# Techno-Economic System and Component Analysis for Hybrid Power Plants

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**Abstract— This paper presents TESCA, a novel techno-economic analysis tool for assessing the feasibility, profitability, and effectiveness of hybrid power plants. Using detailed technical component modules that draw upon a comprehensive market understanding, TESCA supports decision-making to guide the design of hybrid power plants. TESCA enables the rapid evaluation of thousands of scenarios, providing insight through modular component selection, sensitivity analysis, scenario comparison and straightforward implementation of different operation strategies.**

**Index Terms- Techno-economic analysis, Hybrid power plants, Renewable energy, Sector coupling, System simulation**

## I. Introduction

To meet the Paris Agreement's goal of limiting global warming to between 1.5°C and 2°C, a shift from oil and gas to renewable energy is necessary. This energy transition requires large investments, which hence require a commensurate level of security [1]. Conducting a techno-economic analysis (TEA) of a hybrid power plant (HPP) determines the feasibility, profitability, and effectiveness of the project before significant investments are allocated. TEA evaluates both the technical aspects, such as plant design, operational efficiency, and expected energy output, and the economic aspects, such as capital costs, operating costs, revenue potential, and financial risks. As a key decision-making tool, TEA can be used for analysing technology feasibility and viability, selecting application and design options, comparing technologies, forecasting future technologies, analysing research and development needs, conducting replicability and scalability studies, and for performing risk analysis.

In 2019, AIT started developing its own deterministic time-series simulation framework for Techno-Economic System and Component Analysis (TESCA) of HPPs. TESCA specifically analyses HPPs that integrate electricity generation, battery and hydrogen systems, in the context of energy consumption, market, grid and market-service aspects. A list of national and EU-funded projects includes [2–14].

## II. TESCA

Although several TEA tools exist [15], none provide the complete insight into components, functionality, parameterization and operation strategy required by AIT. TESCA was developed as a deterministic simulation framework, whose inputs include generation, demand, and price profiles. This is valuable for considering simultaneity – the alignment of generation, demand, and market prices – which traditional balance-sheet do not provide. Simultaneity is crucial for storage systems that compensate for mismatches in energy availability. TESCA also supports flexible operational strategies, including algorithmic and optimizer-based methods like IESopt [16]. TESCA's modular architecture allows users to implement new operation strategies, adapt existing components, or integrate new ones, and build models closely matching real-world systems. Such models can be validated with empirical data and customized through curve-fitting. The framework also enables black box models, such as machine-learned models and AI-driven models, or functional mock-up units. TESCA's transparency and adaptability make it a powerful tool for evaluating low-TRL technologies, forecasting efficiency advancements, and addressing novel business models.

### A. System architecture

TESCA has three main parts: TESCACore, Profitability, and Data Processing (see Figure 1)

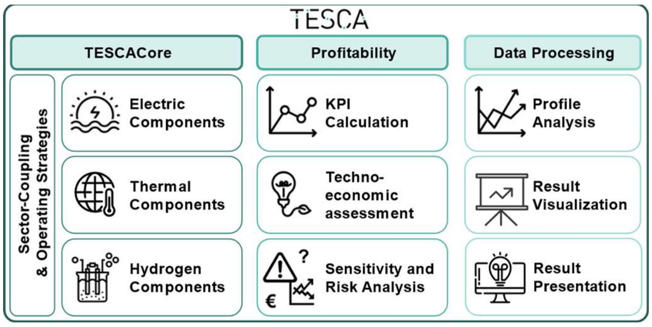

Figure 1. Key features and components of TESCA.

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### 1) *TESCACore*

TESCACore is a deterministic time-series simulation framework, programmed in Julia, which is used to compose the technical model. TESCACore currently includes components from three energy sectors: electrical, heat, and gas (specifically hydrogen). The simulation is typically conducted in time steps ranging from five minutes to one hour (typically aligned to grid consumption measurements, or energy market price recording). The simulation time frame for the TEA is user-defined, and often extends to the planned lifetime of the plant (typically 20 years). Accordingly, the impacts of component ageing on technical performance, and the need for reinvestment at end of lifetime are simulated, to produce an accurate TEA of a particular plant.

Three example components implemented in TESCA are:

- The **Li-Fe phosphate (LFP) battery**. TESCA models state of charge, cell temperature, and charging and discharging current. It also incorporates the impact of both cyclic and calendar ageing for a fuller assessment of accelerated battery ageing due to cell temperature and operation strategy [17, 18], and for the analysis of second life batteries [19].
- The **proton exchange membrane electrolyser (PEM)** [20, 21] and the **alkaline electrolyser (AEL)** [21, 22]. Both electrolysers include electrochemical and thermal models, and can be configured as a plant with a number of stacks of cells arranged in parallel and/or series. The model incorporates properties such as the current and voltage per cell, which is not only crucial for determining hydrogen output, but also models excess heat production (which in turn can be supplied to a district heating network [21]). The electrolyser models can also be calibrated using project specific polarization or efficiency curves [23–25].
- **AC/DC converters** (i.e. rectifiers and inverters). These are defined by their nominal power, minimum operational power, and efficiency curve, which models partial load behaviour. Implementations include both synthetic efficiency curves and real-world converters based on datasheet specifications [4, 9].

Additionally, TESCA includes a model for pumped hydropower based on the hill charts of turbines [26], a model for converting green hydrogen to synthetic methane [27], and multiple DC/DC converters, used to simulate AC/DC hybrid grids [4, 9].

TESCACore is continuously expanding with the incorporation of new components. For example, an in-depth hydrogen storage model [8, 28] is currently in development, which takes into account the impact of hydrogen temperature and tank pressure on charging and discharging flow-rates. Also under development are models for hydrogen liquefaction and liquid hydrogen storage [2], electrochemical hydrogen compression and purification [8], and hydrogen fuel cells [5].

### 2) *Profitability*

The second part of TESCA is the economic assessment. Here, different technical and economic key performance indicators (KPI) are calculated, including (among others) full load hours (FLH), levelized cost of energy (LCOx), cash flow, net present value (NPV), internal rate of return (IRR), payback period.

The **FLH** are the equivalent number of hours a generator would need to operate at nominal power ($p_{\text{nominal}}$), to generate the same amount of energy ($E_{\text{year}}$) as actually generated over the given period (typically one year):

$$FLH := \frac{E_{\text{year}}}{p_{\text{nominal}}}.$$

The **LCOx** defines the cost for producing energy as the price this energy must be sold at for the plant to break even at the end of its lifetime. The generated energy ‘x’ can be, for example, electricity (LCOE), hydrogen (LCOH), heat (LCOHeat), or energy discharged from storage (LCOS):

$$LCOx := \frac{\sum_{t=0}^{T} \frac{CAPEX_t + OPEX_t - v_{\text{res}}}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_{x,t}}{(1+r)^t}},$$

where $t$ is the time in the desired temporal economic resolution (e.g. years), $T$ is the considered time span in the desired temporal resolution, $r$ is the hurdle rate (minimum acceptable rate of return), CAPEX and OPEX are the capital and operational expenditures made at the time $t$, $v_{\text{res}}$ is the residual value of the plant at the end of $T$, and $E_{x,t}$ is the produced energy (‘x’) at the time $t$.

The **NPV** calculates the net present value of upcoming cash flows that can be earned from an investment project during its lifetime:

$$NPV := \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t}.$$

A positive NPV means that the investment option is profitable. $CF_t$stands for cash Flow at time $t$, which equals the costs ($C_t$) minus benefits ($B_t$) at time $t$:

The **IRR** is the discount rate whereby the NPV is zero. Equivalently, it is the expected annual rate of return that will be earned on a project or investment. The IRR is typically compared to a company’s hurdle rate, and if it exceeds it, the investment is considered financially viable.

These technical and economic KPIs are the main output values for the TEA, as they objectively measure the technical and economic effectiveness of the plant setup. TESCA can also be used for risk assessments, analysing the probability of a profitable outcome using a stochastic simulation-based approach, as in [29].

### 3) *Data Processing*

The third part of TESCA is a support package that simplifies the pre- and post-processing of data. This includes validation of input and output profiles, building energy sums and power flow diagrams, and visualization of technical and economic KPIs and sensitivity analysis. The visualization can be generated as a static vector graphic, an interactive HTML graph or implemented in a graphical user interface [30].

### B. *Process Flow*

The process flow of TESCA is shown in Figure 2. The first step for conducting a TEA with TESCA is data input. Data required includes the start and end date for the simulation, load and generation profiles for the involved energies, market data such as day-ahead and intra-day electricity prices, grid tariffs, economic parameters such as CAPEX, OPEX, and balance of plant costs, and component parameters such as nominal power, capacity, and desired operation temperature. The system setup information is collated in a YAML [31] file – a text-based format that enables easy setup with minimal programming knowledge. This structure allows users to track previous decisions and effortlessly recreate scenarios. At this stage, an operation strategy must also be defined. This can either be algorithmic or based on linear optimizer (see section C).

Step 2 collates and composes the data from the previous step and runs the deterministic time-series technical simulation. This simulation loops through controlling the energy flows within the system using the operation strategy (subject to any time-dependent constraints on the components), and accordingly updating the state of the components (including their operating hours, temperature, and states of charge and health), and identifies when it is necessary to exchange (i.e. reinvest) components.

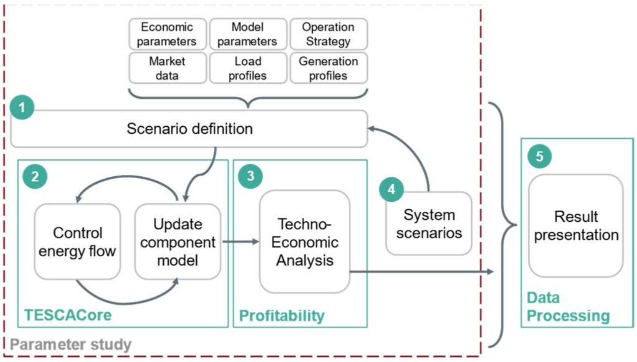

Figure 2. TESCA process flow and operating principle

In step 3, the simulation results are used for technical and economic analysis. The technical evaluation ensures that any desired boundary conditions of the system are met, and evaluates important per-component KPIs such as operating hours, full load hours, maximum power peaks, full charging cycles, component ageing times, and the dates of exchanging components. The economic evaluation takes data from step 1 such as CAPEX, OPEX, grid charges, energy costs, interest rates, CAPEX development, etc., and combines it with the power flows, simulated in step 2, to calculate the aforementioned KPIs.

Depending on the research question, the first three steps can be iterated for different system configurations and parameters, and the results collated (step 4). TESCA's performance enables the processing, evaluation and comparison of multiple scenarios, creating large parameter studies including ideal and non-ideal results. Within a parameter study, inputs such as the nominal power of the generation, or the power and capacity rating of the storage can be varied, one renewable energy source (RES) can replaced with another, or load profiles or energy tariffs can be changed, etc. Conducting multiple simulations and KPI calculations enables a better understanding of cost-benefit factors and influences, which can be analysed through sensitivity analysis and other analytical methods (step 5).

The economic KPIs of each scenario in such a parameter study provides the necessary information for informed plant design choices. This enables the identification of the best system configuration for a project's specific requirements. This may be done by comparing the ROI or NPV, but can also take into account technical KPIs such as the amount of grid dependency, or autarky level (self-sufficiency of electricity/hydrogen demand).

### C. *Operation Strategy*

The operation strategy, executed as part of step 2 (Figure 2), can be individually set by the user. It can be an algorithm, an energy flow optimisation or even use a neural network. TESCA provides an interface that allows the user to customise the operation strategy to suit the specific needs and constraints of the project. Objectives may incorporate self-consumption optimisation, peak shaving, load shifting, grid capacity limitations, energy market prices and differing market sectors such as the day-ahead market and intra-day market, as well as frequency restoration reserve and other grid balancing services. Different objectives and business models may be evaluated in stacks If an optimiser (e.g. IESopt [16]) is used, the optimiser can use the current state of each component at each time step, and accordingly constraint-optimise the power flows between the components, while also optimizing the grid consumption and grid feed-in based on the electricity stock prices, network charges, taxes and levies, among other constraints.

For performance reasons, optimizers used in conjunction with TESCA are typically linear optimisers, which means that the models within the optimizer are less detailed than TESCA's own model, with constant efficiencies, constant auxiliary losses and no component ageing implemented, or missing other model details. These differences may seem insignificant but accumulated over time they can lead to significant divergence between the components' states in the TESCA simulation and in the coupled optimizer. To prevent this, the optimizer can be run in "rolling mode", where model parameters are continuously updated and recalculated over time, ensuring that the optimizer adapts dynamically based on TESCA simulation data. This way, one can obtain refined simulation results from the more accurate (e.g. non-linear, physics-based) models that incorporate factors such as reduced-efficiency from aging, while following a meaningful operational strategy provided by the simpler linear optimizer. This allows the user to consider near-optimal power flows at high simulation speed without losing the necessary model detail required for TEA.

## III. Case study: TEA with TESCA

This section presents a demonstration of how TESCA operates, the type of results that can be expected, and how these results can be analysed. In 2022, a study for the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology was conducted, examining import options for green hydrogen to Austria [23, 24]. The study showed that out of eight possible production locations, Spain was expected to have relatively low hydrogen production costs, and moreover (due to the expected connection to the European Hydrogen Backbone [32]) the cheapest LCOH including transport to the Austrian border.

For this showcase, let us re-examine the scenario in the country (Spain) and location (Zaragoza) that can achieve the lowest LCOH at the Austrian border, incorporating both $H_2$ production costs in the country of origin and import costs. The operational strategy follows the approach from [23, 24], where photovoltaic (PV) and wind power plants generate electricity. The PV generation is converted to AC power, combined with wind generation, and fed into the electrolyser. Any excess power that cannot be utilized by the electrolyser is curtailed. Finally, the produced $H_2$ is transported to the Austrian border via a hydrogen pipeline (specifically the EU Hydrogen Backbone).

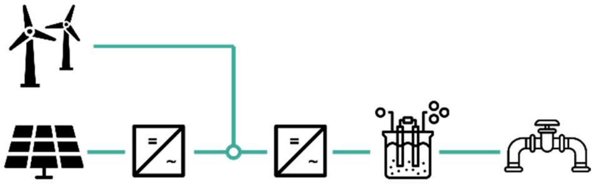

Figure 3. reference system setup.

## A. Input Data

We reanalyse $H_2$ generation using an updated PEM electrolyser model while maintaining the Spanish PV and wind power generation profiles from [23, 24]. The prior study utilized a PEM electrolyser model based on an efficiency curve correlating $H_2$ output with DC electricity input. In contrast, this present study employs an advanced empirical PEM electrolyser model [20]. The PEM electrolyser operates at a set-point internal temperature of 80°C, with a cooling system set to an outflow heat of 65°C (maintained by varying the cooling mass flow rate). This output is in principle suitable for residential hot water applications, or for heating residential buildings. This indicates an opportunity for integrating electrolyser waste heat into district heating systems, enhancing overall system efficiency and improving the economic viability of hydrogen production. However, in this study, the excess heat is considered only from a technical perspective and its potential utilization is not included in the economic analysis.

Consistent with the methodology in [23, 24], the total RES capacity is set at 250 MW, with the PV and wind shares varying across 11 scenarios (ranging from 0% to 100% PV in 10% increments). The nominal power of the PEM electrolyser is also varied between 250 MW (equal to the total RES capacity) and 10% of the RES capacity, leading to an extensive 11 × 10 parameter study. Cost parameters, including capital expenditures (CAPEX), operational expenditures (OPEX), and balance of plant (BoP), are taken from the “optimistic scenario 2040” in [23].

This updated analysis provides a refined assessment of the cost-effectiveness of hydrogen production and import, offering deeper insights into the role of advanced electrolyser modelling in optimizing green hydrogen supply chains.

## B. Result and Discussion

The analysis shows (Figure 4 LHS) that $H_2$ output increases as the share of PV power decreases and wind power increases. This is attributed to the higher FLH of wind power plants, which consequently lead to a higher FLH for the electrolyser. Additionally, $H_2$ output increases with the nominal capacity of the PEM electrolyser, as a larger electrolyser allows for greater hydrogen production while minimizing renewable energy curtailment.

A similar trend is observed in the LCOH (Figure 4 RHS). The lowest LCOH values of 2.69 €/kg are achieved with a 100% wind power share and an electrolyser capacity equal to the total RES capacity. However, the isolines indicate that LCOH do not follow a strictly linear correlation with $H_2$ production. While FLH and hydrogen output significantly influence the LCOH, other critical factors include electrolyser efficiency and (re)investment costs, both of which depend on the operational strategy and overall system configuration. As illustrated in Figure 4 RHS, the lowest LCOH values are concentrated along the diagonal between high electrolyser power and increasing PV share, highlighting the complex interplay between these variables in optimizing cost-effective hydrogen production.

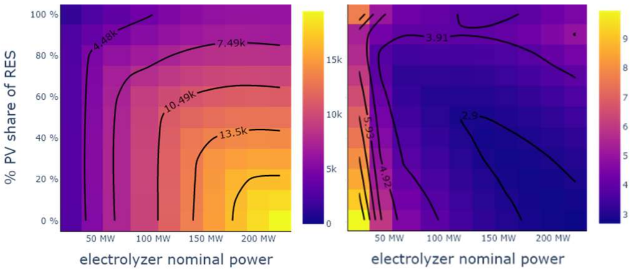

Figure 4. (left) hydrogen production (tons);
(right) LCOH (€/kg)

Figure 5 shows the LCOH cost breakdown for the scenario with the lowest LCOH, detailing the cost contributions from the $H_2$ pipeline, electrolyser, PV, and wind power plant. The largest cost components are the wind power plant (47.78%) and the electrolyser (44.8%).

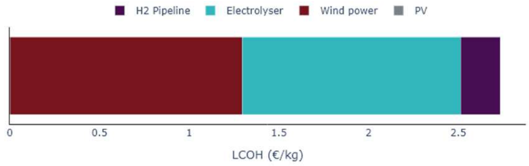

Figure 5. LCOH breakdown

Overall, the LCOH in this case study are lower than predicted by the original study [23], primarily due to the higher efficiency of the PEM electrolyser in the present model.

During the operation of the PEM electrolyser, cell resistance gradually increases, leading to a reduction in efficiency. Figure 6 illustrates the efficiency of the PEM electrolyser at different partial loads in the 1st, 5th, and 10th year of operation (assigning the output Hydrogen a calorific value of 39.39 kWh/kg). After 80.000 h of operation (its expected lifetime), the PEM electrolyser is replaced. In the first year, the maximum efficiency is 71.4%, occurring at a partial load of 83%. By the 5th year, the maximum efficiency decreases to 68.7%, with the optimal partial load shifting to 64.7%. After ten years, the maximum efficiency further declines to 66.2% at a partial load of 54.9%. This highlights both the overall reduction in efficiency and the shift in the efficiency curve over time, where the point of highest efficiency has moved to a lower power value – a nuanced parameter shift that TESCA can model, which linear models cannot. Over this period, a total efficiency loss of 5.25% points is observed. The mean efficiency follows a similar trend, starting at 66.2% in the first year, decreasing to 63.8% in the 5th year, and reaching a mean efficiency of 61.2% in the 10th year.

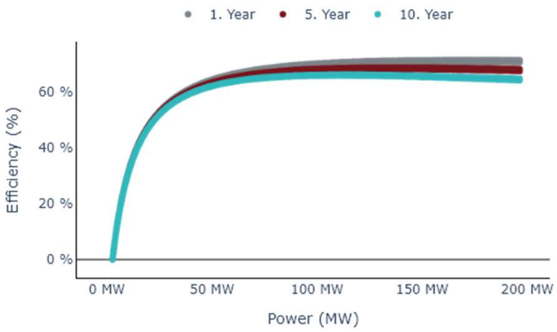

Figure 6. PEM efficiency loss during operation

The detailed PEM electrolyser model not only allows for an accurate assessment of $H_2$ production and efficiency degradation, but also enables the evaluation of excess heat utilization. Figure 7 shows the potential useful excess heat in MWh per month for the scenario with the lowest LCOH. The heat analysis reveals a relatively constant potential for heat recovery throughout the year, with a slight reduction during the winter months. Integrating this excess heat into a local heat distribution network could provide an additional revenue stream, further reducing the LCOH and enhancing the overall profitability of the hybrid power plant. While this study considers the technical aspects of heat production, future research could explore the economic impact of its utilization in greater detail, potentially improving the viability of green hydrogen production in integrated energy systems.

Figure 7. PEM excess heat potential at 65°C

## IV. Conclusion

This study highlights the importance of using a technically detailed simulation approach over traditional linear optimization methods when analysing complex hybrid power plants. While linear optimization models can efficiently determine cost-optimal configurations based on simplified assumptions, they often fail to capture the dynamic and non-linear behaviour of key system components, such as a PEM electrolyser. By integrating empirical and physics-based models with technology-specific data, real partial load behaviour, and ageing algorithms, TESCA provides a more accurate representation of system performance over time.

TESCA offers a unique integrated approach that combines detailed component-level simulations with linear optimisation for flexible operating strategies, and hence facilitates cost-optimised operation without compromising on important technical details. The described “rolling mode” iterative process ensures that optimization results align with the actual physical behaviour of system components. By continuously updating component states and feeding them back into the optimization process, TESCA enhances accuracy, optimizes efficiency, and improves decision-making about hybrid power plant design and operation.

The results of the example TEA demonstrate how these detailed simulations influence the predicted hydrogen production and the LCOH, particularly due to the shifting efficiency curve over the operational lifetime, which cannot be considered in linear models. Additionally, the ability to model curtailment, thermal byproducts, and the interactions between renewable energy generation and electrolyser operation enables a more comprehensive assessment of system feasibility, including potential synergies with district heating applications, which could further enhance the economic viability of green hydrogen production.

Ultimately, while linear optimization remains valuable for high-level economic assessments and scenario comparisons, integrating detailed simulations leads to more robust, realistic insights, helping to bridge the gap between theoretical feasibility and practical implementation.

## ACKNOWLEDGEMENT

This study has received support from the Horizon Europe project TwinVECTOR, funded by the European Union (Grant Agreement No. 101078935).

## References

[1] IEA, *Global Energy and Climate Model.* Paris: IEA, 2024. [Online]. Available: https://www.iea.org/reports/global-energy-and-climate-model

[2] "ALRIGH2T - liquid hydrogen aircraft," *alrigh2t*, 19 Mar., 2024. https://alrigh2t.eu/ (accessed: Jan. 22 2025).

[3] *Transparent AI Forecasts for Green Energy in Austria.* [Online]. Available: https://transpairent.energy/ (accessed: Jan. 22 2025).

[4] *Austrian DC Pilot Factory - NEFI.* [Online]. Available: https://www.nefi.at/de/projekt/austrian-dc-pilot-factory (accessed: Jan. 22 2025).

[5] *cells4.energy.* [Online]. Available: https://projekte.ffg.at/projekt/4849884 (accessed: Jan. 22 2025).

[6] *EEGas.* [Online]. Available: https://projekte.ffg.at/projekt/4805451 (accessed: Jan. 22 2025).

[7] EU-Project Twinvector, *EU-Project Twinvector.* [Online]. Available: https://twinvector.eu/ (accessed: Jan. 22 2025).

[8] *HyCentA COMET-Zentrum Area 2; P2.1 HyDestiny & P2.4 HyEmpire.* [Online]. Available: https://www.hycenta.at/comet-zentrum/green-energy-and-industry (accessed: Jan. 22 2025).

[9] HYPERRIDE, *Home - HYPERRIDE.* [Online]. Available: https://hyperride.eu/ (accessed: Jan. 22 2025).

[10] Klima- und Energiefonds, *H2Real – Klima- und Energiefonds.* [Online]. Available: https://www.klimafonds.gv.at/projekt/h2real/ (accessed: Jan. 22 2025).

[11] *plan4 - Energie Kompass GmbH.* [Online]. Available: https://www.plan4.energy/ (accessed: Jan. 22 2025).

[12] Reformers Energy Valleys, *Regional Ecosystems FOR Multiple-Energy Resilient Systems.* [Online]. Available: https://reformers-energyvalleys.eu/ (accessed: Jan. 22 2025).

[13] *SETHub.* [Online]. Available: https://projekte.ffg.at/projekt/4805446 (accessed: Jan. 22 2025).

[14] Y. Wimmer and Daniel Schwabeneder, Michael Niederkofler, Patrizia-Ilda Valentini, "The plan4.energy Approach for Planning Support for Positive Energy Districts," in *Energy Informatics Review: DACH+ Conference on Energy Informatics Special Issue*, ACM SIGENERGY, Ed., 2024, pp. 111–117.

[15] M. Thirunavukkarasu, Y. Sawle, and H. Lala, "A comprehensive review on optimization of hybrid renewable energy systems using various optimization techniques," *Renewable and Sustainable Energy Reviews*, vol. 176, p. 113192, 2023, doi: 10.1016/j.rser.2023.113192.

[16] S. Strömer and K. Maggauer, "IESopt: A Modular Framework for High-Performance Energy System Optimization," in *2024 Open Source Modelling and Simulation of Energy Systems (OSMSES)*, Vienna, Austria, Sep. 2024 - Sep. 2024, pp. 1–6.

[17] Corina Theresa Schwarz, Judith Kapeller, Yannick Wimmer, "Techno-economic modelling of stationary energy storage systems with focus on temperature's influence on aging," 2023.

[18] C. Schwarz, "Techno-economic evaluation of stationary energy storage systems with focus on temperature's influence on aging," 2022.

[19] A. Fazeli *et al.,* "A Techno-economic Investigation for the Application of Second-Life Electric Vehicle Batteries for Behind-The-Meter Services," in *2021 IEEE Electrical Power and Energy Conference (EPEC)*, Toronto, ON, Canada, 2021, pp. 20–27.

[20] Natalie Frassl, Yannick Wimmer, J. Kapeller, and K. Maggauer, "Optimizing large-scale PEM electrolysis for green hydrogen production: a comprehensive techno-economic study case," in *NEFI New Energy for Industry (Hg.) 2024 – Conference Proceedings NEFI NEW ENERGY*, pp. 17–19. Accessed: Jan. 22 2025.

[21] N. Frassl, N. R. Sistani, Y. Wimmer, J. Kapeller, K. Maggauer, and J. Kathan, "Techno-economic assessment of waste heat recovery for green hydrogen production: a simulation study," *Elektrotech. Inftech.*, vol. 141, no. 5, pp. 288–298, 2024, doi: 10.1007/s00502-024-01231-y.

[22] Davide Tommasini et al, "Electrolysis waste heat utilization for district heating – a Norwegian case study," in.

[23] Johannes Kathan *et al.,* "Importmöglichkeiten für erneuerbaren Wasserstoff," Wien, 2022. [Online]. Available: https://www.bmk.gv.at/themen/energie/publikationen/importmoeglichkeiten.html

[24] Judith Kapeller, Stefan Reuter, and Philipp Ortmann, "Zusatzbetrachtung zur Studie Importoptionen für erneuerbaren Wasserstoff," Wien, 2023.

[25] Jürgen Zajicek, Judith Kapeller, and Klara Maggauer, "ATHU114 LOW CARB MOBILITY Anforderungen an die Energiewirtschaft für alternative Antriebe im öffentlichen Verkehr," 2022. [Online]. Available: https://www.vor.at/fileadmin/CONTENT/Bilder/Projekte/ATHU114_Low_Carb_Mobility_Endbericht_Energiewirtschaft_extern.pdf

[26] A. Patha, S. Steinlechner, J. Kathan, A. Golab, and J. Auer, "Techno-Economic Assessment of Pumped Storage Hydro Power in Hybrid Operation with Floating Photovoltaic and Battery Energy Storage," (in en), *41st European Photovoltaic Solar Energy Conference and Exhibition*, 2024, doi: 10.4229/EUPVSEC2024/5DV.2.20.

[27] Andreas Patha, Johannes Kathan, Judith Kapeller, Stefan Reuter, Philipp Ortmann, and Christoph Zauner, "Techno-Economic Assessment Of Production And Transport Of Synthetic Methane From PV And Wind Energy," (in Englisch), *Proceedings of the International Renewable Energy Storage and Systems Conference (IRES 2023)*, 2024. [Online]. Available: https://publications.ait.ac.at/de/publications/techno-economic-assessment-of-production-and-transport-of-synthet

[28] Lukas Eßletzbichler, *Modeling compressed gas hydrogen storage for techno-economic assessment of green hydrogen production in hybrid power plants*. currently under development. Vienna: TU Vienna.

[29] K. Maggauer and B. Fina, "Monte Carlo simulation-based economic risk assessment in energy communities," *Energy Reports*, vol. 13, pp. 987–1003, 2025, doi: 10.1016/j.egyr.2024.12.046.

[30] Judith Kapeller, "D3.2 Component Sizing Tool," 2021. [Online]. Available: https://hyperride.eu/resources/

[31] Oren Ben-Kiki, Clark Evans, Ingy döt Net, *YAML Ain't Markup Language (YAML™) revision 1.2.2.* [Online]. Available: https://yaml.org/spec/1.2.2 (accessed: Feb. 5 2025).

[32] Robert Slowinski, Yasin Sagdur, Rik van Rossum, and Alex Kozub, *European Hydrogen Backbone: IMPLEMENTATION ROADMAP — CROSS BORDER PROJECTS AND COSTS UPDATE.* [Online]. Available: https://ehb.eu/files/downloads/EHB-2023-Implementation-Roadmap-Part-1.pdf