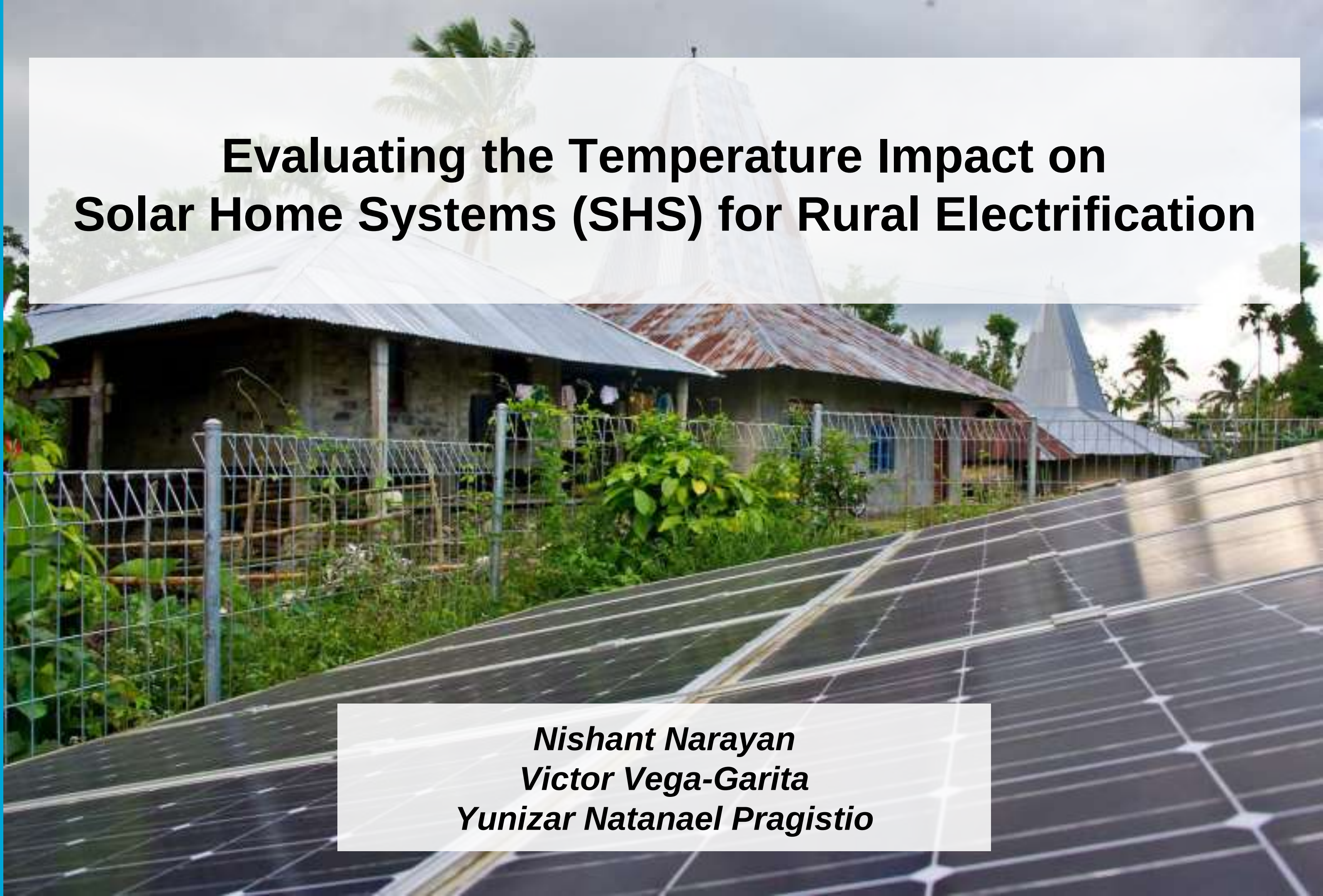
Evaluating the Temperature Impact on Solar Home Systems (SHS) for Rural Electrification



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Content

1. Motivation
2. SHS and temperature influences
3. Evaluating PV modules
4. System sizing
5. Evaluating Batteries
6. Conclusion

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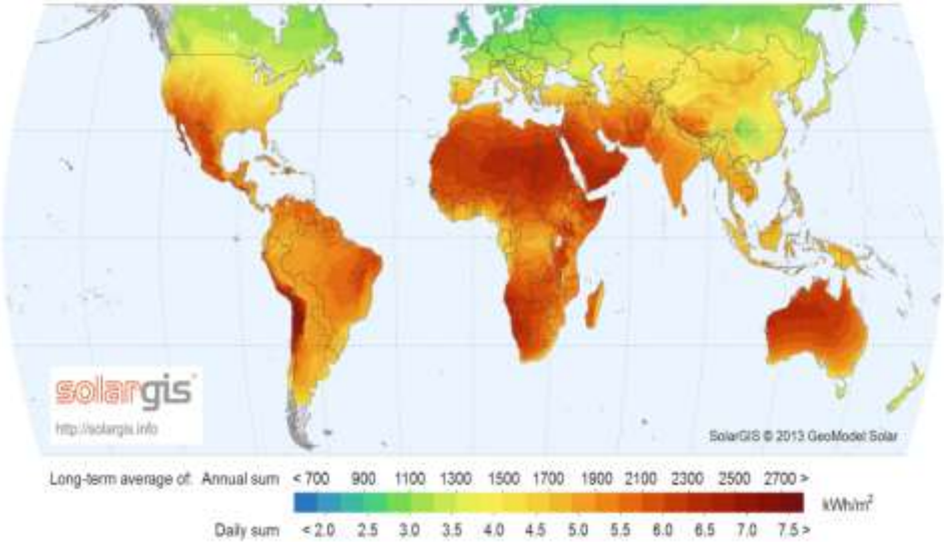
Motivation

1.1 billion people are living in the dark



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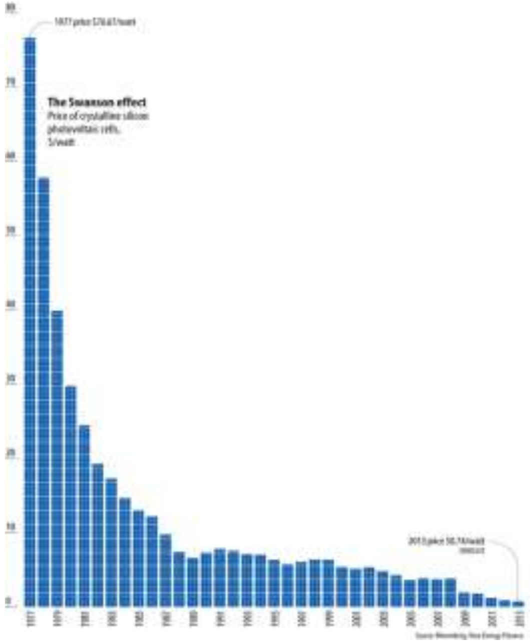

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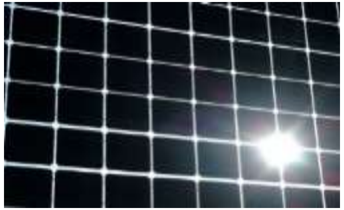
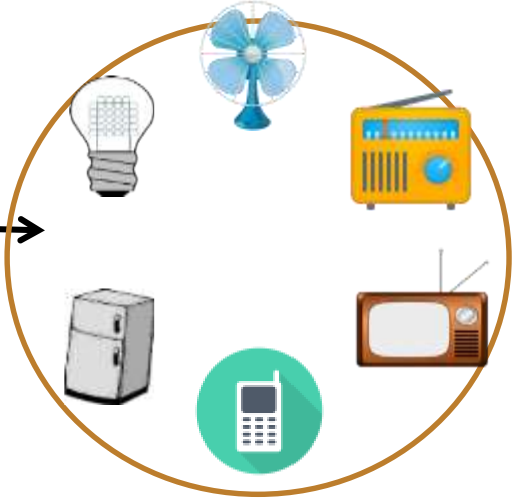
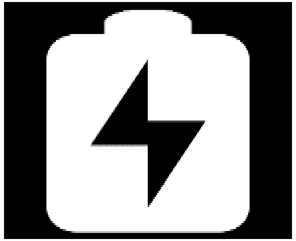
Solar Home System (SHS)

Poly c-Si



Power Conversion

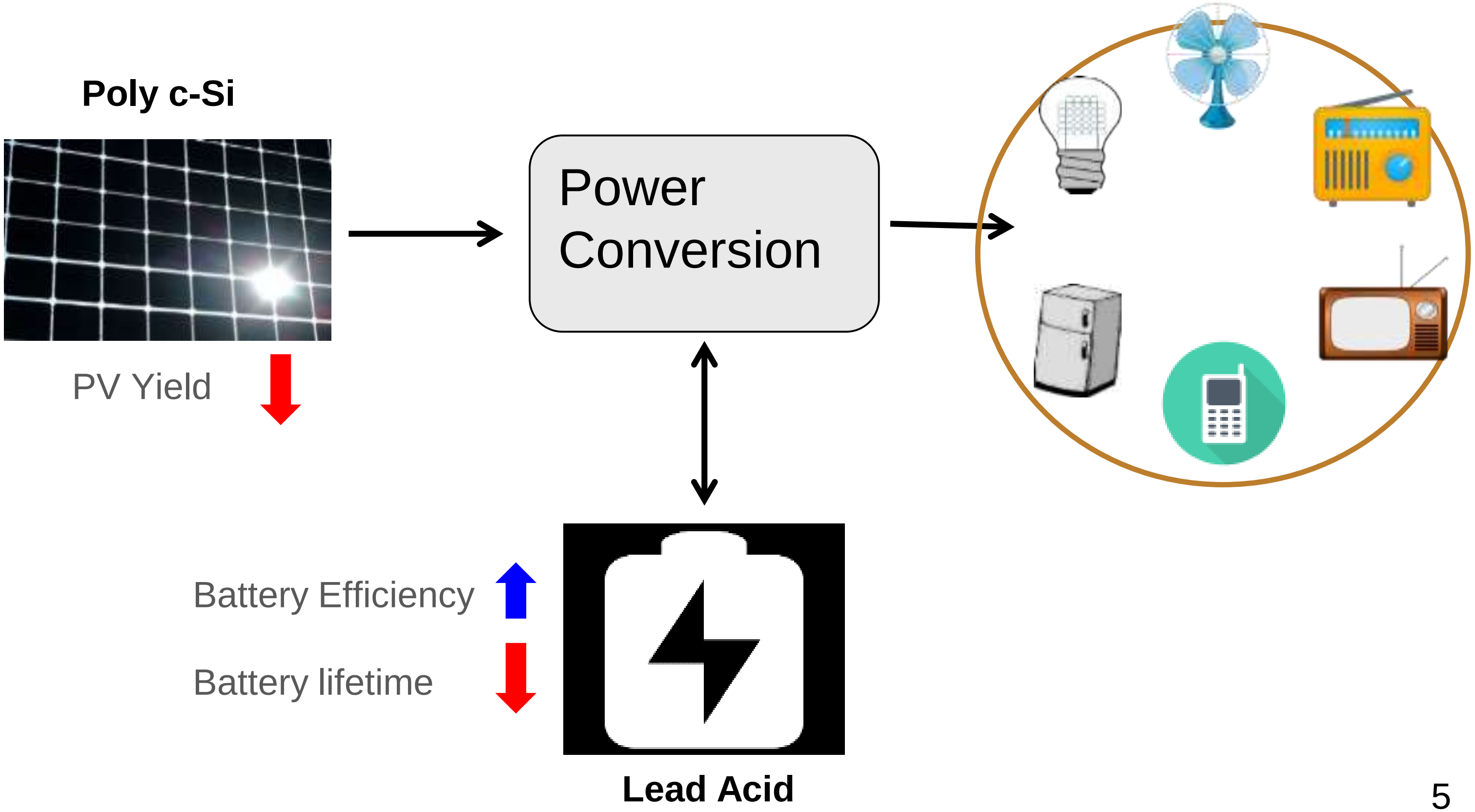




Lead Acid

- Standalone
- DC loads
- Battery storage

Temperature Influences



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Research Questions

1. What is the performance-drop in SHS energy yield due to temperature?

2. How to get the optimum size of the system?

3. What is the impact of temperature on the lifetime-degradation of batteries in SHS?

1. Motivation
2. SHS and Temperature Influences
3. Evaluating PV Modules
4. System Sizing
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SHS Application

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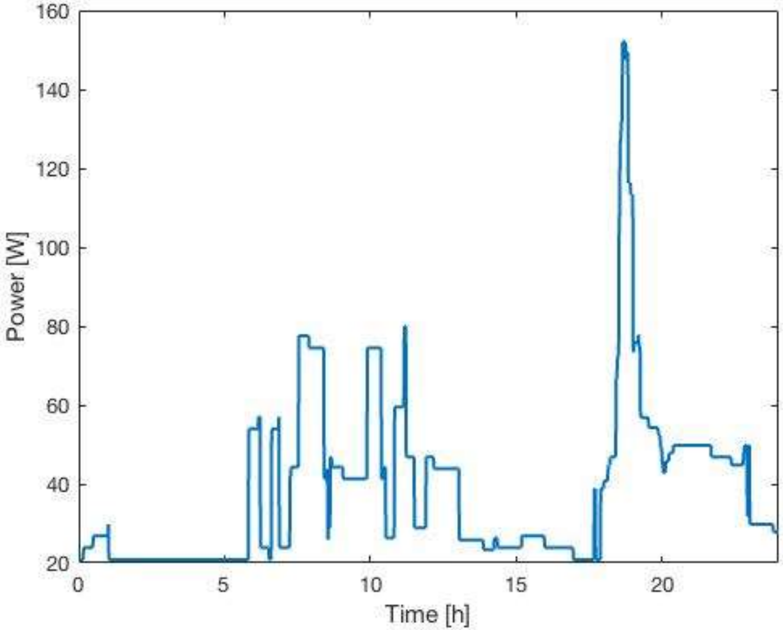
Sumba Island, Indonesia
(-9.699,119.974)

4.96 ESH
1,812 kWh/year

24.7 ºC (avg)
9.80 ºC (min)
33.4 ºC (max)

2.05 m/s (avg)
0 m/s (min)
16.8 m/s (max)

Load profile: Tier 3 (0.914 kWh/day)



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Modeling Performance of PV Modules

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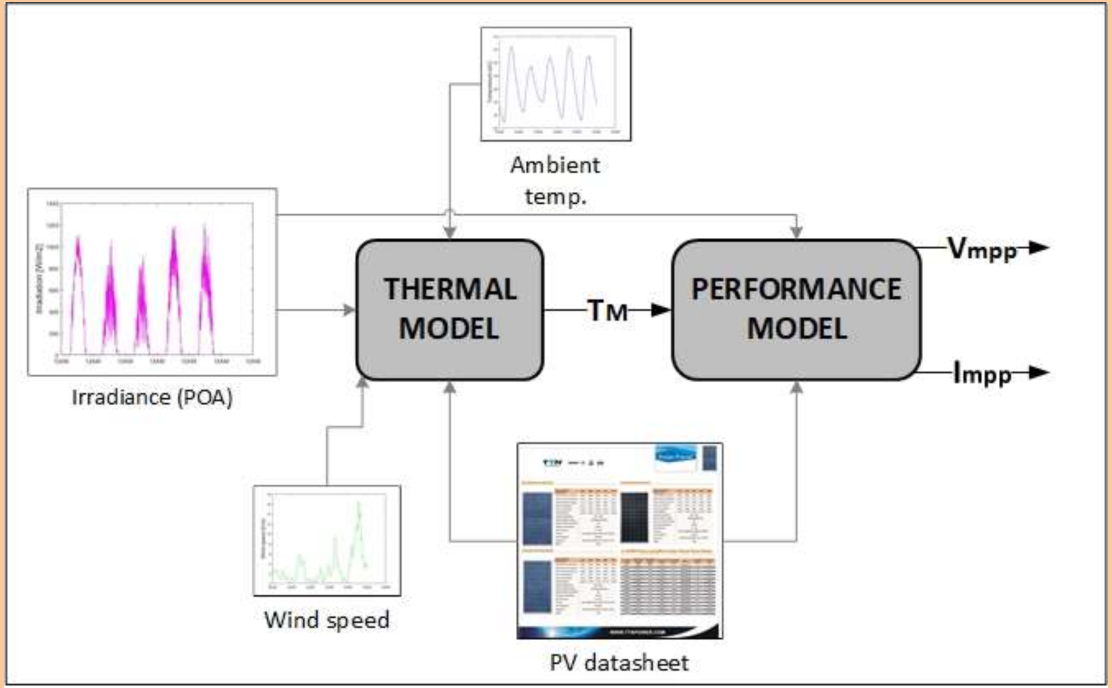

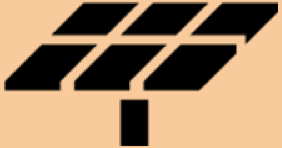

PV MODULES

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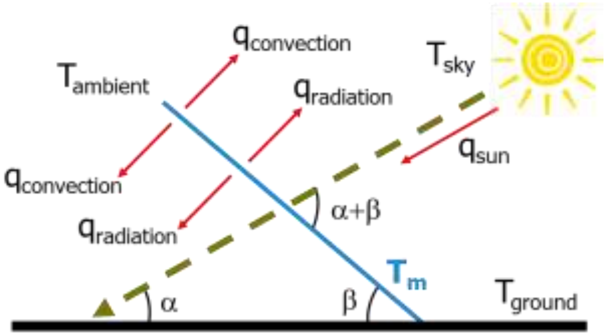
Estimating Module Temperature

1. NOCT Model

$$T_m = T_{amb} + \frac{(T_{NOCT} - 20°C)}{800\ W/m^2} G_m$$



Source: [5]

2. Fluid Dynamic Model

$$T_m = \frac{\varphi G_m + h_{convection} T_{amb} + h_{rad,top} T_{sky} + h_{rad,bottom} T_{ground}}{h_{convection} + h_{rad,top} + h_{rad,bottom}}$$

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Temperature impact on the PV yield

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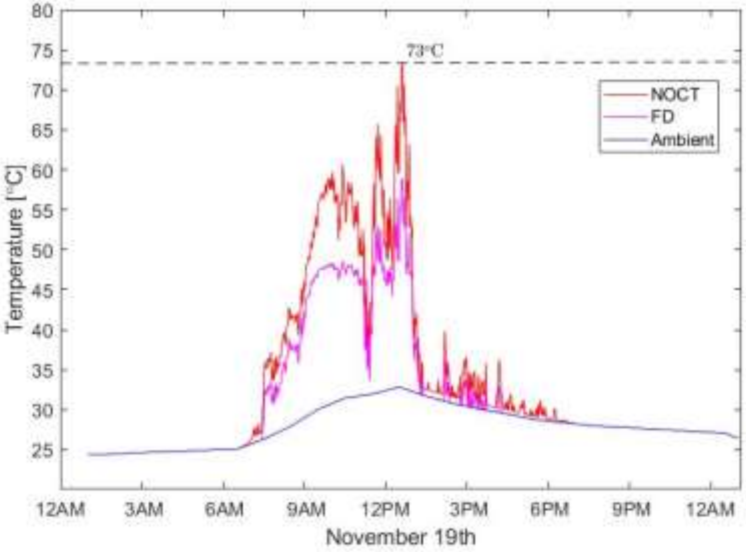

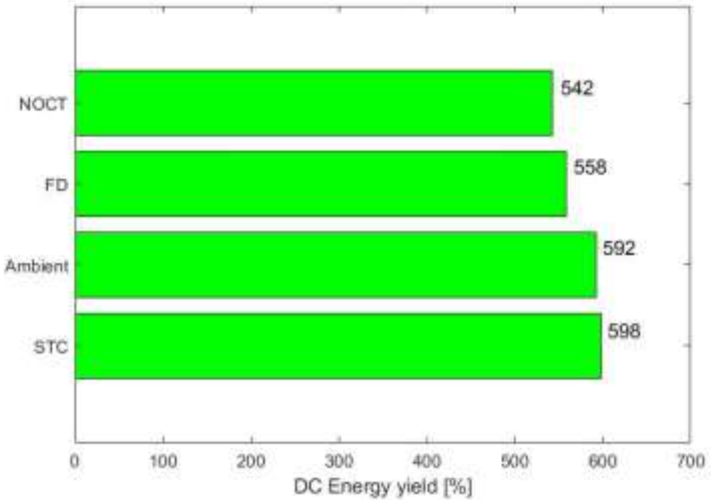

Metric	STC	Ambient	FD	NOCT
c.f. [%]	20.68	20.47	19.30	18.74
MIF [-]	1	0.99	0.93	0.90

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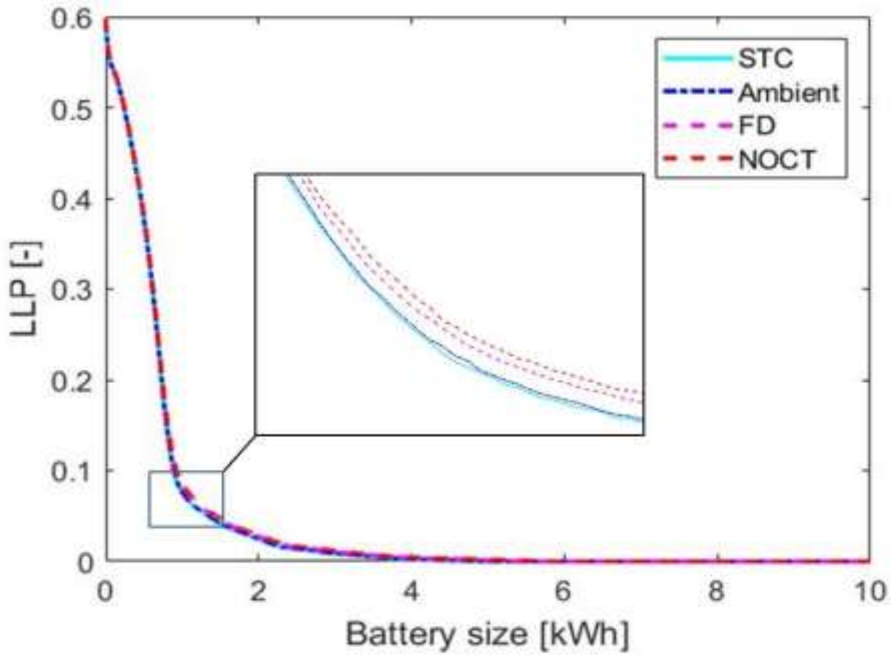
Optimizing SHS Size

Loss of Load Probability $$LLP = \frac{\text{Total number of failed events}}{\text{Total number of events the system was designed for}}$$



LLP = 7.5%
Battery size = 1.06 kWh
PV = 330 Wp
(1 PV Module)

Evaluating Battery Lifetime

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Failure mechanisms

- Thermal runaway
- Loss of active mass material
- Grid corrosion (Lead acid)

Physical processes

Lifetime models

- Electrochemical/ physical model
- Experimental model
- Abstract model
- Analytical model

Process knowledge/ behavior

Manufacturer's data

- Datasheet
- Based on industrial experiments
- Lifetime curves

Non-empirical usage

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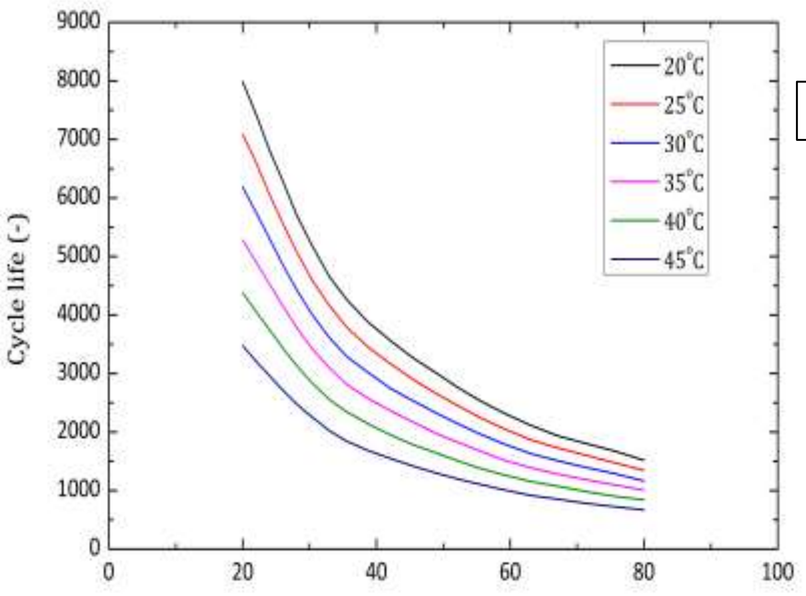
Reconstruction of lifetime curve



Source: [4]

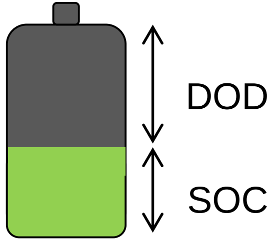
Look-up function

$$\boldsymbol{n(T, DOD)} = n(T_{ref}, DOD) - f(T_{avg})\, Dn(DOD)$$

$$n(Tref, DOD) = p_4 d^4 + p_3 d^3 + p_2 d^2 + p_1 d + p_0$$

$$f(T_{avg}) = pl_1\, T_{avg} + pl_0$$

$$Dn(DOD) = p_{d4} d^4 + p_{d3} d^3 + p_{d2} d^2 + p_{d1} d + p_{d0}$$



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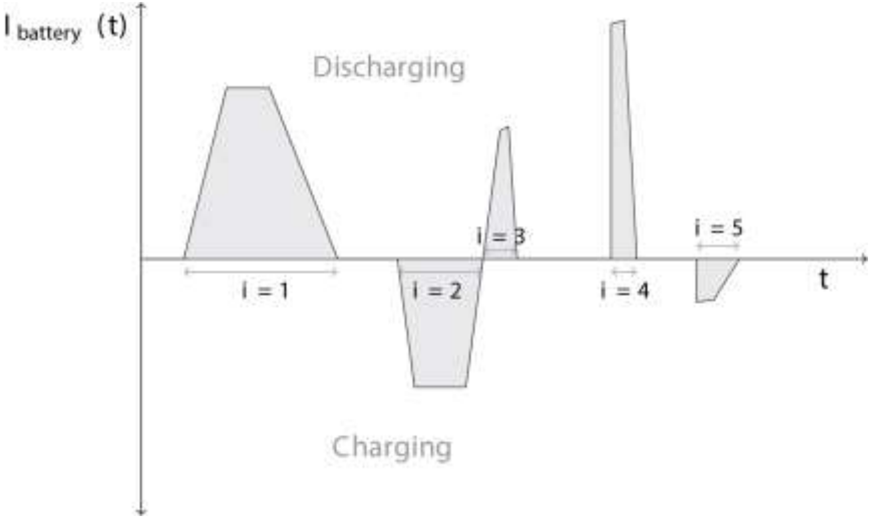
Modeling Battery Lifetime Prediction



Average active DOD and temperature

$$\overline{DOD} = \frac{\sum_{i=1}^{N} E_{throughput_i} \cdot \overline{DOD}_i}{\sum_{i=1}^{N} E_{throughput_i}}$$

$$\bar{T} = \frac{\sum_{i=1}^{N} t_i \cdot \bar{T}_i}{\sum_{i=1}^{N} t_i}$$

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Modeling Battery Lifetime Prediction

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$$L = n \times \overline{DOD} \times \frac{2 \times E_{nom}}{E_{throughput}}$$

- L: battery lifetime in years
- n: number of cycles at the average DOD and average temperature (lookup function)
- $\overline{DOD}$: average DOD (simulation)
- E_{nom}: Nominal battery capacity (sizing)
- $E_{throughput}$: Total energy throughput (simulation)

Source: [6]

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Evaluating Battery Lifetime

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T [ºC]	T= 20 ºC	T = Tamb	SF = 1.2	SF = 1.5
T,avg [ºC]	20	24.74	29.69	37.11
L [years]	8.11	7.41	6.59	5.35

SF = Scale Factor

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Conclusion

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1. Total PV yield lost is affected by **7%** to **10%** due to high module temperature

2. LLP-based sizing
   - 1.06 kWh Battery
   - 330 Wp PV (1 PV modules)

3. Battery lifetime is dropped by **9%** to **34%** due to high temperature

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Future Work

- Incorporate the dynamic capacity degradation (e.g. capacity fading & internal resistance) and dynamic performance
- Include the model of power converters

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