Green Hydrogen Production for Use in Off-Grid Applications, Nigeria

Techno-economic feasibility study

7. Dec. 2022

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Electricity Situation in Nigeria

- Generation is 35,700 GWh whereas, demand is around 29 TWh
- Major source of generation: Gas turbine and hydropower
- There are a total of 23 generation stations
- Electricity is transmitted at 330 kV, covering over 20,000 km
- Distribution to users is done at voltage between 11 kV and 33 kV
- 11 distribution companies are responsible for final distribution of electricity to users

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Goal of Study

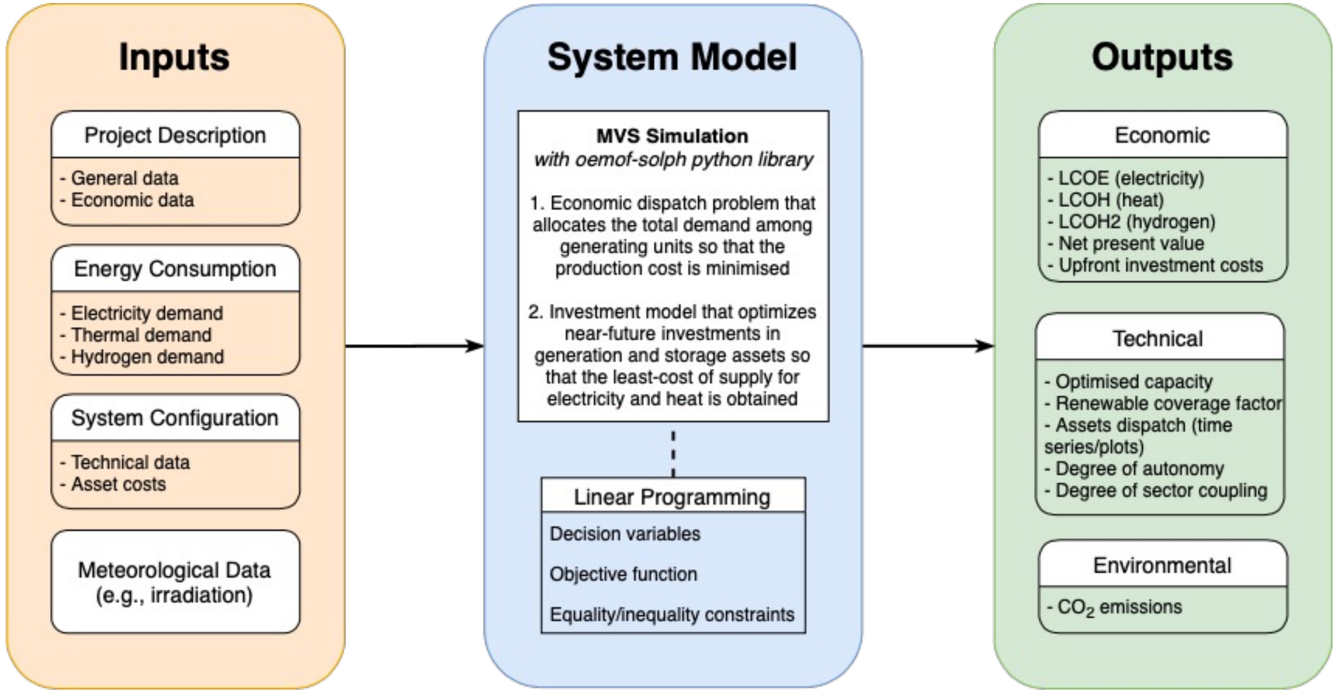
Determine whether the integration of green hydrogen production is a profitable solution for mini grids

- 100 % renewable electricity source (PV + battery storage)
- Hydrogen for electricity storage
- Hydrogen for external sales

Multi-Vector Simulator (MVS) – Input/Output Transformation

The MVS was deployed to obtain:

- Economic Key Performance Indicators (KPI) of the 4 scenarios
- Technical Key Performance Indicators (KPI) of the 4 scenarios

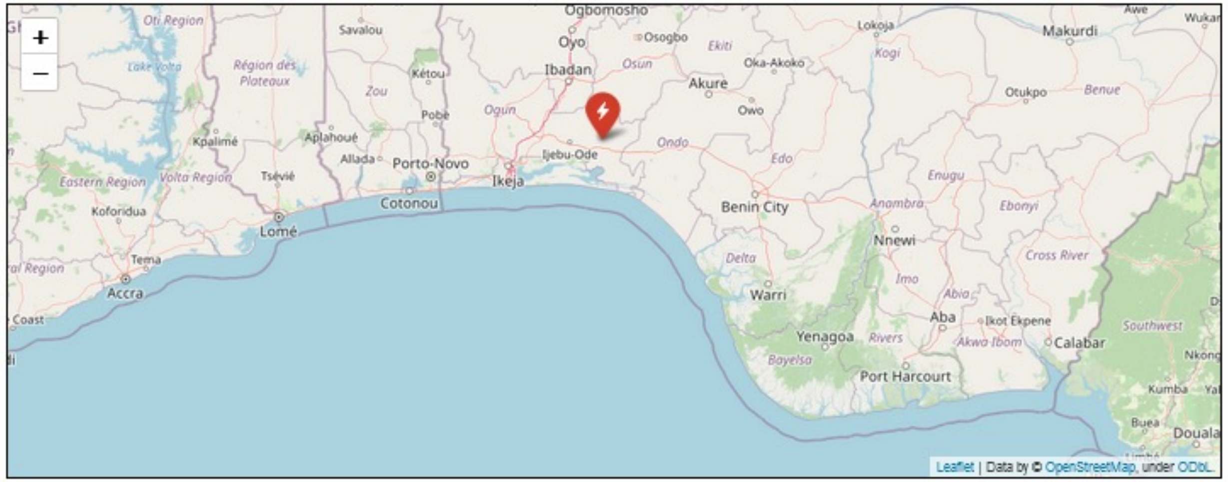


Identified Location: Case Study

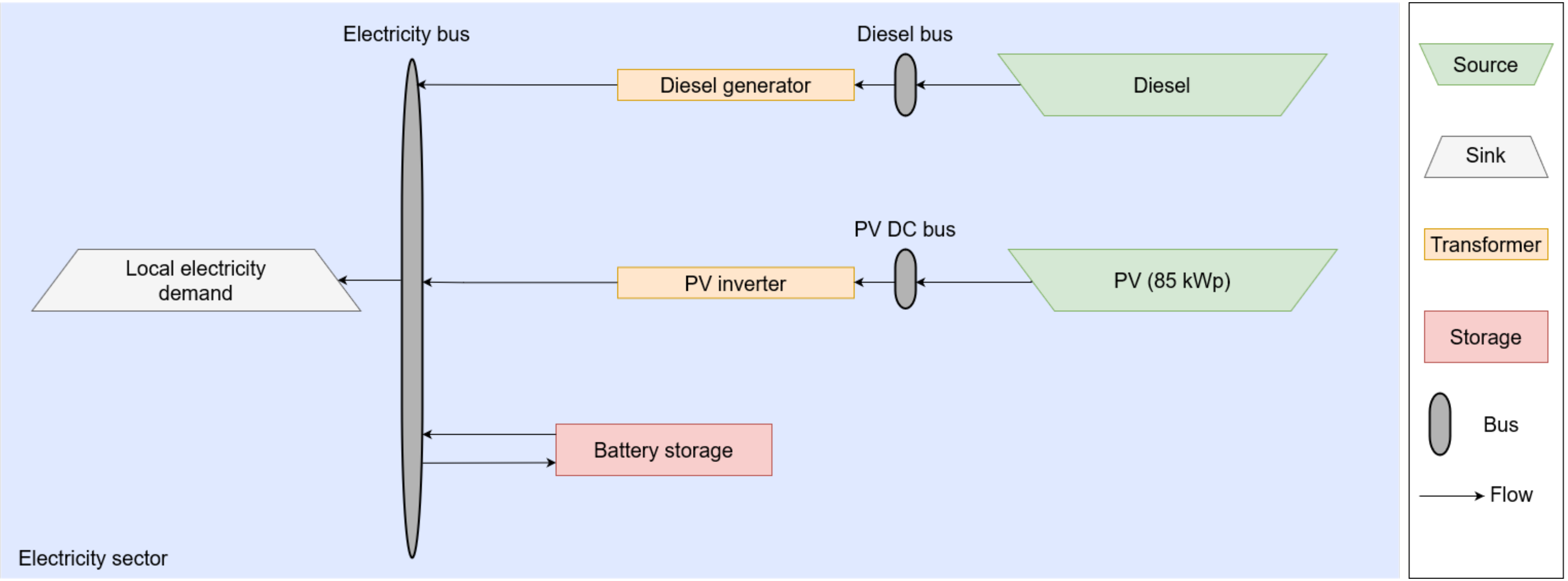
Gbamu Gbamu

- Existing diesel generator + supply
- Mini-grid
- PV + battery storage (current renewable sources)

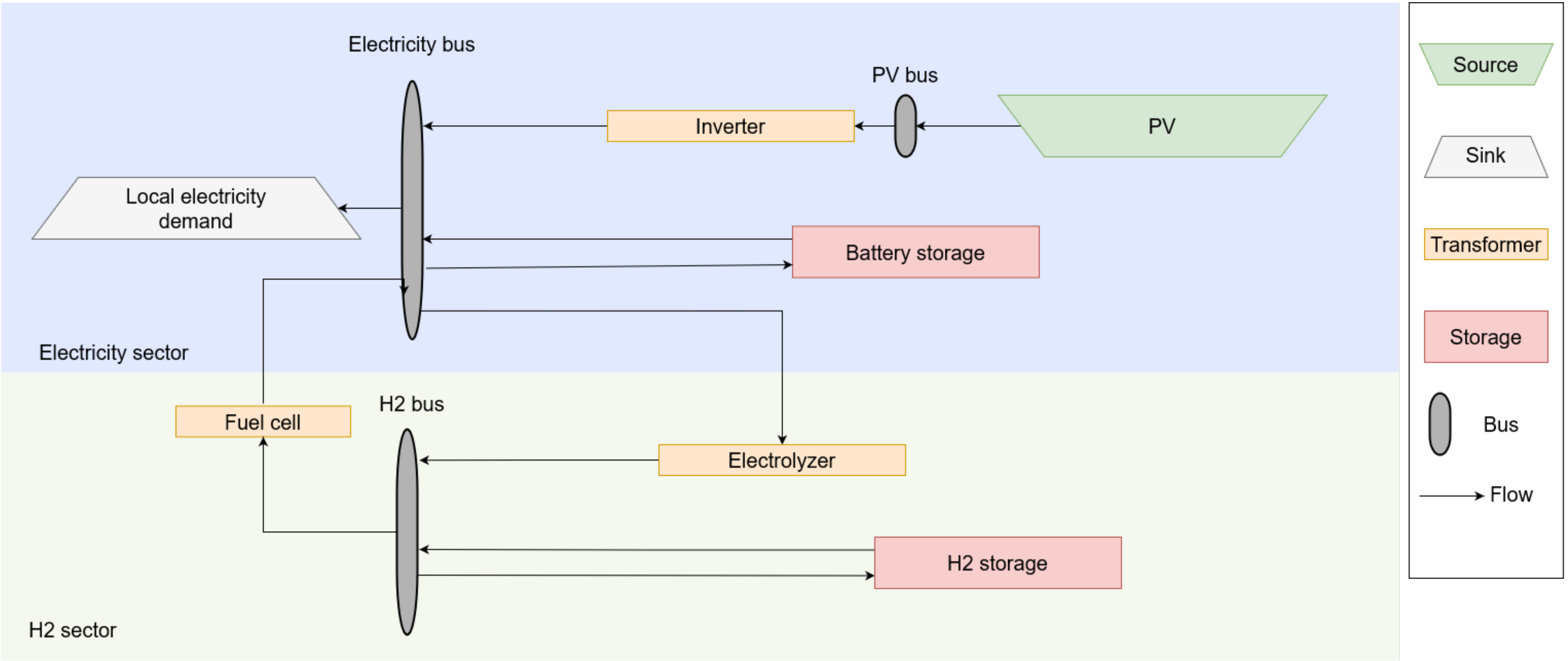
Project Location



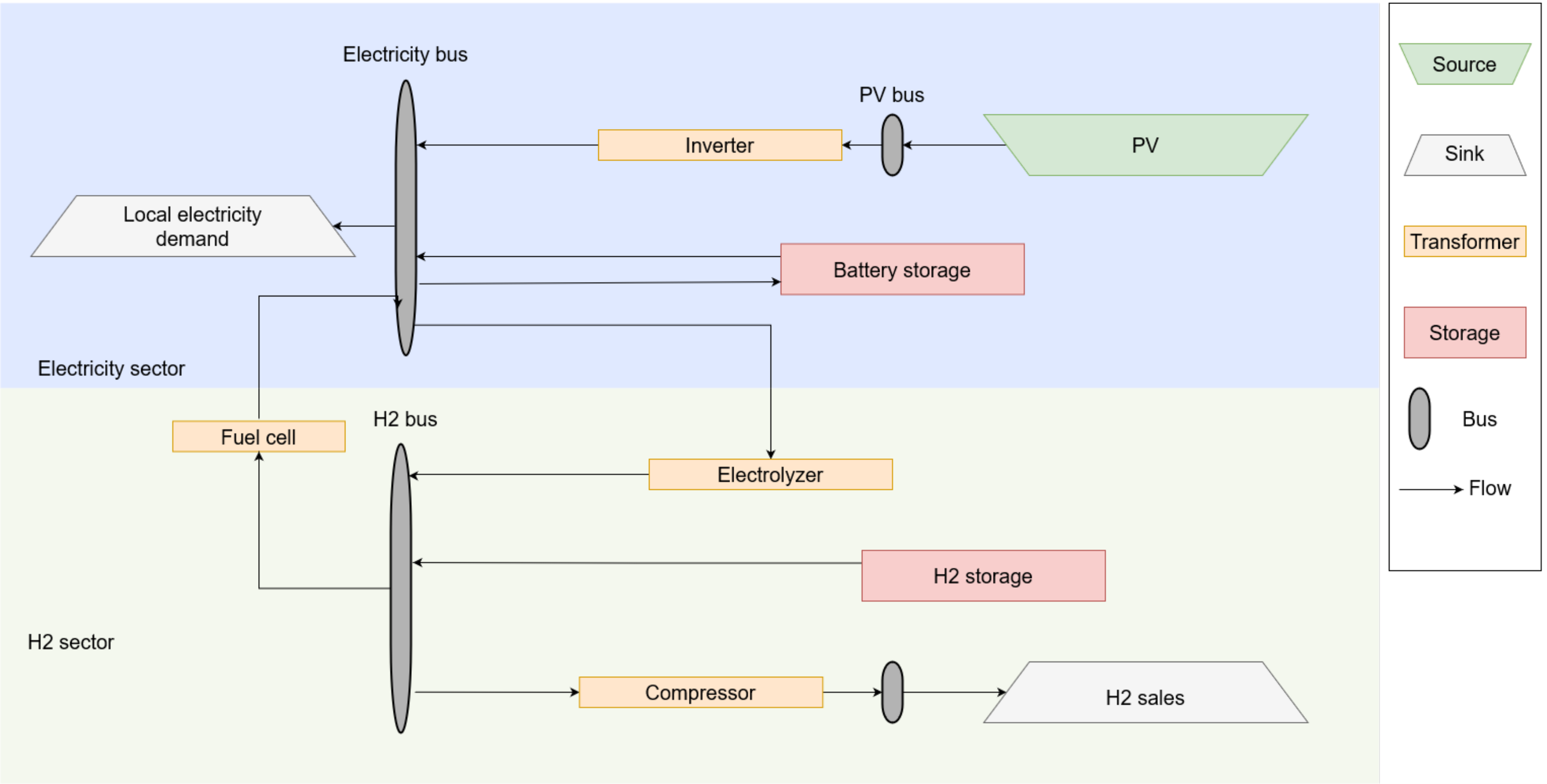
Scenario 1: Gbamu Gbamu - status quo



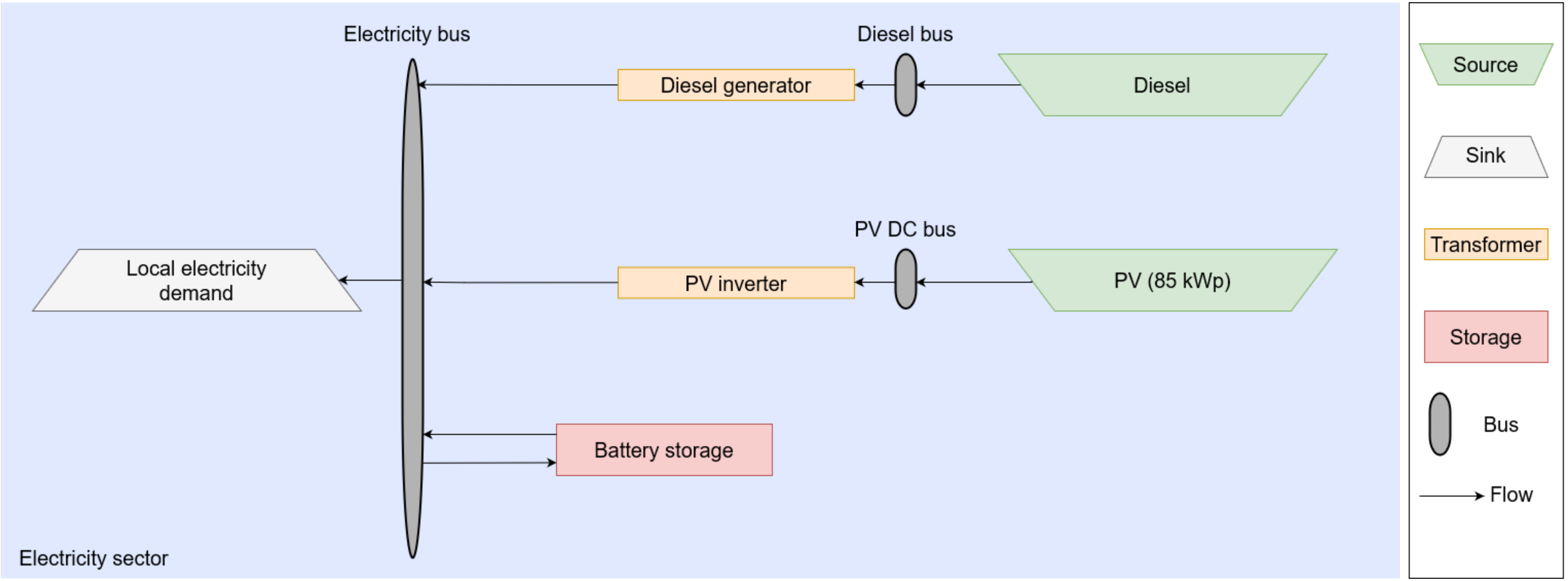
Scenario 2: Gbamu Gbamu
100% renewable + option for H2 elec. storage



Scenario 3: Gbamu Gbamu
100% renewable + option for H2 elec. storage and sales



Scenario 4: Gbamu Gbamu PV (95%)+ Diesel Genset



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Already existing capacities

Assets \ Scenarios	Status quo [I]	100% renewable + option for H2 elec. storage [II]	100% renewable + option for H2 elec. storage and sales [III]
Diesel generator [kW]	53	-/-	-/-
PV [kWp]	85	85*	85*
Battery storage (Li-ion) [kWh]	288	288*	288*
Electrolyzer [kW]	-/-	-/-	-/-
Fuel cell [kW]	-/-	-/-	-/-
H2 storage [kgH2]	-/-	-/-	-/-
H2 compressor [kgH2]	-/-	-/-	-/-

* The additional capacities will be optimized

Already existing capacities

- Total actual annual electricity demand for Gbamu
  Gbamu: 171, 809 kWh/a
- From data received by RUBITEC for multiple serial numbers, first and second serial numbers identified as supply to system
- First and second patterns similar -> first serial number chosen

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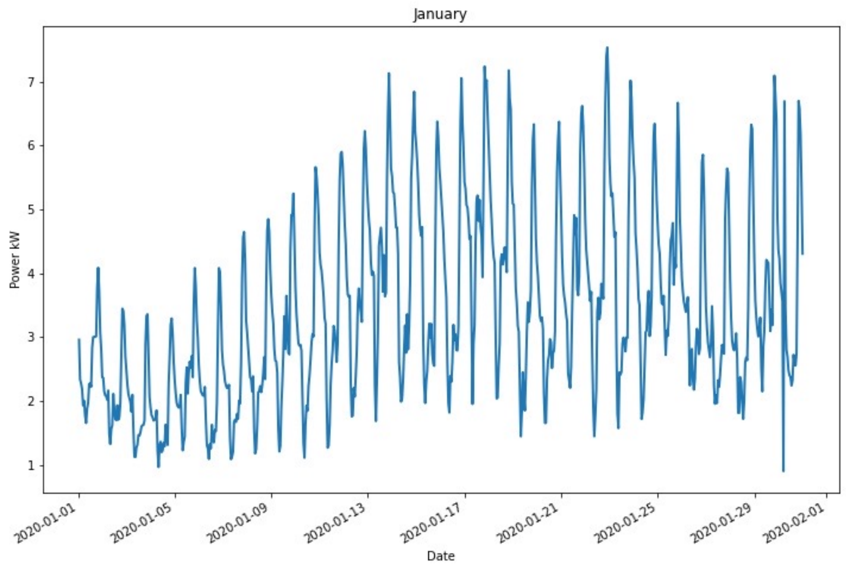
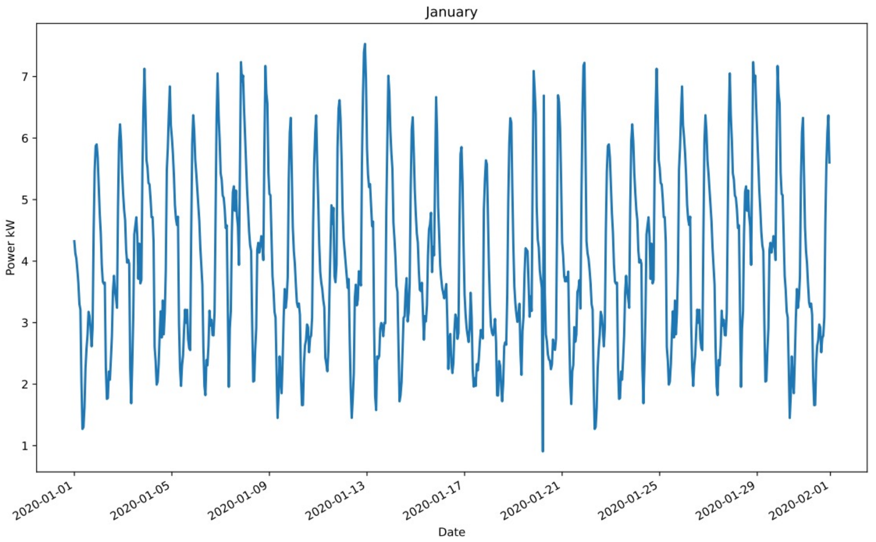
Electricity demand - Approach

- January only month with complete data given (no connection losses/blackouts)
- January load pattern is taken (final two weeks because first weeks were significantly lower)
- The pattern is repeated for the rest of the year and scaled according to annual electricity demand

Original

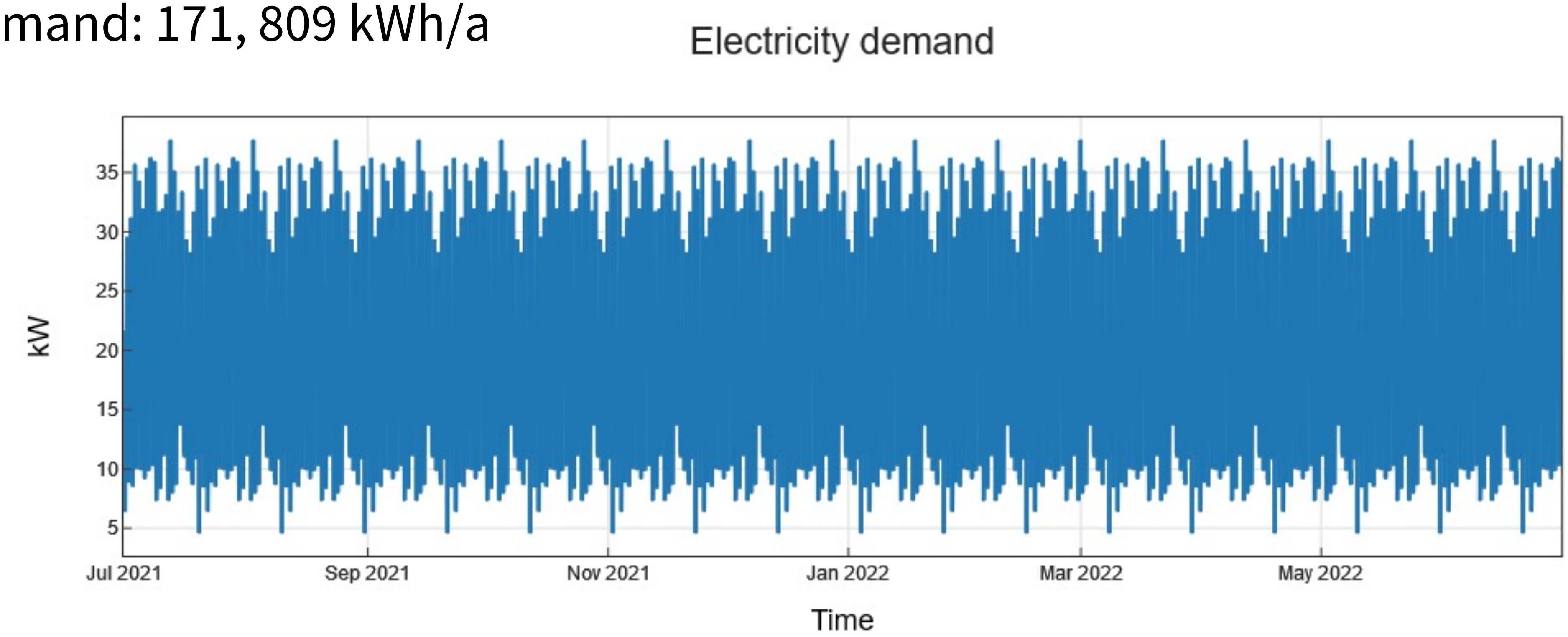


Adjusted



Electricity demand

- Peak demand: 38 kW
- Annual demand: 171, 809 kWh/a



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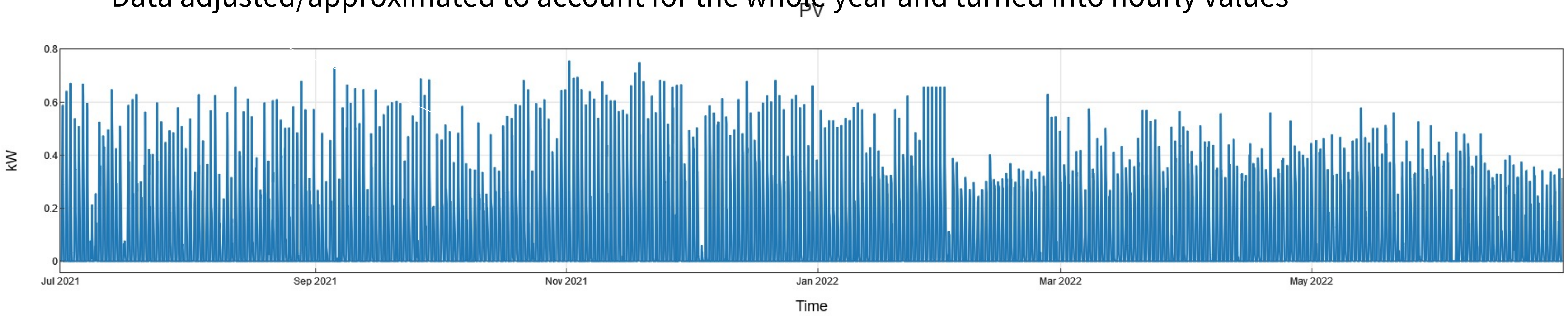
PV generation time series

- 5 minute data for most of the year provided by RUBITEC
- Data adjusted/approximated to account for the whole year and turned into hourly values



- Peak normalized production: 0.76 kW/kWp
- Specific yearly production: 1021.5 kWh/a

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Data assumptions (assets NGN)

	CAPEX (NGN/kW)	OPEX (NGN/kW/year)	Dispatch price (NGN/L)	Electrical efficiency (%)	Lifetime (years)
Electrolyzer (AEC)	15,651,500 (/kgH2) [2] (312,250 NGN/kW)	782,500 (/kgH2) [2] (5% of capex)		66.5 [2]	25 [2]
Fuel cell (AFC)	293,000 [1]	14,500 [*]		60 [1]	20 [1]
Solar panel	343,750 [5]	3,500 (1% of capex)			25 [5]
Solar inverter	99,000 [5]			98 [6]	20 [*]
Solar cables, connectors, support structure	68,750				20 [*]
Diesel generator	264,250		Diesel price (+ transport) 670 [5]	31.8 [5]	12 [5]
H2 storage capacity (gas)	961,250 (/kgH2) [4]	10,000 (/kgH2) [4]			25 [4]
Battery storage capacity (Li-ion)	85,250 [5]				10 [5]
Battery storage input				98 [4b]	10 [5]
Battery inverter	264,000 [5]			95.8 [5]	7 [5]
H2 compressor	4,695,500 (/kgH2) (30% of ely capex) [7]			88 [4]	25 [4]

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Other assumptions

- General operation and maintenance costs provided by RUBITEC
- Connection tariff provided by RUBITEC
- H2 sales price taken to be equivalent of 4 USD/kg, the average selling price of H2*
- The CAPEX of existing assets is not included in the financial evaluation, as it is assumed the investments have already been made

Operation and maintenance costs (general)	6,536.4 EUR/a 22.8 M NGN/a
Connection tariff	0.6 EUR /kWh 260 NGN/kWh
H2 sales price	3.9 EUR/kg 1,660 NGN/kg

Simulation scenarios

Assets \ Scenarios	Status quo [I]	100% renewable + option for H2 elec. storage [II]	100% renewable + option for H2 elec. storage and sales [III]
Diesel generator	Set capacity	-/-	-/-
PV	Set capacity	Capacity optimized	Capacity optimized
Battery storage (Li-ion)	Set capacity	Capacity optimized	Capacity optimized
Electrolyzer	-/-	Capacity optimized	Capacity optimized
Fuel cell	-/-	Capacity optimized	Capacity optimized
H2 storage	-/-	Capacity optimized	Capacity optimized
H2 compressor		-/-	Capacity optimized

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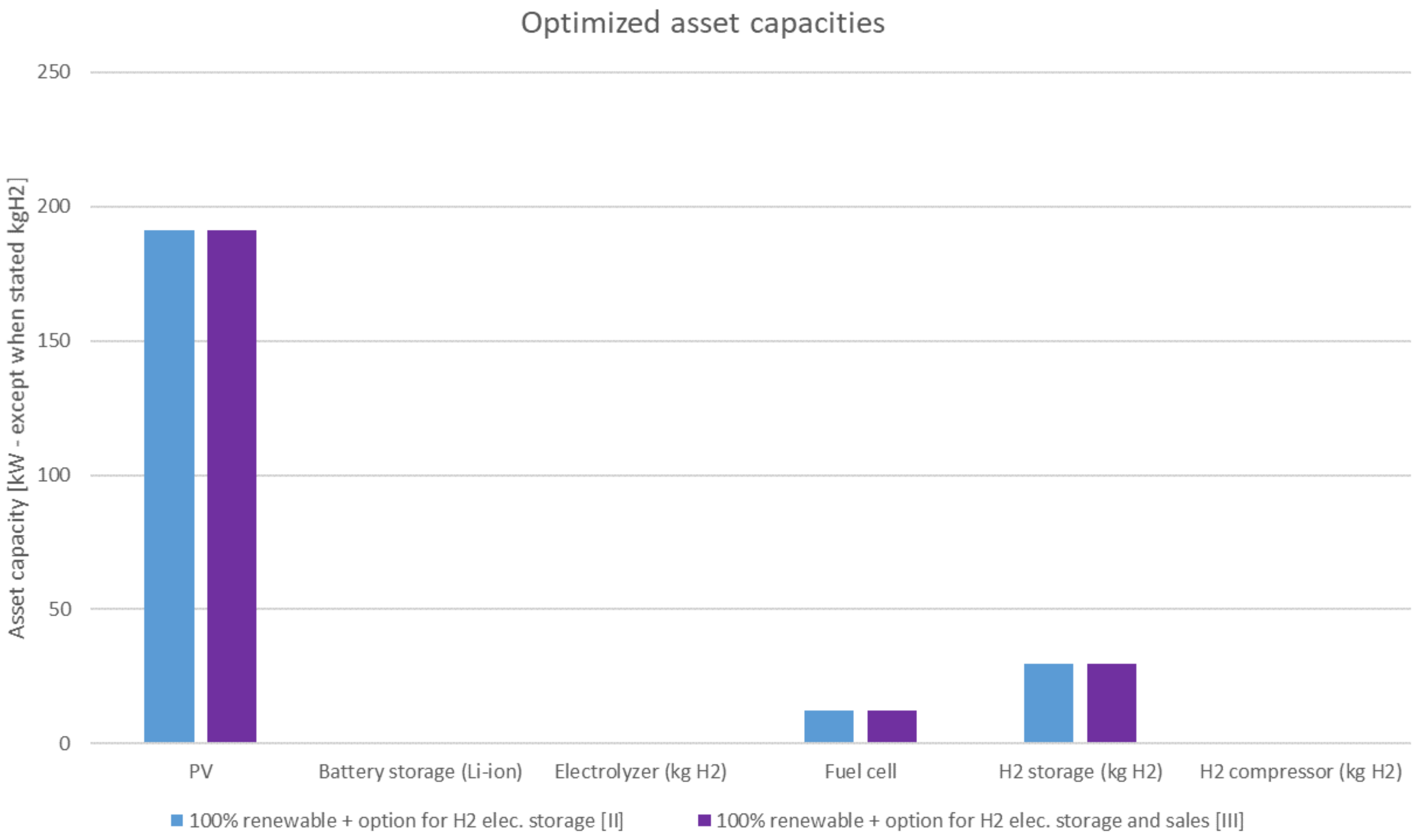
Optimized additional capacities



- No Li-ion battery is installed in scenarios [II] and [III] as H2 is more economically viable
- Scenarios [II] and [III] are identical except scenario [III] has installed a compressor
- The existing 85 kWp PV and 288 kWh battery storage is not included here

Key Performance Indicators

Parameters \ Scenarios	Status quo [I]	100% renewable + option for H2 elec. storage [II]	100% renewable + option for H2 elec. storage and sales [III]
LCOE (Levelized costs of electricity supply) (NGN/kWh)	102	96	90
NPV (net present value) (M NGN)	114	107	101
Upfront investment (M NGN)	0	107	108
Replacement costs (lifetime) (M NGN)	112	109	109
Annual O&M costs + tariffs (M NGN/a)	0.2	-17	-18
Diesel consumption (L/a)	27 700	0	0
Renewable factor (%)	25	100	100
Emissions (kg $_{CO2\ eq}$ /a)	74 791	0	0

LCOE decreases in scenario 2 due to less replacement costs over lifetime as well as the removal of purchasing fuel + paying for the transportation of it -> the cost of diesel supply + transportation contributes to 33.2 % of the total system annuity

Despite higher upfront investment costs, the LCOE of scenario 3 is reduced from scenario 2 because of an additional source of income (H2 sales from excess RE)

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Sensitivity analysis summary – vary diesel price

System/s Factor variation	Status quo [I] 100 % renewable + option for H2 elec. storage and sales [III]
Diesel price (inc. transport) (NGN/L)	335 - 1005 i = 167.5 (25% of 670)
Base Diesel price (inc. transport)	670 (NGN/L) 1.6 (EUR/L)
Base H2 sales price	1,660 (NGN/kg) 3.88 (EUR/kg)

- The financial KPIs of the status quo scenario with increasing diesel price are compared to the financial KPIs of scenarios [II] and [III]

- The goal is to see at which diesel price hydrogen becomes a competitive alternative for the mini grid

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Key Performance Indicators

	SCENARIO 1	SCENARIO 2	SCENARIO 3
Diesel consumption	25,079 litres/a	0	0
Renewable factor	25	100	100
Plant carbon emission	67,714 $T_{CO_2\,eq}$/a	0	0
Renewable generation	86,752 kWh/a	281,825 kWh/a	281, 825 kWh/a
Share of renewable generation that is excess (%)	0	22	18
Excess generation	0 kWh/a	62,052 kWh/a	50,686 kWh/a
Yearly revenue generation	104,275.7 EUR/a 44,725,216 NGN/a	147,322.6 EUR/a 63,189,020 NGN/a	157,160 EUR/a 67,322,745 NGN/a
Payback time	3 yrs, 9 months, 3 days	3 yrs, 4 months, 6 days	3 yrs, 2months

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Key Performance Indicators

Scenarios / Parameters	100 RES	95 RES	90 RES	85 RES	80 RES
LCOE (Levelized costs of electricity supply) (NGN/kWh)	90	59	53	51	50
NPV (net present value) (M NGN)	101	66	59	57	56
Upfront investment (M NGN)	108	69	57	49	42
Replacement costs (lifetime) (M NGN)	109	109	109	109	109
Annual O&M costs + tariffs (M NGN/a)	-18	-17	-16	-15.5	-15
Diesel consumption (L/a)	0	1365	2605	3852	5134
Renewable factor (%)	100	95	90	85	80
Emissions (kg $_{CO2\ eq}$ /a)	0	3687	7032	10400	13862

Summary

1. The LCOE of the system reduces by 34 % from 100 RES to 95 RES, and only by 10 % from 95 RES to 90 RES
2. All H2 asset capacities have to significantly increase to achieve a 100 % renewable scenario:
   - Electrolyzer increases by 76 % from 95 RES to 100 RES, 42 % from 90 RES to 95 RES
   - Fuel cell increases by 140 % from 95 RES to 100 RES, 67 % from 90 RES to 95 RES
   - H2 storage increases by 400 % from 95 RES to 100 RES, 50 % from 90 RES to 95 RES
3. An optimal solution for Gbamu Gbamu might be to look at allowing for a small amount of back-up diesel with a majority PV/H2 storage system e.g. 95 % renewable energy share

Summary

- Due to the on-going costs of diesel (high fuel + transportation costs of 1.56 EUR/L as well as diesel generator replacement costs), the 100 % renewable scenarios involving H2 as a means of electricity storage are financially feasible solutions
- H2 becomes a competitive alternative with diesel from approx. 1.45 EUR/L for H2 as electricity storage
- The inclusion of H2 production for sales (from excess renewable generation) increases the profitability of the system, becoming a competitive alternative with diesel from approx. 1.4 EUR/L.
- Considering a 95 % renewable scenario instead of a 100 % renewable scenario can reduce the LCOE by 34 %

Future research gaps

- Real-life demand profile for Gbamu Gbamu
- H_2 cost data specifically for Nigeria
- More in-depth analysis of the emissions involved in each scenario, and how the system changes impact them
- Assessment into additional routes for H_2 such as for transportation and ammonia production

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