Techno-Economic Aspects of Grid Forming Inverters in Small Power Systems

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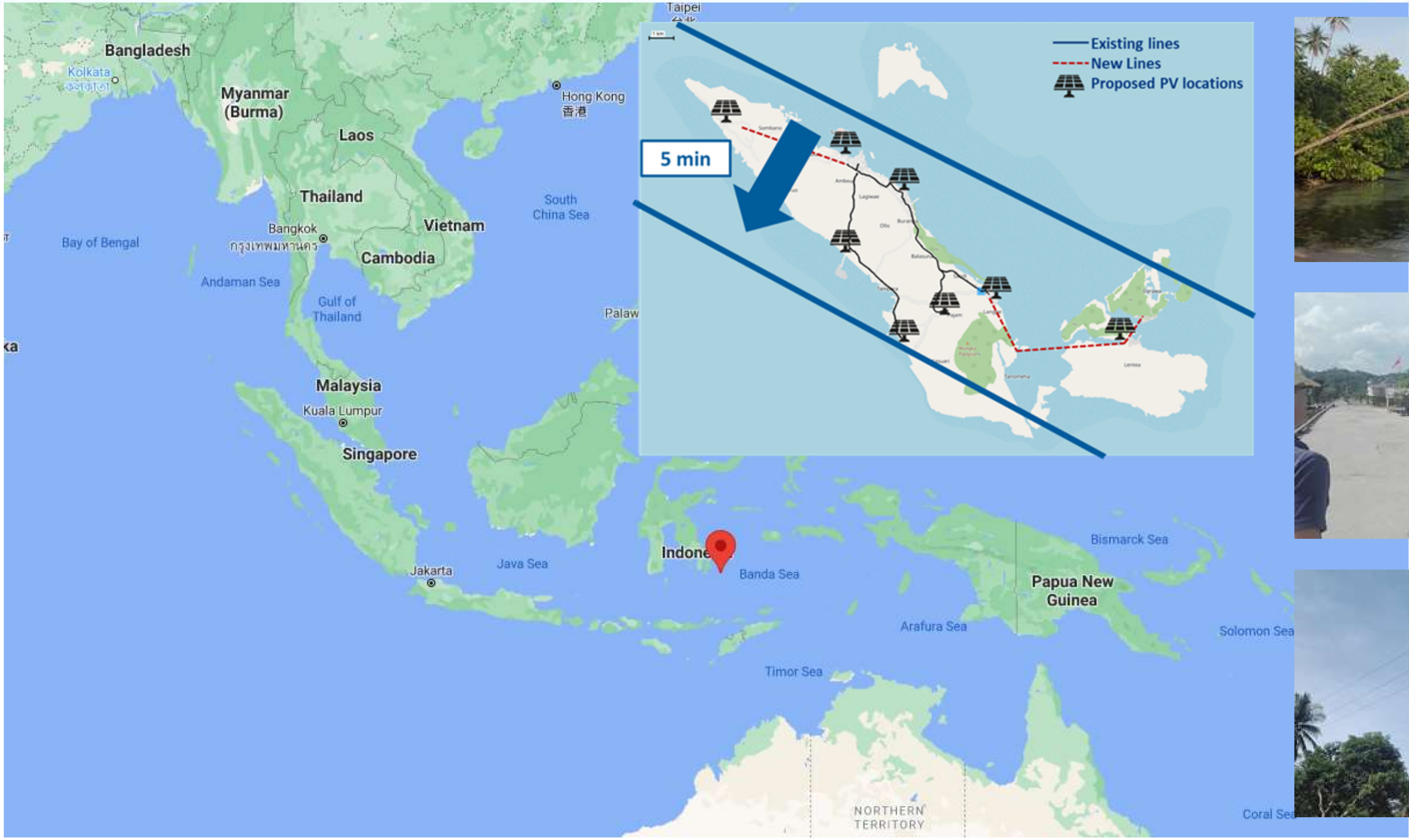
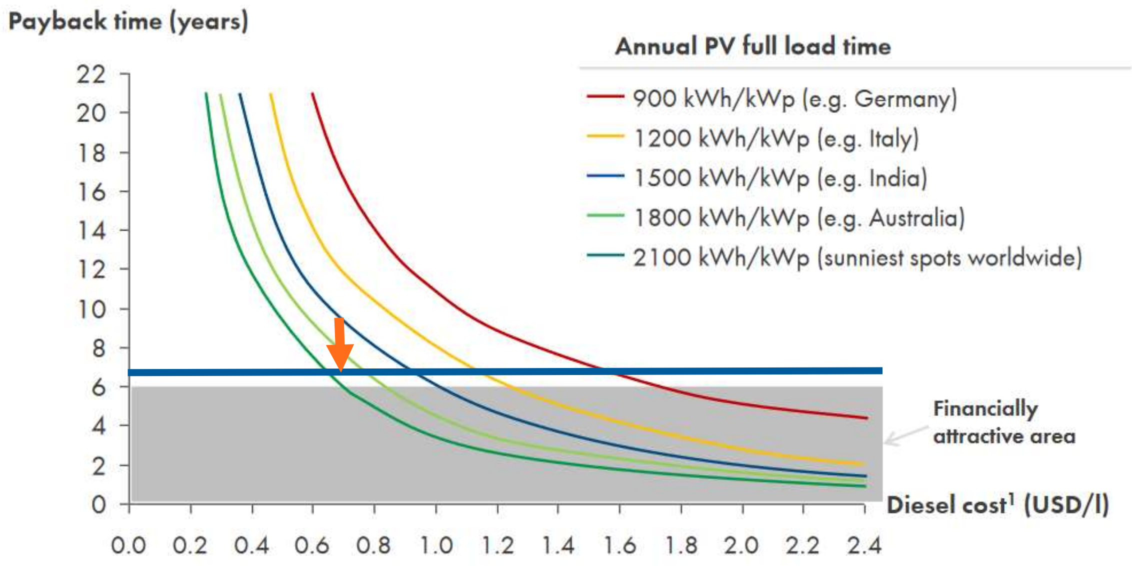
Background: Kaledupa, Indonesia, 2018 (1)



When does PV become interesting?

This graphic is very nice and useful.

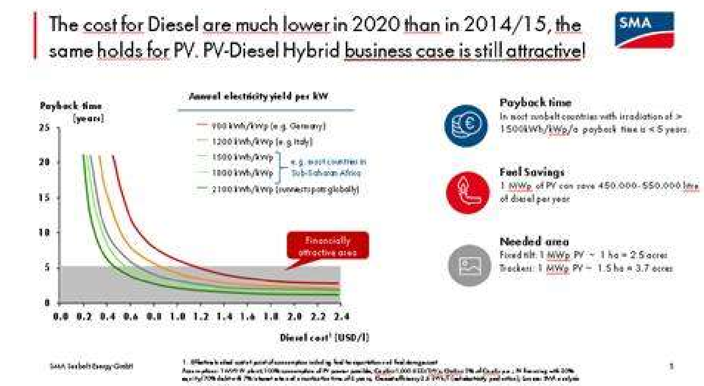
SMA publication on diesel-PV-battery hybrids



Source: Birkholz, SMA, https://www.solarwirtschaft.de/fileadmin/media/pdf/offgrid_2015/Off-Grid_Forum_JensEikoBirkholz.pdf

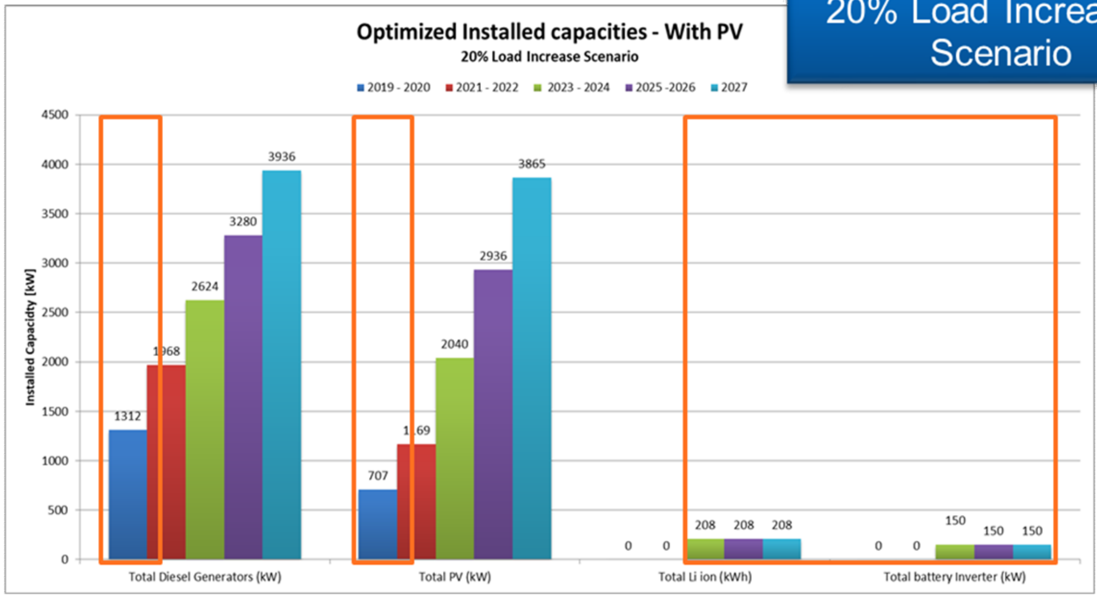
(And it has developed a life of its own online... and especially in Indonesia.)

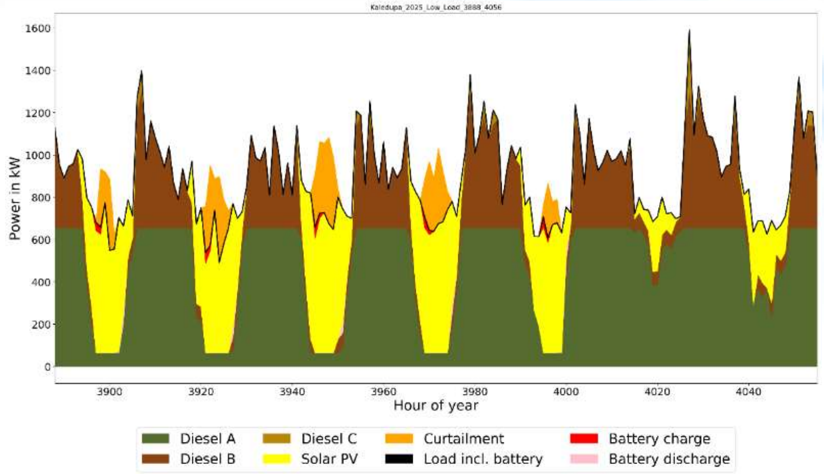
Updated versions are available – thanks SMA!



Background: Kaledupa, Indonesia, 2018 (2)

20% Load Increase Scenario





First Stage

2 Cummins diesel gensets

700 kWp PV

200 kWh / 150 kW Li Ion

Recommended in year 1 already!

Hybridization of Indonesian island

- 1 MW peak load
- New and flexible diesel generators
- Fuel cost 65 – 70 US ct per l
- Optimization result: Batteries are too expensive, use as little as possible
- Diesels can take very high PV share

Different Situations – Different Solutions

Kaledupa: Modern diesels and control system

- PV and diesel can work well together
- Fuel prices low, gensets efficient -> investment in large battery not worth it, at least in the first iteration

Many other islands: Ancient generators

- Manual control, little flexibility
- No chance to integrate large PV shares without battery
- Grid forming inverters would allow for old diesels to be “moved out of the way” during daytime.

But when does this make economic sense?

Island Study Case 1: Caribbean

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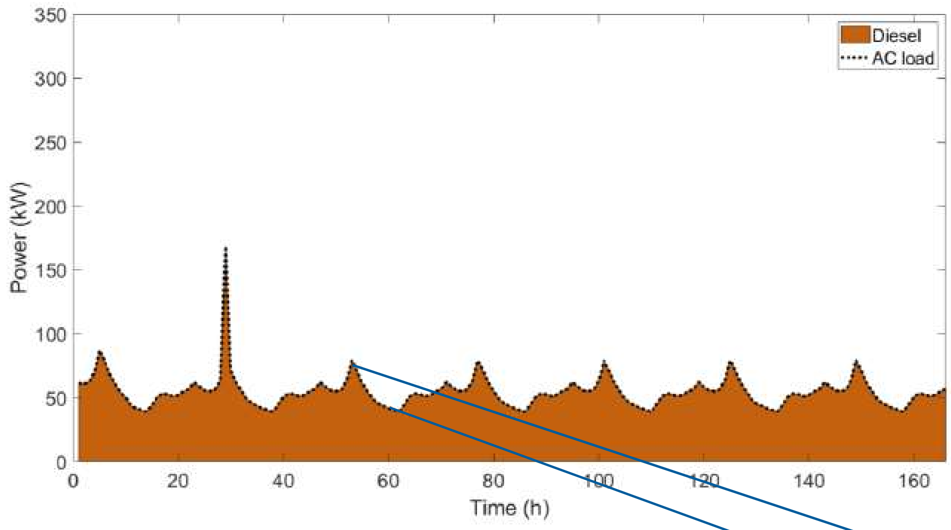
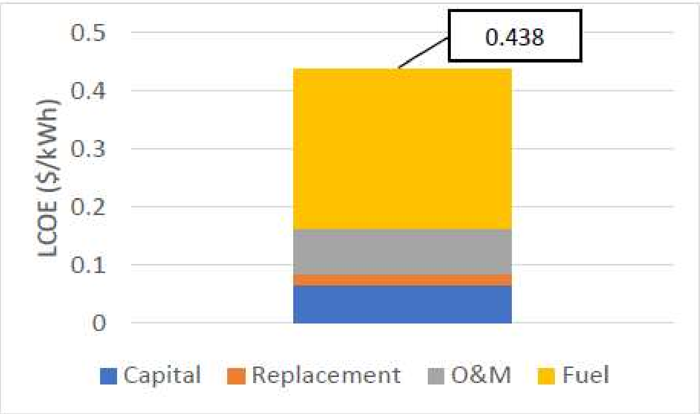
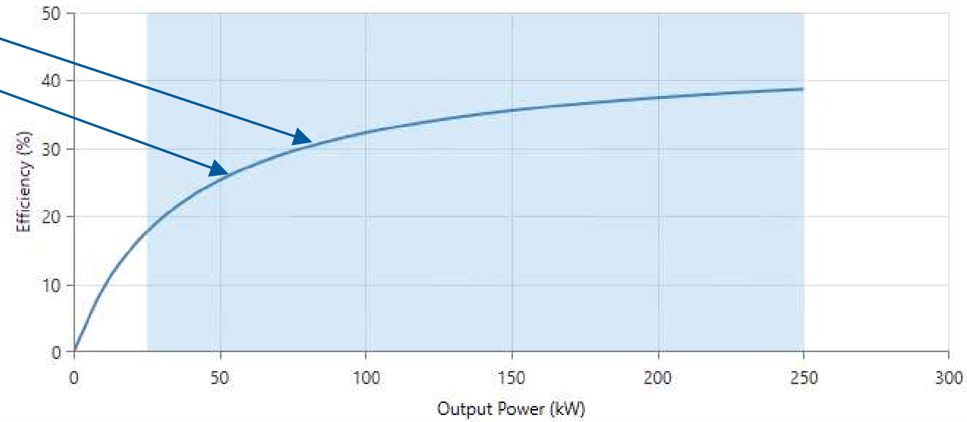


- Average load between 50 and 100 kW
- Extreme peaks up to 200 kW (high load coincidence factor)
- Supplied by single 250 kW genset in isochronous mode
- Fuel price ca. 70 US ct/l diesel





Study Case 1: Sensitivity Analysis

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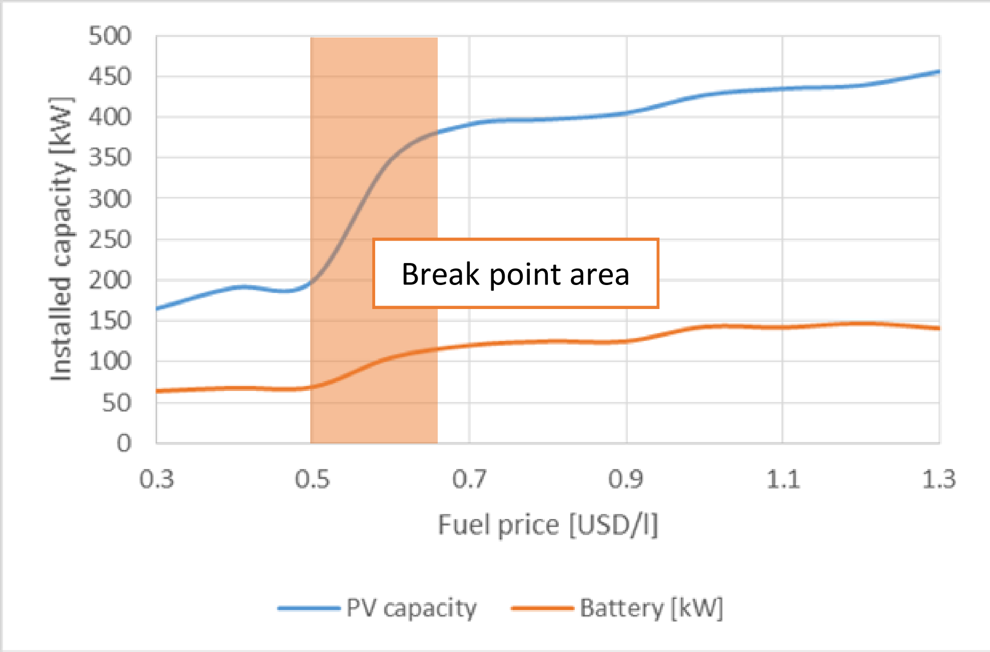
Inputs

	Diesel	PV	Li-Ion battery	Battery inverter
CAPEX	700 USD/kW	1000 USD/kWp	364 USD/kWh	336 USD/kW
O&M	0.011 USD/kW/h	14.8 USD/kWp/a	6.65 USD/kWh/a	0.43 USD/kW/a

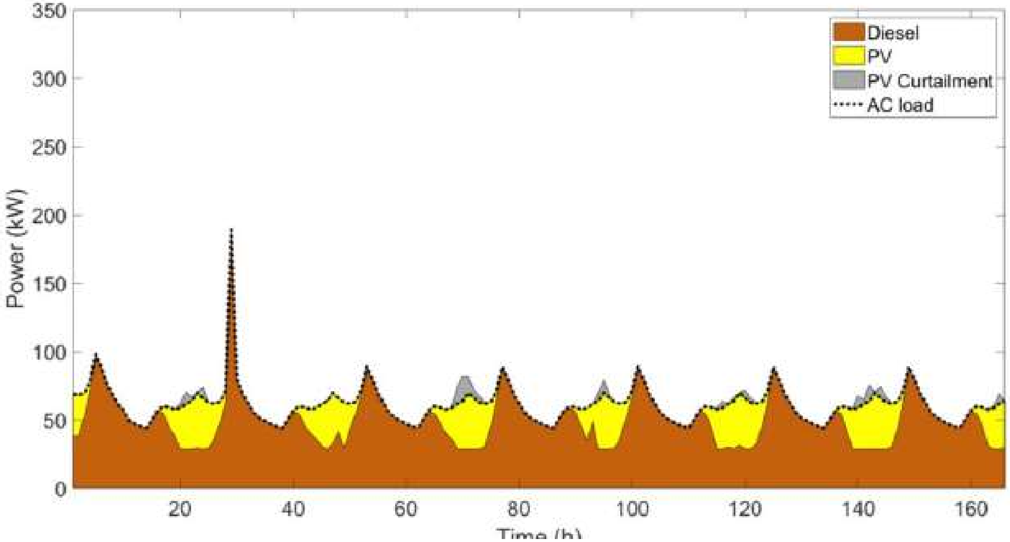
HOMER Pro

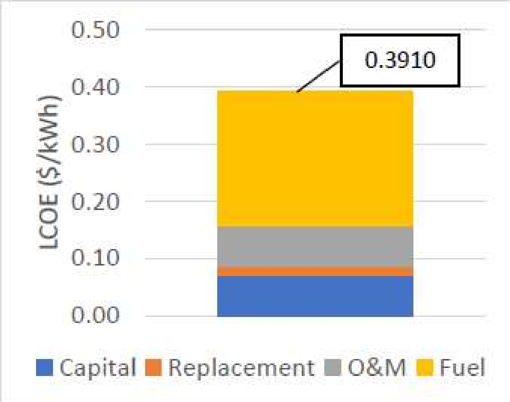
Results

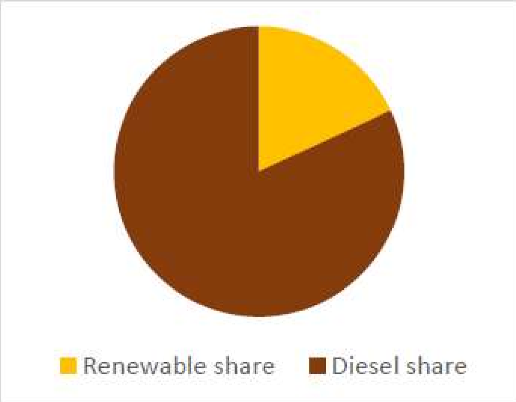
Fuel price [USD/l]	PV capacity [kWp]	Battery [kWh]	Battery [kW]
0.3	165	90	64
0.4	191	96	68
0.5	199	105	69
0.6	348	849	105
0.7	391	1030	120
0.8	397	1031	125
0.9	405	1057	125
1	427	1211	143
1.1	435	1199	142
1.2	439	1203	147
1.3	456	1204	141



Study Case 1: PV without Batteries







Client request Step 1: PV without batteries (not uncommon!)

- Ca 65 kW of PV
- 15 % annual PV contribution
- Instantaneous penetration up to 60 %
- Ca. 25 % curtailment
- No stability problems (single, relatively modern diesel with isoc mode)
- 9 % reduction in generation cost

Nice, but with a bit of advanced technology, we could probably do better.

Study Case 1: PV with Batteries

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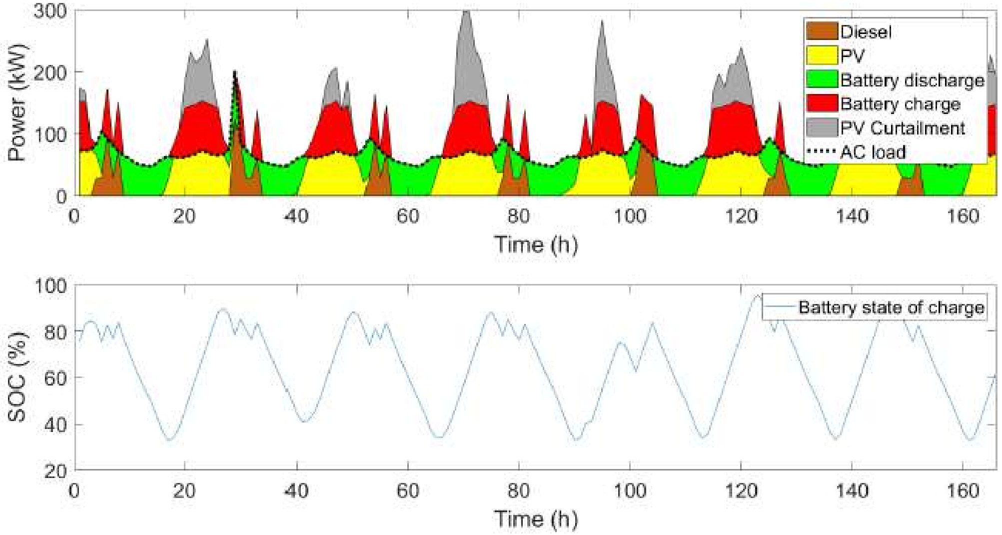

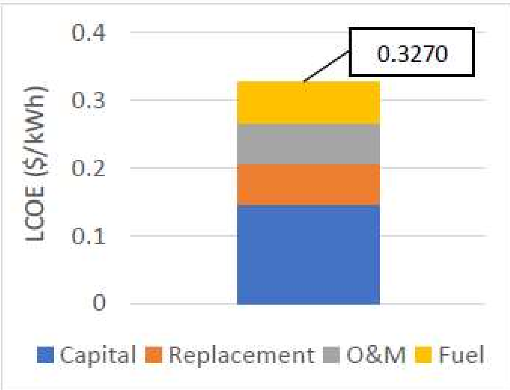

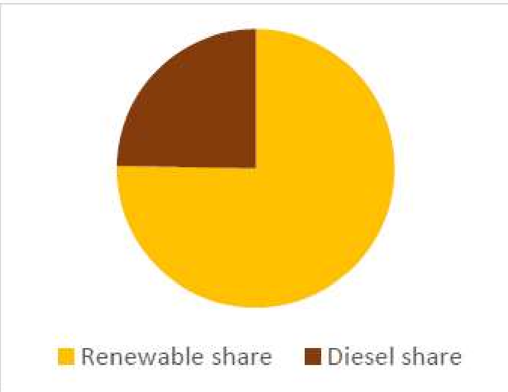

Step 2: PV and batteries

- As expected from sensitivity analysis, optimization was “won” by a grid forming system
- Battery used to store PV power, control the system, and also optimize diesel setpoint
- 360 kWp PV, 1000 kWh Li-Ion battery, 127 kW grid forming inverter
- Still 25 % curtailment, but 75 % PV contribution and 25 % cost reduction vs base case

Study Case 2: Indonesia

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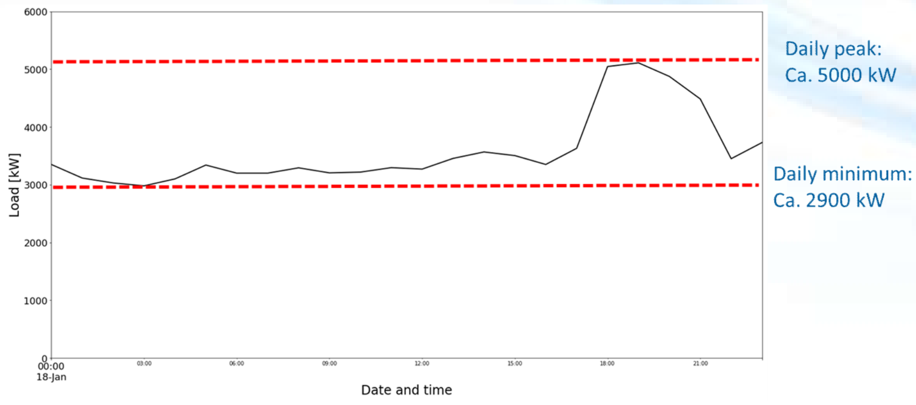
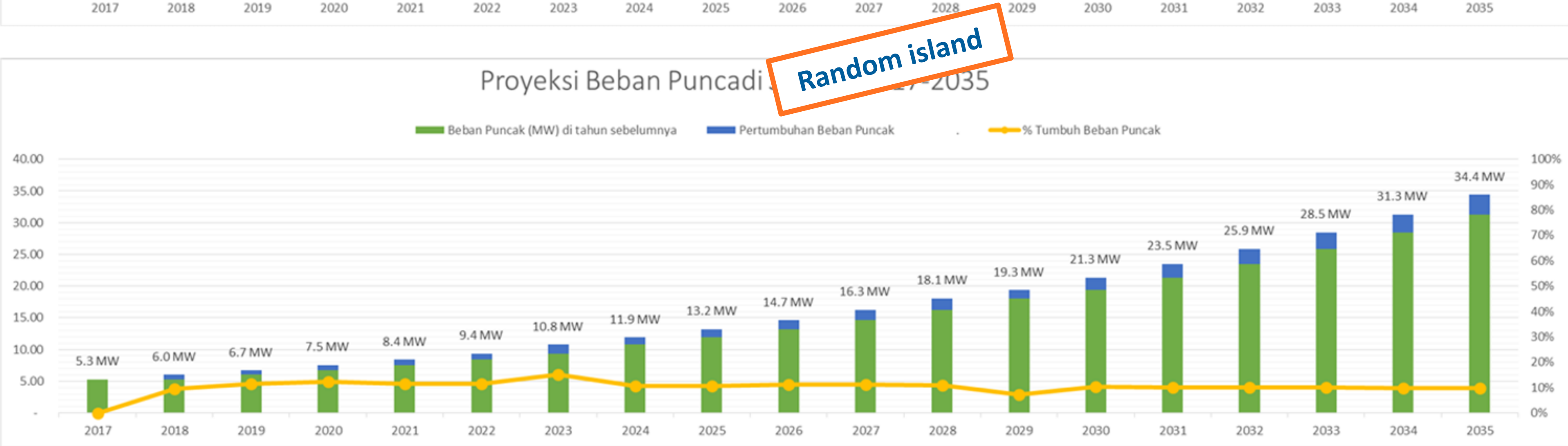
(Yet another) Island in Indonesia

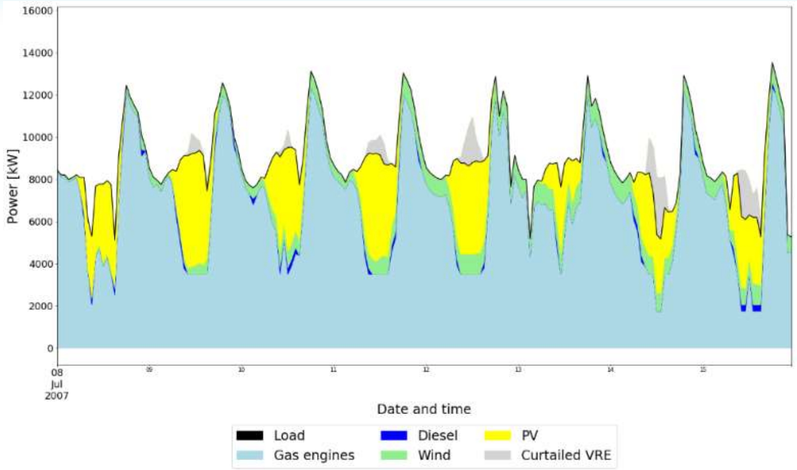
- 80 x 15 km (quite large), 100k inhabitants
- 6 MW peak load
- Mixed fleet of new, reasonably flexible diesels and anciently old engines, all in the 1 MW range
- Generation cost ca. 22 US ct/kWh
- Plan: Upgrade to larger LNG fired engines soon

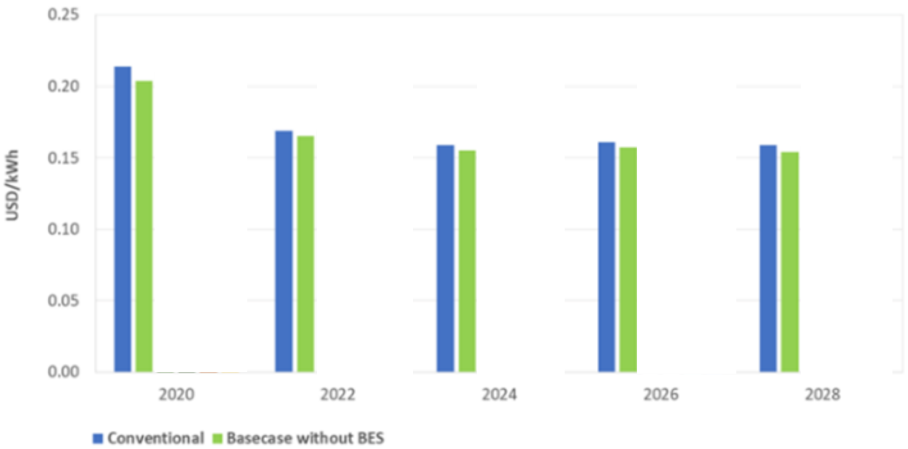


Study Case 2: Demand Projection



Study Case 2: Results

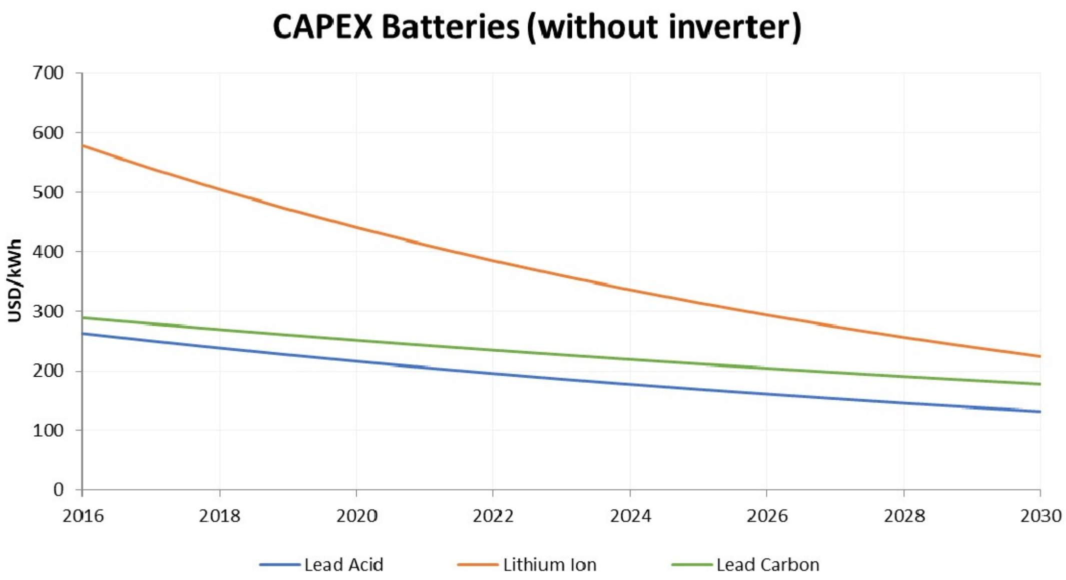


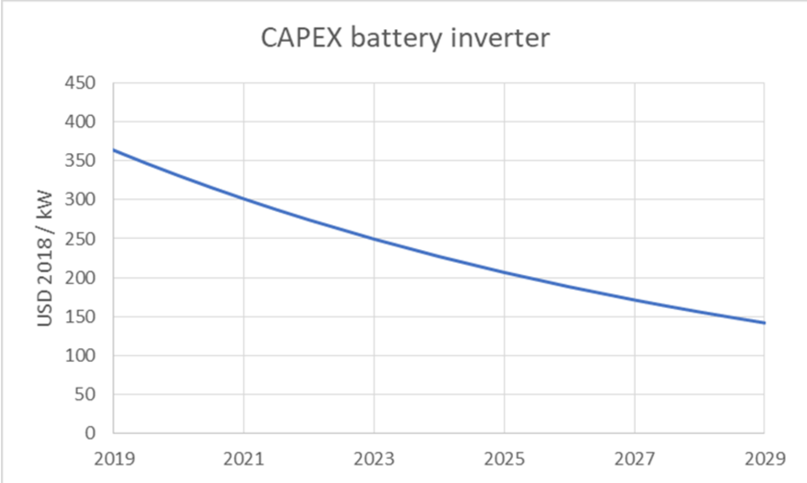


PV integration yields ca. 5 % decrease in generation cost

- Generators here are less flexible (stability issues confirmed in DIgSILENT)
- Reserves are more expensive
- Upgrade to digital controls / EMS would be required
- Important to mention: PV is somewhat distributed, otherwise it wouldn't work without batteries!

Study Case 2: Battery Cost Projection





Full installation cost and projections for lead acid and lithium ion taken from IRENA Storage Report (2016)

There are a few more parameters here that play a role – C rate, cycle depth, # of cycles etc.

These always need to be considered when analyzing battery economics!

Study Case 2: Sensitivity Analysis

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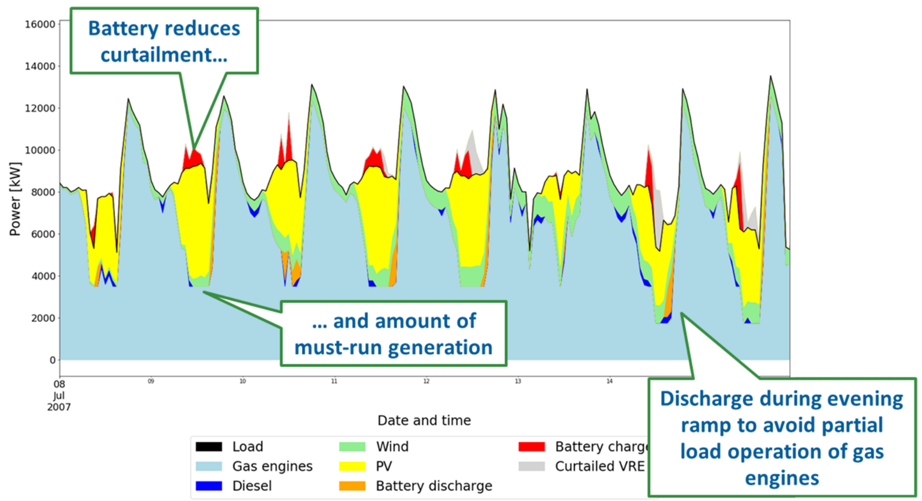
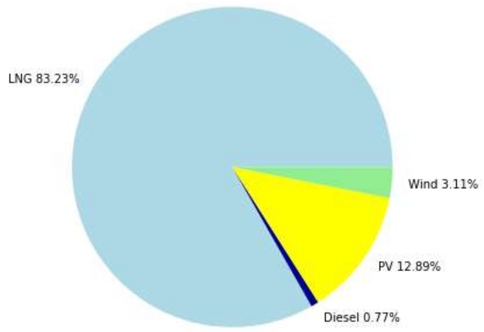
"Why no batteries?"

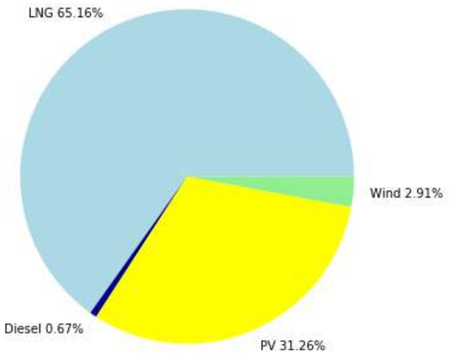
- Again, low fuel cost, relatively efficient generators
- Optimization result: Put as much PV on the system as possible, but batteries just make everything more expensive
- Sensitivity case A: Smoothing batteries of 40 % capacity at each PV site
- Sensitivity case B: 1 h / daytime load grid forming battery at the diesel power plant
- Results: Batteries don't do much
- Grid forming system can double PV contribution (no surprise)

	Installed capacity [MW]		**Optimal annual PV contribution**		
	Diesel	***LNG***	***PV only***	***PV + Smoothing battery***	***PV + Grid forming***
2020	10	0	11 %	11 %	35 %
2022	2	10	12 %	13 %	33 %
2024	2	10	12 %	14 %	32 %
2026	2	14	14 %	16 %	31 %
2028	2	17	16 %	17 %	30 %

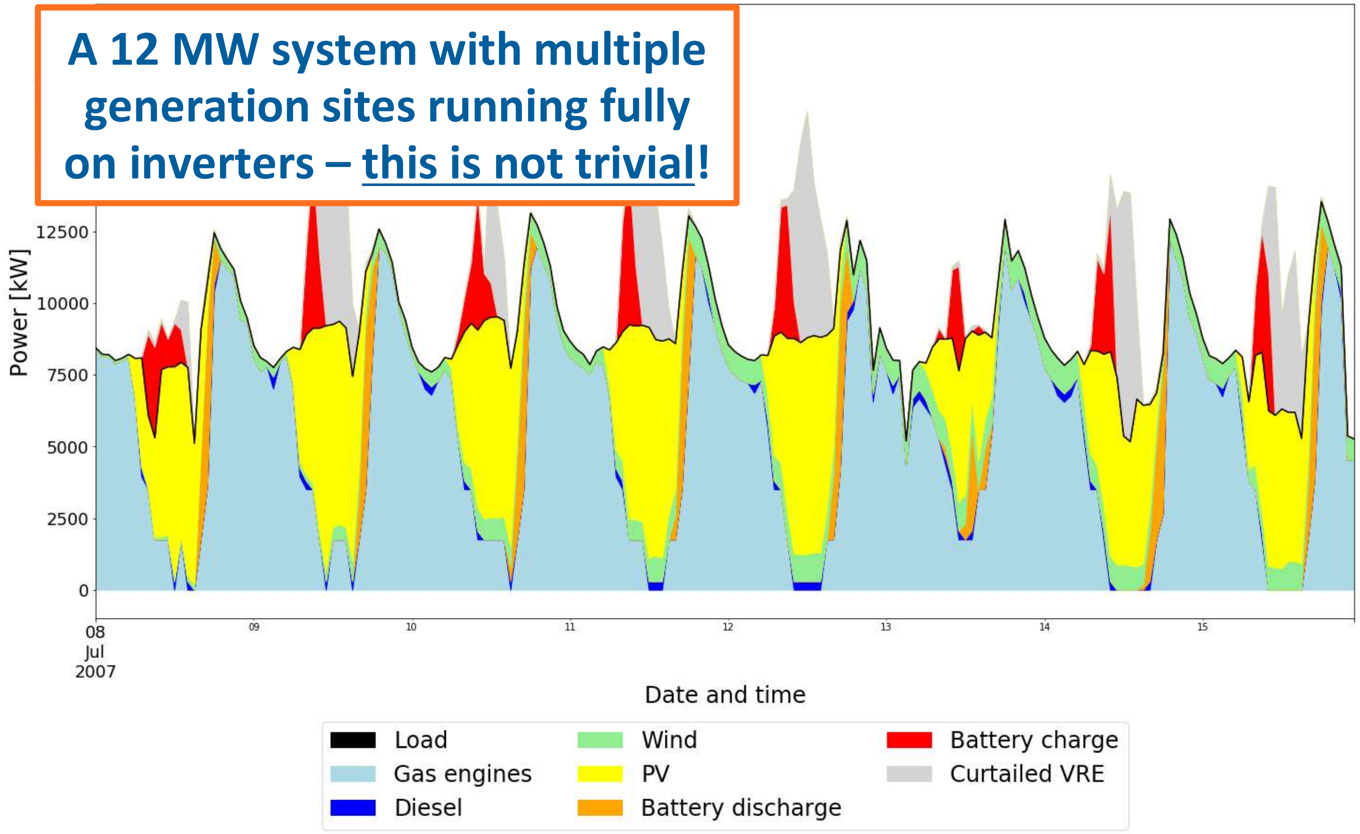


Study Case 2: Grid Forming System (1)

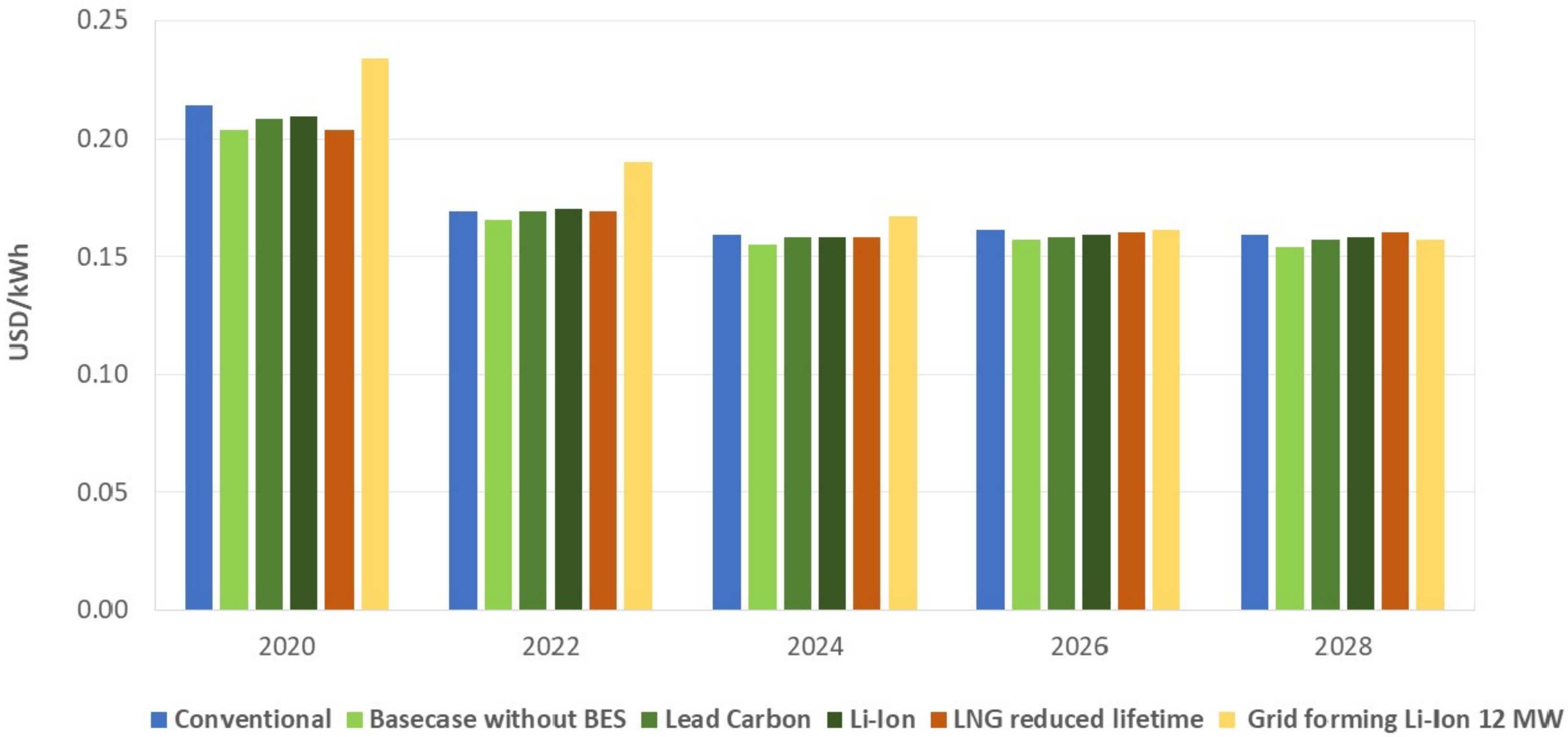




A 12 MW system with multiple generation sites running fully on inverters – <u>this is not trivial</u>!



Study Case 2: Grid Forming System (2)



Conclusions and Outlook

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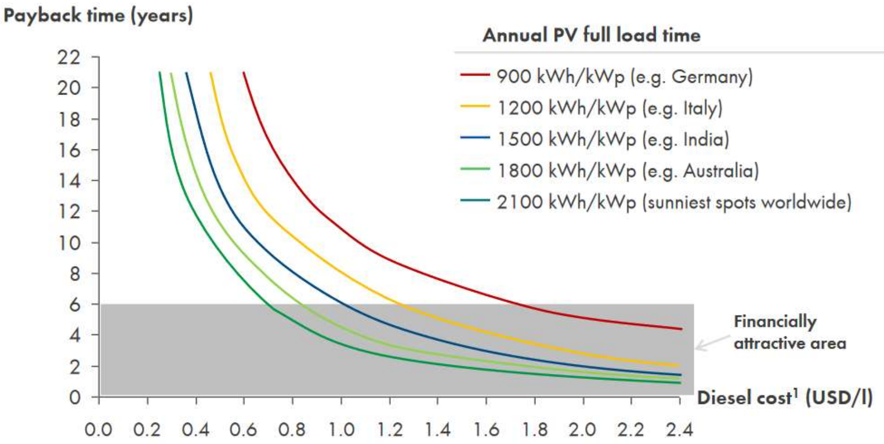
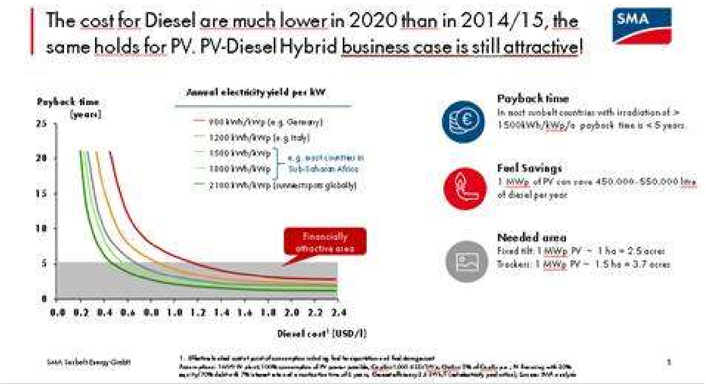


Source: Birkholz, SMA, https://www.solarwirtschaft.de/fileadmin/media/pdf/offgrid_2015/Off-Grid_Forum_JensEikoBirkholz.pdf



This graphic is a great basis. But we would like to take it further.

- Economic feasibility of PV and batteries depend on different characteristics
- We have found a few: Generator flexibility, fuel price, generator efficiency, communication systems, controls...
- Authors intend to gather more project data and develop a more thorough assessment tool (Excel)
- This presentation shows a few glimpses of work in progress, we are happy to discuss.

Thank you for your attention!

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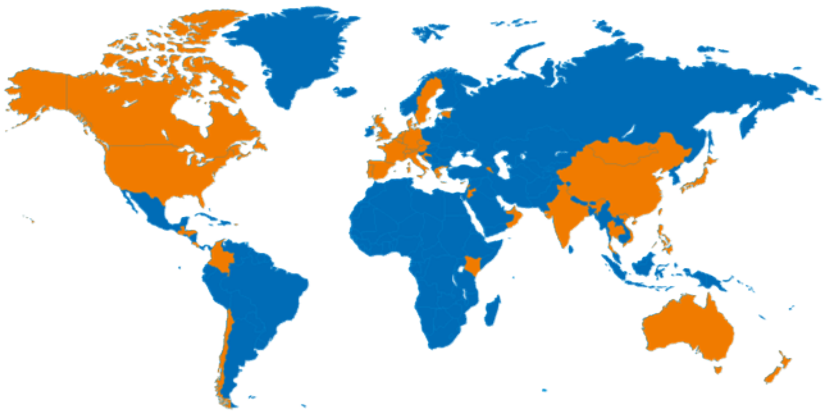
Island Systems and Developing Countries



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