A Case Study: Fiji

Nukubati Great Sea Reef Resort

The German New Zealand Chamber of Commerce

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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 Nukubati Great Sea Reef Resort is a four-star resort located on the island of the same name, Nukubati, near the island of Vanua Levu. The small island of Nukubati is not connected to the electrical grid, so the resort is self-sufficient, powered by a solar array, a battery storage system, and a diesel generator. Recently, smart meters were installed to facilitate the further development of the energy system's design. The resort has its own seawater desalination plant, which is currently rarely in operation because the primary water source is collected rainwater. Since the water cycle of a decentralized energy supply system, consisting of an electrolyser (splitting water into hydrogen and oxygen using electricity) and a fuel cell (combining hydrogen with filtered atmospheric oxygen to produce water while releasing electricity), is closed, there are very minimal water needs. Should hydrogen be extracted from the cycle (e.g., for refuelling vehicles), covering the additional water demands through onsite seawater desalination could be considered. The operators of the resort are very interested in sustainable power supply and aim to increase the share of renewable energies in the system long term.

Subsequently, all the important input parameters for this case study will be presented. Then, a brief overview of the key results of the energy system modelling for the Nukubati Great Sea Reef Resort will be given.

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1. Electricity Consumption

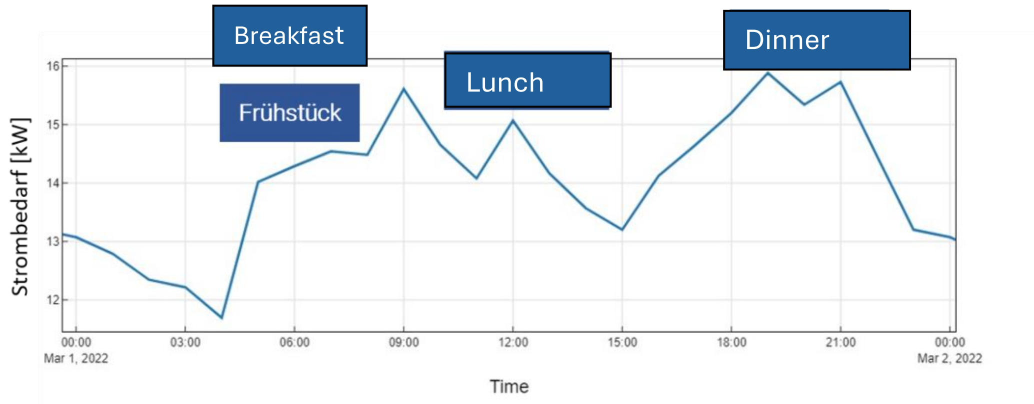
1.1. Nukubati Great Sea Reef Resort

The load estimation for the Nukubati Great Sea Reef Resort is based on manual readings of electricity demand over a 24-hour period by resort staff. The daily demand follows a consistent pattern, strongly linked to meal preparation and kitchen activities. Illustration 1 shows an example of such a progression.

Below is a breakdown of the main events in the load profile:

- 5:30 AM: The kitchen begins operation.
- 7:00 - 10:00 AM: Breakfast service.
- 12:00 PM: Start of lunch preparation.
- 12:30 PM - 1:30 PM: Lunch.
- 5:00 PM: Start of dinner preparations.
- 7:30 PM - 10:00 PM: Dinner.

Illustration 1 Daily Load Profile of Nukubati Great Sea Reef Resort



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The blue markings in Illustration 1highlight the load peaks corresponding to these events.

The data presented represents a typical daily consumption pattern for the resort, assuming full occupancy. According to discussions with the operators, slight variations may occur depending on the level of occupancy, although these are minimal. According to the resort's statements, there are no noticeable differences between weekdays and weekends to consider. The daily profile is used as the basis for creating an annual profile due to the lack of availability of long-term measurements or electricity bills (no grid connection). The key demand characteristics are listed in the table below.

Illustration 2 Load Requirements of Nukubati Great Sea Reef Resort

Parameter	Unit	Value
Peak Load	kW	15,9
Average Load	kW	14,1
Annual Consumption	kWh	123.506

2. Solar Potential

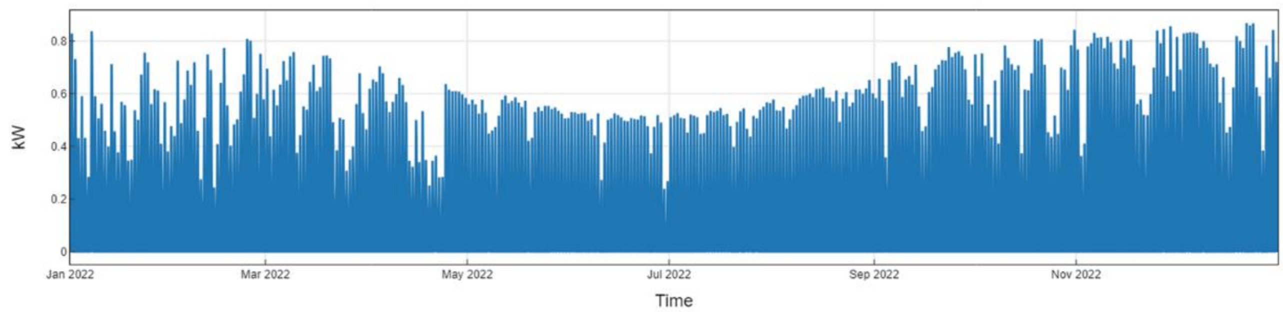
The online tool "Renewables.ninja" was used to calculate the potential hourly electricity generation from PV systems at the location of the Nukubati Great Sea Reef Resort. The tool considers weather information and data, particularly solar irradiation, and converts these into electricity generation using the GSEE model (Global Solar Energy Estimator) (see Pfenninger and Staffell, 2016). The chosen coordinates correspond to the location of the resort, and the optimal tilt and azimuth angles were calculated based on these coordinates. They are listed in the table below.

Illustration 3 Solar Potential of Nukubati Great Sea Reef Resort

Coordinates (Lat., Long.)	-16.463846, 179.020674
Tilt angle	18,3 °
Azimut angle	0 ° (Geographic north)

The following illustration demonstrates the specific PV potential over the course of a year. The annual potential amounts to 1,521 kWh/kWp, with peak production occurring in the winter months and reaching up to 0.87 kW/kWp.

Illustration 4 Annual Solar Potential for Nukubati Great Sea Reef Resort



2.2. Site-Specific Input Parameters

Since the Nukubati Great Sea Reef Resort operates off-grid, there is already a mini-grid powered by a solar system and a diesel generator for supplying the hotel complex. The already installed energy system components were considered in the simulation and are listed in the following table. The data is based on information provided by the resort. The diesel price was also transmitted by the resort operators. For financial calculations, the MVS also requires the weighted average cost of capital (WACC), which is based on an analysis by the Asian Development Bank for Fiji.

Illustration 5 Input Parameters for Nukubati Great Sea Reef Resort

Parameter	Unit	Value	Source
Weighted average cost of capital (WACC)	%	6,04	Alpha Spread, verifiziert von Resort[1]
Diesel price	EUR/l	1,46	Resort
Installed Diesel Generator	kW	62,5	Resort
Installed PV	kWp	86	Resort
Installed Battery Storage	kWh	110	Resort
Installed Inverter	kW	35	Resort

[1] Alpha Spread, "FIJ Current Discount Rate," October 9, 2023, https://www.alphaspread.com/security/asx/fij/discount-rate.

3. Summary of Results

The Nukubati Great Sea Reef Resort would benefit from the addition of hydrogen technology as a long-term or seasonal storage solution. The cost of electricity generation could be reduced by 42% compared to the status quo. The break-even point would be reached after about 7 years. The cost-minimizing system involves a combination of PV and diesel power generation, with solar power production being dominant. The battery storage in combination with the hydrogen storage is central to balancing short-term and long-term fluctuations and ensuring energy security.

The results for three calculated scenarios are summarized below. The following table lists the energy system components and the capacities required for each scenario. The total capacities required for each scenario can be found as the first value in the respective cells, while the second value (in the case of existing infrastructure) represents the additional capacity calculated as optimal by the MVS for the respective scenario.

Illustration 6 Evaluation Nukubati Great Sea Reef Resort

Component (Unit)/Scenario	**Dieselgenera-tor** (kW)	**PV** (kWp)	**Battery Storage (kWh)**	**Electrolyzer (kW)**	**Fuel Cell (kW)**	**Hydrogen Storage (kg H2)**
Status quo	62,5/-	86/-	110/-	-	-	-
Cost Minimization	- /4*	138/52	201/91	31	6	13
100 % RE (PV, H_2)	- /-	228/142	110/-	97	16	62
100 % RE (PV, Bat, H_2)	-/-	151/65	278/168	26	5	46

**Note: This is not the additional diesel generator capacity required, but the remaining necessary capacity for the scenario.*

In addition to design parameters, economic indicators such as the cost of electricity generation, total investment costs, and initial investment costs at project start are important and must be considered in the analysis of the various scenarios, as well as the resulting renewable energy shares, surplus electricity, and CO2 emissions. Another important indicator is the break-even point, which compares the status quo with the investment costs including the operation and maintenance costs of the other scenarios, indicating how many years of operation of the energy system it takes for the initial investments to pay off. These parameters are summarized in the following table and Illustration 7 visualizes the calculation of the break-even point.

Illustration 7 Scenario Parameters for Nukubati Great Sea Reef Resort

Indicator (Unit)/ Scenario	LCOE (€/kWh)	RE-Share (%)	Net Present Value (NPV) (€)	Initial Investment Costs (€)	Operation /Maintenance Costs (€/year)	Break Even Point (years)	Surplus Electricity (MWh/ year)	CO2 Emissions (kgCO2eq/ year)
Status quo	0,25	46	356.953	0	26.781	-	48,3	43.366
Cost Minimization	0,15	93	206.258	117.777	7.063	7	25,1	4.441
100 % RE (PV, H_2)	0,21	100	294.396	250.853	5.817	13	80,0	0
100 % RE (PV, Bat., H_2)	0,19	100	264.846	192.406	5.500	10	43,5	4.854

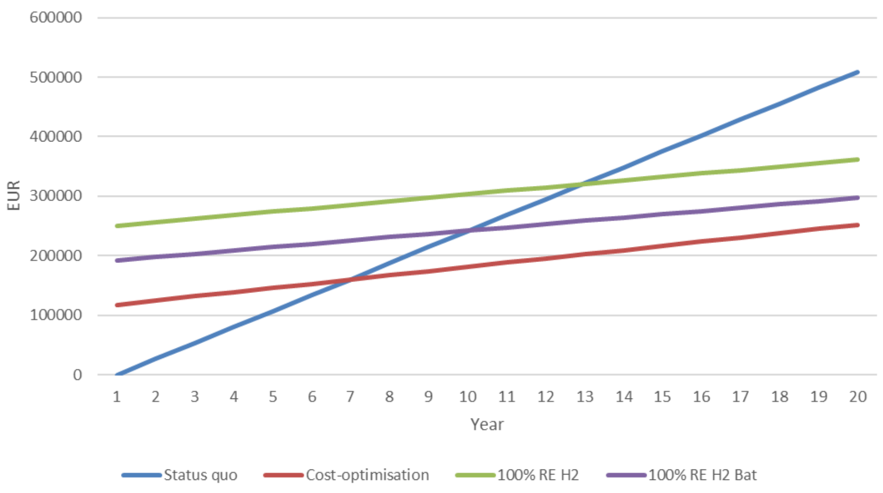
Compared to other off-grid projects, the electricity generation costs are very low, ranging from 0.15 to 0.25 EUR/kWh, as the Nukubati Resort already has a solar system, battery storage, inverters, and a diesel generator, which keep the initial investment costs and hence the electricity generation costs low.

Compared to the status quo, the cost of electricity generation can be significantly reduced in the cost minimization scenario. The initial investment costs for installing additional PV modules, enhancing battery storage, and adding hydrogen components in the cost-minimized scenario amount to 118,000 EUR, with the break-even point being reached after seven years. In the 100% Renewable Energy scenario (PV and hydrogen technology), the break-even point is reached after 13 years.

In each scenario, there is a significant reduction in CO2 emissions, despite the already high share of renewable energies in the system (at 92%, well above the national average). However, the surplus electricity generated in this case study cannot be fed into the grid, as the resort is in an off-grid area. However, this could be used to operate the (already installed but seldom used) seawater desalination plant, which could produce both water for hydrogen production and drinking water for the resort and sale.

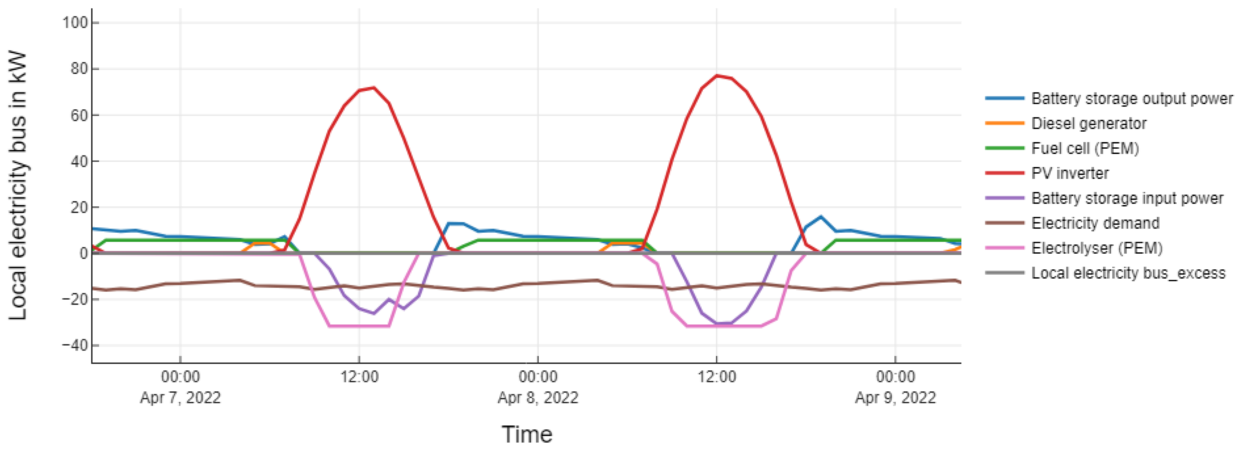
In each scenario, ideally, it involves a closed hydrogen cycle; assuming a 'worst case' scenario with a water demand of 9 litres per kilogram of hydrogen produced, this would result in a water quantity of about 13,266 litres per year (approximately 36 litres per day) in the cost-minimized scenario. Analogously, for the 100% renewable scenario (PV, battery storage, and hydrogen technology), 11,376 litres per year (approximately 31 litres per day) would be needed, and for the 100% Renewable scenario without battery storage, 35,541 litres per year (approximately 97 litres per day) would be needed.

Illustration 8 Visualization of the Break-Even Point Calculation



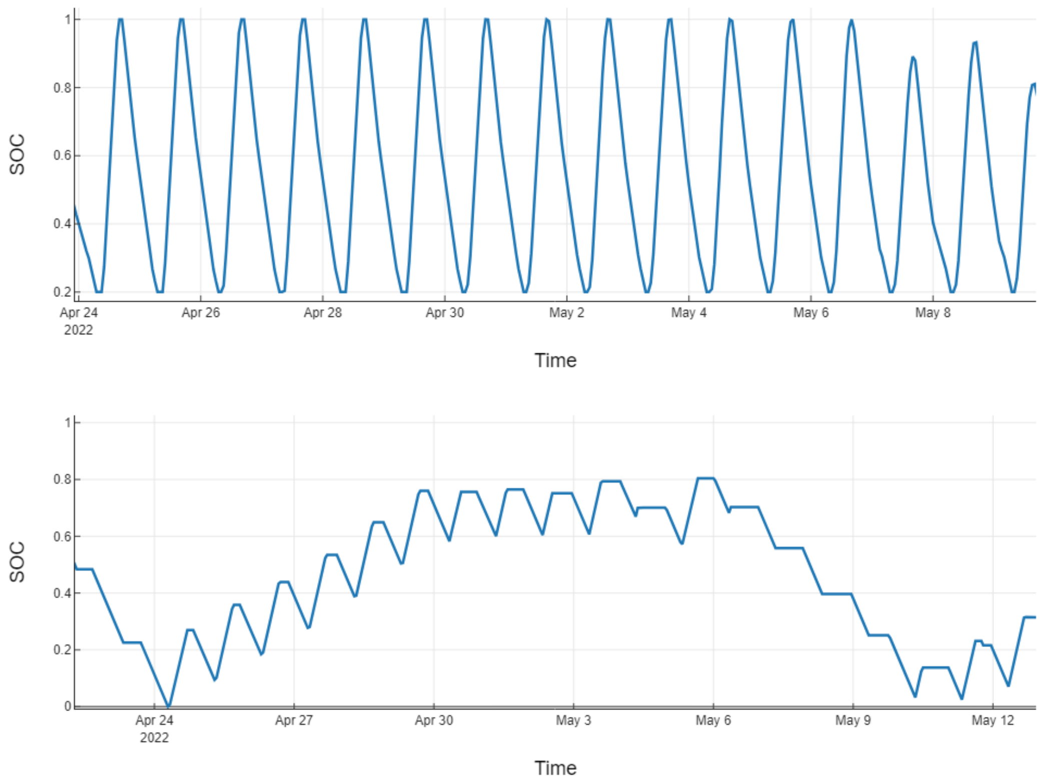
The following illustrations are excerpts from the MVS result page and provide insights into the functioning of the optimized energy systems. First, the energy flow of the system, including all components, is shown over three days for the cost-minimizing scenario in Illustration 9. During the day, the electricity demand (see the brown line, Electricity demand) is mostly covered by the solar plant (see the red line, PV inverter), with the demand at night initially covered by the battery (blue line, battery storage output), then the fuel cell (green line) adds to the supply just before sunrise, followed by the diesel generator (orange line). With lower solar irradiation, the use of the diesel generator and fuel cell generally increases. Besides serving the electricity demand, the solar plant charges the batteries during the day and allows the electrolyser to produce hydrogen.

Illustration 9 Visualization of the Break-Even Point Calculation



To analyse and compare the different operating characteristics and functions of the two storage technologies (battery and hydrogen) more closely, the respective storage levels over a period of one week are shown below. While the battery storage (first image) follows about the same pattern every day (charging during the day, discharging at night), the fluctuations in the hydrogen storage (lower image) are less pronounced. Especially on May 7 and the following days, the functional distinction between the two storage technologies can be observed. While the battery storage compensates for strong day/night fluctuations in the short term, the hydrogen storage comes into play when solar irradiation is lower over entire days, thus reaching a critical charge state of the battery storage. Now, the hydrogen storage steps in, and the stored hydrogen is re-electrified through the fuel cell. Therefore, hydrogen technology can be beneficial for this application example as a long-term and seasonal storage for the system.

Illustration 10 State of Charge (SOC) of the Battery Storage (top) and the Hydrogen Storage (bottom) Over a Week



4. Sensitivity Analysis

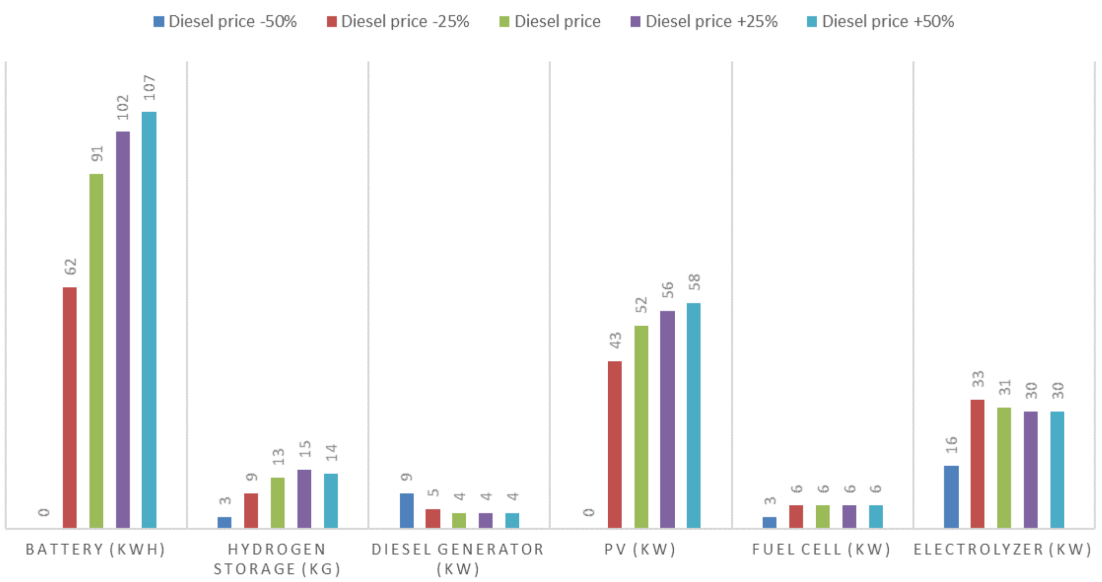
4.1. Diesel Price

First, the influence of the diesel fuel price on the simulation results was examined. With a diesel price of 1.46 EUR/L for this case study in Fiji, the following changes in the diesel price occur for the various sensitivity cases (25% and 50% higher and lower diesel prices):

- +50% => 2.19 EUR/L
- +25% => 1.83 EUR/L Status Quo = 1.46 EUR/L
- -25% => 1.01 EUR/L -50% => 0.73 EUR/L

Simulated in the MVS for the cost-minimizing scenario, the results visualized in the following graphic emerge. Displayed are the capacities of the respective system components to be installed in addition to the existing system. The reference scenario (cost minimization) is shown in green (in the centre) for comparison.

Illustration 11 Optimized Additional Capacities of Individual Technologies at Diesel Price Fluctuations

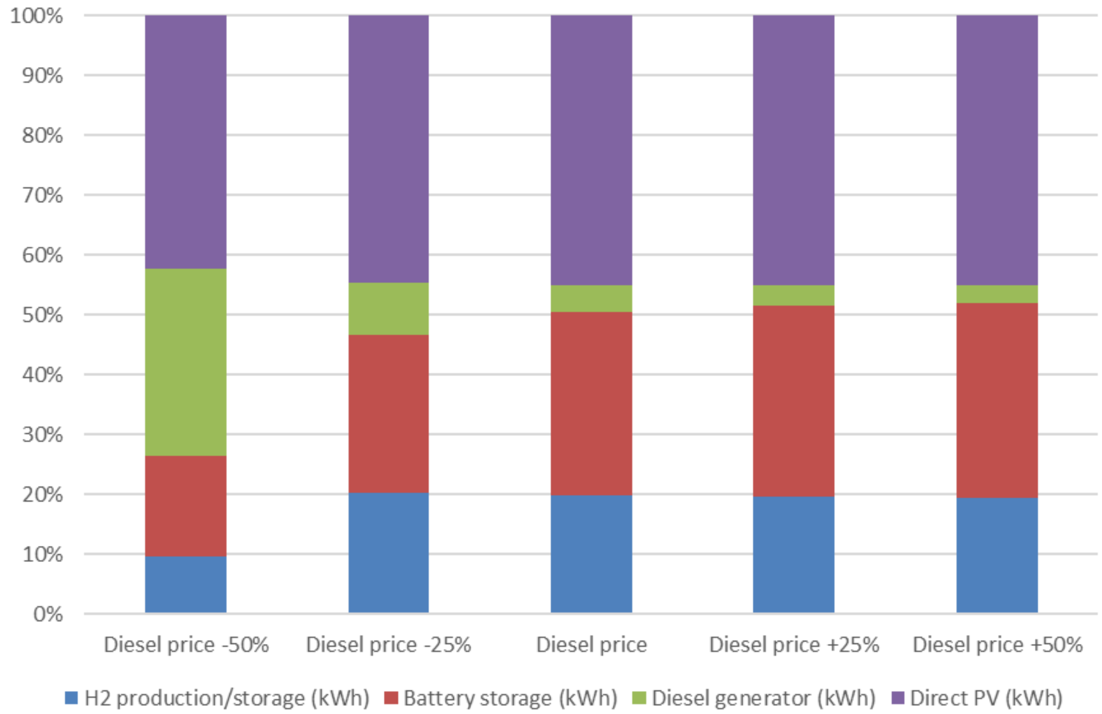


The construction of new local hydrogen and electrolyser technology is recommended for cost minimization in all cases according to the sensitivity analysis. Except for the (unlikely) case of very sharp declines in fuel prices, the installed capacity remains at a relatively constant level. Aside from the -50% sensitivity case, a strong expansion of the existing battery capacities is also recommended. These increase—in line with the diesel price—up to a doubling of the currently available capacities (110 kWh) in the most expensive price regime. Significant savings potential exists according to the model also through an addition of solar capacity. This is thus recommended for cost optimization already from a diesel price 25% below today's level. Overall, the composition of the energy system fluctuates less with price increases than with price reductions.

That the sizing of hydrogen technology remains largely unaffected by fluctuations in diesel fuel prices is due to the function of hydrogen technology as long-term storage. In contrast, the battery storage, which compensates for short-term fluctuations, is more strongly influenced using the diesel generator.

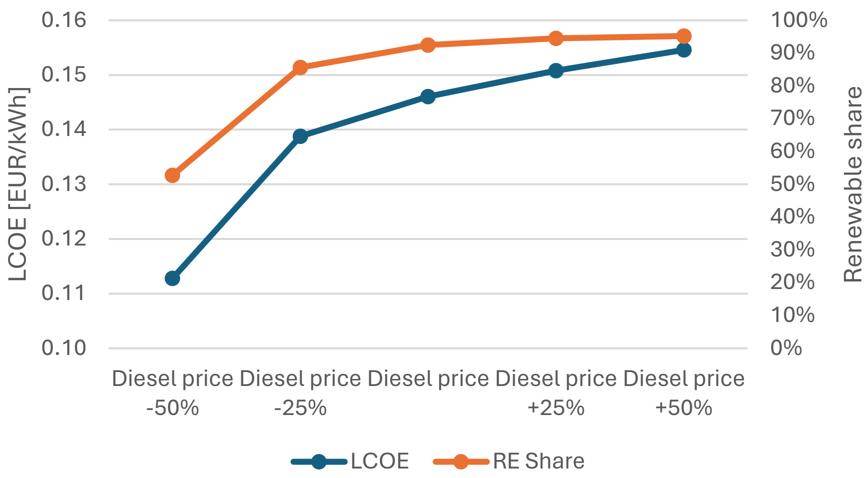
The following illustration graphically represents the percentage share of individual system components in covering the electricity demand. "Direct PV" refers to the PV electricity that is fed directly into the system without being directed to the battery storage or the electrolyser for hydrogen production.

Illustration 12 Share of Electricity Demand Coverage at Diesel Price Fluctuations



Here too, it is clear that the hydrogen components, as well as the direct PV electrification and battery storage feeding, remain largely unaffected by diesel price fluctuations. With a 50% reduction in the diesel price, the use of diesel for electricity generation increases significantly, while both storage technologies accordingly contribute less to the power supply. As the last illustration of this sensitivity analysis, the development of electricity generation costs and the share of renewable energy in the system is visualized.

Illustration 13 Development of Electricity Generation Costs and Renewable Energy Share at Diesel Price Fluctuations



The electricity generation costs (LCOE) fluctuate between 0.11 - 0.15 EUR/kWh. In the case of permanently low fuel prices, the attractiveness of the existing generator infrastructure increases, and the LCOE moves at a relatively low level. As a result of moderate price increases (from -50 to -25%), the LCOE and the cost-minimizing shares of renewable energy carriers increase significantly, highlighting the vulnerability of a diesel-based energy system to external shocks (higher oil prices). The share of renewable energy in the system ranges from 53% to 95% (the higher the diesel costs, the higher the renewable energy share).

Investment Costs for Hydrogen Technology

For calculating sensitivities regarding fluctuations in investment costs in hydrogen technology, price increases and decreases of 25% and 50% were also assumed. This results in the following changes in 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

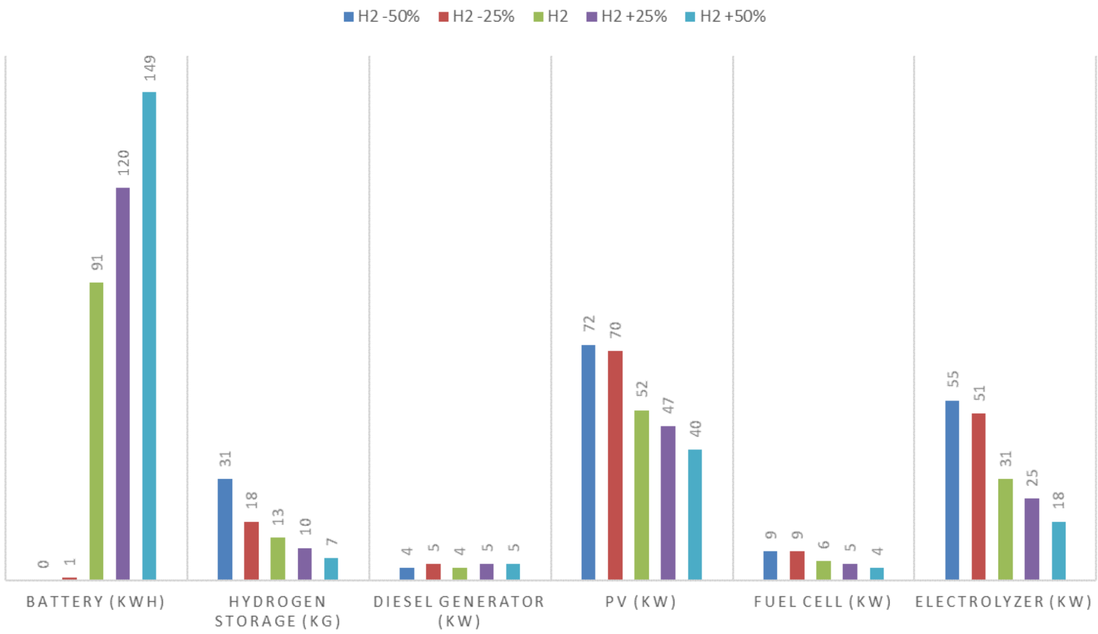
Fuel Cell (original price at 870 EUR/kW):

- +50% => 1.305 EUR/kW

- +25% => 1.088 EUR/kW
- -25% => 653 EUR/kW
- -50% => 435 EUR/kW

Analogous to the sensitivity analysis of diesel prices, the development of the capacities of individual system components at price fluctuations of the investment costs of hydrogen components is illustrated. Here too, the reference scenario (cost minimization) is shown in green.

Illustration 14 Optimized Additional Capacities of Individual Technologies at Fluctuations in Hydrogen Investment Costs



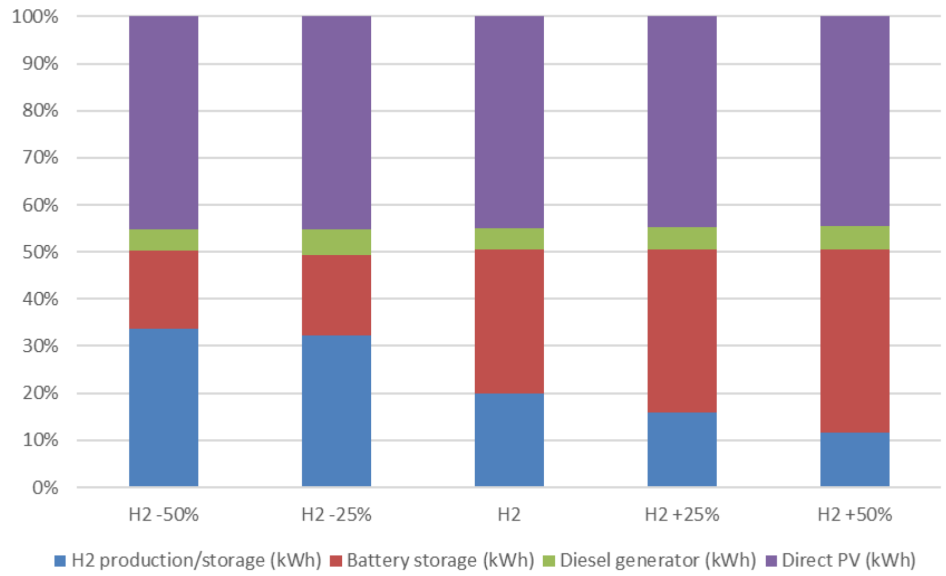
When prices for hydrogen components decrease by 25% or more, the additionally to be installed battery storage capacities become insignificant. If the investment costs increase, the additionally to be installed PV capacity decreases and the battery storage becomes larger. If the prices for hydrogen components rise compared to the current price, a larger battery storage and a larger diesel generator capacity are required.

With rising hydrogen technology costs, the additionally to be installed capacity of the PV system decreases, while the battery storage and diesel generator need to be sized larger. This is the case because the hydrogen storage is significantly reduced, and thus fluctuations in the system must be compensated more through the battery storage and the use of the diesel generator. The hydrogen storage is primarily filled by surplus electricity from the solar plant, which is why it can also be sized smaller with rising hydrogen technology costs.

Overall, it can be said that especially the interplay of battery storage and hydrogen technology is influenced by price fluctuations in hydrogen technology and corresponds accordingly. The cheaper the hydrogen technology, the greater its role in balancing load and power production fluctuations, and this is reflected in the capacities to be installed.

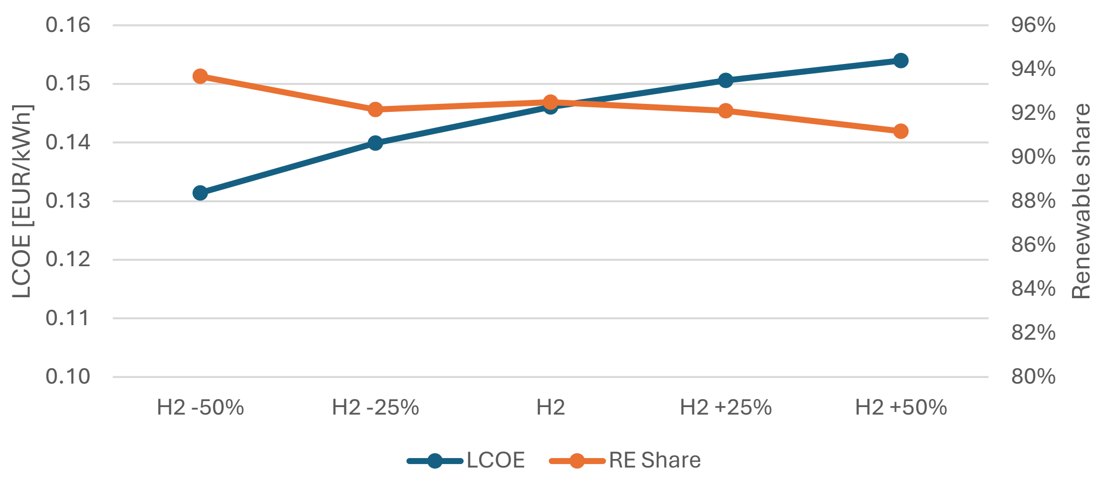
This is also clear from the following illustration: The share of direct electrification (from the PV system and the diesel generator, without intermediate storage) remains largely constant at varying investment costs of hydrogen components, while the share of power supply from the hydrogen storage is gradually replaced by the battery storage at rising investment costs or increases at decreasing costs.

Illustration 15 Share of Electricity Demand Coverage at Fluctuations in Hydrogen Investment Costs



Fluctuations in hydrogen technology prices initially have a minor impact on the resulting electricity generation costs and the share of renewable energy in the system. This can be explained in this case study by the currently relatively small size of the hydrogen system compared to the solar plant and the battery storage. The fluctuations in electricity generation costs are between 0.13 - 0.15 EUR/kWh, and the renewable energy share is between 91% - 94%.

Illustration 16 Development of Electricity Generation Costs and Renewable Energy Share at Fluctuations in Hydrogen Investment Costs



5. Conclusion

The Nukubati Great Sea Reef Resort would benefit from the addition of hydrogen technology as long-term or seasonal storage, as well as additional PV and battery storages in its mini grid. The optimized system of PV, battery storage, hydrogen technology, and diesel generator would reduce electricity costs by 42%. Both 100% Renewable Energy scenarios include the application of hydrogen technology and promise a cost reduction compared to the status quo. Diesel price fluctuations have only a minor impact on the energy system design; only at a diesel price reduction of -50% does the design change significantly.

This is related to the already high share of renewable energies in the cost-minimized system: When there is little diesel in the system, price fluctuations have a lesser impact on the system sizes. In all sensitivity cases, hydrogen technology plays a role, but the optimized size decreases significantly when diesel prices fall by 25% or more. The battery storage capacity is most strongly influenced by varying CAPEX for hydrogen technology and increases with rising prices. A combination of battery storage and hydrogen technology is chosen, where the share of battery storage correlates with the CAPEX for hydrogen technology.

Translation Disclaimer

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Published by
German-New Zealand Chamber of Commerce Inc.
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Publication month
May 2024

Image sources
Atosan, Canva (p. 1)

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Supported by:
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
based on a decision of the German Bundestag

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