for HPPs from different markets is shown in the table below along with the degree of influence of siting and regulation on the revenue potential. The last column identifies those markets addressed for HPPs modelled in the REALISE project:

Type of sale/ support	Stream (cash inflow)	Location influence	Regulation influence	Modelled in REALISE
Electricity	Day-ahead (or) spot market	High	Medium-High	Yes
	Balancing market	High	High	Yes
	Capacity market	High	High	No
	Power purchase agreements (PPAs)	Medium-High	Medium-High	No
Heat	District heating	High	High	No
	Industrial offtake	High	High	No
Hydrogen	Commodity market – Gas market via grid injection	High	High	Yes
	Direct trade/ bilateral contracts. Consumers e.g. Industry (chemicals, fertilizers, refineries), Filling stations	High	Low-Medium	No

The table below addresses the opportunities for different support schemes for HPPs. Where possible, these support schemes were taken into account in REALISE modelling of HPPs.

Type of sale/ support	Stream (cash inflow)
Support schemes	CfD (contracts for difference) - electricity
	CfD (contracts for difference) - hydrogen
	Feed-in Premium
	Feed-in Tariffs (FiTs)
Subsidy	CAPEX subsidy
	OPEX subsidy
Tax credits	Production tax credits (PTC) – hydrogen (per kg basis)
	Investment tax credits (ITC)
Other	Oxygen sales
	Green gas certificates

Sources of uncertainty were identified to fall under mainly 4 categories: energy market uncertainty, weather resource, technology performance and finance. Uncertainties along with key system design parameters were evaluated with respect to the magnitude of impact to HPP profitability and costs. The figure below captures the impact of input parameters on profitability of HPPs:

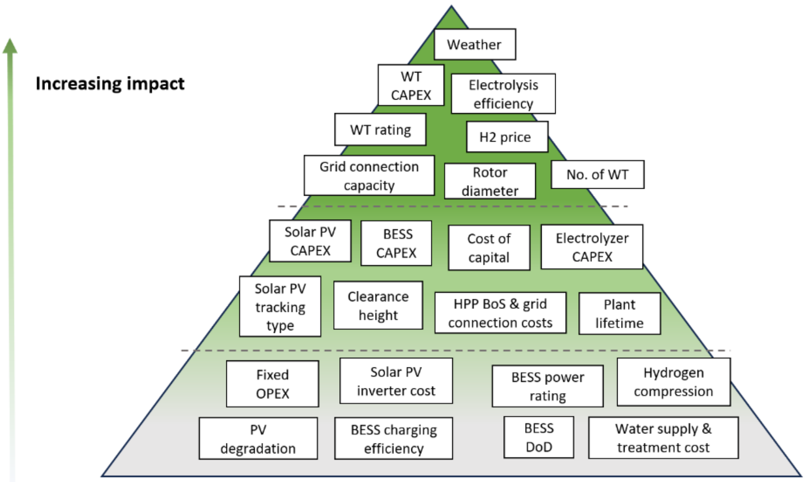


Figure 1: Representation of the impacts of different design parameters and sources of uncertainty on overall HPP profitability. (Source: Aegir Insights)

Of these impact drivers, key uncertainties that drive profitability include: weather resource and hydrogen prices. It is notable that early in project development, there is also high uncertainty associated with project costs (CAPEX, OPEX), financial, and other parameters. It was determined to use sensitivity analysis in REALISE modelling work to assess the impact of the key uncertainties on HPP profitability.

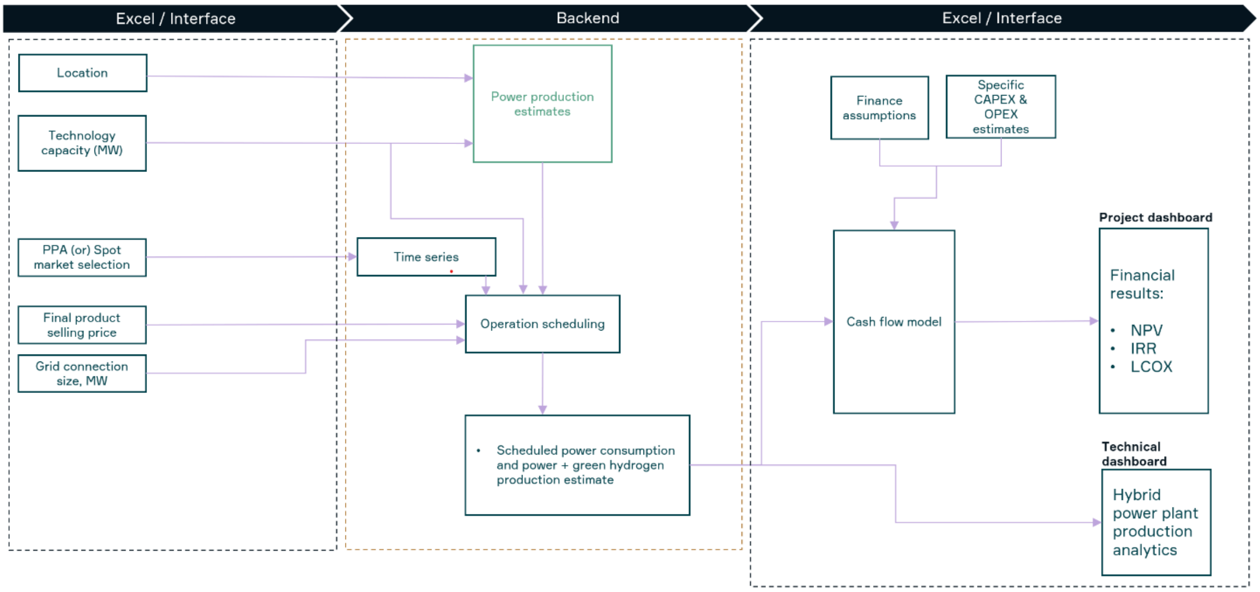
5.5 WP5: Productization, Visualization and User Interface

Main activities in WP5 involved implementation of capabilities developed in work packages 2 to 4. The outcome of WP5 is a techno-commercial decision support tool for fast-investment analysis of hybrid power plants. Based on data specifications developed in Task 5.1, Aegir Insights worked with DTU in Task 5.2 to integrate HyDesign capabilities with Aegir's workflows. In Task 5.3, Aegir Insights adapted the user interface and financial valuation capabilities of its commercial software Aegir Quant for hybrid power plant applications. This created a new tool, Aegir Integrate, which was tested and validated in Task 5.4 as well as in Work Package 6.

The minimum viable product developed offers three main value propositions:

- Rapid early-stage project & portfolio assessment: Conduct scenario & sensitivity analysis on global sites and deep dive into operation of hybrid facilities via dedicated analytics
- Single user interface which strengthens collaboration: Streamlined interface for efficient business case setup and overview of key technical and commercial inputs
- Independent benchmarking: Increased transparency and credibility of investment decisions for early-stage market screening

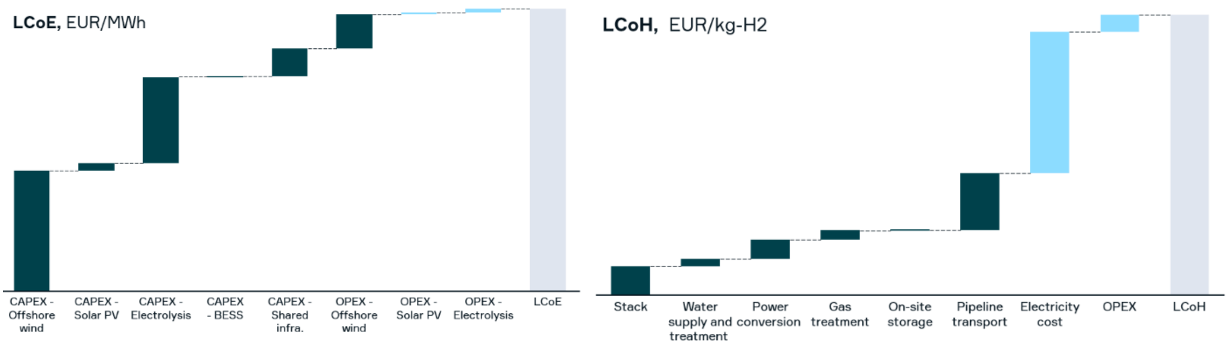
Task 5.2 and 5.3 focused on developing portfolio, project and technical analytics capabilities in the form of dedicated interface and dashboards for efficient business case setup. The main interface and project analysis is based in Aegir's Excel-based software Integrate with the technical simulations being performed in the backend in HyDesign, whereafter the results are visualized on dedicated dashboards. The overall workflow for the software is illustrated in the below figure.



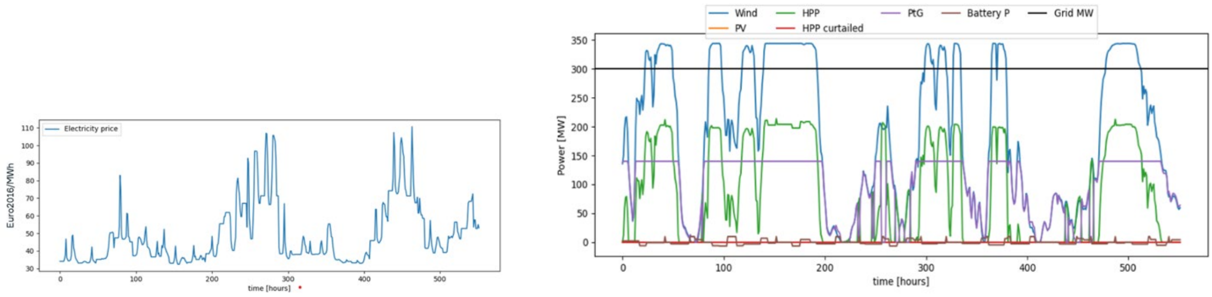
Figur 2: Aegir Integrate wraps the DTU capability HyDesign in a sophsiticated financial analysis tool to do project and portfolio valuation of hybrid power plants (Source: Aegir Insights)

A streamlined interface allows the user to quickly set up the business case by providing a range of techno-commercial inputs such as technology capacities of wind farms, solar PV plants, battery sizes and electrolysis plants to commercial inputs such as CAPEX & OPEX estimates. The user can use default values or override them, while being able to adjust the cost base.

The tool then uses HyDesign for scheduling the operation of the hybrid power plant given a range of inputs. The results are then fed into detailed financial analysis to assess the profitability of a single scenario for a project, a number of scenarios for a project, or a full project portfolio. Below are snapshots from the software of the visualizations of financial, technical and operational performance of a hypothetical project.



Figur 3: Financial Visualizations from Aegir Integrate: Levelized cost waterfall plot – representation of key drivers behind levelized cost of hydrogen and electricity. (Source: Integrate, Aegir Insights)



Figur 4: Visualizations of detailed operation for a project for a typical weather-price year where the energy management system optimizes the production from different assets and the use of system storage (Source: HyDesign, DTU)

5.6 WP6: Demonstration and Validation

In this work package, three demonstration cases are analyzed. Two cases are related to Vattenfall's onshore portfolio, while the third to its Offshore activities. The work package is concluded with validation of the software framework.

5.6.1 Demonstration case 1: Onshore wind including hydrogen production in the Netherlands

This demonstration case focuses on an alternative onshore wind offtake configuration with a hydrogen production plant. The case concentrates on a Vattenfall area of interest in the Netherlands that also offers the potential for solar farm development. This demonstration case investigates and shows, given the case constraints, how hybridizing can increase the profitability of one of Vattenfall's potential future assets.

The demonstration case results show clearly how various input decisions impact the hybrid sizing output. For example, a higher hydrogen price results in increased additional installed solar and electrolyzer capacity. HyDesign also calculates the break-even hydrogen price to reach the minimum desired profitability level. For hydrogen prices below the break-even price, no solar capacity is added as it will not lead to increased net present value. The results show clearly that the additional solar capacity is barely decreasing the hydrogen break-even price, showing that adding solar capacity is not making the hydrogen selling price more competitive. It is only a solution to increase the total volume of hydrogen produced.

The demonstration case results have given Vattenfall additional insights and knowledge on the sizing of hybrid plants.

Demonstration case 2: Onshore wind including battery storage in Germany

The second demonstration case focuses on an onshore wind farm in Germany with potential addition of battery storage.

Battery energy storage can help to partly offset the issues from intermittent renewable production by, for example, providing ancillary services to stabilize frequency disturbances, storing energy to enable a more stable production curve to the grid, and arbitrage trading to benefit from the price differences. Multiple scenarios are run with a range of fixed power prices to model the impact of subsidies.

First observation is that in the scenarios with a fixed power price, adding battery storage does not contribute to the profitability of the project. This obviously makes sense, as there is no revenue to be gained for batteries when the power prices are fixed and the only assumed revenue stream is spot market trading. It, although out of scope of this case, would have been interesting to analyse the outcome if the wind farm earns its revenues with a fixed power price, while the battery is operating on the variable spot market.

Also, in the case of a variable price, adding battery storage is not improving the business case. Only when introducing a very significant reduction on battery CAPEX, the net present value returns positive. This shows that the current battery costs are still too high to allow for viable battery projects that solely earn revenues from day ahead spot market (arbitrage) trading.

Battery revenue modelling is a complex exercise, especially as battery storage can participate in various markets such as spot (day ahead, intra-day, balancing) and ancillary services. The modelling and optimization on multiple markets is by itself already a complex exercise, but together with the hybrid sizing optimization makes it even more (computationally) difficult. This topic is further addressed in the validation section.

5.6.2 Demonstration case 3: Offshore wind and power-to-hydrogen in Denmark

The third demonstration case focuses on a new offshore wind farm off the cost of Western Denmark. The project does not currently exist but is inspired by the upcoming offshore wind tender in Denmark where a minimum grid interconnection capacity is guaranteed but an opportunity for overplanting exists at the site.

The case involves only offshore wind and hydrogen production from an electrolyzer. No electrical or hydrogen storage is considered. The case includes overplanting of the wind farm to supply the electrolyzer. The wind farm and electrolyzer are connected to the grid in a unidirectional set-up where the offshore wind farm can supply power to the electrolyzer, grid or both. However, the electrolyzer only draws power from the offshore wind farm and not the grid. In a real project, the electrolyzer would most likely be able to draw power from the grid as well, but for simplicity, this was neglected in the modelling. Only the day ahead grid and hydrogen markets were considered (i.e. no inclusion intra-day, balancing or ancillary service market participation).

Modelling of the energy management system and financial valuation of the project was performed using the integrated DTU-Aegir developed modelling capability “Aegir Integrate” as discussed in section 5.5. Sensitivities were conducted around key uncertainties for the hydrogen price levels and electrolyzer costs. In addition, sensitivities on the design parameters for the electrolyzer size and grid connection capacity were explored.

Not surprisingly, the overall profitability and LCOH of the case was significantly affected by Hydrogen prices and electrolyzer costs. More interestingly, the combination of undersizing the electrolyzer while increasing the grid interconnection capacity resulted in a financial valuation with a comparable LCOH to the baseline case but with a much higher grid utilization factor. Grid interconnection fees are a significant cost and the results provide some insights into the opportunity for potential project options given the uncertainties associated with project development. Such options and the modelling of the case with a bidirectional set-up were identified as two areas for future model development and case work.

5.6.3 Validation

In this section, various elements of the demonstration cases are validated. No exact comparisons will be made due to confidentiality, but more rough feedback is provided.

Wind production

Comparing the wind capacity factor of the cases to actual project information can indicate whether the current wind resource methodology leads to realistic results.

- For some demonstration cases, the HyDesign outcomes came close to the actual figures, but for other's it was over-estimated. Different versions of the global wind atlas were compared to the actual project wind production information to identify the most reliable source. It must be kept in mind that such types of wind atlases bring significant levels of uncertainty to estimating the energy production, but that this is unavoidable at early stage of project development without the access the actual measurement data.
- It must be noted that HyDesign makes the distinction between three production loss types: wake losses, plant efficiency and degradation. In practice there is a large variety of production losses, ranging from losses due to noise, icing, availability, electrical efficiency and degradation. Each loss type requires its own specific way of modelling as it impacts the hourly production profile in its own way. For example, wind turbine availability losses only impact the production during the hours that maintenance is being performed and brings the production for the particular turbine to zero. However, icing often occurs in the winter months while electrical losses occur at all time instances.

Wind turbine sizing

Demonstration case 2 was initially given the freedom to optimize the wind turbine specifications, the rated power, specific power and number of turbines. In the case with variable pricing, the optimal rated power was 2.1 MW and the corresponding rotor diameter 117 m. For the cases with fixed prices, the results appeared to be very sensitive to the input parameters. A slight change in the fixed price level resulted in an optimal rated power three times as large. From Vattenfall's industry experience, these findings do not seem realistic. The general industry trend is that bigger wind turbines lead to lower costs per produced MWh.

Revenue streams

In the demonstration cases, the electricity produced is either sold to the spot day ahead market or traded at a fixed price. The same price assumptions (fixed or variable) apply to both the renewable production as the flexible assets (battery storage and electrolyzer). In practice, usually more refined revenue setups are in place. Such as the wind farm securing its revenues through either a power purchase agreement or government subsidies, while simultaneously the flexible asset operates on the spot market to benefit from the volatile market prices. This allows for each individual technology to have the optimal revenue strategy in place and can be ensured by including multiple energy flow meters on site.

Demonstration case 2 showed that battery storage was not viable, but only when a significant reduction of battery CAPEX was assumed. The observation that battery storage does not easily lead to a positive business case might be a result of that the only assumed revenue source is the day ahead spot market. In practice, there are many more ways to generate revenues with battery storage such as ancillary services (e.g., FCR, FRR) and various wholesale markets (day ahead, intraday, balancing). Stacking and optimizing multiple revenue streams can then lead to an improved battery storage business case.

DTU acknowledged that trading the battery only on the day ahead market will in most cases not lead to sufficient revenues, as the daily spread in power prices is limited. DTU is developing, in parallel to HyDesign, other high-fidelity capabilities to simulate more granular and complex battery storage revenues. The challenge is to cleverly incorporate some of these high-fidelity capabilities into HyDesign without causing a too extreme increase in computational requirements, to allow for a more realistic representation of battery storage revenues. An example is the work done on the balancing market described in Work Package 3.

Hydrogen production

The REALISE software landscape has been presented to Stiesdal. Stiesdal is a company that develops and aims to commercialize technologies with high impact on climate change mitigation. An electrolyzer for low-cost hydrogen production is one of the technologies being developed. Stiesdal gave valuable insights into modelling the electrolyzer efficiency, and specifically on how the efficiency rate varies with electrolyzer load. These insights, including additional research and input from the project partners led to updates accordingly. There exists a large range in variation for the electrolyzer efficiency across the available technologies and manufacturers. It is observed that the current efficiency curve (kWh per kg hydrogen as function of electrolyzer load) is on the conservative side of this range.

It must be noted that most modelling software assume annual instead of hourly granularity in the modelling resolution, next to a constant instead of a variable electrolyzer efficiency rate. The HyDesign tool therefore delivers insights on how more granular input assumptions influence the modelling outcome.

Operational period

The demonstration cases are sized using one year of price data to allow for less computational resources than when analysing the full 25-year operational period. The results from one year are then extrapolated to the entire operational lifetime. This is reasonable for sizing the technologies. However, in the case of quantifying the final financial metrics for the optimized scenario, it is worth using the full 25 year of price data. Given the large changes in the energy system over the next couple decades, it is not likely one year of price data is representative enough for the entire operational period of the asset.

CAPEX and OPEX assumptions

The default CAPEX and OPEX assumptions have been reviewed.

Onshore wind
The wind turbine CAPEX has seen a significant increase in the last years due to inflation and supply chain bottlenecks. The default assumptions (which were also set before recent price increases) therefore also underestimate current market prices (even accounted for that the default assumptions are in 2016 terms) by 20-30%. The default civil CAPEX assumption is reasonable, although these costs vary significantly across projects due to soil, terrain and access conditions.
The onshore O&M cost assumptions are in line with the actual cost of maintaining an asset. Besides maintenance costs, (WTG, Balance of Plant etc.) a project encounters other operational expenses (OPEX) such as grid fees and land leases that in some cases can cover a significant share of the OPEX. Therefore, these should not be overlooked.

Battery
The BESS CAPEX is significantly underestimated by the default assumptions, also when compared to publicly available data on BESS costs (https://www.nrel.gov/docs/fy23osti/85332.pdf).

Offshore Wind

Similar to onshore wind, offshore wind has seen substantial cost increases over the past three years. However, due to the increased size and complexity of offshore projects relative to their onshore counterparts, as well as a supply chain that is considerably tighter, the cost increase is significantly higher. The default assumptions from the energy technology catalogue are therefore generally substantially underestimating the costs of offshore wind. When comparing those assumptions on all in cost in the same base year, for an offshore wind farm with a complete scope including the electrical transmission infrastructure, to the costs seen on actual current development projects with commissioning in 2030, an increase of ~60% per MW_e can be observed. Similarly, the O&M cost assumptions also see an increase of ~50%.

Electrolysis

In general, it should be said that costs for PEM electrolysers, particularly for very large installations of 1 GW or above, are associated with very significant uncertainty, since they rely on scaling and learning rates of which it is not known how realistic they are. There are many projects for large scale electrolysers in development around the world. However, none of them are close to realisation or construction. With that in mind it should be said that some cost estimates in industry could also have significant inherent conservatism in an attempt to account for these risks. The technology catalogues estimate a unit cost of 0.6 M€/MW_e (2020 base) for a PEM electrolysis plant in 2030. Whereas cost indications for real development projects generally outweigh that estimate by a factor ~2.5. This disparity has a very significant impact on required breakeven H2 prices.

5.7 WP7: Dissemination and Stakeholder Engagement

An advisory board meeting was held with participation from Vestas, SGRE, NREL and AU. The focus of the meeting was to discuss the implications of the developed market projections on the design of hybrid power plants. This contributed to said projection being a good platform for further development. Later in the project meetings were held with Stiesdal Hydrogen and Energi Danmark to get input on electrolyzer modelling and balancing market participation respectively.

An overview of the projects online presence, various news and LinkedIn articles and conference participation can be found below:

- Project publiced on ECD website incl. project movie (link)

- News article on ECD website and press release, project funded (link)
- News article on ECD website and press release, “Radikal innovation kræver frie rammer” (link)
- Article about the project in Maskinmesteren (link)
- LinkedIn post: “Without soft funding, we would not have achieved the results which make others now believe in us on a large scale” (link)
- Energy-Supply.dk: Soft funding gør dansk vind-software interessant for investorer (link) (and multiple other news sites)

- 21. Wind and Solar Integration Workshop,
- Wind Europe, 2023
- Wind Energy Science Conference, Glasgow, 2023
- Danish Hybrid Power Plant Forum, 2023
- 22. Wind & Solar integration workshop, Copenhagen, 2023
- Energy Cluster Denmark Annual meeting, Copenhagen, 2024
- InnoNet: Realise final event, Copenhagen, 2024

In addition, the project was shortlisted at Power-to-X Innovation Award at Wind Investment Awards 2024, but did not win. At the projects final event one of the interesting take-aways from the panel discussion between the project partners and the DEA was that REALISE provides a fast method for modelling an optimized hybrid renewable energy park with a high utilization factor.

6. Utilisation of project results

6.1 DTU

DTU has made huge progress in the development of the open-source tool HyDesign (https://topfarm.pages.windenergy.dtu.dk/hydesign/) in this project. HyDesign is used both for design and operation of hybrid power plants (HPPs). HyDesign will be continued to be used in research in the future as well. Following are some of the research and development activities to be carried out in the future –

i. Extending the capabilities of HPPs to include P2X technologies like ammonia, methanol, methane, etc.
ii. Extending the capabilities of HPPs to include physical and electrical design of HPPs.
iii. Validating the operation of the HPP in a real HPP, i.e. Risø HPP facility.
iv. Value quantification of large-scale deployment of HPPs in the future European energy system.
v. Machine learning based methods for reducing computational complexities and computational time.
vi. Implementation of design and operational optimisation in cloud computing platform.

The uniqueness and advanced capability of HyDesign allows it to be potentially used for research-based consultancy support to power plant owners, operators and developers. Future HyDesign development through research and consultancy projects will allow for hiring of multiple (5-10) researchers (PhD students, postdocs, assistant professor/researcher) and development engineers. HyDesign is an open-source tool, so it does not compete with other commercial tools in this domain. However, the advanced capability of HyDesign renders it to achieve the ambition to be the global leading software in this domain. There is only another open source tool in this domain – NREL's HOPP tool (https://www.nrel.gov/wind/hybrid-energy-systems-research.html). The HyDesign team is in regular interaction with the HOPP team to be updated with the state-of-the-art and maintain their lead especially in the European energy system.

As mentioned before, HyDesign does not have the interest in generating revenue but to expedite the green transition by helping faster deployment of hybrid power plants and by reducing the risk of project development.

HyDesign is already being actively used in teaching activities in BSc (https://kurser.dtu.dk/course/2024-2025/46060), Master (https://kurser.dtu.dk/course/2024-2025/46W47), and PhD level courses. It is also used for industrial training courses. Online master and industrial training courses are other potential revenue generation sources for DTU.

6.2 Vattenfall

Vattenfall is an energy company, its main product being the sale of electricity to private and business customers. Additionally, other products such as heat, power distribution, electricity trading among others, are also offered. In the context of this research project, Vattenfall's commercial product is the development, construction and operation of renewable energy plants. Despite future market uncertainties, the improved knowledge and tooling on the sizing, design and valuation of such plants will lead to increased turnover in this product segment.

Vattenfall believes that hybrid renewable energy parks will be necessary for the energy transition to succeed. Products supplementary to wind and solar must be developed to solve the intermittency of renewable energy. Additionally, the latest offshore wind tenders incorporated requirements for energy system integration. The REALISE tools for design of multi-technology plants ensure Vattenfall has a competitive advantage over other renewable energy developers. Vattenfall's strategy is to be on the forefront in modelling and evaluation of such energy plants, as improvements in design can easily lead to significant upsides in turnover.

In Vattenfall, various departments are involved in the design, modelling and valuation of renewable energy projects. Most departments have their focus areas, e.g., designing offshore wind, onshore wind or solar farms, hydrogen plants, energy storage units etc.. There are interfaces between the various departments, but often each technology is often optimized individually. The design of single technology plants is already a complex exercise. The knowledge, tools and methods developed in the REALISE research project provide Vattenfall with a one-stop shop to optimize single and multiple integrated technologies simultaneously, and enable further optimization of hybrid renewable energy parks. This will increase the value of all projects where there is the need to understand how various technologies should be sized when located behind the same grid connection. Additionally, it will allow Vattenfall to reduce development costs by quickly retrieving insights on the feasibility and optimal configuration of these assets using significantly fewer resources. This is particularly helpful for early development stage projects with significant design freedom and limited resources.

The project also addressed topics which are barriers in the realisation of hybrid renewable energy parks. Among other, even though the spread in spot prices is growing due to the increased renewable penetration in the electricity mix, it is still challenging to ensure a profitable business case for battery energy storage based on energy arbitrage alone. As a result, additional revenues from ancillary services and balancing services are currently required to boost and optimize the revenues. This requires that the software to evaluate such projects is being updated on a regular basis to reflect the right market characteristics and opportunities. This was further elaborated on Chapter 5, work package 6.

The tools developed in the research project are relativity straightforward in use, provided the required IT infrastructure and back-end software knowledge are in place. As such, REALISE's tools can be used by any design and engineering department working on projects where there is an interface between various technologies.

Vattenfall is not directly commercializing any of the REALISE project outcomes as any software is solely used internally to support the development of new renewable assets. However, insights from the REALISE projects and learnings of the software tools will be taken into commercial activities of Vattenfall in terms of renewable energy park development.

6.3 Aegir Insight

Aegir Insights is developing the first generation of its software solution *Aegir Integrate* based off of the REALISE project work. Section 5.5 on Work Package 5 provides details of the approach taken where the DTU capability for optimization of design and operational strategies of Hybrid Power Plants was integrated with advanced financial valuation capabilities adapted from Aegir's existing offshore wind software solution, Aegir Quant. The combined software is arguably the most sophisticated solution available for integrated technical and financial modelling of hybrid power plant systems. The software is able to take on a wide range of technology configurations (wind, solar, electrical storage, hydrogen, and broader power-to-x technologies) as well as different financial configurations (operating with PPAs, energy markets in electricity for spot, intra-day and balancing, hydrogen and other power-to-x markets). Furthermore, the software is currently able to support analysis of projects and portfolios anywhere in Northern and Southern Europe – leveraging advanced energy market modelling to project correlated weather resource and price profiles into the future based for a range of future energy system scenarios. The users of the software can include, but are not limited to:

- Commercial teams: analysts working on early-stage project development and financial valuation as well as management of project and portfolios for single and multi-technology energy projects
- Technical system designers: engineers working on early-stage design of projects to evaluate a large range of potential technical configurations and to assess and optimize their financial performance

Longer term, there are opportunities to also support projects in operation for ongoing assessment and development of energy management and O&M strategies as well as financial activities which may include re-insurance, mergers and acquisitions and more.

The capabilities developed in REALISE for Aegir Integrate will join Aegir's data-intelligence-software product portfolio to expand the market opportunity from offshore wind (where Aegir currently operates) to renewable energy parks broadly. Offshore wind alone is a large and growing sector where Aegir has a leading position with its integrated solution for data and analytics, intelligence, and software. The broader renewable energy sector is orders of magnitude larger. Furthermore, there are important synergies between the offshore wind and related sectors – particularly power-to-x. Thus, both the existing client base for Aegir as well as an even larger potential new client base can benefit from the solutions developed in the REALISE project. In addition to working directly with Vattenfall in the project on product development, demonstration, and validation, Aegir is working with two additional lighthouse customers who are actively developing power-to-x projects in other regions of Europe and the world. The indications from initial commercial activities is that the product Aegir has developed fills a gap that *no current solution on the market fills* and addresses a need that is acute particularly with commercial teams in early stages of developing hybrid and power-to-x projects. Aegir's solution can support these commercial teams on scouting for opportunities, early-stage valuation of projects, and ongoing valuation of projects and portfolios as they move towards FID and beyond.

Aegir plans to offer the Integrate software solution via subscription platform similar to the structure by which it has commercialized its offshore wind solution Aegir Quant. Quant is part of a larger subscription package including data and intelligence products. Customers interested in hybrid power plant and power-to-x projects will now be able to find that Aegir's integrated offerings support these projects as well. It is expected that shortly after the end of the project, Integrate will have one or more customers and Aegir will have one or more staff dedicated to its Integrate product. Longer term, however, the potential is massive – going well beyond the market opportunity for offshore wind only solutions where Aegir is currently focused. Internally, Aegir has done risked-assessment of the market potential for the offshore wind and integration solutions. If Aegir is successful in securing market-leadership, building from the foundation established in the REALISE project, the longer term potential customer base involves *hundreds of companies* across the globe. Significantly, the export potential for the solution is much larger than the domestic market opportunity. More detail on growth expectations is provided in the below table.

Several companies today offer software solutions for hybrid power plants. There are open-source solutions like the HyDesign software solution developed at DTU (for example REOpt, HOPP, SAM from NREL) and also commercial solutions (for example HomerEnergy Pro). However, these tools are primarily focused on project engineering and technical design. Similar to positioning in the offshore wind sector, Aegir seeks to develop solutions for commercial teams – creating ability for fast and accurate financial valuation of projects and portfolios. In Aegir Integrate, technical complexity is abstracted away while keeping sufficient accuracy to support financial valuation. This creates an ability to perform rapid analysis to support commercial team activities. No other solution on the market can match Aegir's Integrate solution in terms of combined speed and accuracy. Aegir thus expects to be not only lead but be a key stakeholder in realising the development of the market for hybrid power plant software solutions for commercial teams for developers, manufacturers, financial companies, and more.

The key barriers for entry and sales of software solutions for hybrid power plants is the volatility and immature nature of the hybrid power plant and power-to-x sector itself. Development of hybrid and power-to-x projects involves massive capital investment and coordination across a complex set of stakeholder groups from the energy generation to offtake and end-use. The last several years have seen a start-stop paradigm with many companies monitoring the market developments without taking significant action. The sector is risk averse and the uncertainties associated with evolving energy markets impedes development. However, massive commitments of some governments towards renewables and power-to-x technologies instil optimism that it is a matter of time. As previously mentioned, early commercial discussions indicate that the need is there and is growing. REALISE has helped accelerate and derisk the development of the technical product and positioned Aegir to take on a leadership position as development of markets for hybrids and power-to-x unfold in 2024 and beyond.

Having both an open-access and a commercially available tool to model hybrid power plants in Denmark and abroad democratizes development of the very complex energy projects that hybrid power plants are. With the open access tools public authorities can get neutral input for decisions regarding framework conditions etc. for hybrid power plants in their country, an area where they might otherwise be dependent on input from very large energy developers such as Vattenfall. Likewise, Aegir Integrate significantly lowers the barriers to entry in the hybrid RE market. Without the capabilities developed in the project especially smaller developers would not be able to make an integrated assessment of the investment opportunity a hybrid power plant represents. This would expose them to significant risks which would either keep them from entering the market or potentially bankrupt them. In combination it is expected that the REALIZE project will accelerate the deployment of hybrid power plants in Denmark and elsewhere.

7. Project conclusion and perspective

In WP 2 the surrogate for the Balmorel energy system model developed in this work is a useful tool for energy, wind, and control systems engineering by allowing for the efficient sampling of realistic stochastic electricity price timeseries given an aggressive decarbonization scenario. This can be useful for assessing the impacts of energy policies, feasibility of proposed power plants, and viability of different control strategies. These applications often necessitate hundreds or thousands of energy systems model evaluations to characterize uncertainty in forecasted electricity prices, which would be computationally prohibitive without the developed surrogate.

In WP3, the optimization methodology for the operation and sizing of hybrid power plants (HPPs) comprising wind, solar, battery and power-to-hydrogen was developed. A python-based open-source software platform– HyDesign [3.1], was further developed and used for design and operation of utility-scale hybrid power plants. This tool can perform sizing optimization of HPP or evaluation of a specific plant design with a user-specified objective function, i.e., minimize levelized cost of electricity (LCoE) or maximize net present value over the capital expenditures (NPV/CAPEX). This was for a number of test and use cases, e.g. profitability analysis with participation in multiple markets, especially balancing market and Hydrogen (H2) markets. Combining Power-to-Hydrogen (P2H) technology within HPP reduces the fluctuation from non-dispatchable production and reduces the amount of curtailment in the system similar to storage devices. Case studies performed at various sites in Europe show notable improvement in the techno-economic benefits of HPP with P2H. Also, the analysis has been done to identify the financial improvements in HPP operations producing hydrogen with or without grid connection for a few offshore and onshore locations in Europe to identify the value of asking for a grid-connection.

In WP4, the specifications, requirements and framework for business case evaluation of RE parks were established. A theoretical review of economic metrics and methods used for techno-economic evaluation of energy projects was carried out to determine appropriate metrics for energy systems analysis in REALISE. The metrics were classified into two categories: profitability indicators and cost indicators. The Net Present Value (NPV) was chosen as the appropriate profitability metric since it accounts for both the cost and revenue side of the project and can include all possible incoming or outgoing cash flow with varying periods. The levelized cost metrics levelized cost of energy (LCOE) and levelized cost of hydrogen (LCOH) were chosen as the appropriate metrics for representing the cost side. Updates to the cost modelling Sources of uncertainty were identified to fall under mainly 4 categories: energy market uncertainty, weather resource, technology performance and finance. Uncertainties along with key system design parameters were evaluated with respect to the magnitude of impact to HPP profitability and costs. Of these impact drivers, key uncertainties that drive profitability include: weather resource and hydrogen prices. It is notable that early in project development, there is also high uncertainty associated with project costs (CAPEX, OPEX), financial, and other parameters. It was determined to use sensitivity analysis in REALISE modelling work to assess the impact of the key uncertainties on HPP profitability.

WP5 has developed Aegir Integrate, a techno-commercial decision support tool for fast-investment analysis of hybrid power plants. The minimum viable product developed offers three main value propositions:

- Rapid early-stage project & portfolio assessment: Conduct scenario & sensitivity analysis on global sites and deep dive into operation of hybrid facilities via dedicated analytics
- Single user interface which strengthens collaboration: Streamlined interface for efficient business case setup and overview of key technical and commercial inputs
- Independent benchmarking: Increased transparency and credibility of investment decisions for early-stage market screening

A streamlined interface allows the user to quickly set up the business case by providing a range of techno-commercial inputs such as technology capacities of wind farms, solar PV plants, battery sizes and electrolysis plants to commercial inputs such as CAPEX & OPEX estimates. The user can use default values or override them, while being able to adjust the cost base. The tool then uses HyDesign for scheduling the operation of the hybrid power plant given a range of inputs. The results are then fed into detailed financial analysis to assess the profitability of a single scenario for a project, a number of scenarios for a project, or a full project portfolio.

WP6 has demonstrated and validated the developed tools through review of assumptions and methodologies throughout the project and in the following three specific cases:

1. Onshore wind including hydrogen production in the Netherlands
2. Onshore wind including battery storage in Germany
3. Offshore wind and power-to-hydrogen in Denmark

The first two cases were done directly in HyDesign with DTU using the tools, the third case was done by Aegir through the of Aegir Integrate software. In both cases Vattenfall defined the cases and compared the results to their internal results. Some learnings across the cases can are: 1) increased hydrogen prices increased the installed solar and electrolyzer capacity, but increased solar did not significantly reduce the cost of the produced hydrogen, it only increased the volume. 2) Batteries were only relevant at variable prices and are not yet profitable assuming only spot market trading i.e. further battery CapEx reductions are required. 3) an undersized electrolyzer and significant grid capacity gave a comparable levelized cost of electricity to the base case with a high electrolyzer capacity and limited grid connection.

Generally on the modelling side it would be relevant to consider the following future development points:

- further detail the electrolyzer modelling, cover more types of electrolysis and further steps in the value chain, e.g. methanol and ammonia production.
- further differentiate market participation, e.g. analyze the outcome of a wind farm with fixed power price, while the battery is operating on the variable spot market.
- model battery revenue through participation in multiple markets in a computationally efficient manner.
- improve modelling of GW scale offshore wind farms

The capabilities developed in REALISE for Aegir Integrate will join Aegir's data-intelligence-software product portfolio to expand the market opportunity from offshore wind (where Aegir currently operates) to renewable energy parks broadly. Offshore wind alone is a large and growing sector where Aegir has a leading position with its integrated solution for data and analytics, intelligence, and software. The broader renewable energy sector is orders of magnitude larger. Furthermore, there are important synergies between the offshore wind and related sectors – particularly power-to-x. Thus, both the existing client base for Aegir as well as an even larger potential new client base can benefit from the solutions developed in the REALISE project. Vattenfall will work with integrating the learnings from the project in their internal models. This is simultaneously expected to reduce project development costs and, more importantly, develop more competitive projects. Energy Cluster Denmark will investigate the possibility for disseminating directly to the Danish Energy Agency's modelling department so learnings from the project can be considered further development of Danish energy policies as well as with foreign development-oriented delegations.

Having both an open-access and a commercially available tool to model hybrid power plants in Denmark and abroad democratizes development of the very complex energy projects that hybrid power plants are. With the open access tools public authorities can get neutral input for decisions regarding framework conditions etc. for hybrid power plants in their country, an area where they might otherwise be dependent on input from very large energy developers such as Vattenfall. Likewise, Aegir Integrate significantly lowers the barriers to entry in the hybrid power plant market. Without the capabilities developed in the project especially smaller develop-ers would not be able to make an integrated assessment of the investment opportunity a hybrid power plant rep-resents. This would expose them to significant risks which would either keep them from entering the market or potentially bankrupt them. In combination it is expected that the REALIZE project will accelerate the deploy-ment of hybrid power plants in Denmark and elsewhere.

8. Appendices

When possible links to publicly available papers etc. has been provided above. Further documentation for the deliverables can be provided upon request to the EUDP secretariat. But it may not be possible to provide them to other parties due to confidentiality.