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The Potential of Hydrogen-based Storage Systems in Sub-Saharan Africa

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Agenda

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1 Research Question

- In a decentralized mini-grid: How does the addition of
  - hydrogen production components
  - hydrogen storage components
  - hydrogen fuel cell for electricity production
- affect the
  - efficient usage of the existing photovoltaic production capacity
  - self-sufficiency of the mini-grid

2 Case Study: Mini-grid in Tema, Ghana

Electricity situation in Ghana

- In 2020 14.1 % of the population in Ghana had no access to electricity [5]
- National grid mix: 62% oil and natural gas [6]
- Diesel generators are widely used [6]
- Renewable mini-grids are a low emission possibility to satisfy the increasing electricity demand with high reliability [7] [8]

Existing mini-grid in Tema, Ghana

- Provides energy for the campus of the Don Bosco Renewable Energy Center
- Five individual solar power systems with different types of batteries

Don Bosco Campus, Tema (GH).
Source: Google Maps, Michele Velenderic.

2 Case Study: Mini-grid in Tema, Ghana

Existing installation

Solar Center	Provincial House	Chapel	Hostel	Canteen
57 kWp	42 kWp	11 kWh	16 kWh	38 kWh
175 kWh	30 kWh	58 kWh	30 kWh	61 kWh
	39 kWh			

PV Modules
Lead-acid batteries
Lithium-Ion batteries
Sodium-nickel chloride batteries

Totals

PV power: 165 kWp

Battery capacity: 394 kWh

3 Potential of Hydrogen

How does the mini-grid currently operate?

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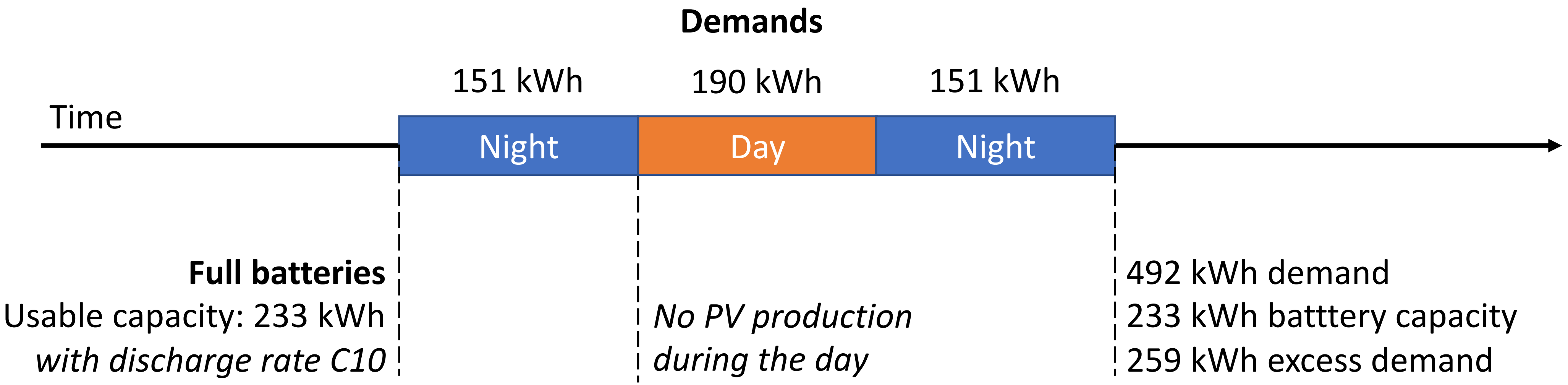
- Average electricity demand: 341 kWh
  - 190 kWh during the day
  - 151 kWh at night
- 4 full load hours per day are expected in Tema
  - Existing PV modules could produce 660 kWh per day
- PV modules are curtailed regularly due to the lower overall demand and no possibility for feed-in to the grid due to regulatory reasons
- Potential to produce hydrogen with the excess generation power

3 Potential of Hydrogen

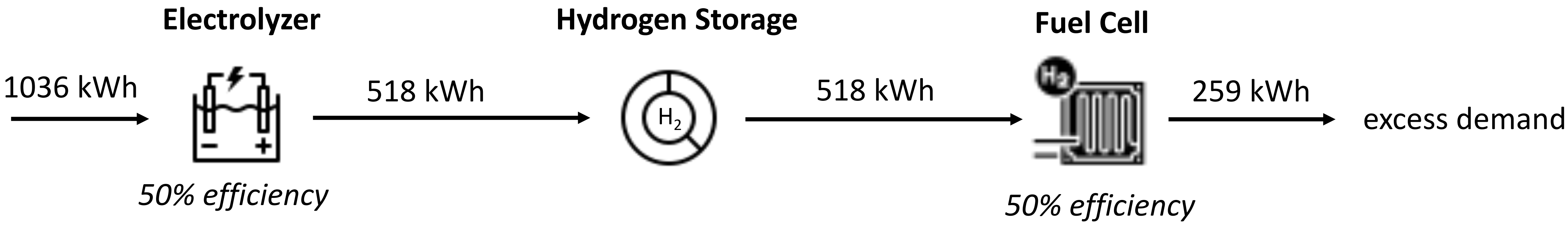
When hydrogen-storage could help?

- Situtations with low PV production due to bad weather
- Consider a period of 36 hours with 2 nights and one day



3 Potential of Hydrogen

Sizing of hydrogen components



Electrolyzer

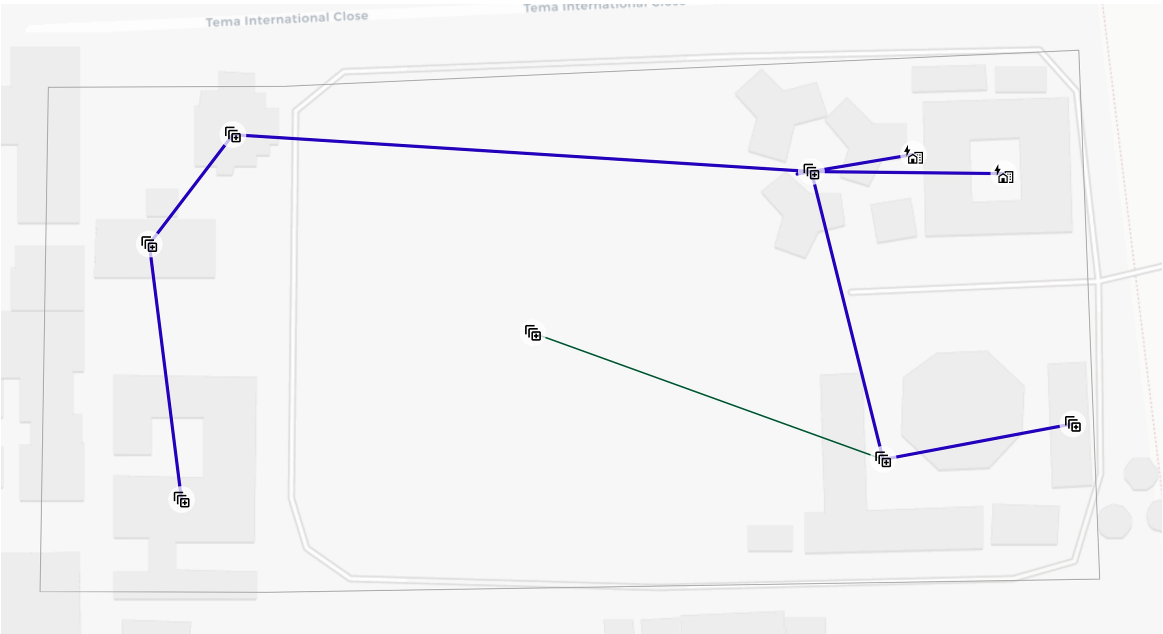
- One day per week with no PV production
- 8 hours per day to use the electrolyzer: 48 hours per week
- Power of 21.6 kW (1036 kWh / 48h) is needed

Fuel cell

- Generate 259 kWh over a 36hour period
- Power of 7.2 kW is needed

4 Simulation Methodology

- Model of the mini-grid with energy simulation software Kerith[1]
- Each location is a node with energy components attached to it
  - PV modules with power capacities
  - Batteries with storage capacities
  - Demands with measured demand curves
  - Connection to the national grid to buy electricity
  - Electrolyzer, hydrogen tank and fuel cell with power / storage capacities
- Simulation of the operation for the years 2022 to 2025



Nodes of the mini-grid modelled at the locations of the Don Bosco campus.
Source: Kerith

[1] kerith.net

4 Simulation methodology

Demand and PV timeseries

- PV availability timeseries calculated by the software based on historical reanalysis of weather data for the location, azimuth angle and tilt angle of the real components [4]
- Demand timeseries based on smart meter measurements during August 2022
  - Derive parameters of normal distribution for every group of *weekday, hour*
  - Median as estimate of the centre of the distribution
  - $\min[0.1 * \text{median}, q_{75} - q_{25}]$ as estimate of the scale of the distribution
- 44 MWh total yearly demand obtained by this methodology
- Known yearly demand is 124 MWh, thus all demand curves were scaled by 2.8

5 Simulation Scenarios

Base	Hydrogen	Increased PV	Increased Demand
All components based on existing mini-grid	Based on market available hydrogen components 19 kW electrolyser 395 kWh hydrogen tank 10 kW fuel cell	Increase of all PV power capacities by 25%	Scaling of all demand curves by 50%

Operation of the mini-grid was simulated 8 different circumstances based on these scenarios

1	Base		
2	Base	Hydrogen	
3	Increased PV		
4	Increased PV	Hydrogen	
5	Increased Demand		
6	Increased Demand	Hydrogen	
7	Increased Demand	Increased PV	
8	Increased Demand	Increased PV	Hydrogen

6 Results and Discussion

1	Base	
2	Base	Hydrogen

Electricity Energy Balance in MWh

	demand	electrolysis	fuel cell	PV	battery	buy
1	-124.7	-	-	216.8	-92.2	**0.0**
2	-124.7	**-12.6**	**5.5**	**215.3**	**-83.6**	**0.0**

Hydrogen Energy Balance in MWh

	electrolysis	fuel cell	hydrogen tank
1	-	-	-
2	**10.5**	**-10.4**	0.0

- Self-sufficient mini-grid without the need to buy electricity
- 5.9% of PV generation for electrolysis
- 5.5 MWh electricity generated with stored hydrogen with an efficiency of 43.7%
- Energy for battery storage decreases by 9.3%

6 Results and Discussion

3	Increased PV	
4	Increased PV	Hydrogen

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Electricity Energy Balance in MWh

	demand	electrolysis	fuel cell	PV	battery	buy
3	-124.7	-	-	**242.8**	**-118.1**	0.0
4	-124.7	-17.4	7.6	**174.6**	**-40.3**	0.0

Hydrogen Energy Balance in MWh

	electrolysis	fuel cell	hydrogen tank
3	-	-	-
4	14.5	-14.4	0.0

- Without hydrogen: PV production and battery storage increases by 26 MWh relative to Base
- With hydrogen: PV production and battery storage decreases by 68 MWh
- Technically implausible, highly oversized PV capacity may cause issues in the simulation

6 Results and Discussion

5	Increased Demand	
6	Increased Demand	Hydrogen

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Electricity Energy Balance in MWh

	demand	electrolysis	fuel cell	PV	battery	buy
5	-187.0	-	-	**245.8**	-61.2	**2.5**
6	-187.0	-26.7	**11.7**	**255.5**	-54.0	**0.4**

Hydrogen Energy Balance in MWh

	electrolysis	fuel cell	hydrogen tank
5	-	-	-
6	22.2	-22.1	0.0

- PV production increases by 13.4% without and 17.8 % with hydrogen
- The hydrogen addition saves to buy 2.1 MWh electricity from the grid
- 404€ savings per year at a price of 190€/MWh
- Mini-grid remains almost self-sufficient in a scenario with increased demand due to hydrogen

6 Results and Discussion

7	Increased Demand	Increased PV	
8	Increased Demand	Increased PV	Hydrogen

Electricity Energy Balance in MWh

	demand	electrolysis	fuel cell	PV	battery	buy
7	-187.0	-	-	**279.4**	-93.4	**1.0**
8	-187.0	-18.5	**8.1**	**276.1**	-78.8	**0.0**

Hydrogen Energy Balance in MWh

	electrolysis	fuel cell	hydrogen tank
7	-	-	-
8	15.4	-15.3	0.0

- Results fit between those of the *Base* and *Increased Demand* scenarios
- The hydrogen addition saves to buy 2.1 MWh electricity from the grid

7 Conclusion and Outlook

Hydrogen production becomes more valuable in the simulation of a high-demand scenario to ensure the self-sufficient operation of a decentralized mini-grid

Increase accuracy of simulation model with more precise demand measurements

Investigate simulations with multiple use-cases for stored hydrogen

Study short-term operation of hydrogen and battery storage in more detail

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