ENVIRONMENTAL PROTECTION *made in Germany*

AHK Repräsentanz der Deutschen Wirtschaft German- New Zealand Chamber of Commerce Inc.

A Case Study: Tonga

Tanoa Tusitala Dateline Resort

The German New Zealand Chamber of Commerce

The German New Zealand Chamber of Commerce (GNZCC) was founded in 1983 with offices in Auckland and Wellington, New Zealand. The GNZCC is part of a global network of German Commerce and Industry Chambers (AHKs) located at 140 locations in 92 countries worldwide. AHKs are co-funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK). The GNZCC offers a range of services including:

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- Consulting Services for Market Entry
- International Trade Fair Participation

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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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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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A Case Study:

Tonga – Tanoa International Dateline Resort

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 three-star Tanoa International Dateline Resort is located in the capital of Tonga (Nuku'alofa). It is connected to the national power grid but also owns and operates a backup diesel generator for occasional power outages (once or twice a month for 2-3 hours). In the following, all important input parameters for this case study will be introduced. Then, there will be a brief overview of the key results of the energy system modelling for the resort.

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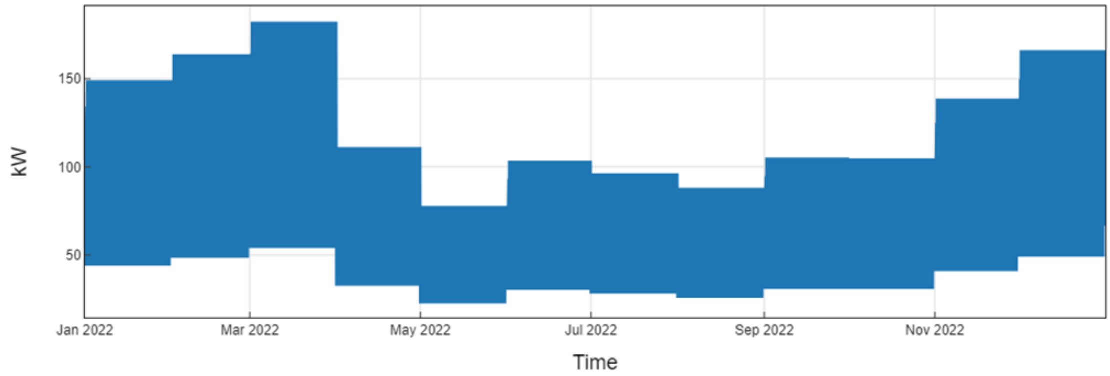
1. Electricity Consumption

1.1. Tanoa International Dateline Resort

The load estimation for the Tanoa International Dateline Resort in Tonga is based on a monthly electricity bill provided by the resort for a period of one year. On this basis, a possible load profile was simulated assuming three peak loads per day (breakfast, lunch, and dinner). The following illustration visualizes the monthly fluctuations in the resort's electricity consumption. Notably, there is relatively low consumption in May and over a longer period in the summer (July, August, September).

Illustration 1 Annual Load Profile for the Tanoa International Dateline Resort



The key demand characteristics are listed in the table below.

Illustration 2 Tanoa International Dateline Resort

Parameter	Unit	Value
Peak Load	kW	182
Average Consumption	kW	80
Annual Consumption	kWh	699.234

2. Solar Potential

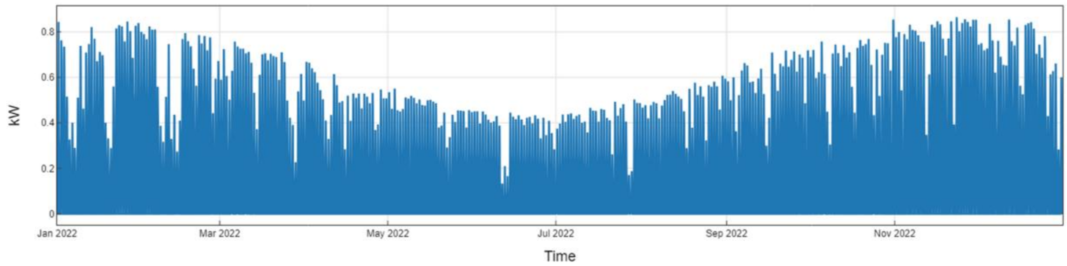
The online tool "Renewables.ninja" was used to calculate the hourly electricity generation from PV systems at the location of the Tanoa International Dateline Resort. The tool takes into account weather information and data, especially solar irradiance at specific locations, and calculates it using the GSEE model (Global Solar Energy Estimator) (Pfenninger and Staffell, 2016). The selected coordinates mark 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 Tanoa International Dateline Resort

Coordinates (Lat., Long.)	-21.134926230726172, -175.19422982323678
Tilt Angle	22 °
Azimuth Angle	0 ° (geographic North)

The following illustration demonstrates the specific PV potential over the course of a year. The annual potential is 1,515 kWh/kWp, with peak production occurring in the winter months, reaching up to 0.87 kW/kWp.

Figure 4 Annual Solar Potential for the Tanoa International Dateline Resort



2.2. Site-Specific Input Parameters

The site-specific input parameters important for scenario calculations are summarized in the following table. The data are based on information provided by the resort or from online research. Additionally, it is important to note that the resort regularly experiences power outages (about once or twice per month) lasting 2-3 hours, which are managed with the resort's diesel generator.

Illustration 5 Input Parameters Tanoa International Dateline Resort

Parameter	**Unit**	**Value**	**Source**
Weighted average cost of capital (WACC)	%	9,22	ADB, verified by resort
Electricity Price	EUR/kWh	0,36	Bill provided by resort
Dieselpreis	EUR/l	1,29	Statement from resort
Installed Diesel Generator	kW	350	Statement from resort

2. Summary of Results

The Tanoa International Dateline Resort would benefit from the installation of a PV system, a battery storage, and hydrogen technology as supplements to the grid power supply, potentially reducing its electricity costs by 60% in the long term. In this case, the diesel generator would no longer be needed to bridge occasional power outages. The break-even point for the investment would be reached after 7 years.

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

Illustration 6 Evaluation Tanoa International Dateline Resort

Component (Unit)/ Szenario	**Diesel Generator** (kW)	**PV** (kWp)	**Battery Storage** (kWh)	**Electrolyser** (kW)	**Fuel Cell** (kW)	**Hydrogen Storage** (kg H_2)	**Grid Power Peak Load**
Status quo	350	-	-	-	-	-	182
Cost Optimization	-	807	503	232	53	67	182
100 % EE (PV, H_2)	-	1.163	-	542	182	581	-
100 % EE (PV, Bat, H_2)	-	1.075	419	445	109	548	-

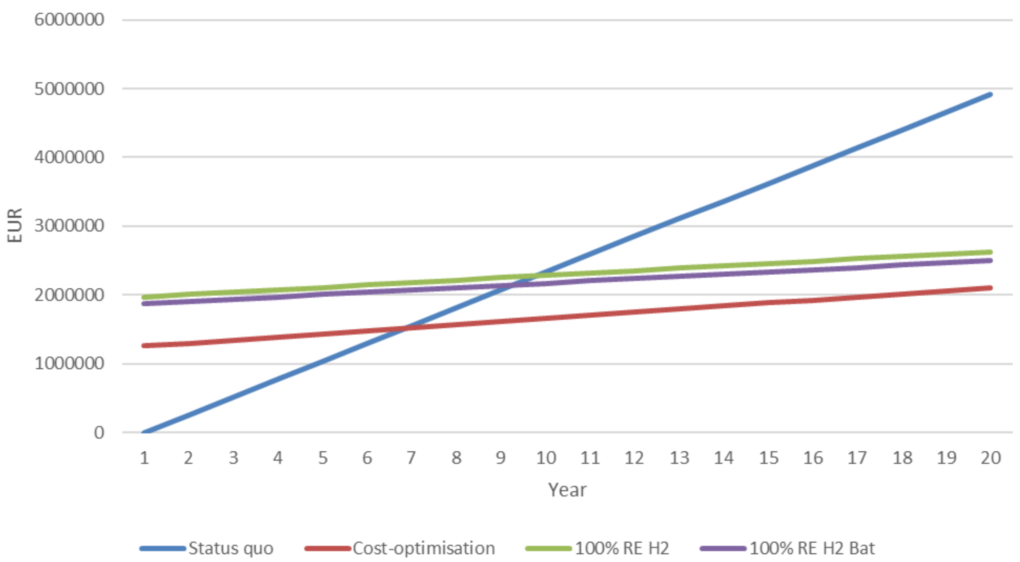
In addition to the design parameters, economic indicators such as the share of renewable energy, surplus electricity, and CO2 emissions are also important to consider in the analysis. These parameters are summarized in the following table, and Illustration 6 visualizes the calculation of the break-even point.

Illustration 7 Scenario Parameters Tanoa International Dateline Resort

Metric (Unit)/ Szenario	LCOE (€/kWh)	RE Share (%)	**Net Present Value (NPV)** (€)	**Initial Investment** Costs (€)	**Operation/ Maintenance Costs** (€/year)	**Break Even Point** (years)	**Surplus Electricity** (MWh/ years)	**Emissions (kgCO2eq/ year)**
Szenario	€/kWh	%	€	€	€/y	a	MWh/a	$kgCO_2eq/a$
Status quo	0,405	0	4.631.585	0	258.805	-	0	146.633
Cost Optimization	0,162	95	1.853.940	1.256.188	44.769	7	169	12.455
100 % RE (PV, H_2)	0,197	100	2.252.070	1.972.248	34.666	10	367	0
100 % RE (PV, at, H_2)	0,193	100	2.202.160	1.872.848	33.070	9	302	0

Electricity generation costs for this case study range from 0.16 EUR/kWh to 0.41 EUR/kWh. The cost-minimizing scenario can reduce electricity generation costs compared to the status quo by 60% and no longer requires diesel generator capacity to bridge occasional grid power outages. Both 100% renewable energy scenarios include hydrogen technology and can also lead to cost savings compared to the current power supply (PV plus hydrogen technology by 51% and an additional 2% if a battery storage is added). The break-even points are reached, as visualized in the following illustration, after 7 years (cost minimization), 10 years (100% renewable energy with PV and hydrogen technology), and 9 years (100% renewable energy with PV, hydrogen technology, and battery storage).

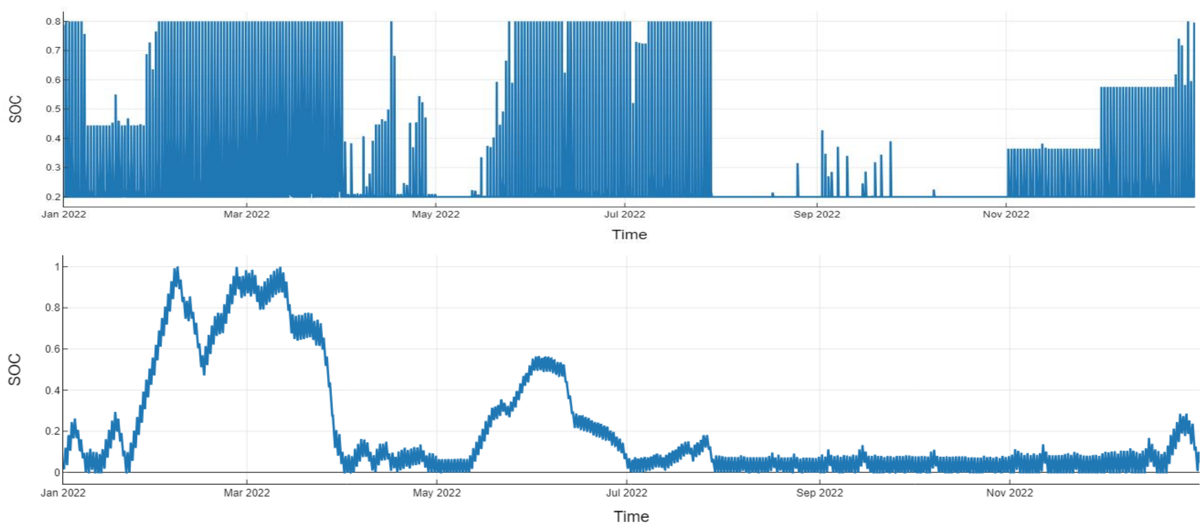
Illustration 8 Visualization of the Break-Even Points Calculation



Compared to the status quo, CO_2 emissions can be significantly reduced in the cost-minimizing scenario (92%). This results in surplus electricity, which could potentially be used elsewhere (grid feed-in under appropriate regulations or operation of a seawater desalination plant). In this case study, water consumption for hydrogen production is assumed at 9 litres per kilogram of hydrogen produced, requiring a water amount of about 94,743 litres per year. This corresponds to a daily consumption of 260 litres in the cost-minimizing scenario if the hydrogen cycle cannot be operated as a closed system. In the scenario with 100% renewable energy, based on PV, battery storage, and hydrogen technology, the annual water consumption amounts to 151,452 litres (415 litres daily), while in the scenario with 100% renewable energy without battery storage, 171,828 litres or 471 litres of water per day are needed. The majority of the costs for the individual system components and the operating costs (annuities) in the cost-minimized scenario fall on the PV plant (47%). This is followed by the projected costs for grid power consumption (21%), hydrogen technology (17%), and the battery storage with 15%.

To more precisely analyse the operational characteristics and functions of the two storage technologies (battery and hydrogen), the following illustrates their storage states (SOC) over a year.

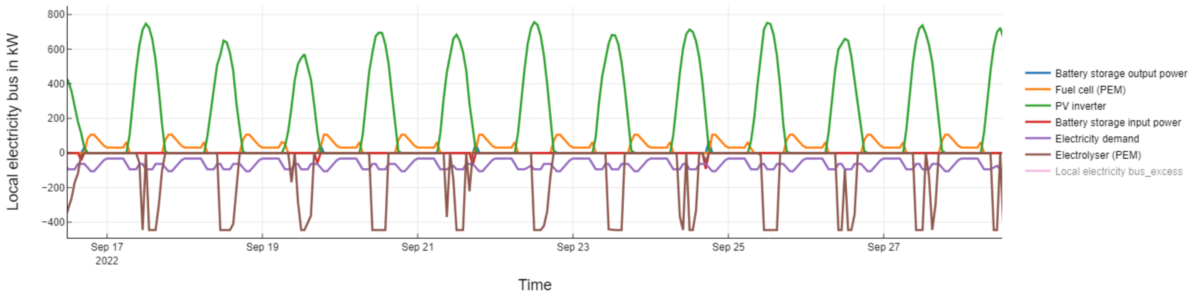
Illustration 9 Visualization of the State of Charge (SOC) of the Battery Storage (top) and the Hydrogen Storage (bottom) for the 100% Renewable Scenario (PV, Battery, Hydrogen) Over a Year



While the battery storage (top) shows strong daily fluctuations (amplitudes) and almost daily deep discharge states, the hydrogen storage is less deeply discharged throughout the day but shows strong changes over the year. Especially in March and June, a high proportion of hydrogen is re-electrified. In both profiles, there are also strong declines in power supply from the storages over the course of the year (second half of May and August/September). This is due to the relatively low consumption compared to the available solar potential, resulting in increased direct solar electricity generation.

To illustrate this, the following illustration visualizes the power flows for a few days in September. The power consumption (purple) is significantly below the electricity generation from the solar plant (green).

Illustration 10 Exemplary Visualization of the Power Flow for a Few September Days for the 100% Renewable Scenario (PV, Battery, Hydrogen)



3. Sensitivity Analysis

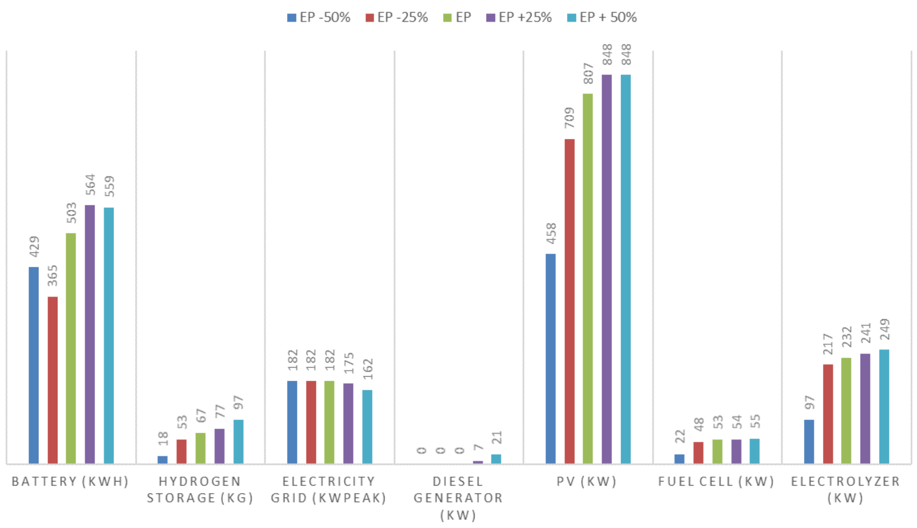
3.1. Electricity Price

Initially, the influence of electricity price fluctuations on the simulation results was examined. For this case study in Tonga with an electricity price of 0.358 EUR/kWh, the following changes in electricity prices occur for the various sensitivity cases (25% and 50% higher and lower electricity prices):

- +50% => 0.45 EUR/kWh
- +25% => 0.27 EUR/kWh Status Quo = 0.358 EUR/kWh
- -25% => 0.27 EUR/kWh
- -50% => 0.18 EUR/kWh

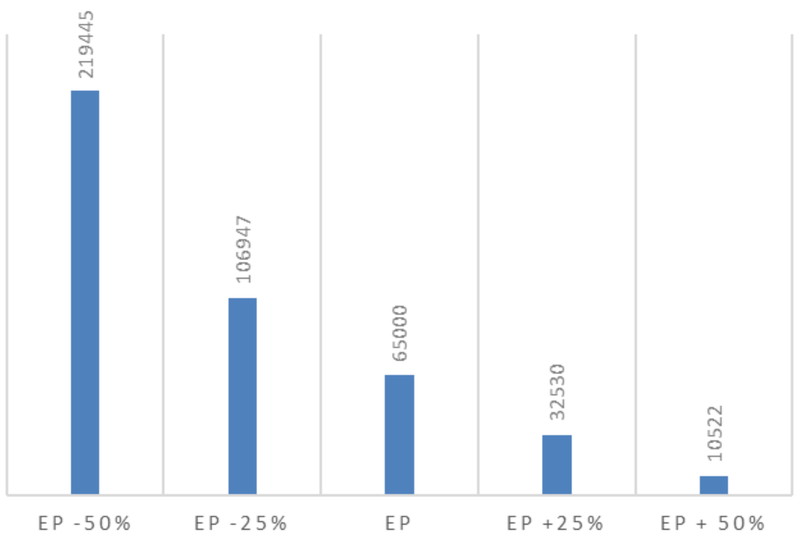
Simulated in MVS for the cost-minimizing scenario, the results are visualized in the following graph. The capacities of the individual system components are displayed. Green (centered) represents the reference scenario under current prices for comparison.

Illustration 11 Optimized Capacities of Individual Technologies with Electricity Price Fluctuations



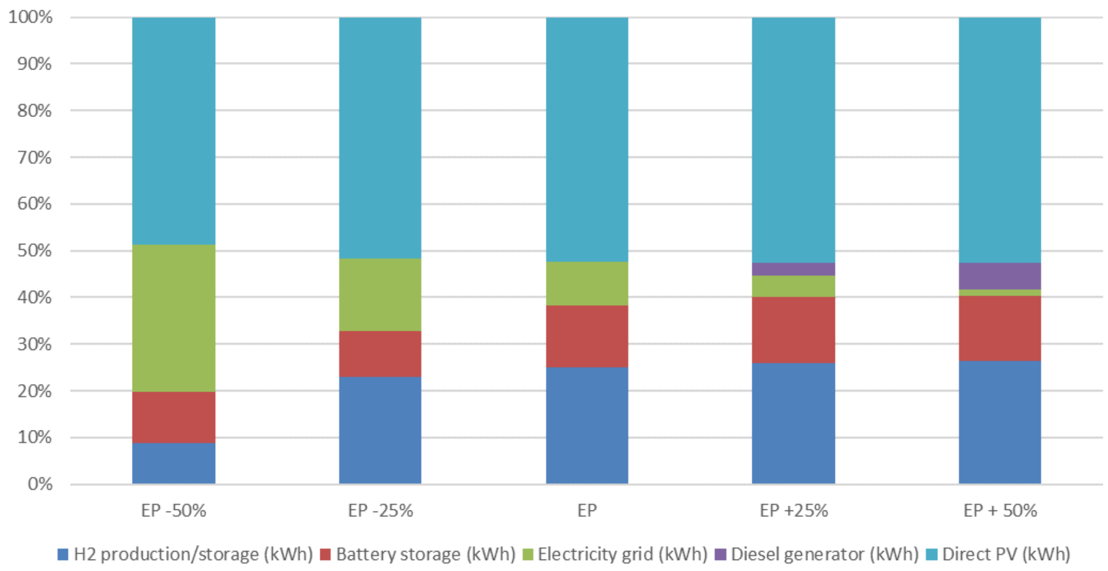
Overall, changes in the dimensioning of the energy system for the Tanoa International Dateline Resort are evident with electricity price developments in both directions. The absolute largest capacity fluctuations are observed in the PV and battery storage components, while the composition of the hydrogen system varies significantly relative to others. Both capacities increase with higher electricity prices (electricity prices – EP), as the system becomes more autonomous and grid power consumption decreases. In this case, the diesel generator is also used (lower peak load coverage through grid power), but it is significantly smaller compared to the previously installed generator. In the case of declining electricity prices, especially the installed hydrogen capacities and the size of the PV plant decrease, with the sharpest cut occurring with a halving of the current electricity price. The installed battery storage capacity initially decreases as well, but increases again at -50% lower electricity prices, as it now stores not only solar but also grid electricity to bridge occasional power outages. The following illustration clearly shows how strongly grid power consumption overall depends on electricity price fluctuations:

Illustration 12 Grid Power Consumption in kWh for the Calculated Sensitivity Cases (Electricity Price Fluctuations)



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

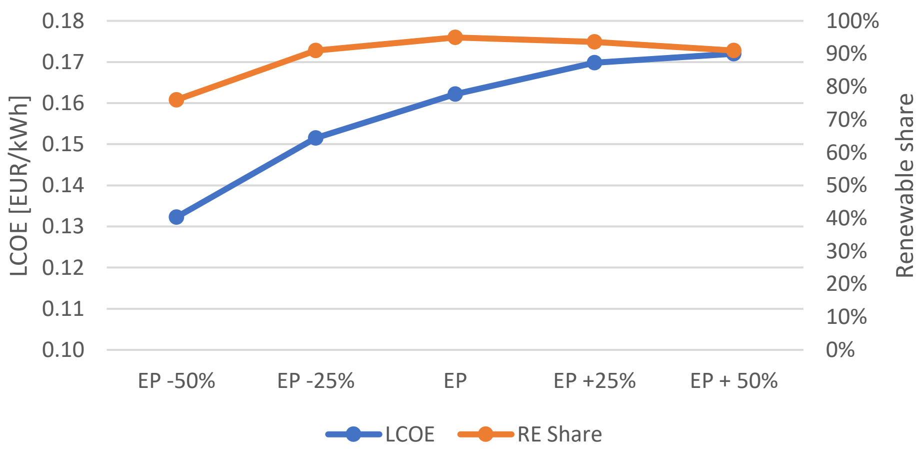
Illustration 13 Share in Covering Power Demand with Electricity Price Fluctuations



The majority of the electricity consumption at the Tanoa International Dateline Resort is fed directly via the PV plant (turquoise) in all scenarios. The lower the electricity price, the more electricity is sourced from the grid (green). The share of hydrogen technology (blue) in load coverage remains largely the same except in the case of a 50% electricity price drop, where its contribution to demand coverage is significantly lower.

As the last illustration of this sensitivity analysis, the development of electricity generation costs and the share of the renewable energy system is visualized.

Illustration 14 Development of Electricity Generation Costs and the Share of Renewable Energy with Electricity Price Fluctuations



Electricity generation costs fluctuate between 0.13 – 0.17 EUR/kWh (the higher the electricity price, the higher the electricity generation costs). The share of renewable energies in the system remains relatively high at 80% to 94%. The highest share of renewable energies is achieved in the status quo. With rising electricity prices, this share decreases slightly due to the integration of the diesel generator into the system, while it decreases somewhat more strongly with decreasing electricity prices due to increased sourcing of grid power.

Investment Costs of Hydrogen Technology

For the calculation of sensitivities regarding fluctuations in the investment costs of 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):

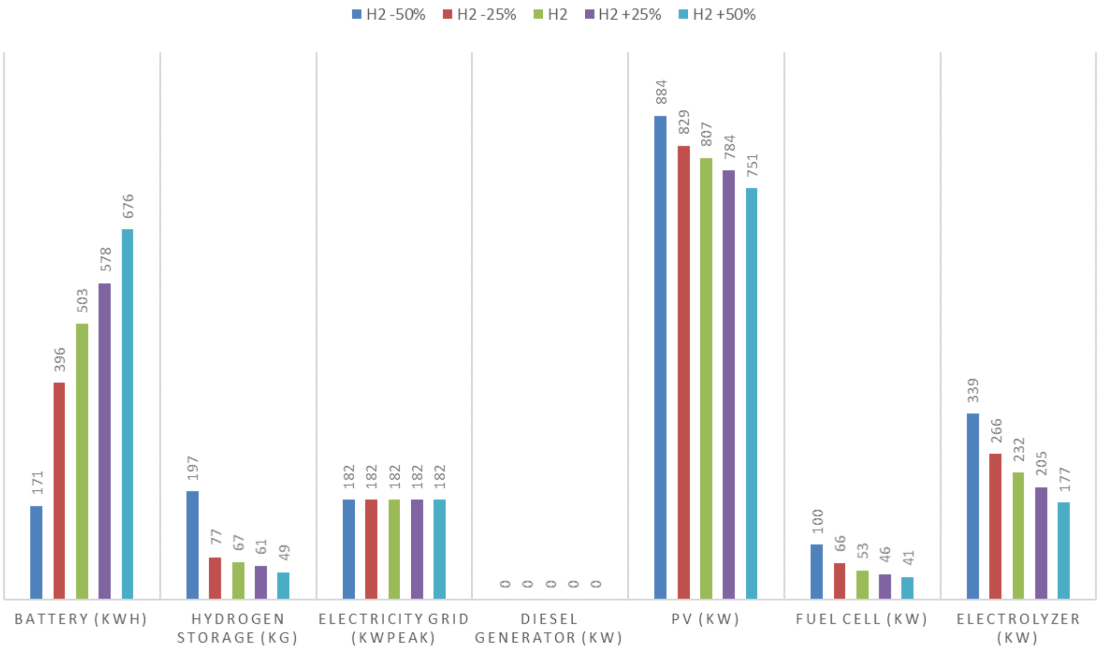
- +50% => 915 EUR/kW
- +25% => 763 EUR/kW
- -25% => 458 EUR/kW
- -50% => 305 EUR/kW

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

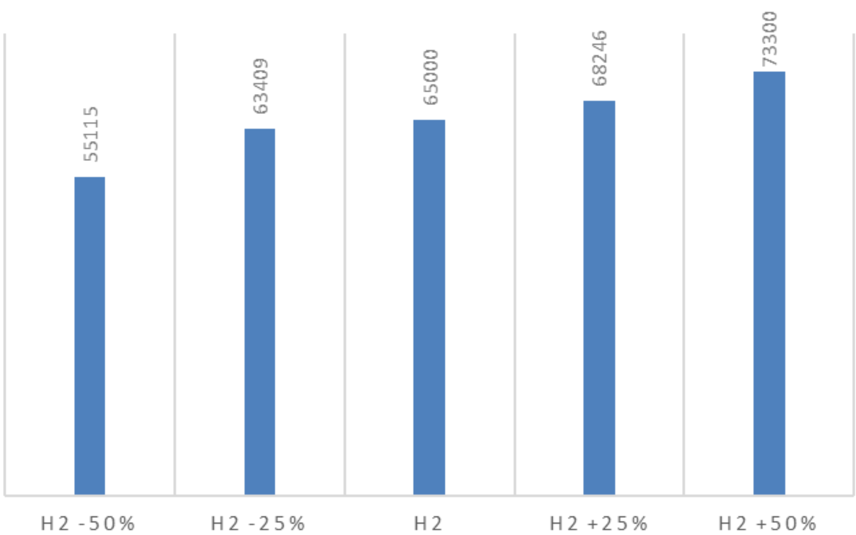
Analogous to the sensitivity analysis of electricity prices, the development of the capacities of the individual system components with price fluctuations in the investment costs of the hydrogen components was shown. Here too, the simulation of the reference scenario (cost minimization) with status quo prices is displayed in green.

Illustration 15 Optimized Capacities of Individual Technologies with Fluctuations in Hydrogen Investment Costs



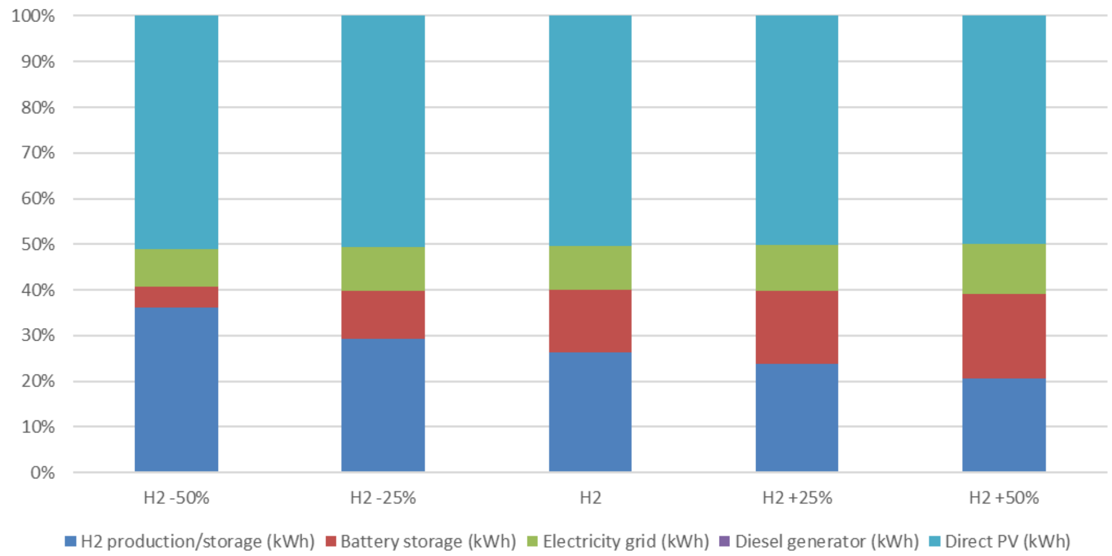
With increasing costs for hydrogen technology, both the capacity of the hydrogen components and that of the PV plant decrease. The battery storage, on the other hand, is dimensioned larger to cover the resulting storage need. If the costs of the hydrogen components decrease, the importance of the PV plant and hydrogen components increases, and a correspondingly smaller battery storage capacity is recommended. Especially with a price reduction of 50%, a clear trend towards more hydrogen and less battery storage is evident. The peak load (182 kWp) is covered from the grid in all cases, and an additional diesel generator is not needed in any sensitivity scenario. As the total amount sourced from the grid decreases slightly when the costs for hydrogen components go down, it increases with an increase in these costs, and the system loses autonomy (see the following illustration).

Illustration 16 Grid Power Consumption in kWh for the Calculated Sensitivity Cases (Investment Costs of Hydrogen Components)



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

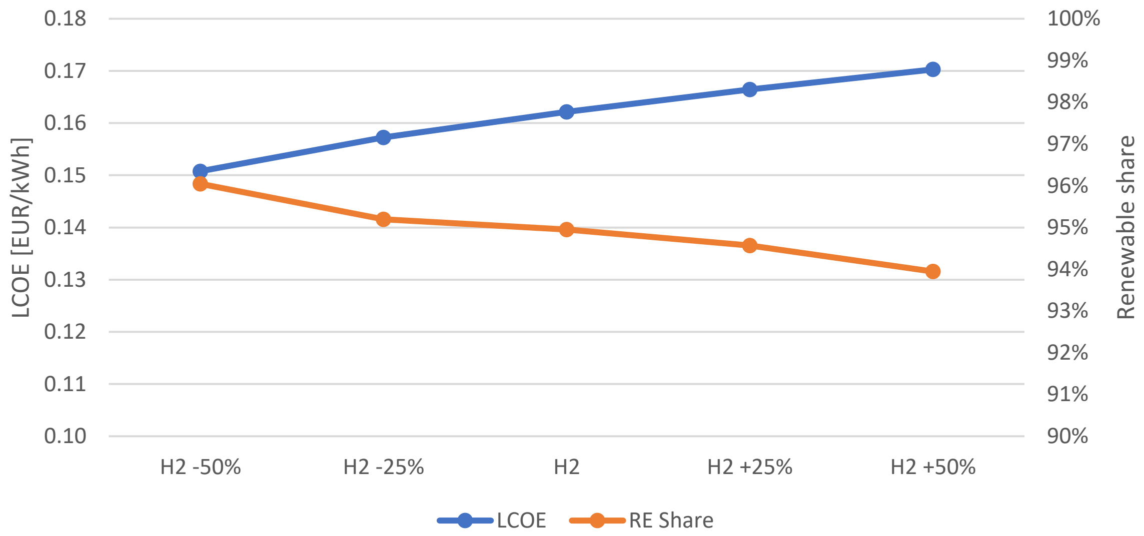
Illustration 17 Share in Covering Power Demand with Fluctuations in Hydrogen Investment Costs



The share of direct PV electricity generation thus remains largely constant, and there are only minor fluctuations in the grid power share (higher hydrogen component costs increase, as mentioned above, the grid power consumption). Thus, the overall share of storage technologies in demand coverage also remains largely constant, and there are only changes in the type of installed technology: Intuitively, the shares of hydrogen components increase or decrease with an increase or decrease in their costs. It is interesting to note that the share of hydrogen technology, even with a cost increase of 50%, never falls below half of the total installed storage capacity, underscoring the importance of the technology as a long-term storage for the system.

Finally, here are the developments of the electricity generation costs and the share of renewables:

Illustration 18 Development of Electricity Generation Costs and the Share of Renewable Energies with Fluctuations in Hydrogen Investment Costs



Electricity generation costs fluctuate only slightly between 0.15 EUR/kWh and 0.17 EUR/kWh, with LCOE increasing slightly at higher hydrogen component costs. The share of renewable energies decreases with rising hydrogen component prices, here too, however, only slightly by a maximum of 2% in the cases considered.

5. Conclusion

The Tanoa International Dateline Resort would benefit from the installation of a PV plant, a battery storage, and new hydrogen technologies to supplement grid power consumption. This could reduce the electricity costs of the facility by up to 60% in the long term and achieve a high share of renewable energies (95%). The backup diesel generator would become redundant, with small capacities only recommended from a 25% increase in electricity prices. Both 100% renewable energy scenarios include the use of hydrogen technologies and promise a cost reduction compared to the current power supply. Hydrogen technology plays a role in all sensitivity cases, its relevance only decreases in the case of a 50% collapse in electricity prices. In the case of declining technology prices, hydrogen would be used as the primary system storage, and even with significant price increases, its share of the total installed storage capacity would never fall below 50%, while the relevance of battery storages with decreasing investment costs for hydrogen components declines significantly.

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