A Data-Driven Simulation-Based Case Study of The Green Village's Hybrid Energy Hub

Schat, D.; Kermansaravi, A.; Trigt, L. Van; Zee, A. Van Der; Taheri, S.; Vahedi, H.

DOI
10.1109/IECON58223.2025.11221847

Publication date
2025

Document Version
Final published version

Published in
Proceedings of the IECON 2025 – 51st Annual Conference of the IEEE Industrial Electronics Society

Citation (APA)
Schat, D., Kermansaravi, A., Trigt, L. V., Zee, A. V. D., Taheri, S., & Vahedi, H. (2025). A Data-Driven Simulation-Based Case Study of The Green Village's Hybrid Energy Hub. In *Proceedings of the IECON 2025 – 51st Annual Conference of the IEEE Industrial Electronics Society* (IECON Proceedings (Industrial Electronics Conference)). IEEE. https://doi.org/10.1109/IECON58223.2025.11221847

A Data-Driven Simulation-Based Case Study of The Green Village's Hybrid Energy Hub

Daan Schat[1], Azadeh Kermansaravi[1], Lidewij van Trigt[2], Arnoud van der Zee[2],
Shamsodin Taheri[3], *Senior Member, IEEE*, Hani Vahedi[1], *Senior Member, IEEE*

[1]Faculty of Electrical Engineering, Computer Science and Mathematics, Delft University of Technology, The Netherlands
[2]The Green Village, Delft University of Technology, The Netherlands
[3]Université du Québec en Outaouais, Canada
d.o.schat@student.tudelft.nl, {z.kermansaravi, l.vanTrigt, a.e.vanderzee, h.vahedi}@tudelft.nl, shamsodin.taheri@uqo.ca

IECON 2025 – 51st Annual Conference of the IEEE Industrial Electronics Society | 979-8-3315-9681-1/25/$31.00 ©2025 IEEE | DOI: 10.1109/IECON58223.2025.11221847

***Abstract*—This paper presents a simulation-based case study of a hybrid energy hub located at The Green Village (TGV), a living lab for sustainable innovations in Delft, The Netherlands. The energy hub integrates photovoltaic (PV) generation, battery storage, hydrogen production, seasonal storage, and usage to provide a fully electrified one-person residence, serving as a realistic testbed for the integration of renewable energy. A model of the hub is developed in Simulink/Matlab using historical operational data to simulate system behaviour under various edge case scenarios and system configurations. The model enables the evaluation of system-level interactions, operational strategies, and the impact of design choices on energy efficiency, self-sufficiency, and hydrogen integration. The simulation results show the sensitivity of the system performance to component sizing and EMS settings. This study provides valuable insights into the control and optimisation of The Green Village's energy hub and its integrated energy systems, contributing to the practical deployment of resilient and sustainable energy hubs in the built environment.**

***Index Terms*—Energy hub, Model, Hybrid, Hydrogen, Fuel Cell, Electrolyser, The Green Village, Residential, Built Environment**

I. INTRODUCTION

The global transition towards a low-carbon energy system has increased interest in hybrid energy hubs that combine multiple energy carriers, such as electricity, heat, and hydrogen, in order to improve flexibility, efficiency, and self-sufficiency. Energy hubs can enable year-round balancing of renewable energy sources, storage systems, and end-user demand. The design and operation of such systems are complex due to the dynamic interactions between components. By simulating different system sizes and demand conditions, insights into how the energy hub performs are given, enabling more informed system sizing decisions [1], [2].

This paper presents a simulation-based case study of the energy hub located at The Green Village that integrates off-the-shelf components for solar photovoltaics (PV), battery storage, an electrolyser, hydrogen storage, and a fuel cell to cover the residential load within an experimental district.

Comparable projects exist globally, but often differ in goals or implementation. For example, the Hopewell Project in New Jersey also demonstrates residential green hydrogen use, where a full hydrogen loop is built, producing hydrogen from solar energy. Being fully disconnected from the grid, it is one of the first examples in the world where such a system is realised. The Hopewell hydrogen house project includes 10 kWp of solar energy generation, with the excess energy used to produce hydrogen. When power is demanded from the system, a 6.8 kW fuel cell is run as a battery charger. The hydrogen integration and residential character of the system make it very comparable to that of TGV energy hub. However, hydrogen is stored in a much larger volume of 37 854 L as no high-pressure storage is used. Because of this, the large storage space can approximately store 1450 kW h of energy in the form of hydrogen, which differs from TGV's energy hub. Like TGV energy hub, it does use batteries for day-to-day energy storage in between the hydrogen cycle [3].

Meanwhile, the H2@Scale initiative in Texas integrates hydrogen into a small-scale testbed with a focus on industrial and mobility applications, diverging from the Green Village's emphasis on residential energy provision [4]. Multiple renewable hydrogen production techniques, such as wind and solar power electrolysis, as well as SMR, are applied at the H2@Scale project.

In addition, larger applications of hydrogen as an energy carrier or as feedstock are being deployed. For example, the HEAVENN project in the Northern Netherlands represents one of Europe's largest integrated hydrogen value chains, combining production, storage, distribution, and end-use in industry, transport, and the built environment [5]. In contrast to the localised and experimental nature of the TGV energy hub, HEAVENN incorporates large-scale renewable generation and hydrogen pipelines for a hydrogen-based economy, highlighting the scalability of hydrogen integration.

Another initiative is Hydrogen Valley Europe, a European Commission platform that maps ongoing hydrogen ecosystem projects across Europe [6]. These valleys represent medium to large-scale hubs where hydrogen is used in multiple sectors simultaneously, from public transport to industrial clusters. Such efforts provide another way to see larger-scale projects, or not even fully integrated hydrogen systems, in microgrids such as the Green Village.

Together, these projects show a spectrum of hydrogen applications from self-sufficient residential pilots such as the Hopewell Project and TGV's hub, to regional and industrial-scale systems. This comparison underscores the role of small-scale energy hubs as both testbeds and stepping stones toward broader hydrogen integration.

II. THE GREEN VILLAGE'S HYBRID ENERGY HUB

The Green Village's 24/7 energy hub, as shown in Figure 1, uses PV power as a means of local renewable energy generation. The excess in PV energy is stored in a battery for short-term storage. The battery is connected to an inverter, which supplies all electricity demands of a small one-person fully-electrified residence. This is achieved by incorporating two main energy storage technologies, designed to be available year-round with the available PV energy. When enough solar power is available and the battery is charged, an electrolyser is turned on, which produces green hydrogen from water through electrolysis. The hydrogen is pressurised by an electrochemical compressor and stored as a gas in high-pressure gas cylinders for long-term energy storage. When not enough power generation has been available for some time, such as during winter, a fuel cell is turned on to generate electricity from the stored hydrogen.

Fig. 1. The Green Village's 24/7 Energy hub

The Green Village Energy Hub is designed to be an experimental energy system that explores the integration of hydrogen with renewable energy sources, with innovative and upcoming technologies regarding the hydrogen cycle, involving the AEM electrolyser and electrochemical compressor, specifically using off-the-shelf components.

The energy hub exists to address key challenges in the integration of renewable energy and hydrogen, particularly by investigating the intermittency and storage of renewables. From the energy hub, a leading example for future hydrogen energy systems, it is aimed to learn more about how to integrate hydrogen regarding technical and regulatory constraints to serve such future energy systems with the necessary background information [7].

A. System Integration

Figure 2 shows a schematic of the energy hub's component integration. The system begins at the photovoltaic (PV) panels, where solar irradiance is converted into DC electricity. This variable DC output is fed into a SolarEdge MPPT inverter, which tracks and extracts the maximum available power. The original design specifies a peak solar capacity of 6 kWp, with any remaining required capacity virtualised. The battery connects to the grid via a Victron inverter/charger, with both electricity supply and demand represented virtually, rather than through hardwiring. It supports daily household electricity needs and provides a stable power supply for the electrolyser and Balance of Plant (BoP). This decoupling from PV generation allows the electrolyser to operate more efficiently, leading to higher hydrogen yields, as shown in [8]. The electrolyser uses electricity to split water into hydrogen and oxygen (as a by-product). To allow sufficient storage within the spatial limits of the system, hydrogen is compressed using an electrochemical compressor capable of up to $410\,\mathrm{bar}$ and $2\,\mathrm{kg/d}$ throughput. The compressed hydrogen is stored in 53 steel cylinders of $50\,\mathrm{L}$ each, rated for a maximum pressure of $270\,\mathrm{bar}$. Using the van der Waals equation with $\mathrm{a} = 0.2476\,\mathrm{L^2\,bar/mol^2}$ and $\mathrm{b} = 0.026\,61\,\mathrm{L/mol}$, the total hydrogen storage capacity is approximately $45.1\,\mathrm{kg}$ [9].

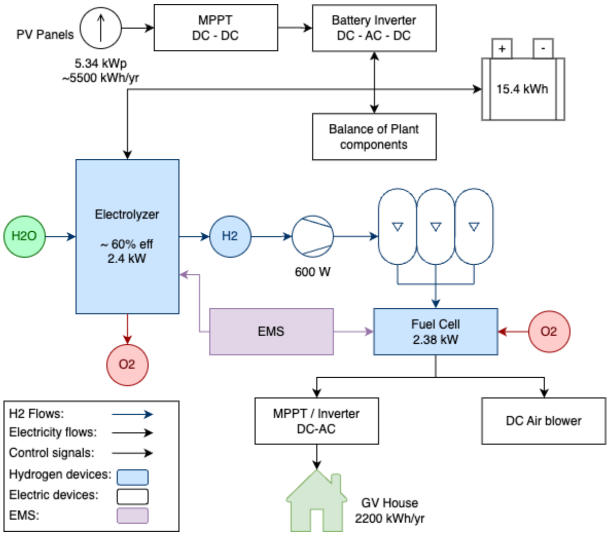

Fig. 2. The Green Village Energy Hub - Setup overview.

When the electrolyser is turned on, a warming-up cycle is first started to heat up the electrolyser, after which the electrolyser will start to produce hydrogen. The electrolyser has a maximum hydrogen flow output of $500\,\mathrm{NL/h}$ [10]. In order to store the hydrogen at higher pressures, an electrochemical compressor from HyET is used to compress the hydrogen. This compressor has a maximum throughput of $2\,\mathrm{kg/d}$, with a maximum power draw of $700\,\mathrm{W}$, which can increase the pressure to a maximum of $410\,\mathrm{bar}$ [11].

During winter, or when the solar generation is insufficient to charge the battery, a fuel cell is used to generate electricity from the stored hydrogen. Specifically, the Nedstack FCS 7-XXL PEM fuel cell stack, which is capable of generating a maximum electrical power of $6.8\,\mathrm{kW}$ at a hydrogen flow of $77\,\mathrm{NL/min}$. At this hydrogen flow, an air supply of $366\,\mathrm{NL/min}$ is needed [12]. Although this fuel cell is theoretically capable of operating at different rates, it is configured to output only a steady rate of 2.3 kW (70 A set point) as the fuel cell is intended as a battery charger and would not have to accommodate sudden load spikes, so no larger than necessary BoP electronics are needed.

The fuel cell is connected to an MPPT solar charge controller to convert the slightly varying DC fuel cell output power to a steady DC voltage that can be inverted by the Victron Multiplus-II inverter. The fuel cell's MPPT is directly connected to a small battery, which acts as a voltage reference point. A blower is directly connected to the fuel cell's stack to supply the fuel cell with air. With the efficiencies and self-consumption of the components above the inverter, the inverter supplies a remainder of 1.8 kW AC to the system.

Wintersol provided an initial analysis of the fuel cell's performance based on information provided by the manufacturer and data collected during normal fuel cell operation. [13] States that for the Nedstack fuel cell, a minimum of 13% of the rated current output should be used. This means that a minimum of about 30 A should be provided by the fuel cell at a voltage of about 40 V i.e. 1200 W.

In order to prevent and limit the wear of the fuel cell and ensure longevity, [14] evaluates PEM fuel cell degradation mechanics, which resulted in the contribution of degradation by load changes during operation (56.5%), start-stop procedures (33.0%), operation at maximum power (5.0%), and idling conditions (4.7%). The optimisation report on the energy hub system [15], written by the project's engineer, mentions the fuel cell's balance of plant power-consuming components. Including a DC Air blower (220 W), hydrogen recirculation pump (58 W), coolant pumps (45 W), and a PLC and instruments (35 W), which amounts to a total added power consumption of 328 W.

B. Energy Management System

The system is controlled by a rule-based basic energy management system (EMS). This EMS controls the electrolyser and fuel cell depending on the battery's state of charge (SoC), available solar power, and time. During summer, which in this case is defined from March 15th to October 15th, the electrolyser will be mostly operational, and during winter, the fuel cell will be mostly operational. When plenty of PV power is available, the SoC is higher than 80%, and the time is before 12:00, the electrolyser will start to produce hydrogen. Then, when the battery SoC drops below 65%, or the PV power is less than 50 W, the electrolyser turns off. When the electrolyser is started, the production rate depends on the SoC of the battery. When the battery SoC is less than 80%, the production rate is set at a constant of 60%, which is the minimum production rate that the electrolyser is able to operate in. When the battery SoC is between 80 and 90%, the production rate changes linearly from 60 to 100%. When the battery SoC is more than 90%, the electrolyser is set to operate at a constant production rate of 100% [15].

During the winter, the fuel cell will be mostly operational. The fuel cell begins converting hydrogen to electricity when different combinations of time and SoC are true, and stops electricity generation when the SoC of the battery is higher than 95%. When the battery capacity is below 25% at any point in time, the fuel cell will also start.

III. REPLICATIVE MODEL OF A HYBRID ENERGY HUB

The primary goal for developing the model is to enhance the understanding of the energy hub's operation and facilitate data-driven decision-making for current energy hub improvements, future energy hubs, and expansion. It allows for scenario and component testing without disrupting physical infrastructure or experimenting with expensive devices. This makes a that a model of such energy hubs can be used as a helpful tool to assess system efficiency, forecast energy flows, and explore different integration strategies and components sizes for the critical components.

The model is built in Simulink using historical data collected from sensors within The Green Village's energy hub, datasheets, and the open-meteo API for weather data, [16], [17], [18], [19]. The development process involves data preprocessing, visualisation, measuring, and model validation against measured system behavior. Key components such as PV generation, battery storage, hydrogen electrolyser, and fuel cells are modelled based on available data and system specifications.

The model is structured with the following components and focuses on energy flows within the energy hub. Key system setup sections include:

- Energy generation (PV panels, grid connection)
- Energy storage (Battery, hydrogen storage)
- Energy conversion (Electrolyser, fuel cell, power converters)
- Control (Energy management systems, operational constraints)

The system operates within a Simulink/Matlab simulation environment that updates based on the main inputs of the model; Number of PV panels, Battery capacity, Hydrogen buffer capacity, Yearly (electric) energy demand, Electrolyser power consumption and hydrogen production, Fuel cell power generation and hydrogen consumption, Various EMS parameters, and Various BoP power consumption levels.

A. Comparison & Validation

The model's accuracy is evaluated by comparing its simulated outputs with real operational data from The Green Village's energy hub, using visual inspection and metrics like efficiency and accumulated energy. This validation confirms the model captures essential dynamics such as power flows, hydrogen production, and storage behavior. Historical data is used to assess performance under different conditions.

The electrolyser operates based on a rule-based energy management system, with power consumption and hydrogen flow rates showing similar trends in both the model and real system, especially across varying solar availability.

The fuel cell follows a fixed profile: ramp-up, constant power, and ramp-down. During constant operation, both modelled and real fuel cell outputs average $1.8\,\mathrm{kW}$ AC.

A key period with mostly available real data is January 2025, when the fuel cell had just become operational. At this time, the hydrogen buffer started at 50 percent capacity. Setting the model to the same level allowed comparison of battery and hydrogen buffer states of charge, shown in Figure 3 and Figure 4. Despite some missing data due to a technical issue, both model and real data show the hydrogen buffer depleting at a similar rate and reaching empty on January 23rd. Overall, the model closely follows the real system's behavior during this month.

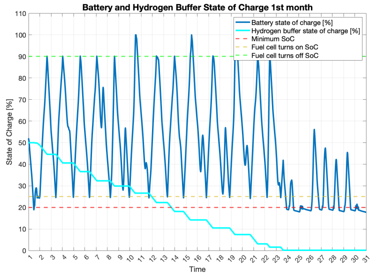

Fig. 3. Model's first month's behaviour.

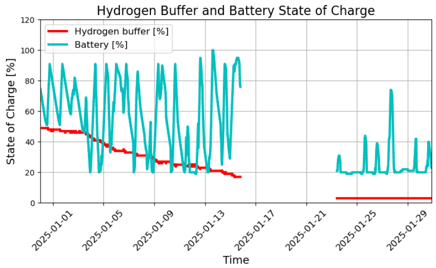

Fig. 4. Real energy hub's first month's behaviour.

IV. SIMULATION RESULTS

With the model now validated, it serves as a valuable tool for analysing system behaviour and testing setups for similar energy hubs. Simulations of the current hub ($2200\,\mathrm{kWh}$ annual demand, $5102\,\mathrm{kWh}$ PV yield) showed an electrolyser efficiency of 48.0% (with compressor) and a fuel cell efficiency of 39.6% (including critical BoP). Over the year, $49.3\,\mathrm{kg}$ of hydrogen was used, while only $25.3\,\mathrm{kg}$ was produced, leading to a shortfall and $655.1\,\mathrm{kWh}$ drawn from the grid. Meanwhile, $770.1\,\mathrm{kWh}$ was exported due to PV surplus. By year-end, the hydrogen buffer was empty.

A. Multiple Sizes Testing

Removing hydrogen capacity limits reveals the total potential hydrogen demand under the current setup. In this case, no grid energy is needed, but $109.3\,\mathrm{kg}$ of hydrogen is consumed—over twice the current capacity. With only $25.1\,\mathrm{kg}$ produced annually, this demand is costly and unrealistic, as the electrolyser can produce about $1.1\,\mathrm{kg/d}$ if run continuously, which is not practical.

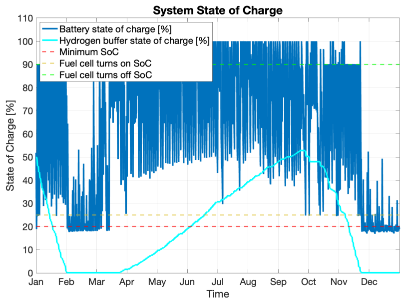

Fig. 5. Model simulations under TGV's setup: State of charge of battery and hydrogen buffer.

Through simulations without hydrogen integration, it has been shown that lower grid energy use and higher energy export are achieved compared to the current hybrid system.

Next, three tests are run for different amounts of solar panels (15, 18, and 21) and battery capacities ($7.68\,\mathrm{kWh}$, $15.36\,\mathrm{kWh}$, and $30.72\,\mathrm{kWh}$). The results of the simulations are visualised, including varying parameters for the number of PV panels and battery capacity on the X and Y axes. These results are given in Figure 6 and Figure 7. The aim is to minimise the pulled and delivered grid energy and maximise hydrogen production, hydrogen consumption is expected to also increase as more hydrogen is available as for the first iteration of the energy hub not enough hydrogen was produced.

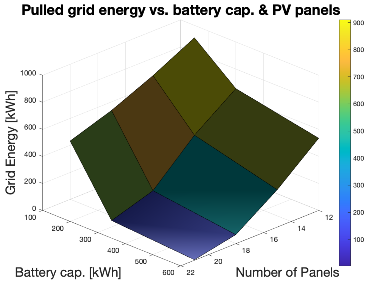

Fig. 6. Results of the energy hub sizing for pulled grid power with battery capacity from 150 to 600 A h and 12 to 21 PV panels.

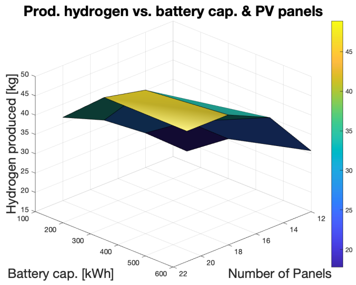

Fig. 7. Results of the energy hub sizing for produced hydrogen in kg with battery capacity from 150 to 600 A h and 12 to 21 PV panels.

From these results, it can be learned that generally increasing the battery capacity size decreases the energy exchange between the grid (delivered and pulled), and typically, hydrogen production and consumption increase with battery capacity; the consumption increases likely due to the larger availability of hydrogen. The increase in the number of PV panels logically increased the PV energy production, increased energy delivered to the grid, and decreased energy pulled from the grid. The addition of PV panels also increased hydrogen consumption and production.

B. Multiple EMS Testing

To enhance the performance of the energy hub, the Energy Management System (EMS) is tested with different values for its settings. The focus of this phase is to evaluate how altering key control conditions affects system behaviour and hydrogen yield and usage. The parameters tested are the electrolyser starting and stopping conditions 'start before' time, minimum battery SoC (at start before time), and shutdown battery SoC. Figure 8 and Figure 9 give a visualisation of the results. It can be observed that generally increasing the allowable starting state of charge of the battery decreased grid energy exchange, with the exception of delivered energy to the grid, which is better for a starting SoC of 70%. This is likely due to the fact that starting earlier will generally pull more solar panel power as the battery is reaching 100% SoC at a later time. Increasing the hour from which the electrolyser is allowed to start during that day also decreases the energy exchange with the grid.

The produced and consumed hydrogen both increase for a later starting hour (15:00) and higher starting SoC, with the greatest hydrogen production being at a starting SoC of 70%. Therefore, a starting condition of 70% until 15:00 is noted to be the best combination within these results.

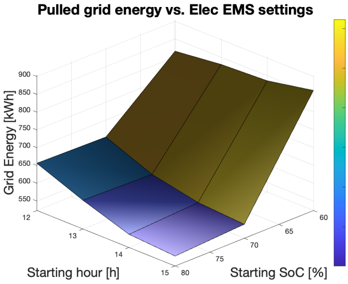

Fig. 8. Results of the EMS electrolyser parameters for pulled grid power with starting hours from 12:00 to 15:00 and state of charge from 60 to 80%.

With the best electrolyser starting conditions, the stopping condition of the state of charge is examined. The goal is to produce as much hydrogen as possible without needing to resort to pulling power from the grid and or turning on the fuel cell the same day. The results for grid energy exchange and produced and consumed hydrogen are given in Figure 10, Figure 11. From the results, it can be noted that larger values for the stopping SoC condition of the electrolyser lead to lower grid energy exchange and larger hydrogen production and consumption.

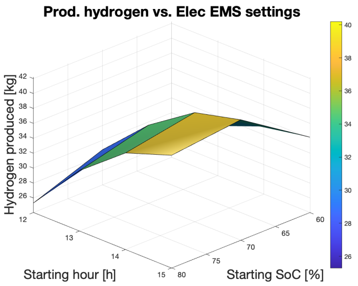

Fig. 9. Results of the EMS electrolyser parameters for produced hydrogen with starting hours from 12:00 to 15:00 and state of charge from 60 to 80%.

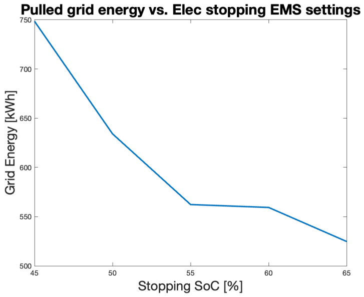

Fig. 10. Results of the EMS electrolyser parameters for pulled grid power with stopping state of charges from 45 to 65%.

Different starting and stopping conditions for the fuel cell are tested, focusing on battery SoC thresholds to reduce unnecessary hydrogen consumption. The tested SoC values are listed below.

The impact of these settings on grid energy exchange and hydrogen flows is shown in Figure 12 and Figure 13. Results indicate minimal influence on grid exchange and no notable differences in hydrogen production or consumption across the tested conditions. The optimal setting, based on the lowest grid energy exchange, is starting the fuel cell at 15% SoC and stopping at 70%.

C. The Improved Energy Hub

To improve the energy hub, some key changes to the system size and EMS have been made. These changes should at least make it possible to go year-round with the hydrogen buffer (starting at 50% and ending up at roughly 50%). The test setup

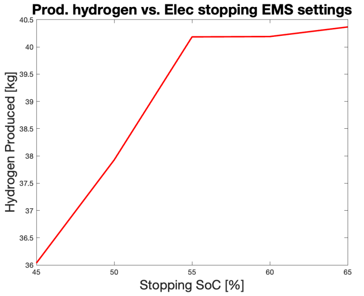

Fig. 11. Results of the EMS electrolyser parameters for produced hydrogen with stopping state of charges from 45 to 65%.

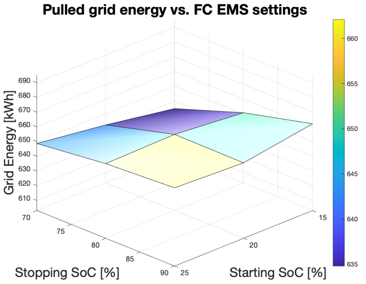

Fig. 12. Results of the EMS fuel cell parameters for delivered grid power with starting and stopping fuel cell parameters.

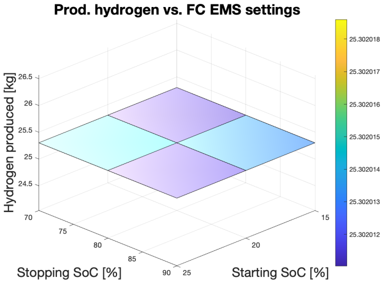

Fig. 13. Results of the EMS fuel cell parameters for delivered grid power with starting and stopping fuel cell parameters.

changes are an increase of power generation to 19 PV panels, a larger battery capacity of 30.72 kWh, and EMS settings from the results mentioned before. The total hydrogen capacity is increased to 70 kg and a starting hydrogen capacity of 25 kg, which are also results of other tests.

From the simulation, the state of charge of the energy hub is plotted and given in Figure 14. This iteration of the improved energy hub ticks the boxes of the criteria for the energy hub. With 19 PV panels of 445 Wp, resulting in a peak solar generation of 8.46 kWp, a hydrogen buffer of 70 kg, and a starting hydrogen capacity of 25 kg, the system is able to go year round whilst using only 30 kWh of grid energy and delivering only 380 kWh. Moreover, the energy hub in this configuration produces slightly more hydrogen than it uses.

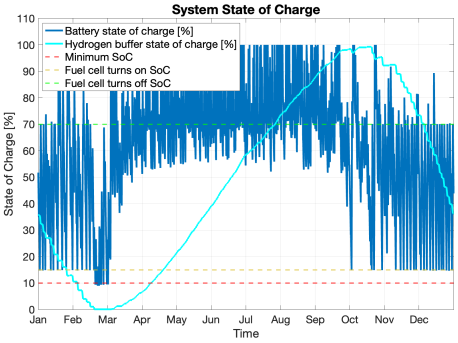

Fig. 14. System SoC results of the energy hub simulations with improved parameters.

V. DISCUSSION AND CONCLUSION

This study developed a model of TGV's energy hub to evaluate system configurations and EMS strategies. Simulations showed the current setup (5.34 kWp PV, 15 kWh battery, 48 kg H2) is too small for year-round autonomy. A larger setup (8.46 kWp, 30 kWh, 70 kg H_2) with improved EMS enabled nearly full off-grid operation. The system is sensitive to PV input and demand, highlighting the importance of reliable renewables and smart control. Performance can be improved through better sizing and EMS logic, especially around electrolyser use and SoC thresholds.

Future work should explore real-time digital twin integration, EMS optimisation, detailed component models, and broader scenarios.

REFERENCES

[1] S. A. Bonab, T. Waite, W. Song, D. Flynn, M. Yazdani-Asrami, "Machine learning-powered performance monitoring of proton exchange membrane water electrolyzers for enhancing green hydrogen production as a sustainable fuel for aviation industry," in Energy Reports, vol. 12, 2024, Pages 2270-2282

[2] R. S. Deshmukh, G. Rituraj, P. Bauer, H. Vahedi, "Real-time digital twin implementation of power electronics-based hydrogen production system," in Energy Reports, Vol. 13, 2025, pp. 5006-5015.

[3] Hydrogen House Project, "Hydrogen House Project: Educating the public on the use of hydrogen as an energy solution," 2025. [Online]. Available: https://hydrogenhouseproject.org/index.html

[4] Ivy SADS, "H2@Scale Project in Texas: A case study," Ivy SADS, 2023. [Online]. Available: https://ivysads.com/case-study/h2scale-project-in-texas

[5] HEAVENN Consortium, "HEAVENN: Hydrogen Energy Applications in Valley Environments for Northern Netherlands," 2023. [Online]. Available: https://heavenn.org

[6] Hydrogen Valley Platform, "Hydrogen Valleys: Mapping EU hydrogen projects," European Commission, 2024. [Online]. Available: https://hydrogenvalley.eu

[7] The Green Village, "24/7 Energy Hub," Delft University of Technology, 2025. [Online]. Available: https://www.thegreenvillage.org/24-7-energy-hub/

[8] D. Schat, "Thesis - H2 Integration into Residential Energy Hub - Electrolyser and Compressor Data Analysis," Delft University of Technology, Tech. Rep., 2024.

[9] J. Busrup, "SHPLES WP1.4 - System-wide analysis focused on balance and efficiency," Wintersol Energy, Tech. Rep.

[10] Enapter, "Electrolyser EL 2.1," Tech. Rep.

[11] HyET Hydrogen, "HyET Hydrogen Compression and Purification Systems," www.hyethydrogen.com, Version BI1207, Arnhem, The Netherlands, 2020.

[12] Nedstack, "Product Data Sheet FCS Nedstack 7-XXL Gen 2.9," Nedstack Fuel Cell Technology, Tech. Rep., Jul. 2022.

[13] J. Bosrup, Wintersol Energy, The Green Village, De Haagsche Hogeschool, and Nedstack, "SHPLES WP1.1 - Electrolyser and fuel cell behavior in a variable power supply system," Wintersol Energy, Tech. Rep.

[14] P. Pei, Q. Chang, and T. Tang, "A quick evaluating method for automotive fuel cell lifetime," Int. J. Hydrogen Energy, vol. 33, no. 14, pp. 3829–3836, 2008. doi: 10.1016/J.IJHYDENE.2008.04.048.

[15] J. Bosrup, "SHPLES WP1.2 - System analysis and hardware optimization of hydrogen storage systems," Wintersol Energy, Tech. Rep.

[16] P. Zippenfenig, "Open-Meteo.com Weather API," Open-Meteo, 2023. doi: 10.5281/zenodo.7970649. [Online]. Available: https://open-meteo.com/

[17] S. Schimanke et al., "CERRA sub-daily regional reanalysis data for Europe on single levels from 1984 to present," ECMWF, 2021. [Online]. Available: https://cds.climate.copernicus.eu/doi/10.24381/cds.622a565a

[18] J.-N. Thépaut et al., "ERA5 hourly data on single levels from 1940 to present," ECMWF, 2023. [Online]. Available: https://cds.climate.copernicus.eu/doi/10.24381/cds.adbb2d47

[19] J. Muñoz Sabater, "ERA5-Land hourly data from 2001 to present," ECMWF, 2019. [Online]. Available: https://cds.climate.copernicus.eu/doi/10.24381/cds.e2161bac