A Case Study: Cook Islands

Motu Beachfront Villas Resort

The German New Zealand Chamber of Commerce

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The GNZCC is an organisation driven by partnerships and collaboration. In its projects, major partnerships include **Chambers for GreenTech**, the **Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection** (BMUV) and **NOW GmbH**, the federally owned National Organisation Hydrogen and Fuell Cell Technology, which holds a government mandate for the implementation of funding schemes for climate-neutral mobility and energy technologies.

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REINER LEMOINE INSTITUT

A Word from our CEO

Dear Reader,

The GNZCC's long-held focus has been on delivering projects with an emphasis on energy and climate change; this has been reflected in our projects in New Zealand. Observing the current situation in the Pacific region, the GNZCC has taken a step in a new direction as it enters a new market and builds new relationships with the Pacific Islands. We look forward to building a collaborative and innovative relationship with stakeholders in the Pacific Islands.

Yours sincerely,

Monique Surges, GNZCC CEO

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As part of this environmental analysis, the techno-economic feasibility study considers hydrogen as a storage technology. Economic factors such as the levelized cost of electricity, capital costs, and the payback of the investment (break-even point) are also considered. Other relevant metrics include the shares of renewable energy sources, surplus electricity produced, and CO2 emissions.

The scenarios and analyses of the case studies created by using a Multi-Vector Simulation software (MVS) show that energy systems based entirely on renewable, as well as hydrogen and fuel cell technologies, promise substantial cost reductions and emission savings in most cases. The information on the respective conditions and the results of this study, collected by the German Chamber of Commerce and analysed by the Reiner Lemoine Institute, demonstrate the possibilities and economic benefits of integrating green hydrogen and fuel cell technology into the decentralized energy supply of island nations. The project was funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).

The Motu Beachfront Villas Resort is located on Rarotonga, the largest of the Cook Islands. Nearby are the Kent Community Hall (about 100 meters away) and the Titikaveka School (about 200 meters away). Due to high electricity and diesel prices, the resort operators are looking for alternative solutions for their power supply and want to start a community project by integrating the resort, the adjacent school, and the community centre into a shared mini grid. Currently, these three institutions receive grid power, which is reliable but cost intensive.

The following will first present all the important input parameters for this case study. Then, there will be a brief overview of the main results of the energy system modelling for the resort.

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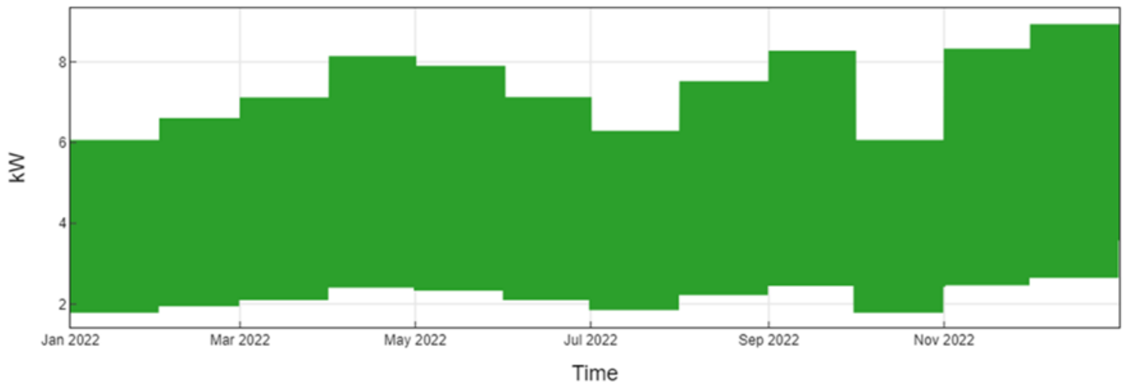
1.1. Motu Beachfront Villas Resort

The load estimation for the Motu Beachfront Villas Resort is based on a monthly electricity bill provided by the resort for a period of one year. Based on this, a potential load profile was simulated with two peak loads per day (breakfast and dusk/return of guests). The following illustration visualizes the monthly fluctuations in the resort's electricity consumption based on the present electricity bill.

Illustration 1 Annual Load Profile for the Motu Beachfront Villas Resort



The key demand characteristics of electricity consumption are listed in the table below.

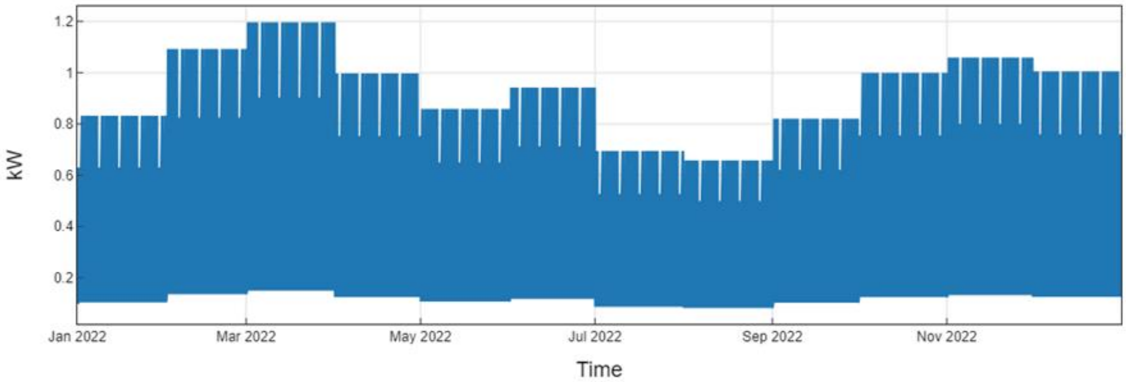
Load Demand Motu Beachfront Villas Resort

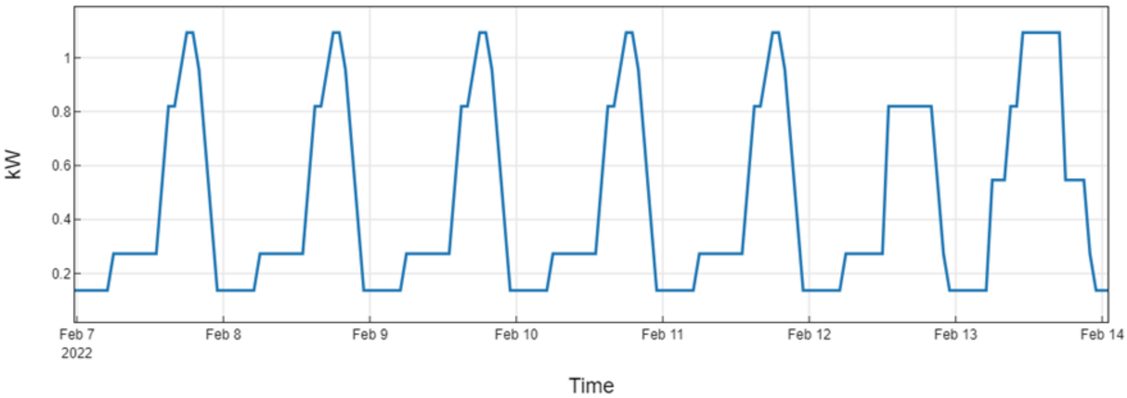
- Peak Load: 8.9 kW
- Average Consumption: 4.7 kW
- Annual Consumption: 40,864 kWh

1.2. Kent Community Hall

The load estimation for the community centre is based on a monthly electricity bill provided for a year. Based on this, a potential load profile was simulated, assuming that consumption firstly increases at 14:30 on weekdays (student activities) and then peaks in the evening at 19:00 (adult activities and community meetings). For the weekend, it was assumed that electricity consumption increases earlier in the day, with Sundays generally having more activities than Saturdays. The following illustrations visualize the monthly fluctuations in electricity consumption of the community centre based on the present electricity bill (above) and the assumed load profiles for weekdays and weekends (below).

Illustration 2 Annual Load Profile (above) and Weekly Load Profile (below) for the Kent Community Hall





The key demand characteristics of the community centre's electricity consumption are listed in the table below.

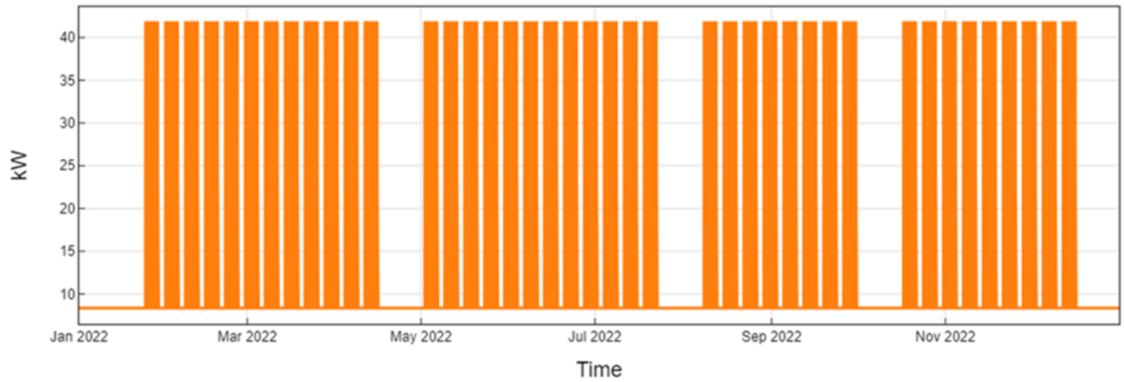
Load Demand Kent Community Hall

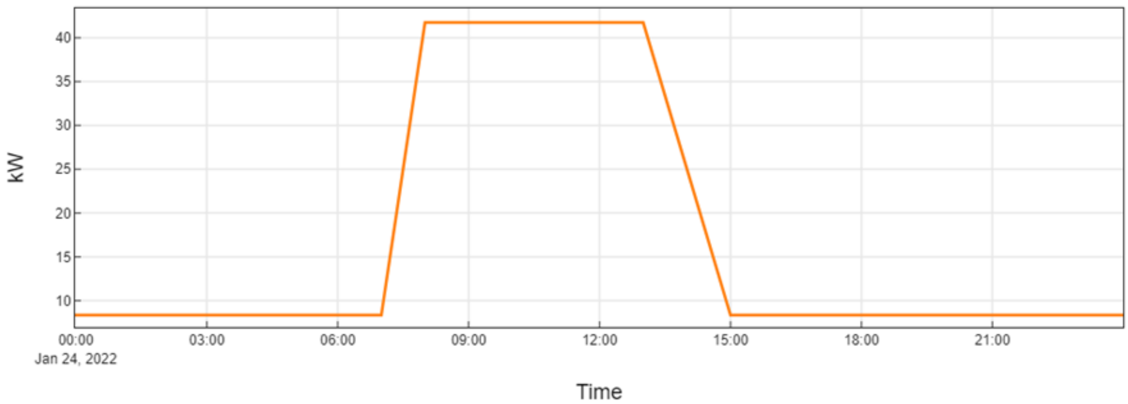
- Peak Load: 1.2 kW
- Average Consumption: 0.39 kW
- Annual Consumption: 3,416 kWh

1.3. Titikaveka School

For the load estimation of the Titikaveka School, there were neither an electricity bill nor other information available. Only the school hours from 8:00 to 14:30 and the number of students (120) were known. According to a study, each student requires about 2.5 m² of space in the classroom, and the school size is thus calculated based on double this space requirement (for the library, sports rooms, etc.). For 120 students, this results in a total area of the school of 600 m². Assuming numbers from the Hertfordshire Council, that a school has an electricity consumption of about 196 kWh/m² per year, results in an annual consumption of 117,600 kWh. The school load profile was also developed considering the official holiday periods of the Cook Islands. This resulted in the load profiles visualized in the following illustration.

Illustration 3 Annual Load Profile (above) and Daily Load Profile (below) for the Titikaveka School





The key demand characteristics of the community centre's electricity consumption are listed in the table below.

Load Demand Titikaveka School

- Peak Load 41.7 kW
- Average Consumption 13.4 kW
- Annual Consumption 117,600 kWh

2. Solar Potential

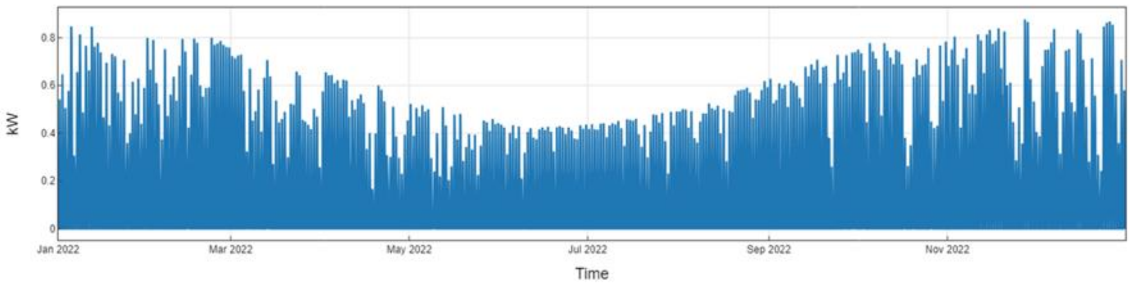
The online tool "Renewables.ninja" was used to calculate the hourly power generation of PV systems for the location of the Motu Beachfront Villas Resort. The tool considers weather information and data, particularly solar radiation at specific locations, and converts it into power generation using the GSEE model (Global Solar Energy Estimator) (Pfenninger and Staffell, 2016). The chosen coordinates are the location of the resort, and the optimal tilt and azimuth angles were calculated based on the location and are listed in the table below.

2.1. Motu Beachfront Villas Resort

- Coordinates (Lat., Long.): -21.271524967753574, -159.75873575301432
- Tilt Angle: 21.9°
- Azimuth Angle: 0° (geographic North)

The following illustration shows the specific PV potential over the course of a year. The annual potential is 1,401 kWh/kWp, with peak production occurring in the winter months, reaching up to 0.88 kW/kWp.

Illustration 4 Annual Solar Potential for the Motu Beachfront Villas Resort



2.2. Site-specific Input Parameters

Any site-specific input parameters relevant for the calculation of the scenarios are summarized in the following table. The data is based on information provided by the resort as well as own research.

Input Parameters Motu Beachfront Villas Resort

Parameter	Unit	Value	Source
Weighted Average Cost of Capital (WACC):	%	6.622	ADB, verified by resort
Electricity Price	EUR/kWh	0.50	billing provided by resort
Diesel Price:	EUR/L	1.50	billing provided by resort

3. Summary of Results

The results for the three calculated scenarios are summarized below. The following table lists the relevant energy system components and their installed capacities in each scenario.

Evaluation Motu Beachfront Villas Resort

Component (Unit) / Scenario	Diesel Generator (kW)	PV (kWp)	Battery Storage (kWh)	Electrolyser (kW)	Fuel Cell (kW)	Hydrogen Storage (kg H2)	Grid Power (Peak Load) (kW)
Status Quo:	-	-	-	-	-	-	-
Cost Minimization:	-	185	127	42	8	18	51
100% Renewable Energy (PV, H2):	-	340	-	95	38	116	-
100% Renewable Energy (PV, Battery, H2):	-	253	270	28	8	103	-

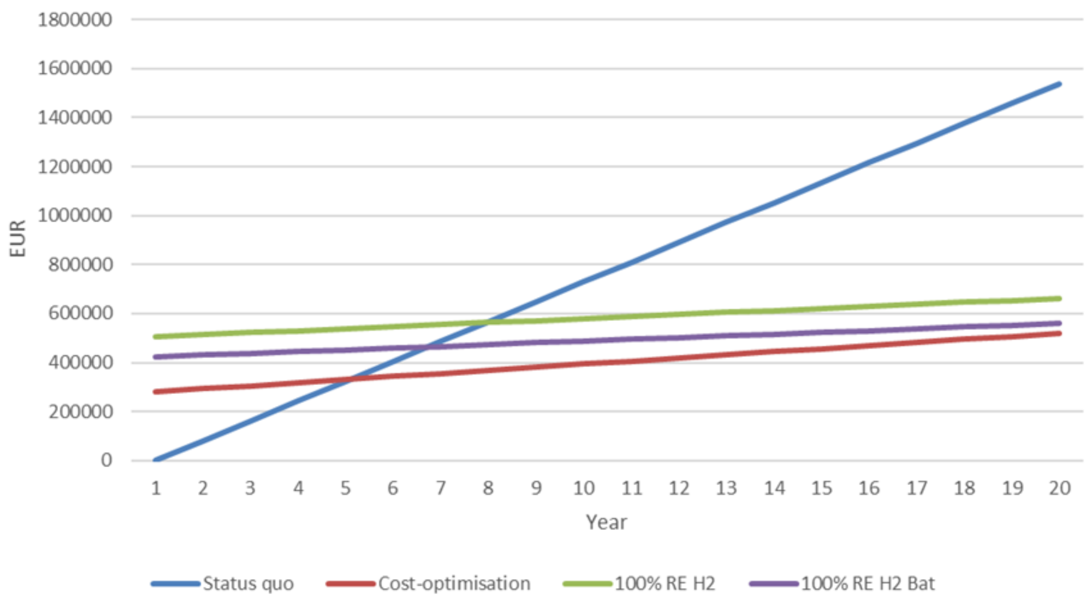
Besides the design parameters, it is important to consider economic and ecological indicators in the analysis of the different scenarios. These parameters are summarized in the following table, illustration 61 visualizes the calculation of the break-even point.

Scenario Parameters Motu Beachfront Villas Resort

Key Figure (Unit) Scenario	LCOE (€/kWh)	Renewable Energy Share (%)	Net Present Value (NPV) (€)	Initial Investment Costs (€)	Operating/ Maintenance Costs (€/year)	Break Even Point (years)	Excess Electricity (MWh/year)	CO2 Emissions (kgCO2eq/year)
Status Quo:	0.50	0	883,399	0	80,940	-	0	33,509
Cost Minimization:	0.23	94	411,709	281,010	12,560	5	40.8	3,259
100% Renewable Energy (PV, H2):	0.32	100	561,058	505,540	8,255	8	179.3	0
100% Renewable Energy (PV, Battery, H2):	0.28	100	502,124	423,361	, 7,152	7	117.6	0

The levelized cost of electricity (LCOE) in this case study ranges from 0.23 EUR/kWh to 0.50 EUR/kWh, with all scenarios reducing electricity costs compared to the current power supply. Both 100% renewable energy scenarios include hydrogen technology and lead to long-term cost savings compared to the status quo due to high local grid electricity prices. The break-even point is reached after 5 years in the cost-minimizing scenario, and after 7 years (PV, battery, hydrogen technology) or 8 years (PV and hydrogen technology) in the renewable energy scenarios, as shown in the following illustration.

Illustration 5 Visualization of the Break Even Point Calculation

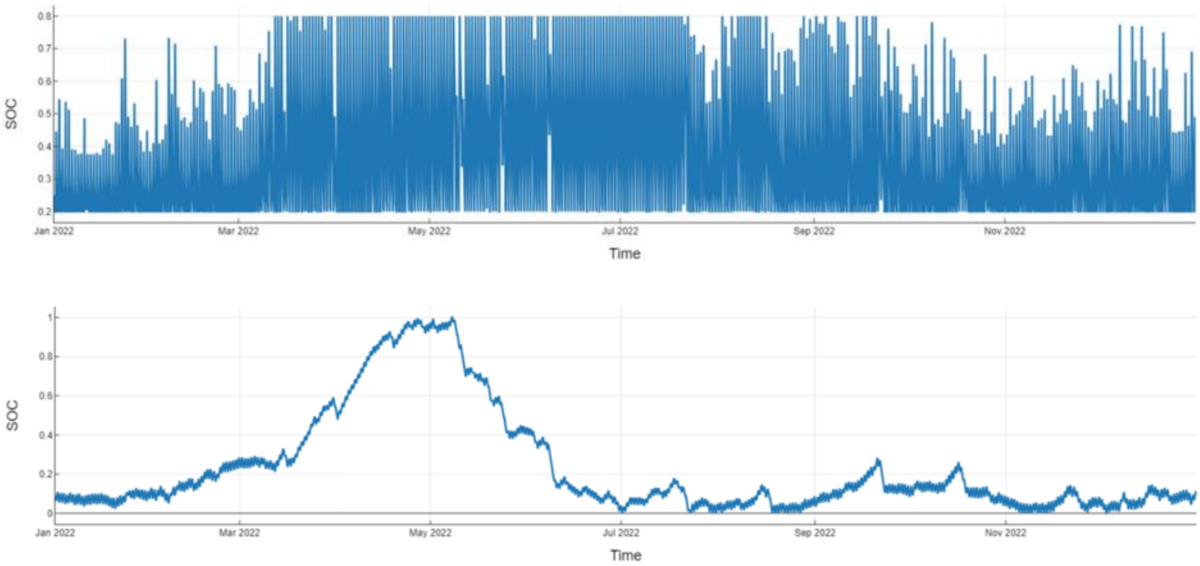


Compared to the status quo, CO2 emissions in the cost-minimizing scenario can be reduced by 90%. Excess electricity is generated, which could potentially be used elsewhere (grid injection under appropriate regulations or operation of a seawater desalination plant). In this case study, the water requirement for hydrogen production is assumed to be high at a water consumption of 9 litres per kilogram of produced hydrogen which translates to about 14,400 litres (approximately 39 litres per day) for the scenario with 100% renewable energy (PV, battery storage, and hydrogen technology). For the scenario with 100% renewable energy based on PV and hydrogen technology only, the total water demand amounts to 32,670 litres per year (about 90 litres per day).

Major cost distribution (annuities) shares of the individual system components used in the cost-minimizing scenario include primarily the investment in the PV system (52%), followed by expenses for the remaining grid supply (21%), and the battery storage with 15%. Hydrogen technology constitutes only 12% of total annual costs (2% for storage and fuel cell, respectively, as well as 8% for the electrolyser).

To further analyse the different operating characteristics and functions of the storage technologies (battery and hydrogen), the storage levels (SOC) of both technologies are visualized over a year in the illustration below.

Illustration 6 Visualization of the State of Charge (SOC) of the Battery Storage (above) and the Hydrogen Storage (below) for the 100% Renewable Energy Scenario (PV, Battery, Hydrogen) over a Year



Similar to other case studies examined for this project, battery storage is used to balance short-term fluctuations in power generation, while the hydrogen storage balances seasonal fluctuations with a noticeable peak in May.

4. Sensitivity Analysis

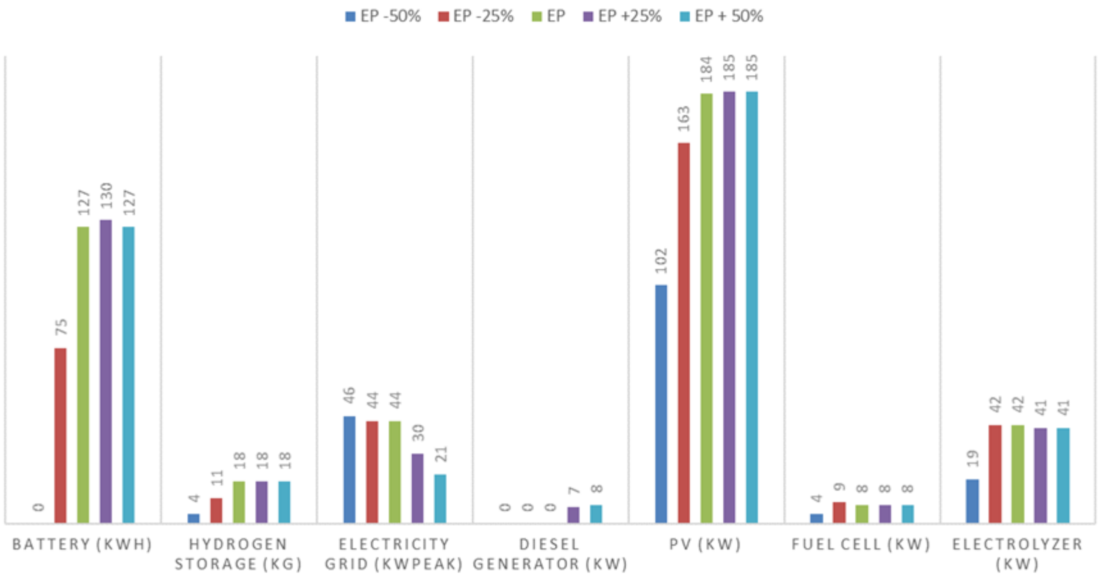
4.1. Electricity Price

First, the influence of fluctuating electricity prices (electricity prices – EP) on the simulation results was examined. With a current electricity price of 0.50 EUR/kWh as in this case study, the following deviations (25% or 50% higher or lower electricity prices) occur:

- +50% => 0.75 EUR/kWh
- +25% => 0.63 EUR/kWh
- Status Quo = 0.50 EUR/kWh
- -25% => 0.38 EUR/kWh
- -50% => 0.25 EUR/kWh

Assuming these values in the MVS for the cost-minimizing scenario, the results shown in the following graph are obtained. The installed capacities of the respective system components are visualized here, with the reference scenario (cost minimization at status quo prices) for comparison:

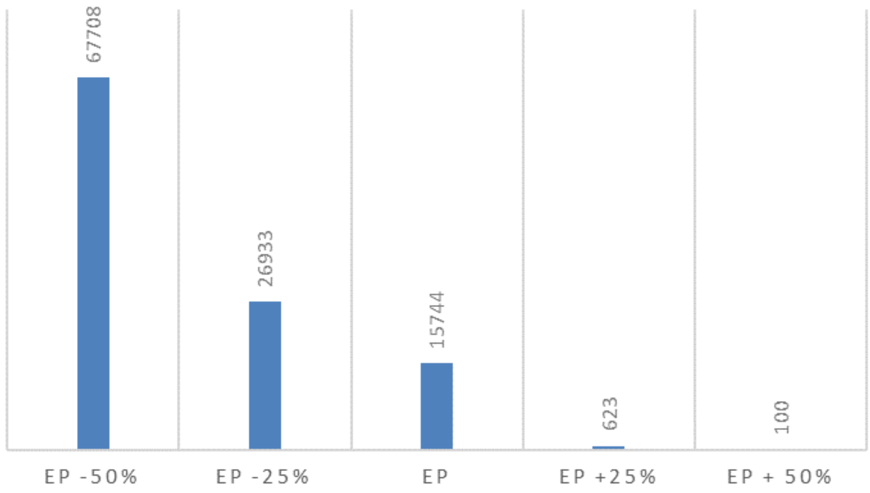
Illustration 7 Optimized Capacities of Individual Technologies at Electricity Price Fluctuations



The largest absolute capacity fluctuations are thus observed in the solar plant and the battery storage. Since large capacities of these components are already recommended in the baseline scenario, there are only minor deviations from the status quo when electricity prices rise, while their role becomes significantly smaller at decreasing electricity prices. In the unlikely scenario of a halving of grid electricity prices, battery storage capacities even completely drop out of the system. Hydrogen components, which are mostly similarly dimensioned in the other sensitivity cases, also face significant cuts in such extreme electricity price reduction. The construction of a new diesel generator is only recommended by the model at rising electricity prices, without considering whether the rise in electricity costs is caused by higher fuel prices (and thus also higher operating costs for the generator).

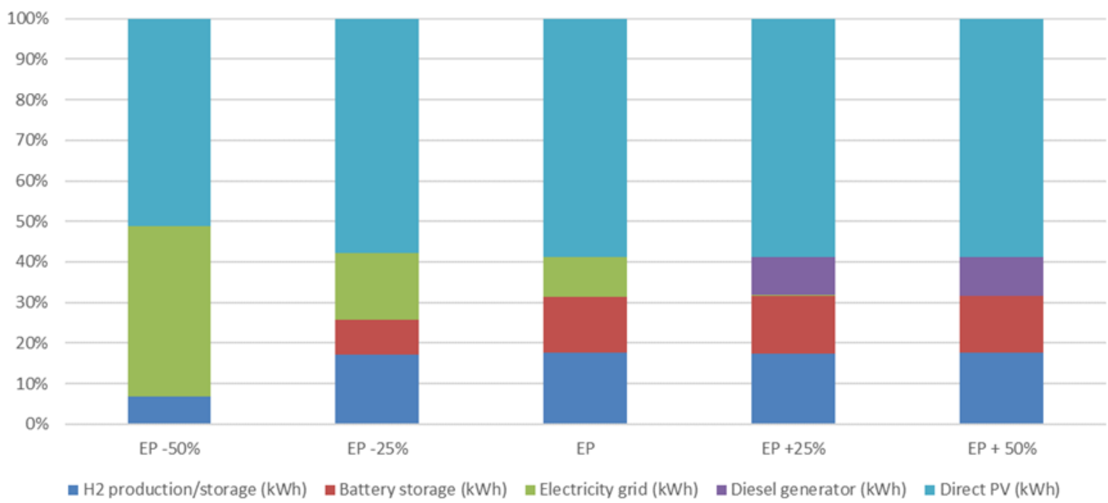
Additionally, fluctuations in the grid-fed peak loads also occur in this case study, as the share of peak loads covered by the grid decreases with a further increase in the already high local grid electricity prices. This reversed correlation can also be transferred to the overall consumption from the grid in the other scenarios, as the following illustration shows.

Illustration 8 Grid Electricity Consumption in kWh for the Calculated Sensitivity Cases (Electricity Price Fluctuations)



The following illustration shows the percentage share of each system component in covering the electricity demand. "Direct PV" refers to the PV electricity that is directly fed into the system without being directed to the battery storage or the electrolyser for hydrogen production.

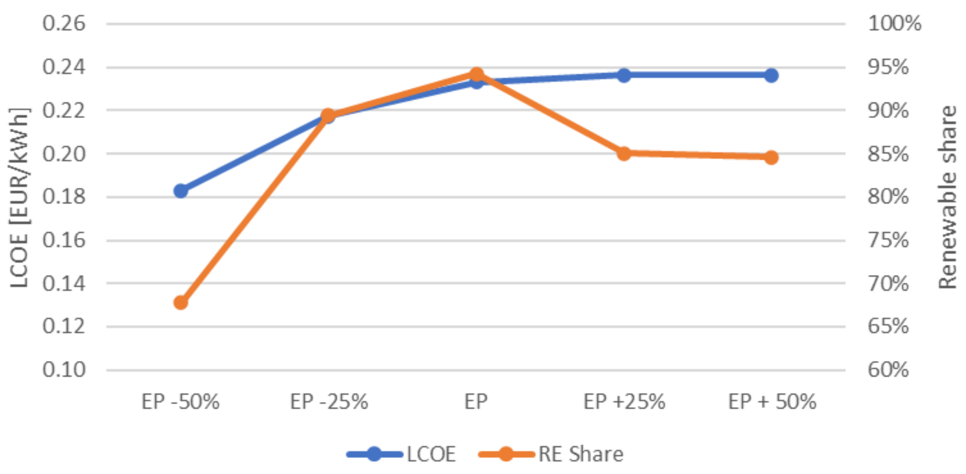
Illustration 9 Share in Covering Electricity Demand at Electricity Price Fluctuations



In each of the depicted price scenarios, PV power covers the largest share of the system's electricity mix. With decreasing grid prices, the share of grid power supply increases, while this share is increasingly replaced by a mix of battery storage, diesel generator, and hydrogen technology when grid electricity prices rise. The share covered by hydrogen technology remains relatively constant, except in the case of collapsing electricity prices.

As the last illustration of this sensitivity analysis, the development of the levelized cost of electricity (LCOEs) and the share of renewable energy in the system is visualized.

Illustration 10 Development of the Levelized Cost of Electricity and the Share of Renewable Energy at Electricity Price Fluctuations



The LCOE ranges between 0.18 and 0.24 EUR/kWh (higher grid electricity prices lead to higher levelized costs of electricity). Due to the increasing independence of the system when grid prices rise, LCOEs remain relatively constant if this happens.

The share of renewable energy carriers remains in the range of 65% - 94%, with the highest share in the status quo. By using a diesel generator (problem of possible correlations described above), this share decreases again at high electricity prices, but remains constant with a further price increase.

Investment Costs Hydrogen Technology

Analogous to the sensitivity analysis of electricity prices, the effects of price fluctuations in hydrogen components on the recommended capacities in the system were simulated. For the calculation of the sensitivities, price increases and decreases of 25% and 50% were also assumed.

This results in the following changes in the CAPEX costs:

Hydrogen Storage (original price at 350 EUR/kg):

- +50% => 525 EUR/kg
- +25% => 438 EUR/kg
- -25% => 263 EUR/kg
- -50% => 175 EUR/kg

Electrolyser (original price at 610 EUR/kW):

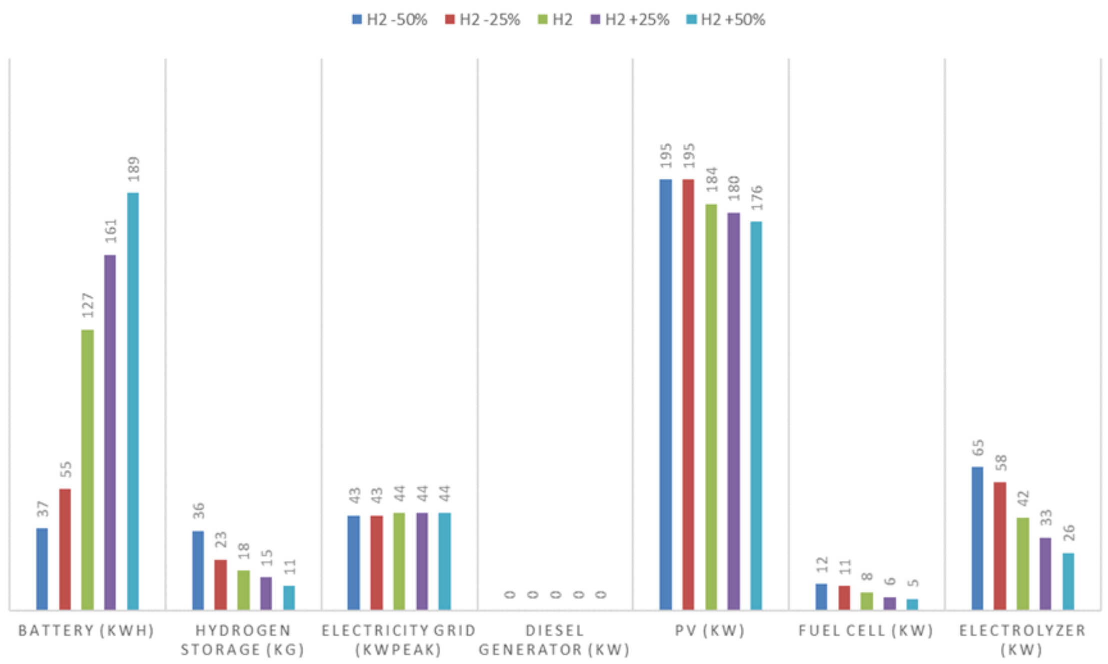
- +50% => 915 EUR/kW
- +25% => 763 EUR/kW
- -25% => 458 EUR/kW
- -50% => 305 EUR/kW

Fuel Cell (original price at 870 EUR/kW):

- +50% => 1,305 EUR/kW
- +25% => 1,088 EUR/kW
- -25% => 653 EUR/kW
- -50% => 435 EUR/kW

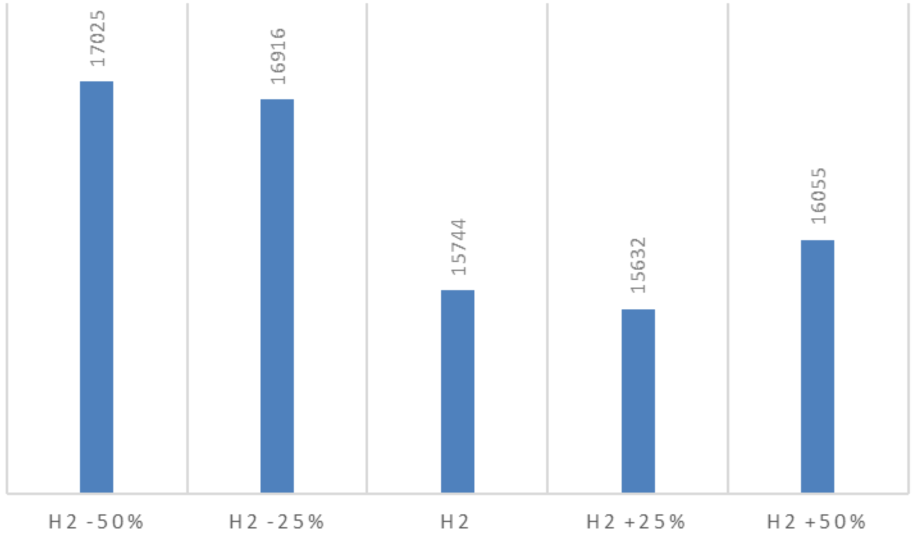
Again, the reference scenario (cost minimization under status quo prices) is shown in green:

Illustration 11 Optimized Capacities of Individual Technologies at Fluctuations of Hydrogen Investment Costs



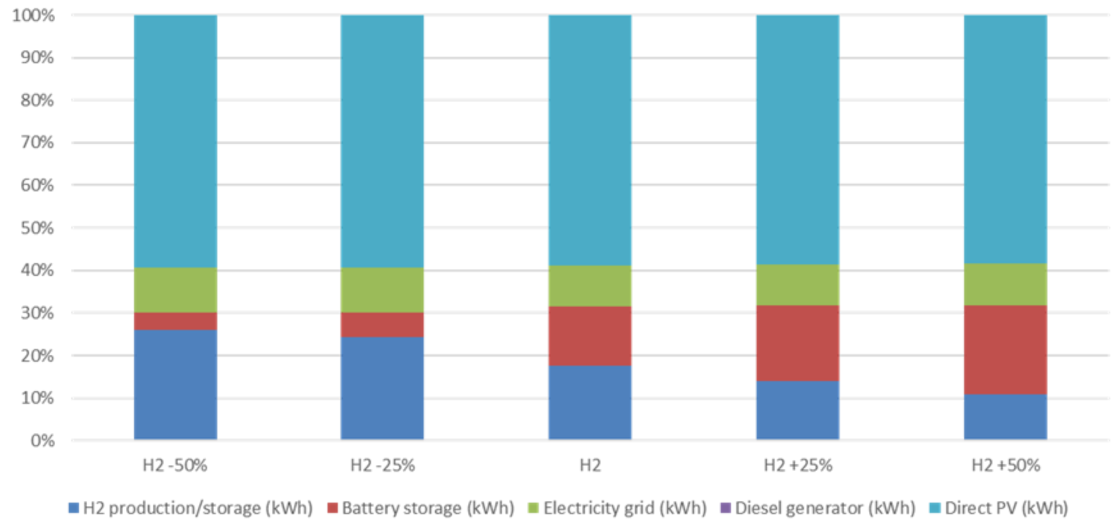
Accordingly, with rising investment costs in hydrogen technologies, the need for battery storage as an alternative increase significantly. Unlike in the case of fluctuating electricity prices, a diesel generator is not integrated into the system in any of the cases. Also, the coverage of peak loads from the grid remains largely constant, in contrast to the previous sensitivity analysis. In the following illustration of grid electricity consumption, it is apparent that their shares increase with a price drop in hydrogen components and initially decrease with higher investment costs, then rise again slightly. Overall, there are fluctuations of a maximum of 1,393 kWh.

Illustration 12 Grid Electricity Consumption in kWh for the Calculated Sensitivity Cases (Investment Costs of Hydrogen Components)



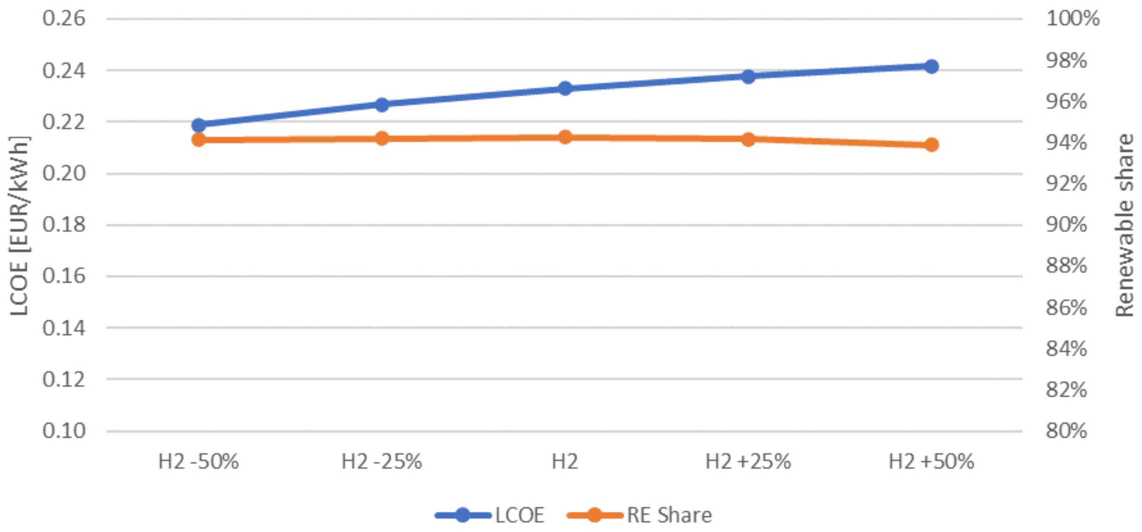
Regarding the entire system, the share of demand coverage from the grid (green) thus remains largely constant, as does the direct electrification from the PV plant. Starting from almost equal shares in the status quo, the choice of storage technology changes analogously to component costs in both directions. However, in none of the extreme scenarios does one of the technologies completely drop out of the system, which underlines the interplay between battery and hydrogen storage.

Illustration 13 Share in Covering Electricity Demand at Fluctuations of Hydrogen Investment Costs



Finally, the following illustration shows both the development of the levelized cost of electricity and the share of renewable energy carriers in the respective sensitivity cases. It becomes clear that the LCOE remain largely constant (between 0.22 and 0.24 EUR/kWh) and only increase slightly even at high component costs, while the share of renewable energy stagnates at 94%. This illustrates, analogous to the previous illustration, the constant share of storage technologies in the system, regardless of their composition.

Illustration 14: Development of the Levelized Cost of Electricity and the Share of Renewable Energy at Fluctuations of Hydrogen Investment Costs



5. Conclusion

For the power supply of the Motu Beachfront Villas Resort, the Kent Community Hall, and the Titikaveka School, the installation of a system consisting of PV, battery storage, and hydrogen technology is profitable and would more than halve electricity costs in the long term (- 53%).

Even with the presence of batteries and a rise in component prices, all scenarios include the use of hydrogen technologies. However, their installed capacity decreases with strongly falling electricity prices or rising investment costs, whereas, in both cases, additional battery storage capacities would be installed as substitutes.

Translation Disclaimer

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