Reducing Risks and Maximising Benefits for PV/Hybrid Mini-grid Systems: Lessons from the Asia Pacific

James Hazelton
Supervisors: Dr. Anna Bruce, A.Prof. Iain MacGill
Outline

1. Definitions: “Mini-grids” and “Risk”

2. Global Context & Problem Statement

3. Method and Framework

4. Case Studies

5. Recommendations

6. Conclusion
Defining a “Mini-grid”

A standalone power network that manages energy supply and demand.

Scope of Research:
- “PV Hybrid” – Includes PV in combination with other generation sources.
- not interconnected to centralised grids
- multi-user rural electrification
- retrofit to existing diesel or greenfield site
Defining a “Mini-grid”

Applications and Categorisations based on System Size
(building upon Lilienthal (2013) and Mauch (2009))
Defining a “Mini-grid”
Defining “Risk”

The basic definition of Risk

“an undesirable implication of uncertainty” (Chapman, Cooper 1982)

For this research:

“uncertainty that impacts outcomes in a positive or negative way.”

- It’s consideration is vital part of any decision making.
- Risk evaluation can fall into classical or conceptual models.
- Risk can accrue to different parties involved in a decision and are perceived differently. Perceptions influence their appetite.

From: Michelez et al 2011 – Risk Quantification and Risk Management in Renewable Energy Projects
Putting “Risk” and “Mini-grids” Together

Uncertainty in Project Development

- Range of accuracy of estimates, equal to estimated cost divided by final cost assuming constant currency value
- Pre-tender estimate, cost accuracy within ±10%
- All tenders received, cost accuracy within ±5%
- Final cost
- Feasibility study, cost accuracy within ±15% to 25%
- Pre-feasibility study, cost accuracy within ±40% to 50%

Time

Proposal → Detailed Feasibility Study → Design → Construction → Commissioning → Operation

Source: RETSCREEN

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Putting “Risk” and “Mini-grids” Together

Uncertainty in Project Development

Uncertainty in Operation & Service Delivery

Does the asset perform as expected?

How do we measure performance?

How do we avoid/

..reduce/

..transfer/

..retain

the risks involved?

Time

Source: RETSCREEN

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Putting “Risk” and “Mini-grids” Together

Uncertainty in Project Development

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- Feasibility study, cost accuracy within ±10%
- All tenders received, cost accuracy within ±5%
- Final cost
- Pre-tender estimate, cost accuracy within ±10%

Uncertainty in Operation & Service Delivery

- Outperformance
  - + +
  - +
  - Expected
  - -
  - Under-performance
    - (Failure)

Project Life (e.g. 15-20 years)

Cumulative Performance

Source: RETSCREEN

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Putting “Risk”, “Minigrids” and “Renewables” Together

Two Mini-grid project technology options – same LCOE

100% Diesel
0% RE

56% Diesel
44% RE
Contextual Background

- Energy plays a critical role in improving lives and reducing poverty.
- Sustainable Energy for All Initiative (SE4ALL)
- MGs identified as a High Impact Opportunity (HIO)
- MGs delivering up to 40% of new energy access 2010 to 2030 [IEA 2010]

Electrification approach required to achieve universal access by 2030 by region, as % of generation (based on IEA, UNDP, UNIDO 2010 via IRENA (2012))
Contextual Background

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- MGs identified as a High Impact Opportunity (HIO)
- MGs delivering up to 40% of new energy access 2010 to 2030 [IEA 2010]

![Chart showing current and future financing requirements by type of financier.](chart.png)

*Current financing and annual financing requirements by type of financier* (source: ENEA 2014, using data from IEA WEO 2011)
Contextual Background

- Energy plays a critical role in improving lives and reducing poverty.
- Sustainable Energy for All Initiative (SE4ALL)
- MGs identified as a High Impact Opportunity (HIO)
- MGs delivering up to 40% of new energy access 2010 to 2030 [IEA 2010]

Off-Grid and Mini-grid Renewable Energy Spending as a Percentage of the Annual Energy Portfolio (Three Year Average FY12, 13, 14)

From: Sierra Club, Oil Change International (Apr. 2016)
Still Failing to Solve Energy Poverty: International Public Finance for Distributed Clean Energy Access gets another "F"
Problem Statement

- Energy Access for 1.2 billion unelectrified users (2.7 billion traditional biomass).
- Conventional approaches will fall short of the global SE4ALL targets - alternative approaches will be necessary.
- Renewable Energy is no longer a new technology but still considered risky
- Inherent due to high capital cost, and payback contingent on long term operation – access to finance and rate depends on level of risk involved. Investment needs to be more attractive.
- “the moneys available, we just need bankable projects” & “pilot fatigue” - poor performance could result in a backlash and localised market spoilage such as what has been observed in SHS where quality was poor.
- Hybrid modelling literature is prolific, there’s a shortage of operational experience that can be used to verify the models and guide decision making.
- **Q: How can we better model and manage the risks involved in PV mini-grid deployment in the Asia-Pacific?**
Aim

To improve the understanding and management of the benefits and risks associated with PV Hybrid mini-grid programs based on experiences in the Asia-Pacific region

Objectives

1. Identify and describe the various risks and benefits of PVHMS deployment.

2. Investigate cases of programmatic PVHMS deployment in the Asia-Pacific region, in order to analyse performance measures, operational experience and the risk proposition associated with the technology’s use.

3. Assess adequacy of current mini-grid modelling software and performance measures, and identify opportunity for and propose improvements based on operational experiences in (ii).

4. Recommend ways to mitigate risk and better manage uncertainty in both the ongoing operations of existing programs and expected future project development.
Method

- Prior research has been broad based, lessons-learnt type reports, lacked particulars, need to capture the “interconnected web of factors” that make up a successful project.
- Case study approach is most appropriate.
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- Case study approach is most appropriate.
Method

- Literature review [identify benefits and risks, formulate framework]
- Multi-stakeholder interviews from Industry, Govt and NGOs tiered to expertise (Painuly’ work on barriers for R. Energy) [describe deployment, program objectives, identify and map risks and their perception]
- Field visits [collect data, verify configurations and operation]
- Data collection (SCADA and documentation) [verify operational performance, develop performance metrics]
- End user surveys [perspectives, service delivery, tangible outcomes]
**Literature Review and Framework**

<table>
<thead>
<tr>
<th>Performance Risk</th>
<th>Commercial Risk</th>
<th>Programmatic Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load uncertainty</td>
<td>Inadequate Business Structures</td>
<td>Community and Social Integrations</td>
</tr>
<tr>
<td>Power Quality Risk</td>
<td>Stakeholder Management</td>
<td>Licensing</td>
</tr>
<tr>
<td>Component Failure</td>
<td>Diesel Cost and Supply</td>
<td>Future Connectivity</td>
</tr>
<tr>
<td>Hardware</td>
<td>Equipment Supply issues</td>
<td></td>
</tr>
<tr>
<td>Compatibility Issues</td>
<td>Tariffs/Pricing</td>
<td></td>
</tr>
<tr>
<td>Installation Issues</td>
<td></td>
<td></td>
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<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geographical Isolation</td>
<td></td>
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</tr>
</tbody>
</table>

**Performance Risk**: technical factors that will influence a project's operation varying from the expected.

**Commercial Risk**: non-technical risks which influence the financial viability of the MG system.

**Programmatic Risk**: the legal, regulatory and political influences that will affect the program's outcomes.

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Case Study: Northern Territory, Australia

- Australia’s 3rd largest State by land area, yet least populous.
- Power and Water Corporation acts as the State utility provider.
- Under their Not-for-Profit subsidiary, Indigenous Energy Services Pty Ltd (IES), they provide services to over 38,000 people living outside of population centres.
- IES own, operate and maintain 52 isolated electrical mini-grids (combined generation capacity of 76MW).
- Fuel mix historically 88% Diesel (2009)

Image Source: PWC, Wikimedia Commons
Case Study: Northern Territory, Australia

Case Study: Northern Territory, Australia

TKLN Projects

- Tender awarded to Epuron to install, own and operate fixed tilt PV arrays and short term storage for ‘smoothing’ of output using lead acid batteries.
- RE plant capacity exceeds 1MWp
  - Kalkarindgi: 402kWp,
  - Ti Tree: 324kWp
  - Lake Nash: 266kWp PV + 45kWp WTG
- Coincided with PWC’s replacement of existing diesel power station at Lake Nash which had reached end of life, along with communications upgrades for remote monitoring at all sites.
Data Analysis – CY13 Ti Tree

<table>
<thead>
<tr>
<th>Measure</th>
<th>Ti Tree</th>
<th>Kalkarindji</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Generation</td>
<td>542 MWh (18%)</td>
<td>527MWh (21%)</td>
</tr>
<tr>
<td>Max. Instantaneous Penetration</td>
<td>77%</td>
<td>96%</td>
</tr>
<tr>
<td>Fuel Saving</td>
<td>~16%</td>
<td>~11%</td>
</tr>
</tbody>
</table>
What is ASIM?

- ASIM is a desktop modelling tool developed to simulate solar/diesel power system operation and conduct analysis of its technical and financial performance.

- Developed by Power and Water and a contractor Radical Systems Pty Ltd, with funding from ARENA - the two elements are an Excel interface and C++ Power system.

- It allows customizable and variable time step analysis (down to 1 second steps) of Generator, PV and Battery Operation.

- Complementary to Homer (limited to 1 hour only), with a number of additional parameters such as Hysterisis bands and set point sampling rates.


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Data Analysis + ASIM Modelling

7 Days Observed Operation

7 Days Simulated Operation – Reference Case

7 Days Simulated Operation – No PV Case
### Actual Performance with PV
From measured 2013 data

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Gen A (450kW)</th>
<th>Gen B (520kW)</th>
<th>Gen C (720kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64%</td>
<td>35%</td>
<td>4%</td>
<td></td>
</tr>
</tbody>
</table>

### ASIM Reference case
Using actual PV and Load as inputs, to verify the accuracy of the model. (Ideally this would be close to recorded data.)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Gen A (450kW)</th>
<th>Gen B (520kW)</th>
<th>Gen C (720kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>68%</td>
<td>31%</td>
<td>2%</td>
<td></td>
</tr>
</tbody>
</table>

### ASIM model of system without PV
Using the load profile for 2013, but without any PV/battery contribution/input

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Gen A (450kW)</th>
<th>Gen B (520kW)</th>
<th>Gen C (720kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>45%</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>

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**Annual Runtime % (PV vs no PV case)**

- **Actual**
- **ASIM (no PV)**

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Data Analysis + ASIM Modelling Small Generator

7 Days Observed Operation

7 Days Simulated – Additional generator

Further fuel saving ~ 1%
Summary of Findings:

- Retrofitted sites - initial diesel configuration may be sub-optimal.

- High penetrations of PV into diesel MGs can introduce additional challenges, such as impact on the diesel generators operating regime. Demonstration of quantifying these effects was demonstrated using ASIM.

- Problem can be worsened by oversized cooling fans on the diesel generators.

- Control integration issues - variability of the solar resource was significantly underestimated during the design phase.

- Equipment failure was evident at Kalkarindji, resulting in some time whereby there was only 2 generators available – resiliency was adequate to cope.

- Uncertainty around demand was not problematic in these cases – indigenous communities had prepayment meters and some control (Noteworthy that population transience has created issues in the past (Nayar 1995) as well as anecdotal evidence of poor planning about other infrastructure projects (Parachilna, SA).)
Summary of Findings:

- PPA arrangement presents novel approach to risk management.
- Interviewee’s observed they could have benefitted from more technical detail in the contract – certain criteria had to be later negotiated with no precedent and this was time consuming. This included factory and user acceptance testing, critical for risk mitigation.
- Some literature (Tenenbaum et al. 2014) don’t recommend such ‘deemed energy’ clauses in PPA as they are difficult to administer and can increase regulatory transaction costs.
- TKLN Solar - Separate entity wholly owned by Epuron
- Equipment Supply: battery supply interruptions caused minor project delays.
NT – Findings and Discussion

Summary of Findings:

- RE integrations will come from green funding, setting aside some funding replacing or modifying diesels might present more value when considering system as a whole.

- Political risks – state and Federal in the NT. The targets presented by the 2010 NT Green Energy Task Force aren’t dissimilar from the 2015 RAR, but do represent a 4 year delay.

- Future grid integration – not an issue in this case.

- Commitments to SAIDI and SAIFI measures – respondents indicate improvement but difficult to ascertain how much is attributable to security of supply offered by renewable energy.
Case Study: Sabah, Malaysia

...but Malaysia’s developed, right?

![Map of Malaysia showing electrification percentages for Peninsular Malaysia, Sabah, and Sarawak.](#)

**Electrification %**
- **Peninsular Malaysia**: 97.5% (2000), 98.6% (2005), 98.9% (2010), 99.9% (2015*), 99.9% (2020*)
- **Sarawak**: 66.9% (2000), 80.8% (2005), 89.6% (2010), 94% (2015*), 99.9% (2020*)
- **Sabah**: 67.1% (2000), 72.8% (2005), 84.4% (2010), 95.1% (2015*), 99.9% (2020*)
Case Study: Sabah, Malaysia

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Case Study: Sabah, Malaysia

SESB’s Utility PV/Diesel/Battery Mini-grid Program

- Financed by the Govt. Ministry of Rural Development (KKLW) and indirectly through Ministry of Finance, as well as a trust fund.

- Eligible villages are those with unlikely to receive central grid connection within 7 years (previously 5) and prioritised based on size and proximity.

- Renewable energy contribution based on annual kWh % (e.g. 70%:30%, 50%:50%) and determined by the relative remoteness.

- End users pay the same rate as on the central grid (State wide tariff equiv.)
Case Study: Sabah, Malaysia

SESB’s Utility PV/Diesel/Battery Mini-grid Program
## Case Study: Sabah, Malaysia

### SESB’s PV mini-grid projects

<table>
<thead>
<tr>
<th>PV Hybrid Station</th>
<th>Connected Households</th>
<th>Hybrid Configuration</th>
<th>Targeted RE Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PV</td>
<td>Controller/Inverter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kWp</td>
<td>kW</td>
</tr>
<tr>
<td>Kg Monsok Ulu &amp; Tengah, Tambunan</td>
<td>35</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Kg Pegalungan, Nabawan</td>
<td>76</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>Kg Meligan, Sipatang</td>
<td>140</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>Kg Pulau Lubukan, Sandakan</td>
<td>40</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>Pulau Banggi Fasa 1, Kudat</td>
<td>602</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Kalabakan, Tawau</td>
<td>654</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>Kg Kuamut Besar, Kinabatangan</td>
<td>270</td>
<td>200</td>
<td>2x100</td>
</tr>
<tr>
<td>Kg Kuamut Seberang</td>
<td>20</td>
<td>30</td>
<td>2x60</td>
</tr>
<tr>
<td>Kg Tg Batu Darat &amp; Laut, Sandakan</td>
<td>128</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>Kg Tundun Bohangin, Kinabatangan</td>
<td>59</td>
<td>144</td>
<td>1x120</td>
</tr>
<tr>
<td>Kg Tidong, Kinabatangan</td>
<td>40</td>
<td>126</td>
<td>1x120</td>
</tr>
<tr>
<td>Kg Tambisan Darat &amp; Laut</td>
<td>168</td>
<td>296</td>
<td>2x120</td>
</tr>
<tr>
<td>Pulau Banggi Fasa 2, Kudat</td>
<td>602</td>
<td>1000</td>
<td>3 Bi-Dir. x 300,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 Grid Con. x 75</td>
</tr>
<tr>
<td>Pulau-Pulau di Semporna, Sabah</td>
<td>647</td>
<td>1569</td>
<td>2x200, 7x150</td>
</tr>
<tr>
<td>(9 SSH/8 Islands/26 villages)</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Tanjung Labian Fasa 1, Tungku, Lahad Datu</td>
<td>681</td>
<td>1212</td>
<td>4 x 200</td>
</tr>
<tr>
<td>Tanjung Labian Fasa 2, Tungku, Lahad Datu</td>
<td>101</td>
<td>259</td>
<td>300</td>
</tr>
<tr>
<td>Kg Sungai Merah, Tg. Labian, Tungku, Lahad Datu</td>
<td>186</td>
<td>328</td>
<td>792</td>
</tr>
</tbody>
</table>
Pulau Banggi – Block Diagram
Case Study: Sabah, Malaysia

Palau Banggi - 24 Hour Data Analysis

Power (kW)

Date/Time

00:00
12:00
23:59

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Case Study: Sabah, Malaysia

Palau Banggi - 24 Hour Data Analysis

Graph showing power output over a 24-hour period with different data sets.
Case Study: Sabah, Malaysia

Palau Banggi - 24 Hour Data Analysis
Case Study – Sabah, Malaysia

Palau Banggi - 24 Hour Data Analysis
Case Study: Sabah, Malaysia

Palau Banggi - 24 Hour Data Analysis

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Palau Banggi - 24 Hour Data Analysis

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Case Study: Sabah, Malaysia

Graphs showing power generation and battery state over time in Pulau Banggi.
Case Study: Sabah, Malaysia

MONTHLY HOUSEHOLD INCOME (RM)

MONTHLY ENERGY EXPENDITURE (RM)

Connected Households  Non Connected Households

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Sabah – Findings and Discussion

Summary of Findings:
- Performance to the RE fraction design point varied substantially, some underperformed (36.7% vs. targeted 70%) while others outperformed (85.4% vs targeted 70%), but to date these indices aren’t monitored or reported.
- Other indicators such as Battery SOC were problematic for the control system to determine, resulting in reduced yield.
- Connectivity problems resulted in no monitoring of systems, although broader question of whether the resources and skills are available to effectively manage this task.
- In reliability terms the systems were found to provide consistent 24/7 supply without limitations beside occasional blackouts,
- End users reported outage durations of 60-180 mins per week and satisfaction levels of 85%.
- The availability of skilled staff to trouble shoot and address problems was a major factor in reducing outage duration.
Sabah – Findings and Discussion

**Summary of Findings:**
- Short warranty period means a lot of the risks are born largely by the utility and govt. Equipment (1 year) and design warranty (5 years) have questionable effectiveness.
- Deficiency in engagement at handover points.

<table>
<thead>
<tr>
<th></th>
<th>Govt. Ministry</th>
<th>Utility</th>
<th>Contractor</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Assessment Risk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE Assessment\Tech. Selection</td>
<td></td>
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<tr>
<td>Design Risk</td>
<td></td>
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<tr>
<td>Cost Risk</td>
<td></td>
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<tr>
<td>Construction Risk</td>
<td></td>
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<tr>
<td>Integration Risk</td>
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<tr>
<td>Operational Risk</td>
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<tr>
<td>Future Connectivity Risk</td>
<td></td>
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</tr>
</tbody>
</table>

- No - Low Exposure
- Medium Exposure
- High Exposure
Summary of Findings:

- Poor coordination between government ministerial programs.
- Existing tariff structure is a major hurdle to recoup costs (common globally). 40% of end users expressed a willingness to pay more if service provision increased.
- Economic Planning Unit (EPU) plan to reach 99.9% electrification may goal, as it flags a decentralized approach, but this competes with other priorities, such as higher SAIDI and SAIFI value for on-grid supply.
- Ongoing support for capex intensive RE projects will depend on political will to increase RE share, which is not currently on a firm footing.
- Future overlap between central grid extension and existing sites, scenario has already affected one of the systems in central Sabah where the PV hybrid system was decommissioned.
- Geo-political, population and military influences on loads
### Improving Design, Modelling and Performance Measures

<table>
<thead>
<tr>
<th><strong>Demand Side</strong></th>
<th><strong>Resource</strong></th>
<th><strong>System Performance</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Annual Demand</td>
<td>- Peak sun Hours</td>
<td>- Annual RE % (kWh)</td>
</tr>
<tr>
<td>- Load Profiles</td>
<td>- Clearness Index</td>
<td>- Annual DG % (kWh)</td>
</tr>
<tr>
<td>- Interday/Timestep Variability</td>
<td>- Hourly Resource Profiles</td>
<td>- Peak RE % (kW)</td>
</tr>
<tr>
<td>- Load Distribution Curves</td>
<td>- Probability Of Exceedance</td>
<td>- Battery SOC Dist.</td>
</tr>
<tr>
<td>- Load Step Changes</td>
<td></td>
<td>- Fuel Consumption</td>
</tr>
<tr>
<td>- Load Factor (dmd side)</td>
<td></td>
<td>- Capacity Factor</td>
</tr>
<tr>
<td>- Coincidence/Diversity Factors</td>
<td></td>
<td>- Normalised PV Yield</td>
</tr>
<tr>
<td>- Load Growth +/-</td>
<td></td>
<td>- Relative PV yield</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Commercial/Contractual</strong></th>
<th><strong>Programmatic/Service based</strong></th>
<th><strong>Economic</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Time based Availability</td>
<td>- New connections</td>
<td>- LCOE</td>
</tr>
<tr>
<td>- Energy based Availability</td>
<td>- Operating Reserves</td>
<td>- NPV</td>
</tr>
<tr>
<td>- Take or Pay minimums</td>
<td>- SAIDI</td>
<td>- IRR (retrofit)</td>
</tr>
<tr>
<td>.. And any of the above system measures.</td>
<td>- SAIFI</td>
<td>- VAR</td>
</tr>
</tbody>
</table>

- Applying Each to the Case Studies
- Reflection on usefulness
- Addressing challenges in application
Design Proposal
Detailed Feasibility Study
Design
Construction
Commissioning
Operation

RET Integration Project Steps

Comparative Analysis

Basic Modelling
HOMER
Calibrated Modelling
Calibrated Modelling
HOMER

Load Calibration

Solar resource & Control Calibration

Sample Rate Comparison
1hr
10min
1min
1sec

Observed Data

Metrics of Comparison:
- RE % (Annual kWh and Peak kW)
- Generator Run hours
- Generator Starts
- Generator Operating Ranges
- ~Fuel Reduction (L) compared to Diesel Only Case
- ~NPC ($) and ~LCOE ($)
Improving Design, Modelling and Performance Measures

School of Photovoltaic and Renewable Energy Engineering
### Improving Design, Modelling and Performance Measures

<table>
<thead>
<tr>
<th>Metric</th>
<th>Ti Tree</th>
<th>Kalkarindji</th>
<th>Pulau Banggi</th>
<th>TL 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSH</td>
<td>5.61</td>
<td>5.15</td>
<td>5.14</td>
<td>5.68</td>
</tr>
<tr>
<td>PV generation (kWh)</td>
<td>542,000</td>
<td>527,000</td>
<td>~798,000</td>
<td>~1,334,000</td>
</tr>
<tr>
<td>PV Capacity (kWp)</td>
<td>324</td>
<td>402</td>
<td>1,130.88</td>
<td>1,223.40</td>
</tr>
<tr>
<td>Normalised PV Yield $Y_N$ (kWh/kWp)</td>
<td>1,672</td>
<td>1,310</td>
<td>705</td>
<td>1,090</td>
</tr>
<tr>
<td>Total PSH$_\tau$</td>
<td>2048</td>
<td>1882</td>
<td>874</td>
<td>1383</td>
</tr>
<tr>
<td>Relative PV Yield ($Y_R$)</td>
<td>82%</td>
<td>70%</td>
<td>36%</td>
<td>52%</td>
</tr>
<tr>
<td>Capacity Factor (CF)</td>
<td>19%</td>
<td>15%</td>
<td>8%</td>
<td>12%</td>
</tr>
</tbody>
</table>
Recommendations

- Hybrid systems will inevitably create a unique challenge for risk management – consideration towards the whole of system impacts is necessary.

- Operators need to able to effectively monitor, operate and understand all the implications in order to realize the intended reduced operating costs. Information must be fed back into the project design.

- MY: Initial design and construction phase has a high dependence on the contractor, in current arrangement has minimal stake on the ongoing performance of the system. Alternative models are available locally, including that in the NT should be considered.

- Both case studies involve significant subsidies to the end user – attracting more local govt, dev. bank and private investment will require cost reflective tariffs (reducing these through demand management, storage, distributed energy) and transparency in electrification planning processes.

- Avoiding a ‘tragedy of the commons’ scenario in regards to data and knowledge sharing. Need to align risk perceptions to realities.
Conclusion

“Uncertainty is an uncomfortable position. But certainty is an absurd one.”
- Voltaire

- Detailed risk benefit analysis is fundamental to good decision making, and better understanding of their measurement and management is key to the success of future projects, and critical to secure projected growth.

- The development of guidelines for improved modelling, performance analysis and focusing on long term operational performance will all help reduce risk in MG & project respectively.

- Academics have a role to play in helping disseminate information, and can offer mutual value to case study partners.

- RE mini-grids set to play a large role in delivering energy access globally, and service delivery in Sabah and the Northern Territory has shown that high penetration wide scale deployment in remote areas is not only possible but highly effective.