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

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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

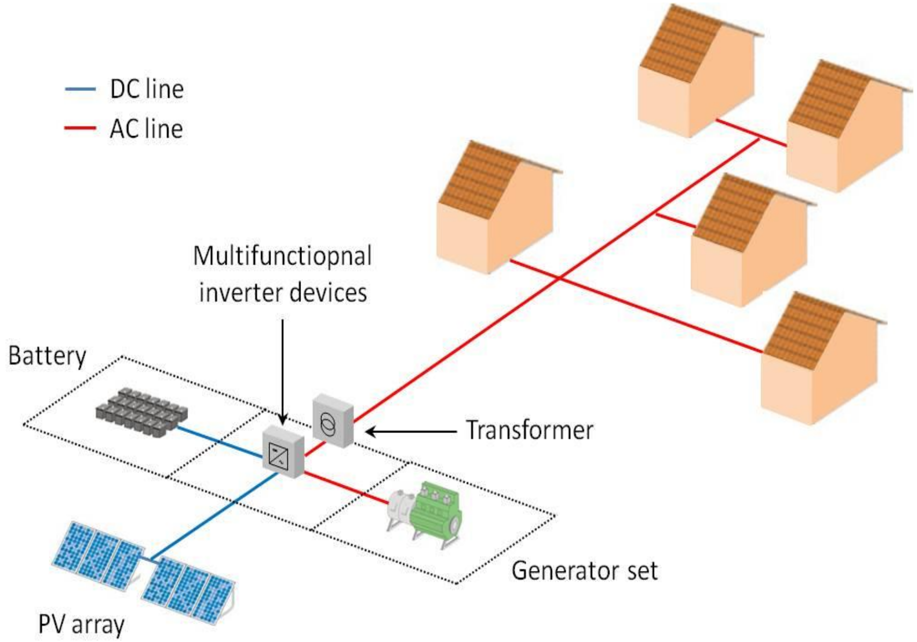
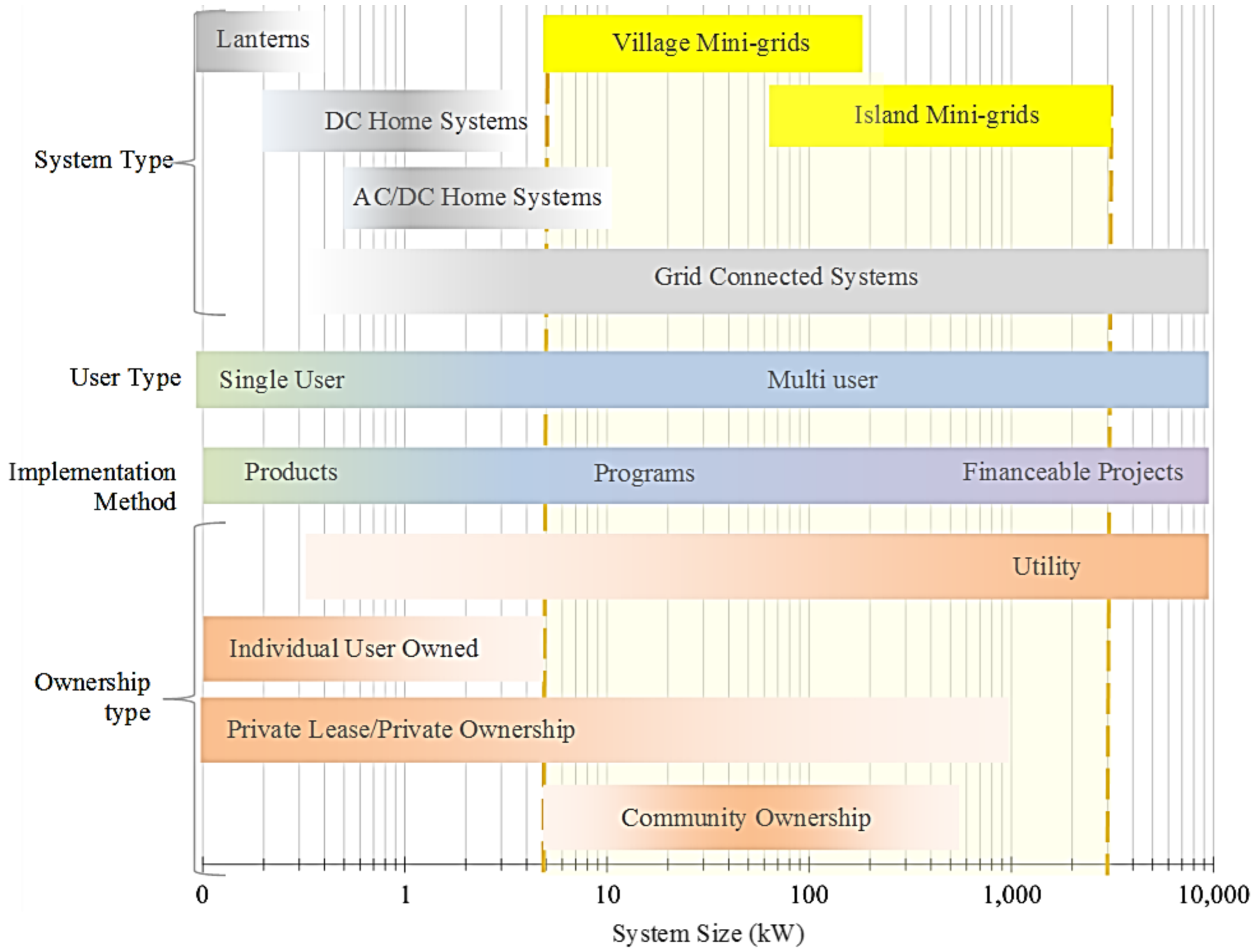


Image: Michelez et al 2011 – Risk Quantification and Risk Management in Renewable Energy Projects

Defining a "Mini-grid"

Applications and Categorisations based on System Size

(building upon Lilienthal (2013) and (Mauch 2009))



Defining a “Mini-grid”

Defining "Risk"

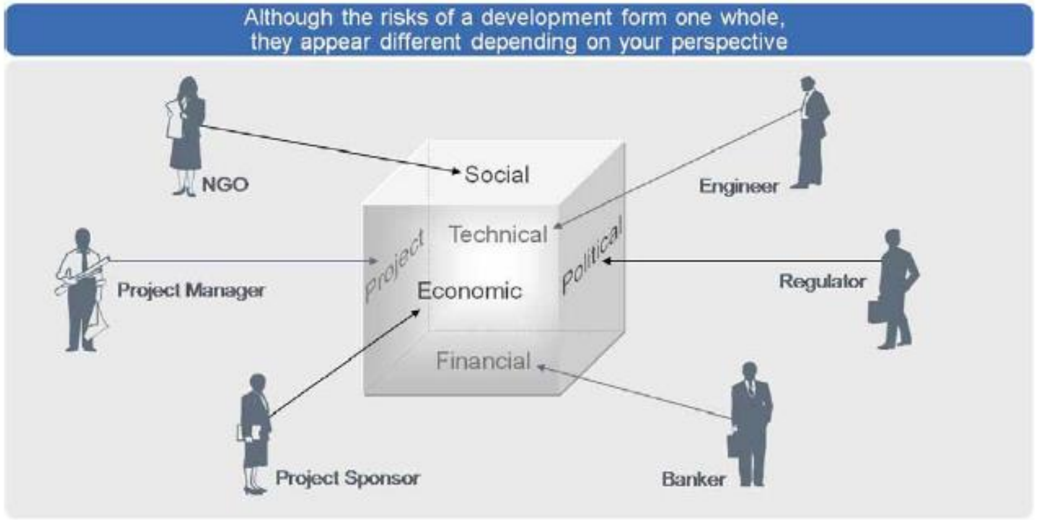
The basic definition of Risk

"an undesirable implication of uncertainty" (Chapman, Cooper 1982)

For this research:

"uncertainty that impacts outcomes in a positive or negative way."

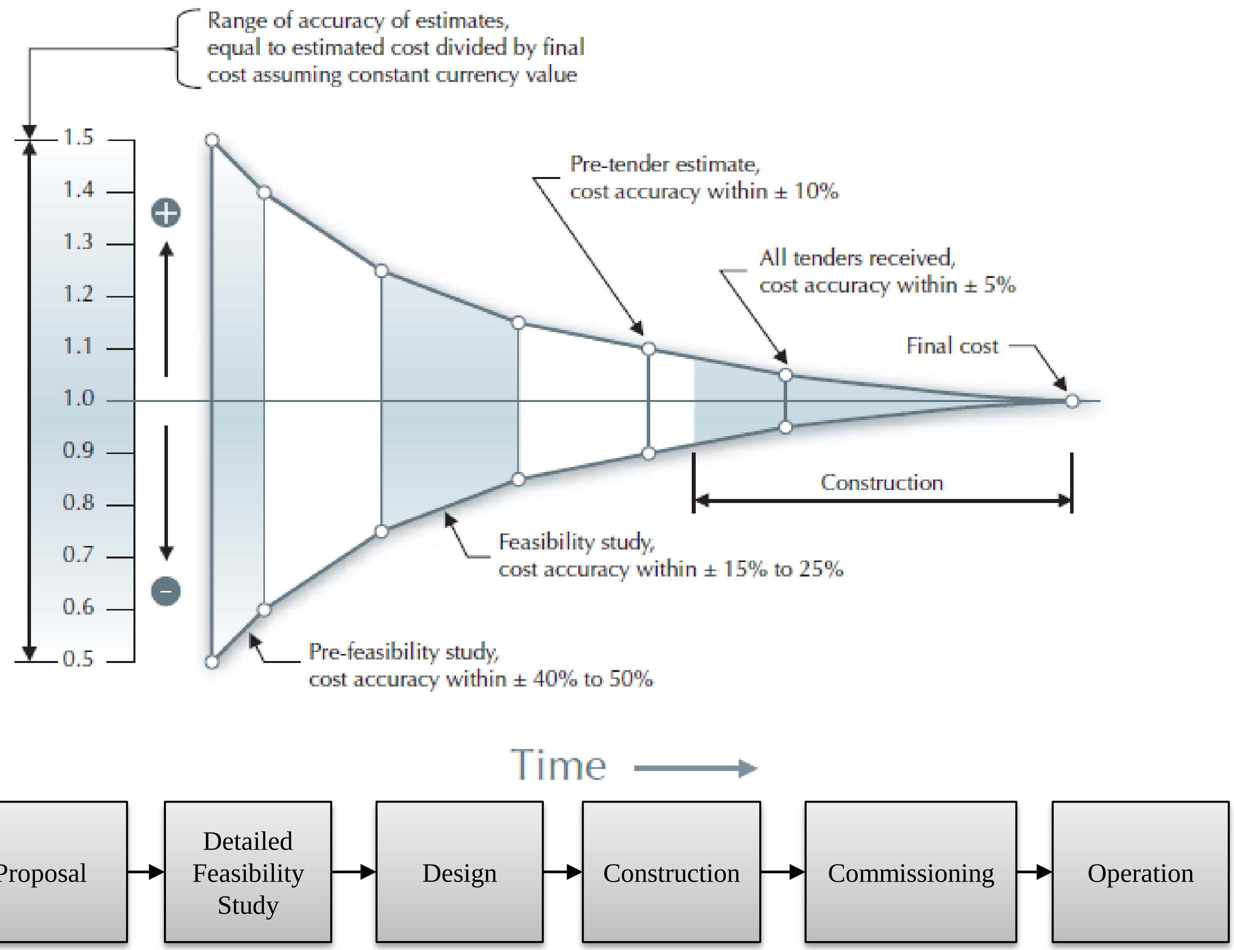
- It's consideration is vital part of any decision making.
- Risk evaluation can fall into classical or conceptual models.
- Risk can accrue to different parties involved in a decision and are perceived differently. Perceptions influence their appetite..



From: Michelez et al 2011 – Risk Quantification and Risk Management in Renewable Energy Projects

Putting “Risk” and “Mini-grids” Together

Uncertainty in Project Development

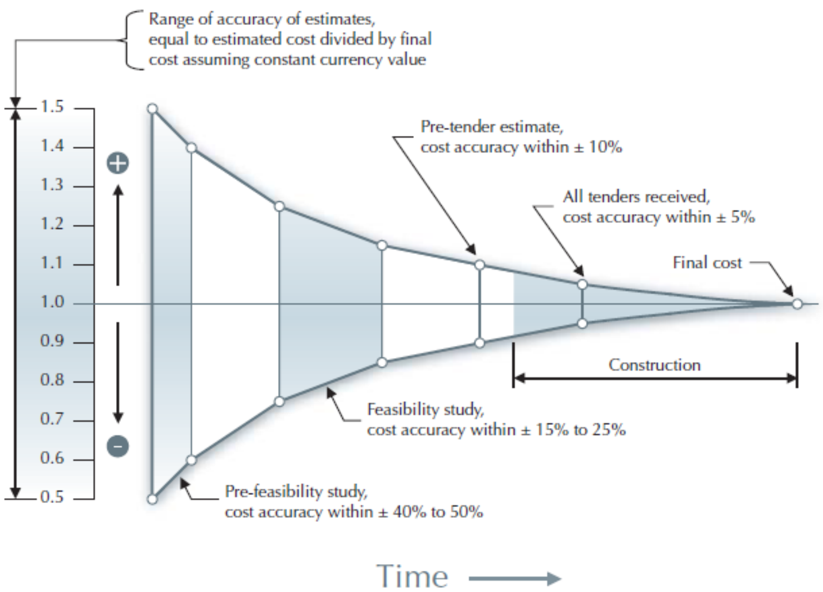


Source: RETSCREEN

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?

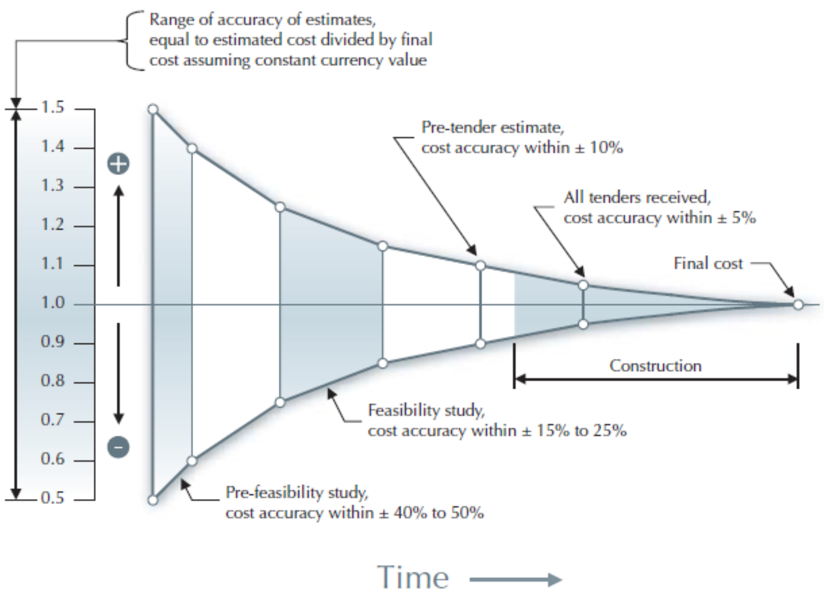
How do we avoid/
..reduce/
..transfer/
..retain
the risks involved?

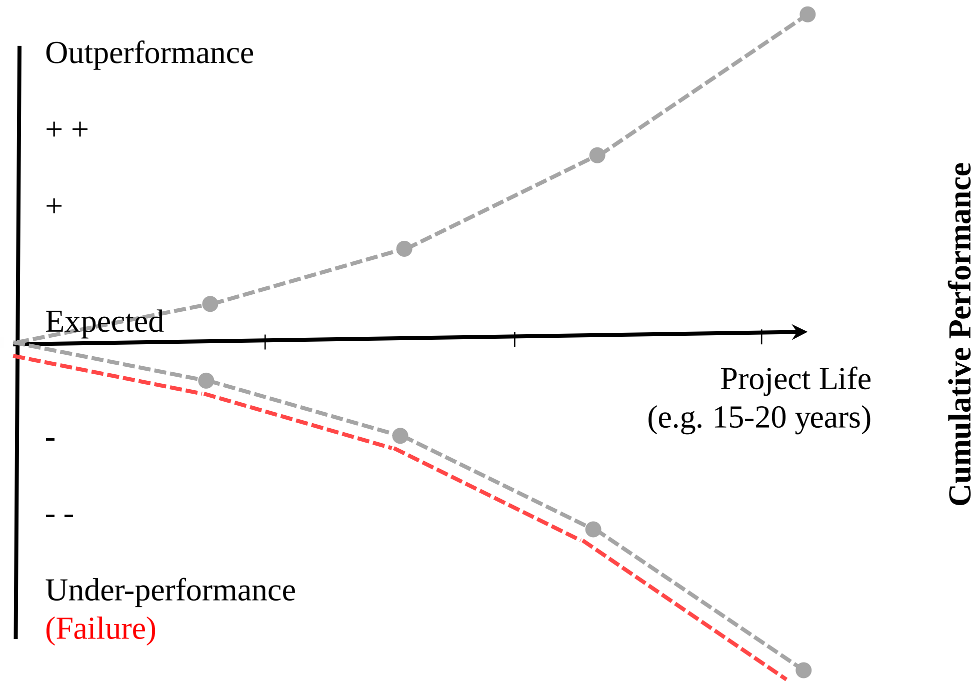
Source: RETSCREEN

Putting "Risk" and "Mini-grids" Together

Uncertainty in Project Development

Uncertainty in Operation & Service Delivery



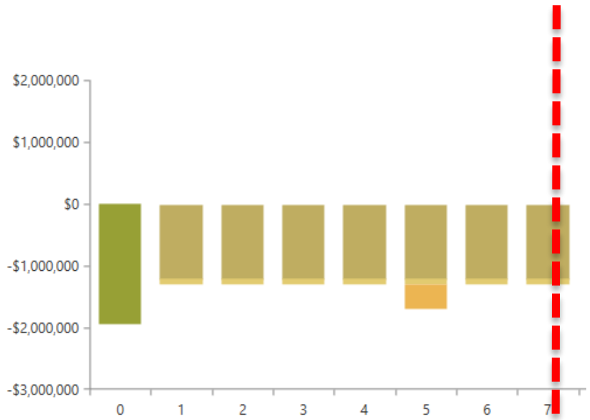


Source: RETSCREEN

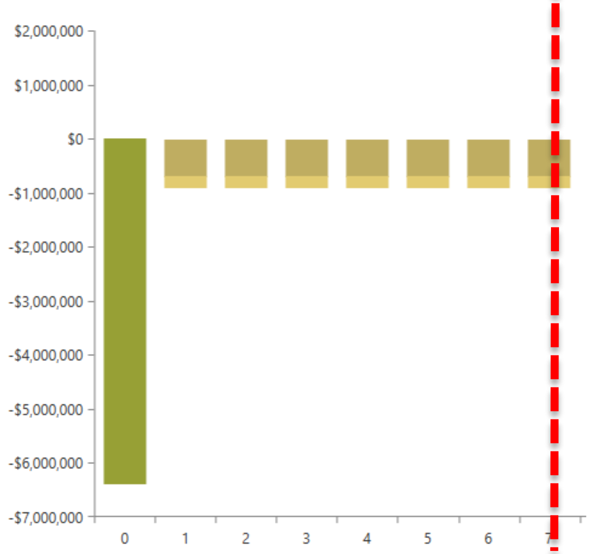
Putting "Risk", "Minigrids" and "Renewables" Together

Two Mini-grid project technology options – same LCOE

100% Diesel
0% RE

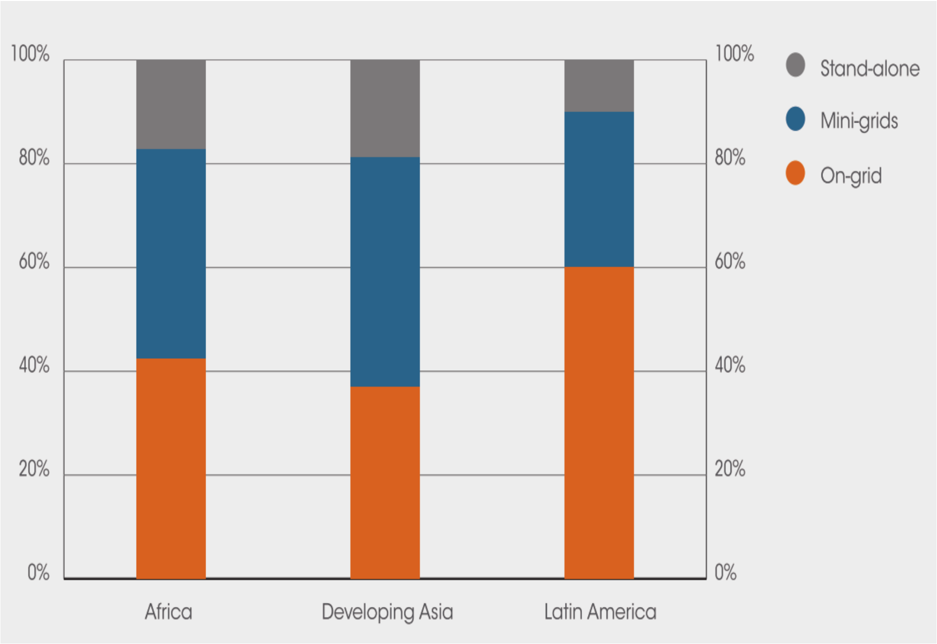


56% Diesel
44% RE



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)****)*

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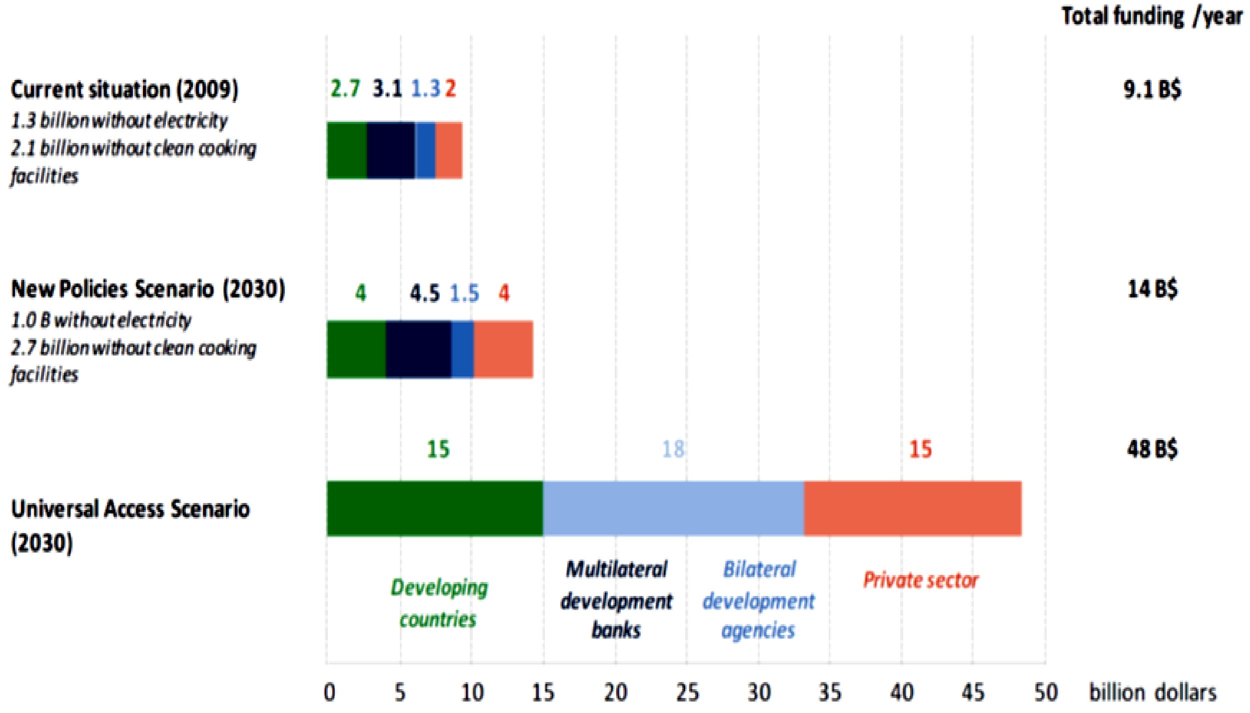
Current financing and annual financing requirements by type of financier (source: ENEA 2014, using data from IEA WEO 2011)



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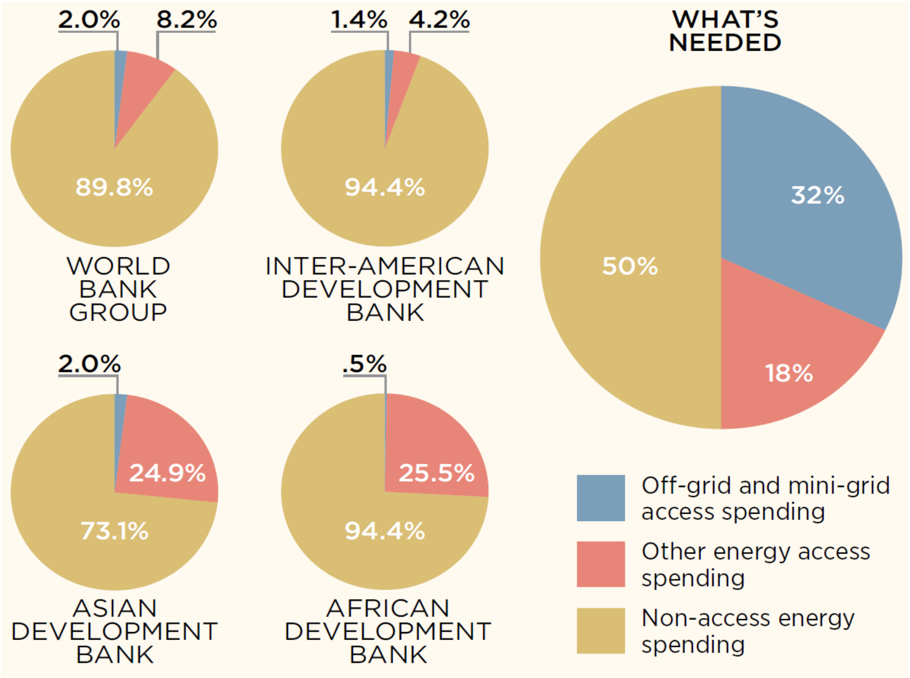

Off-Grid and Mini-grid Renewable Energy Spending as a Percentage of the Annual Energy Portfolio (Three Year Average FY12, 13, 14)

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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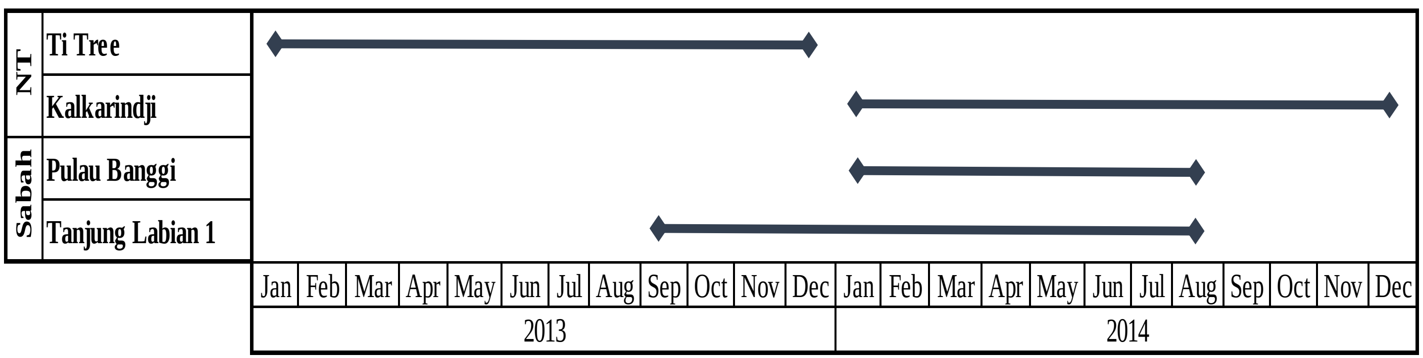


Method

- 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]

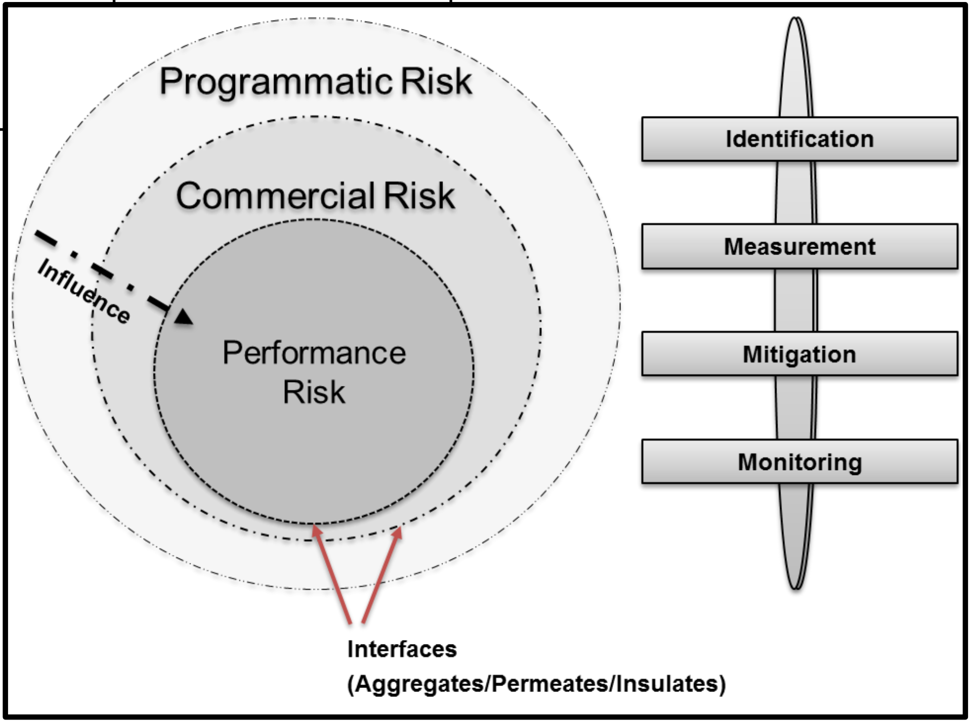
Literature Review and Framework

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

Performance Risk: technical factors that will influence a projects 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 programs outcomes.



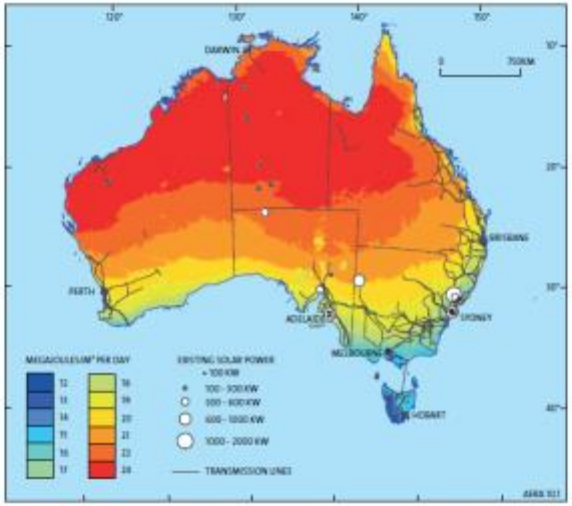
Case Study: Northern Territory, Australia

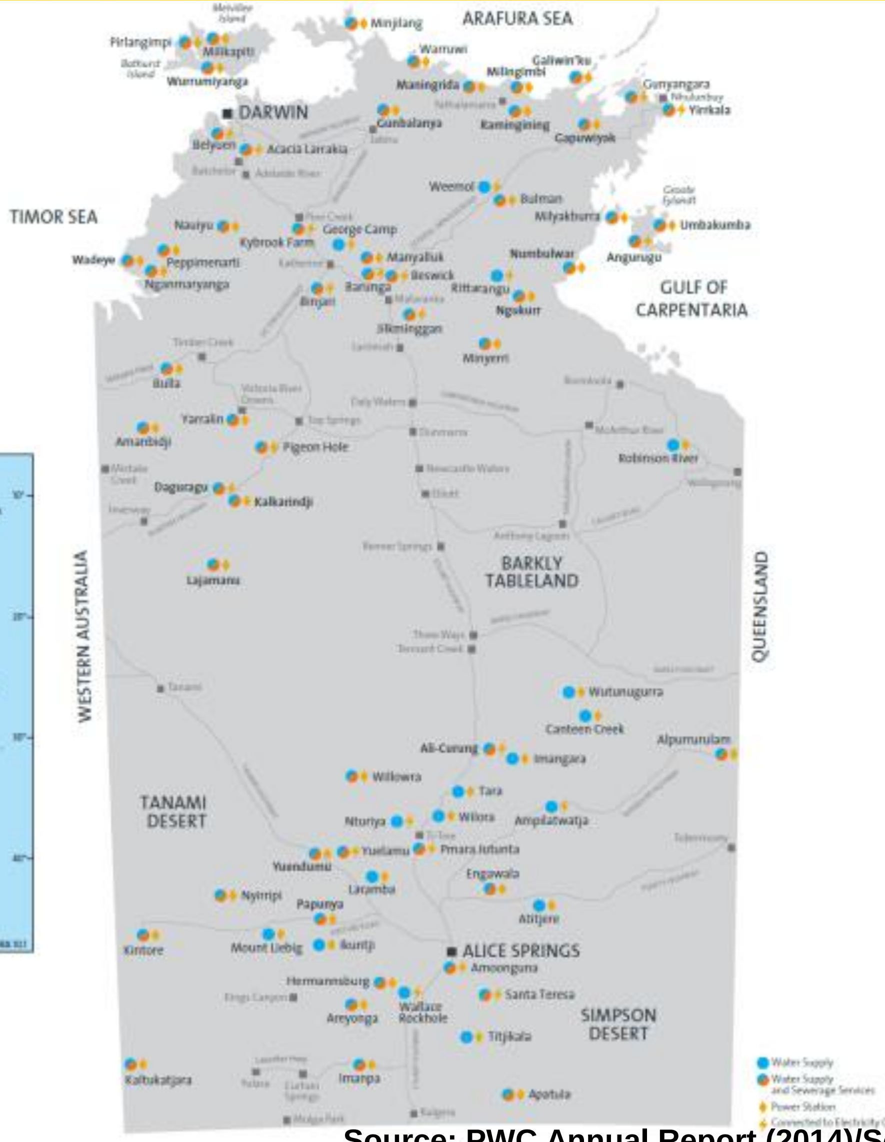
- Australia's 3rd largest State by land area, yet least populous.
- Power and Water Corporation acts as the State utility provider.
- Under their Not-for-Profit subsidiary, Indigenous Energy Services Pty Ltd (IES), they provide services to over 38,000 people living outside of population centres.
- IES 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

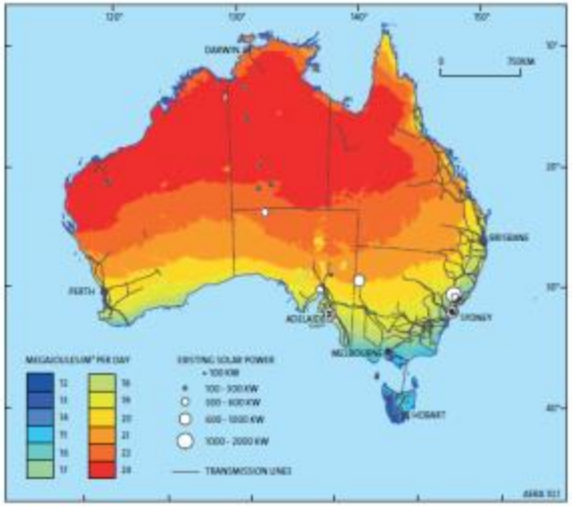
Case Study: Northern Territory, Australia





Source: PWC Annual Report (2014)/Solar-Diesel Handbook (2013)

Case Study: Northern Territory, Australia



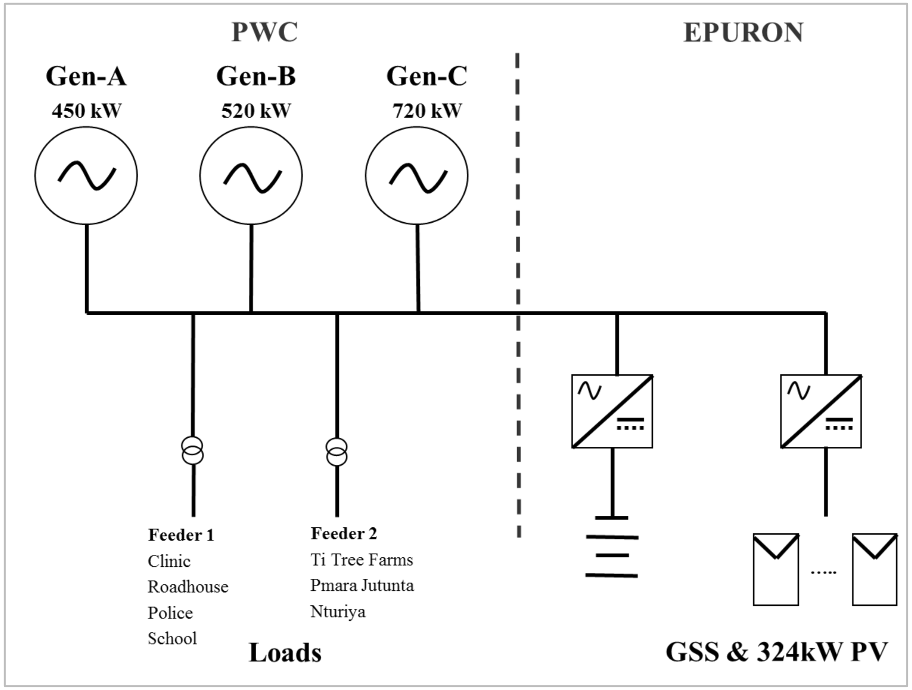
Source: PWC Annual Report (2014)/Solar-Diesel Handbook (2013)

TKLN Projects

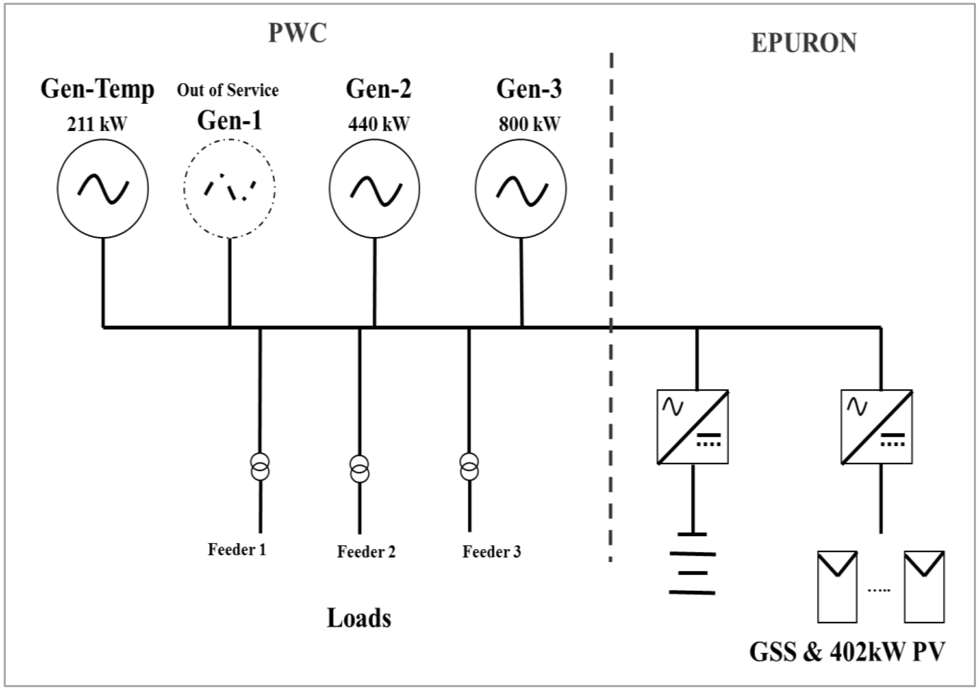
- Tender awarded to Epuron to install, own and operate fixed tilt PV arrays and short term storage for 'smoothing' of output using lead acid batteries.
- RE plant capacity exceeds 1MWp
  - Kalkarindgi: 402kWp,
  - Ti Tree: 324kWp
  - Lake Nash: 266kWp PV + 45kWp WTG
- Coincided with PWC's replacement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

Block Diagram - Ti Tree & Kalkarindji

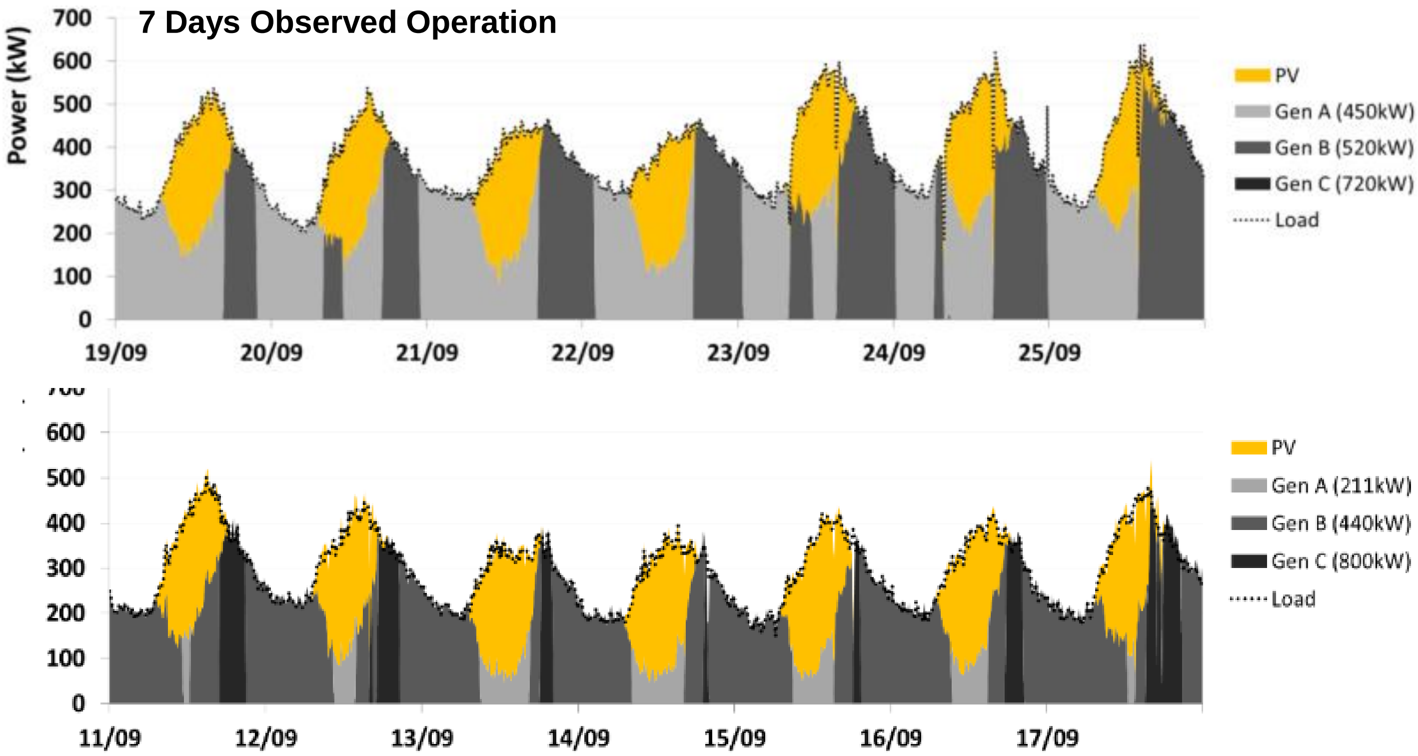
Ti Tree



Kalkarindji



Data Analysis – CY13 Ti Tree



Measure	Ti Tree	Kalkarindji
PV Generation	542 MWh (18%)	527MWh (21%)
Max. Instantaneous Penetration	77%	96%
Fuel Saving	~16%	~11%

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.

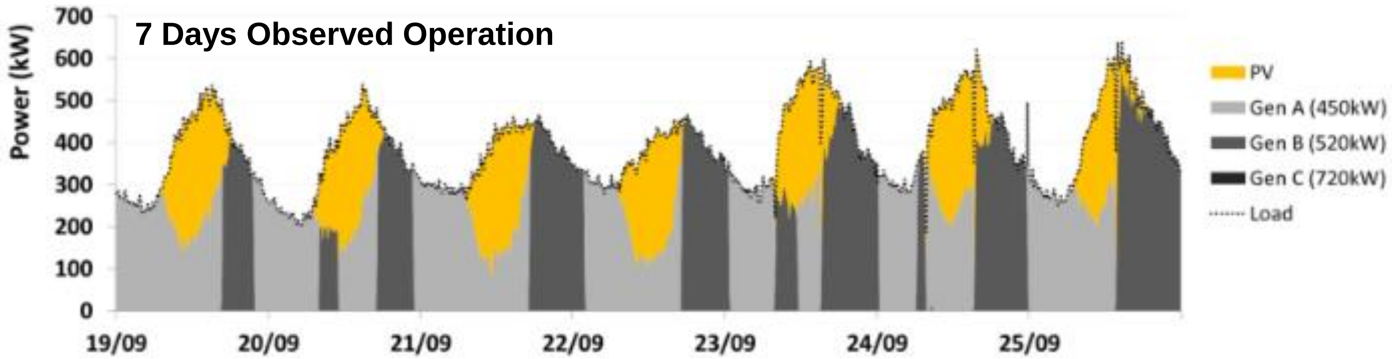
- It allows customizable and variable time step analysis (down to 1 second steps) of Generator, PV and Battery Operation.

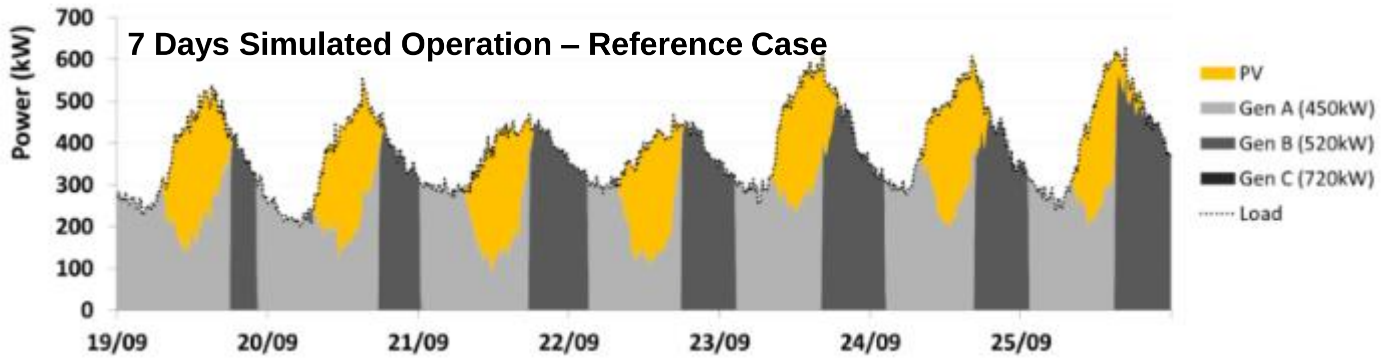
- Complementary to Homer (limited to 1 hour only), with a number of additional parameters such as Hysterisis bands and set point sampling rates.

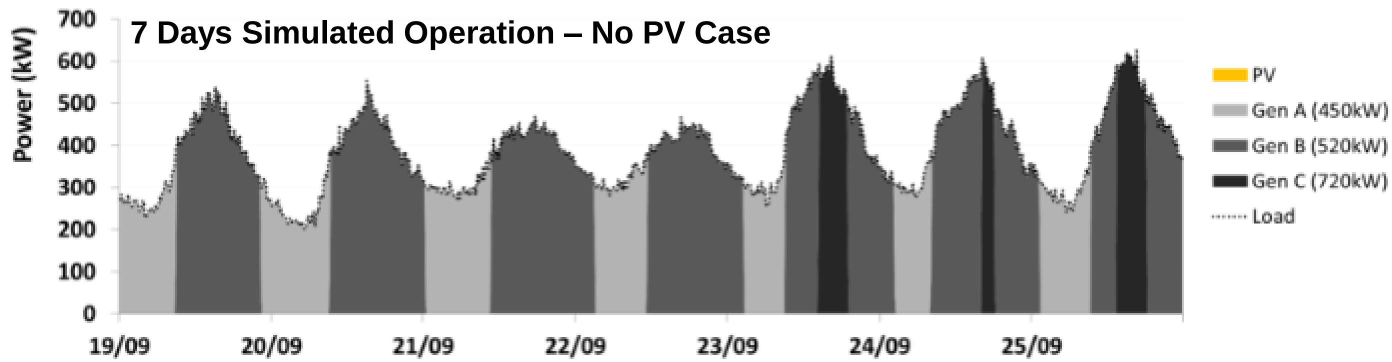
- **It's open source and freely available for download**

  (see http://www.powerwater.com.au/solardiesel)

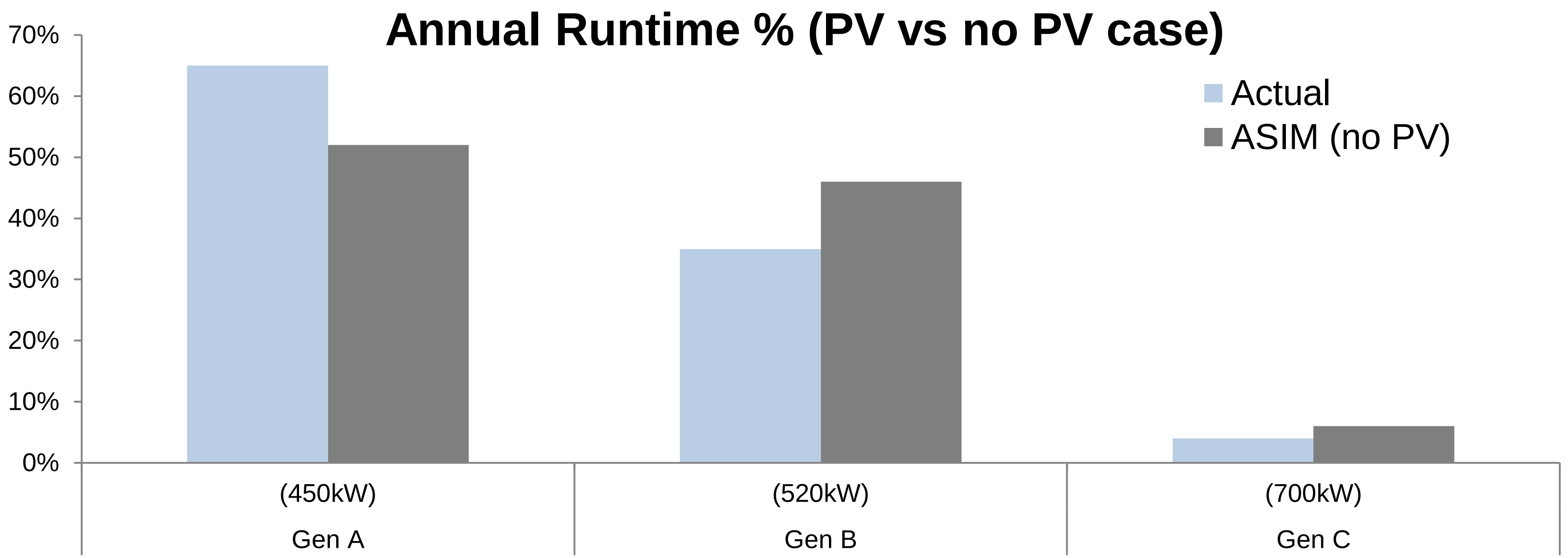
Data Analysis + ASIM Modelling



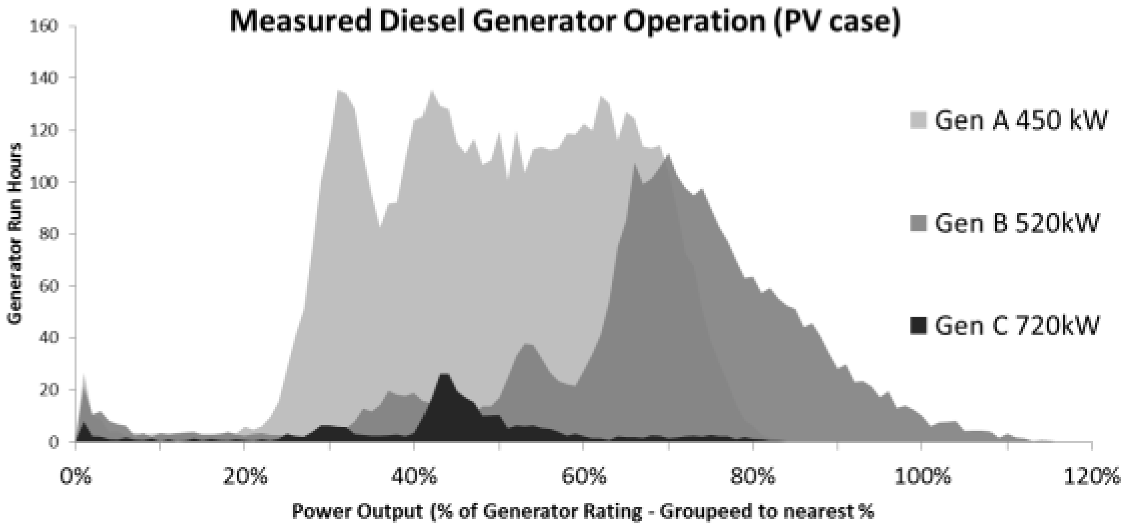


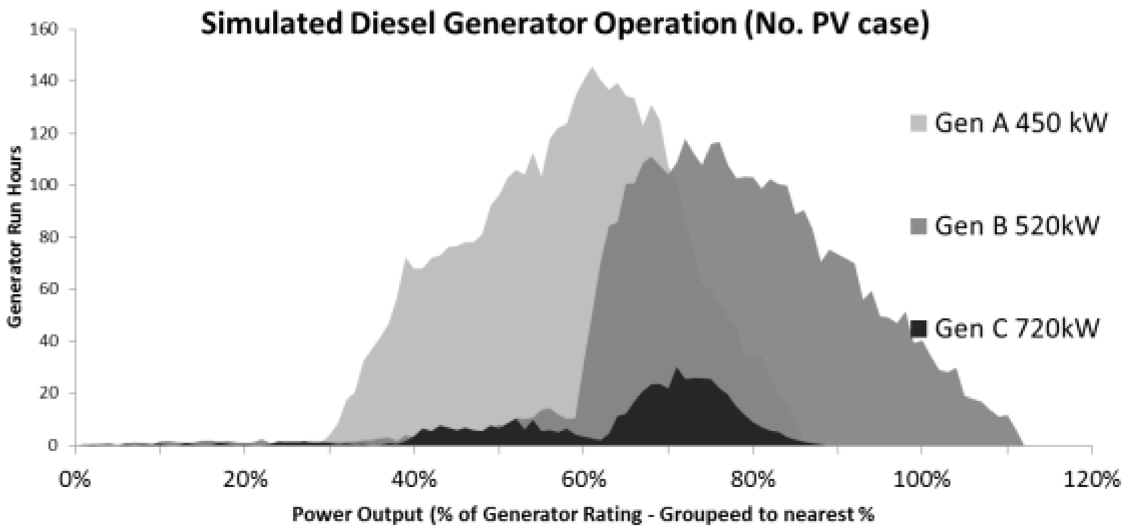


Scenario	Annual Run hour % Gen A (450kW)	Gen B (520kW)	Gen C (720kW)
Actual Performance with PV **From measured 2013 data**	64%	35%	4%
ASIM Reference case **Using actual PV and Load as inputs, to verify the accuracy of the model. (Ideally this would be close to recorded data.)**	68%	31%	2%
ASIM model of system without PV **Using the load profile for 2013, but without any PV/battery contribution/input**	50%	45%	6%

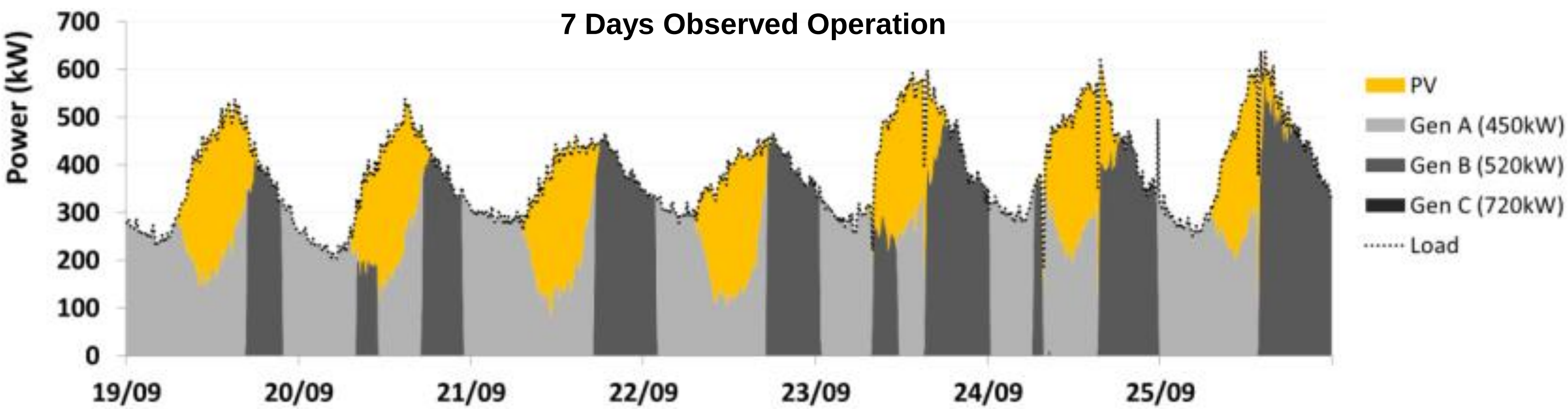


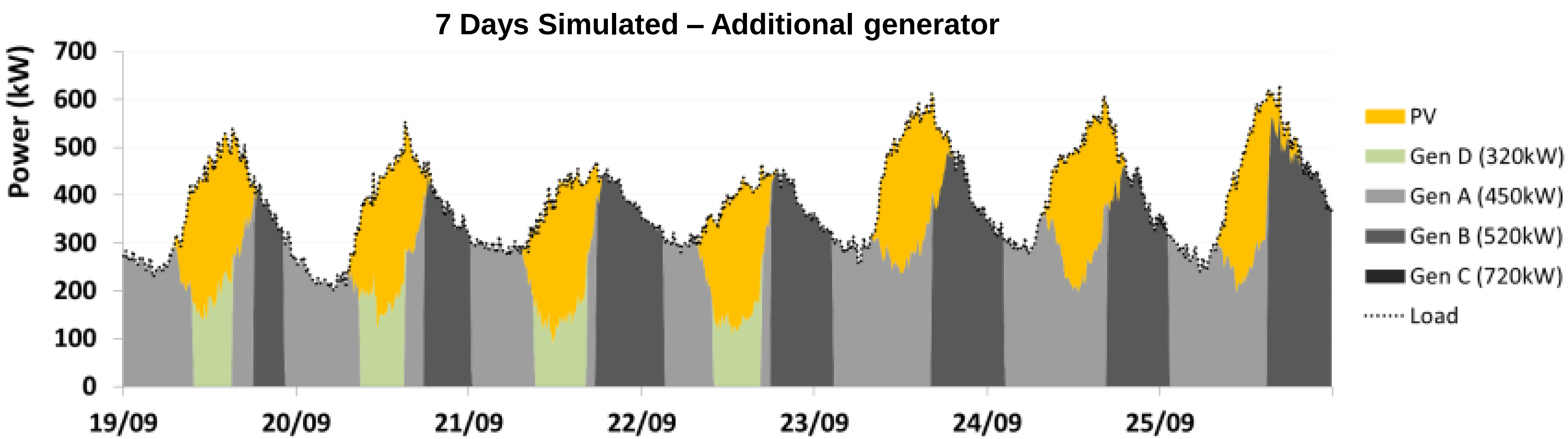
Generator Operating Ranges





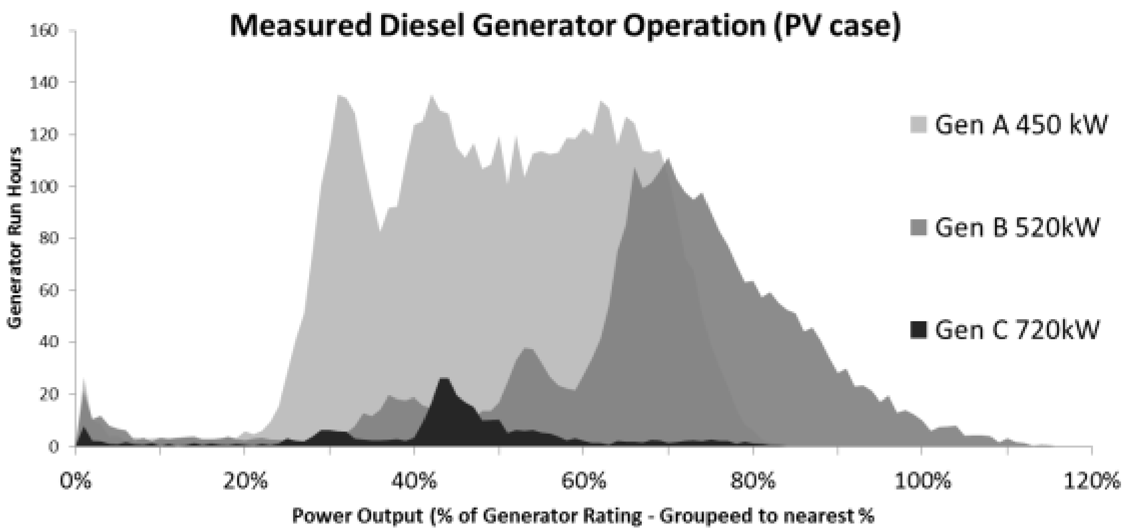
Data Analysis + ASIM Modelling Small Generator

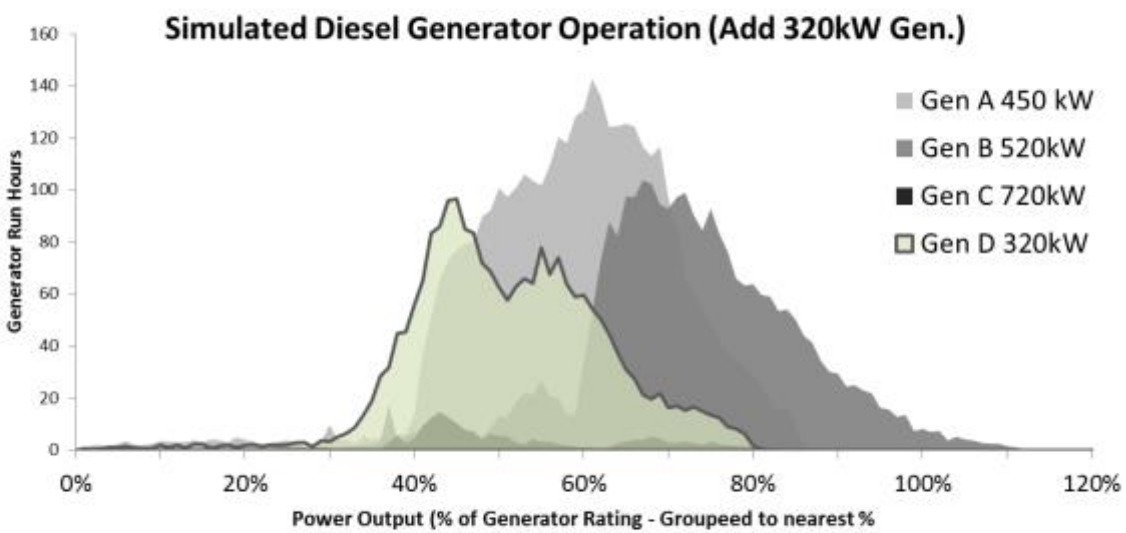




Further fuel saving ~ 1%

Generator Operating Ranges – Adding Small Generator





NT – Findings and Discussion

Performance Risk

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).)

NT – Findings and Discussion

Commercial Risk

Summary of Findings:

- PPA arrangement presents novel approach to risk management.
- Interviewee's observed they could have benefitted form 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

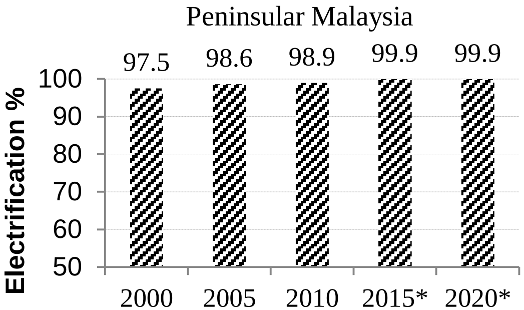
Programmatic Risk

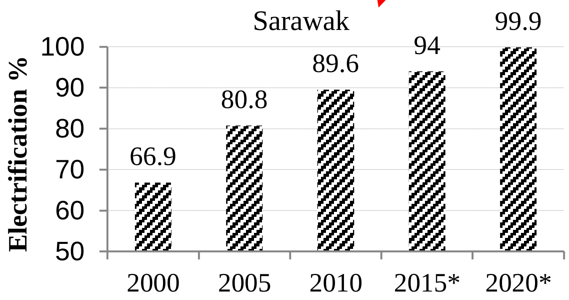
Summary of Findings:

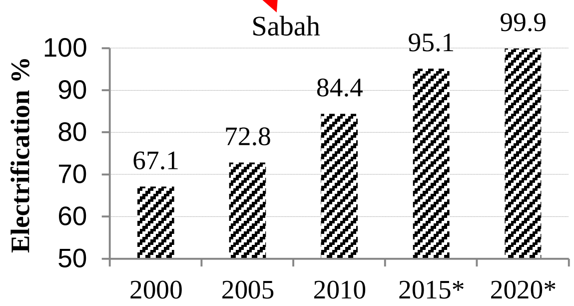
- RE integrations will come from green funding, setting aside some funding replacing or modifying diesels might present more value when considering system as a whole.
- Political risks – state and Federal in the NT. The targets presented by the 2010 NT Green Energy Task Force aren't dissimilar from the 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?







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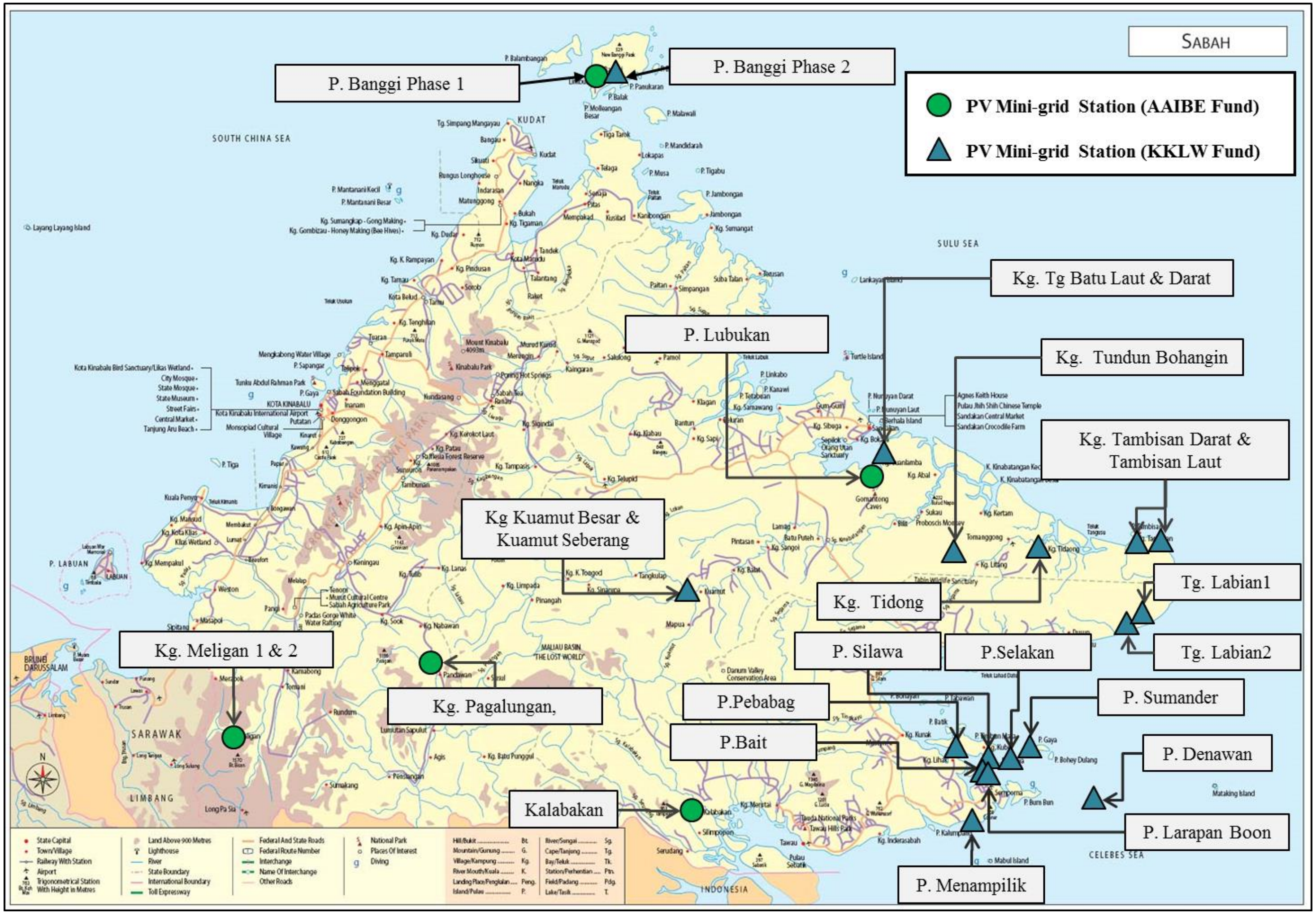
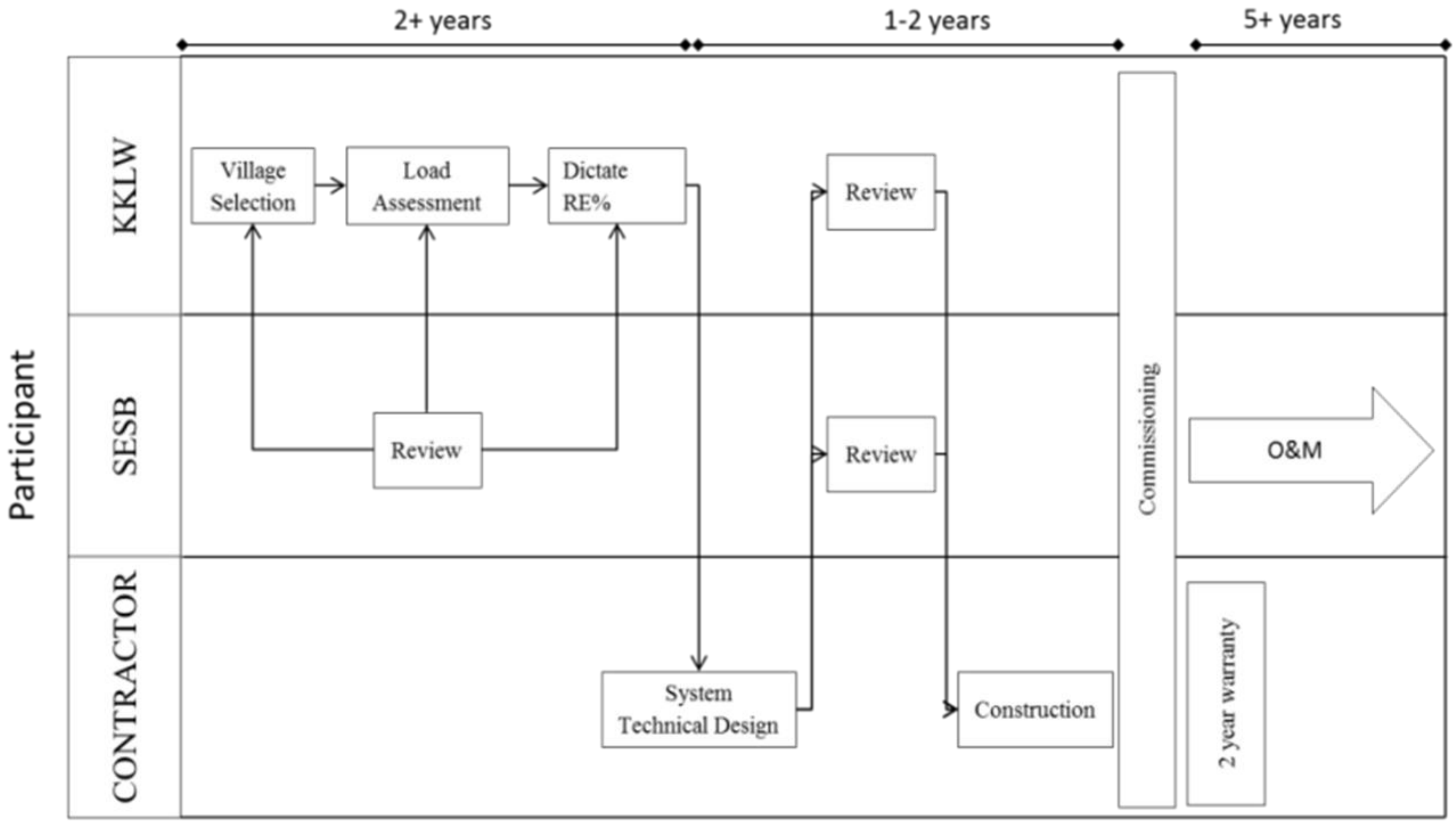


Case Study: Sabah, Malaysia

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.)

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



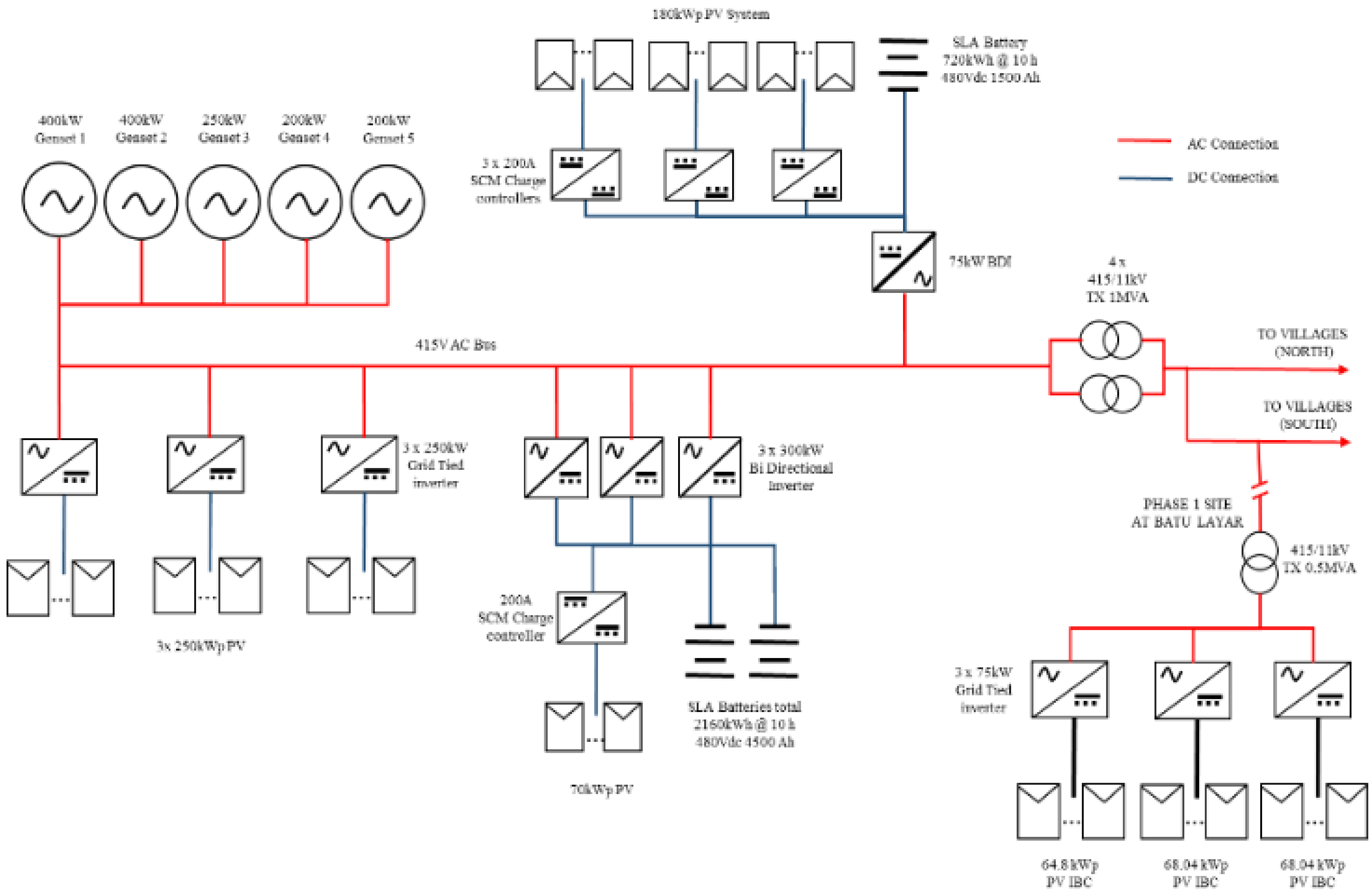
Case Study: Sabah, Malaysia

SESB's PV mini-grid projects

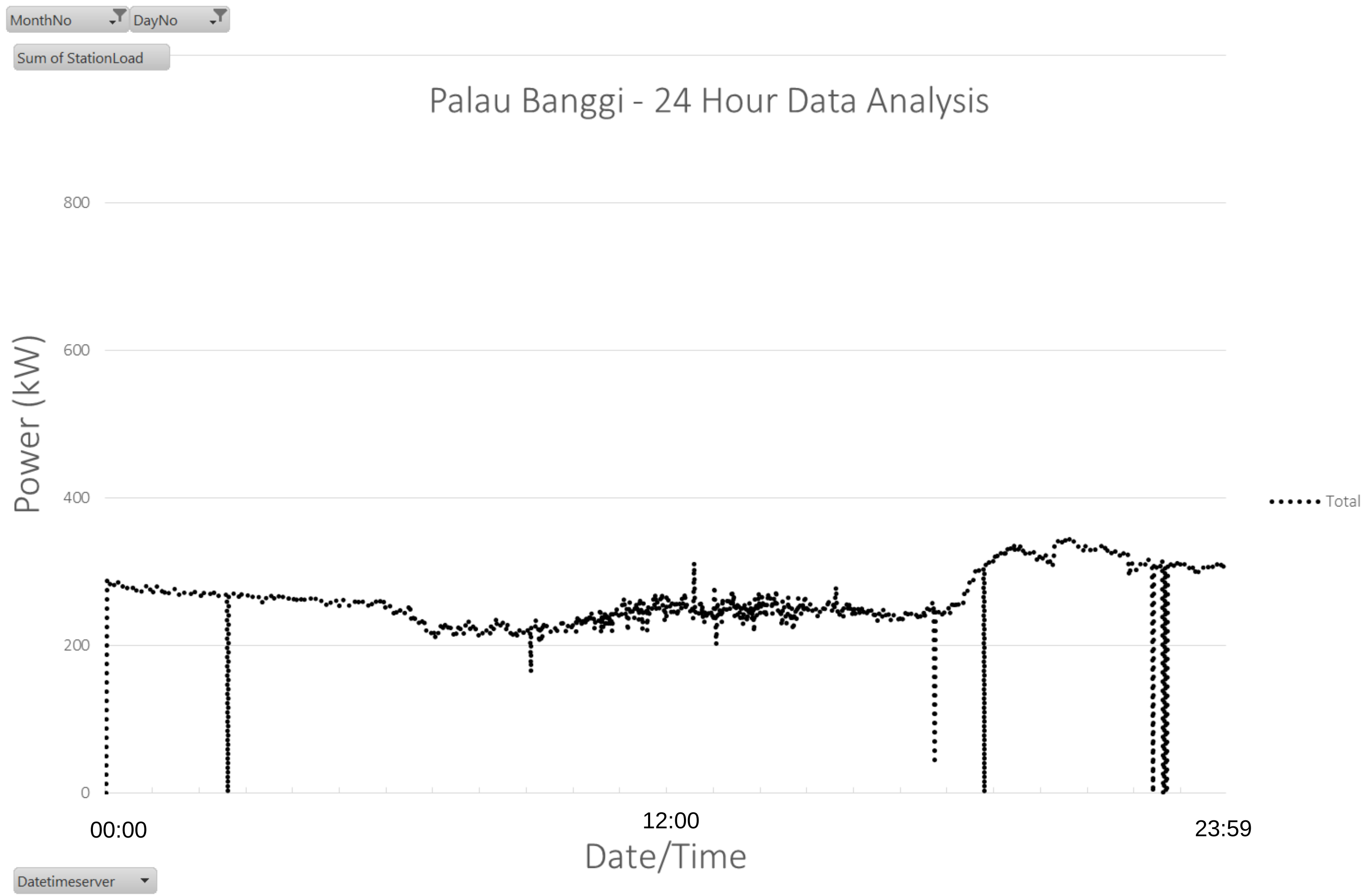
PV Hybrid Station	Connected Households	Hybrid Configuration				
		PV	Controller/Inverter	Disel Genset	Battery Bank	Targeted RE Penetration
		kWp	kW	kW	kWh	RE : Diesel
Kg Monsok Ulu & Tengah, Tambunan	35	15	30	45		70:30
Kg Pegalungan, Nabawan	76	20	45	45	420	70:30
Kg Meligan,Sipitang	140	20	45	45		70:30
Kg Pulau Lubukan, Sandakan	40	12	30	45	288	70:30
Pulau Banggi Fasa 1, Kudat	602	100	200	2x200	720	70:30
Kalabakan, Tawau	654	150	180	2x250	720	30:70
Kg Kuamut Besar, Kinabatangan	270	200	2x100	1x270, 1x350	675	
Kg Kuamut Seberang		20	30	2x60	240	
Kg Tg Batu Darat & Laut,Sandakan	128	200	20	1x270, 1x350	675	
Kg Tundun Bohangin, Kinabatangan	59	144	1x120	1x 60, 1x120	840	70:30
Kg Tidong, Kinabatangan	40	126	1x120	1x90, 1x60	720	70:30
Kg Tambisan Darat & Laut	168	296	2x120	2x180	900	70:30
Pulau Banggi Fasa 2, Kudat	602	1000	3 Bi-Dir. x 300, 3 Grid Con. x 75	2x500	2160	70:30
Pulau-Pulau di Semporna, Sabah (9 SSH/8 Islands/26 villages)	647	1569	2x200, 7x150	4x250, 4x80, 2x200, 2x150	360 - 1200	50:50
Tanjung Labian Fasa 1, Tungku, Lahad Datu	681	1212	4 x 200	2 x 500, 1 x 360	4320	50:50
Tanjung Labian Fasa 2, Tungku, Lahad Datu	101	259	300	2x448	1440	50:50
Kg. Sungai Merah, Tg. Labian, Tungku, Lahad Datu	186	328	792	2 x 300		50:50

Case Study: Sabah, Malaysia

Pulau Banggi – Block Diagram



Case Study: Sabah, Malaysia



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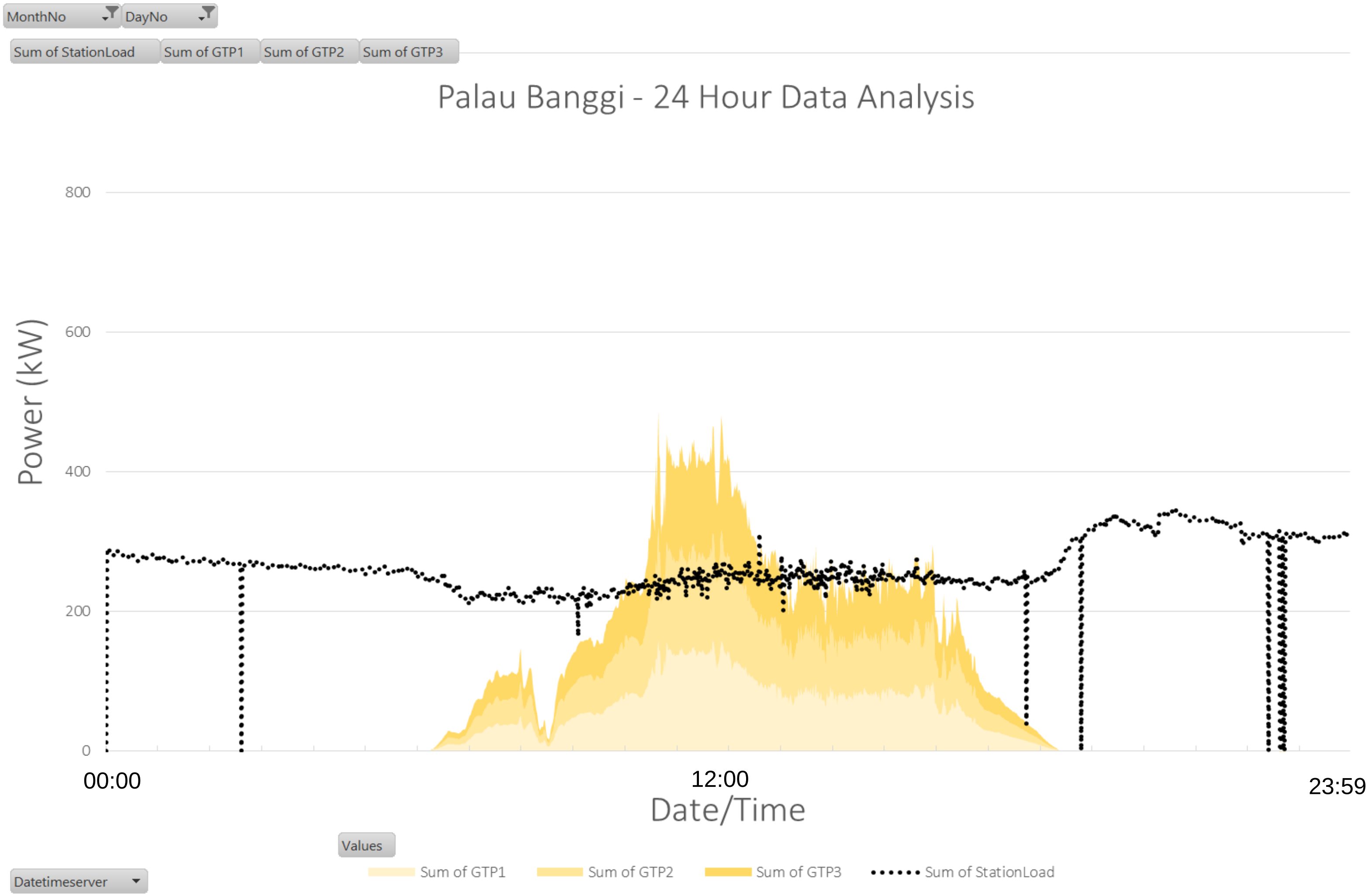

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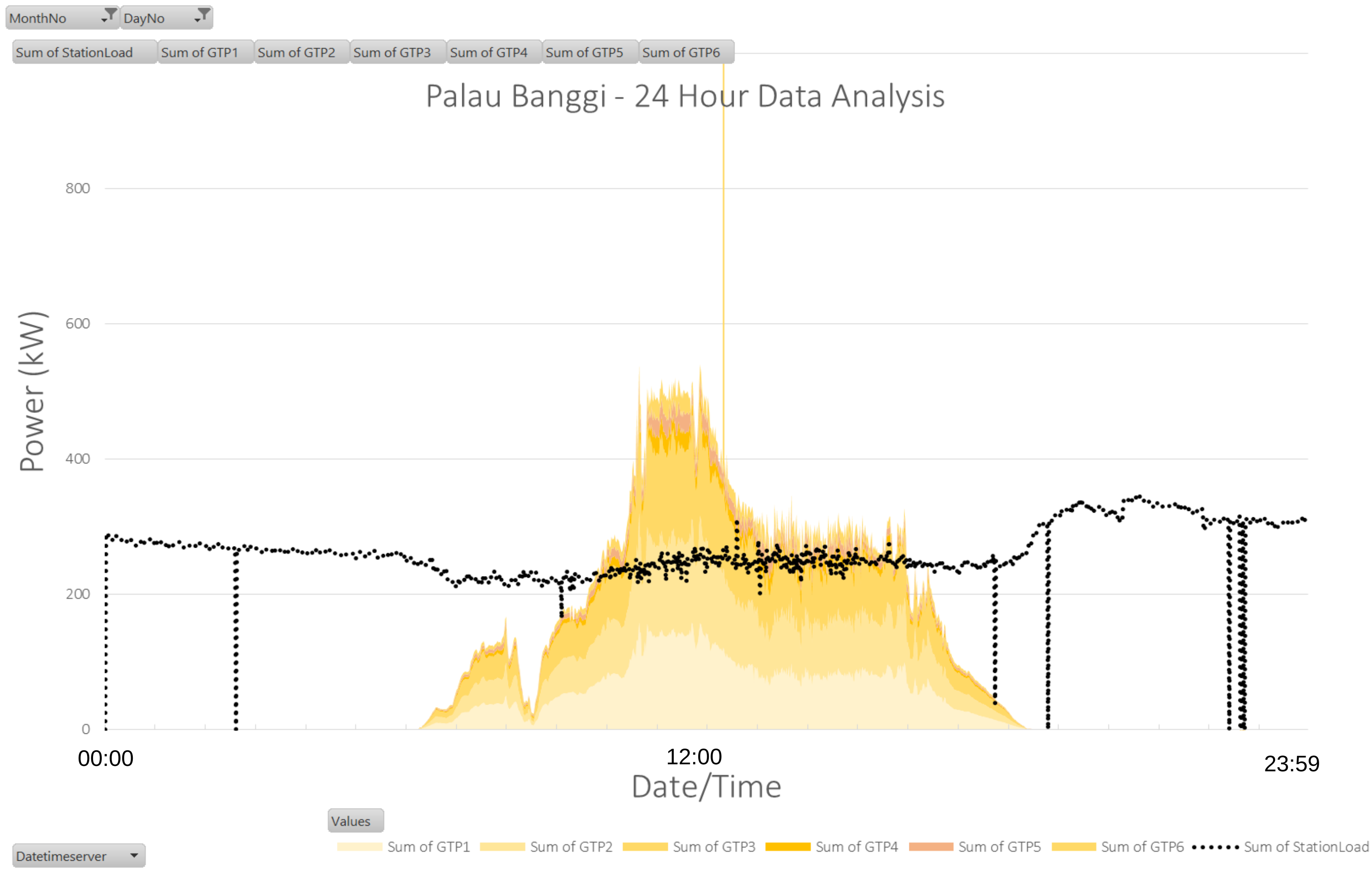
Case Study: Sabah, Malaysia



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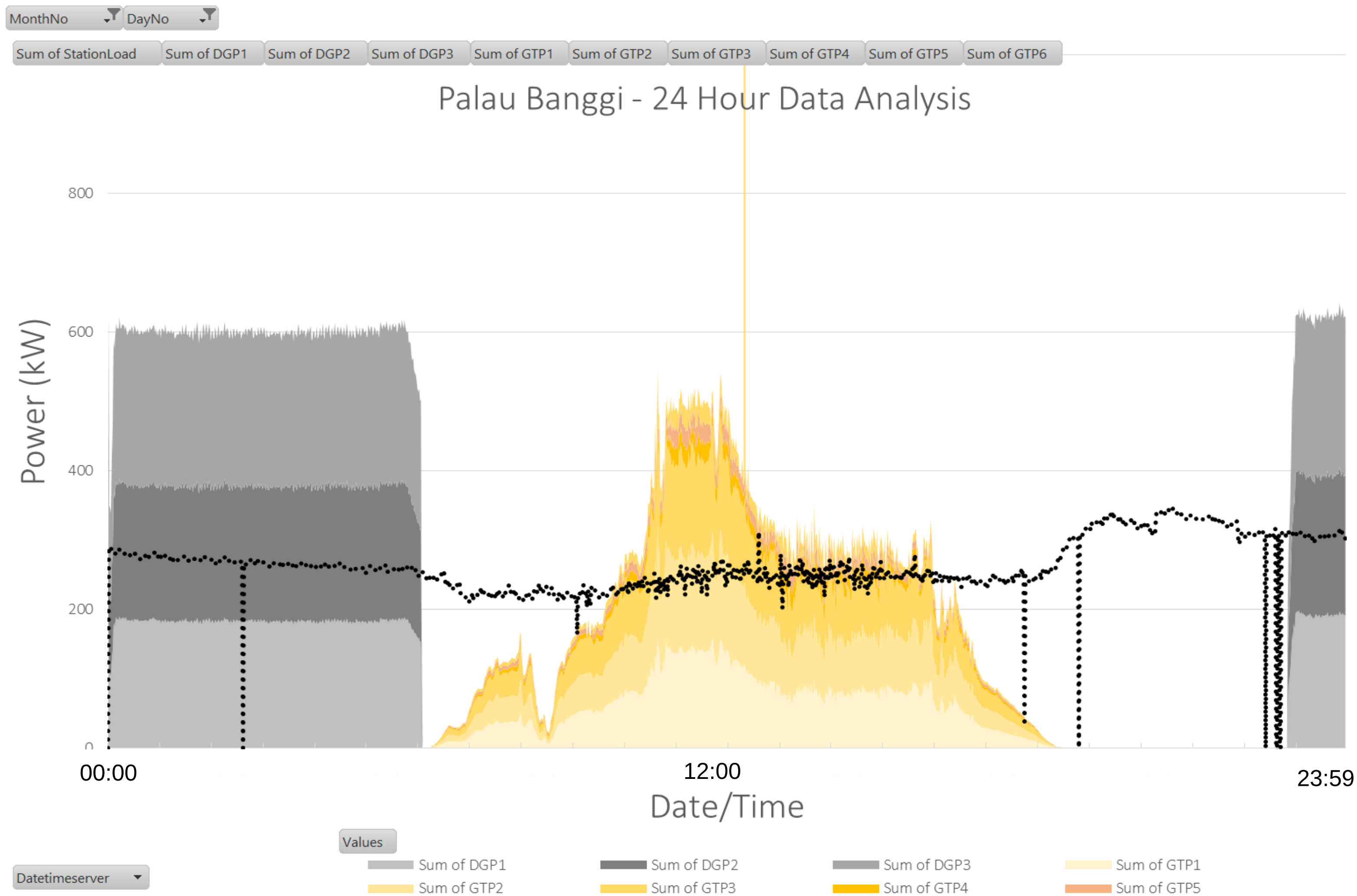
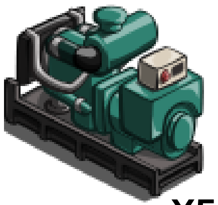
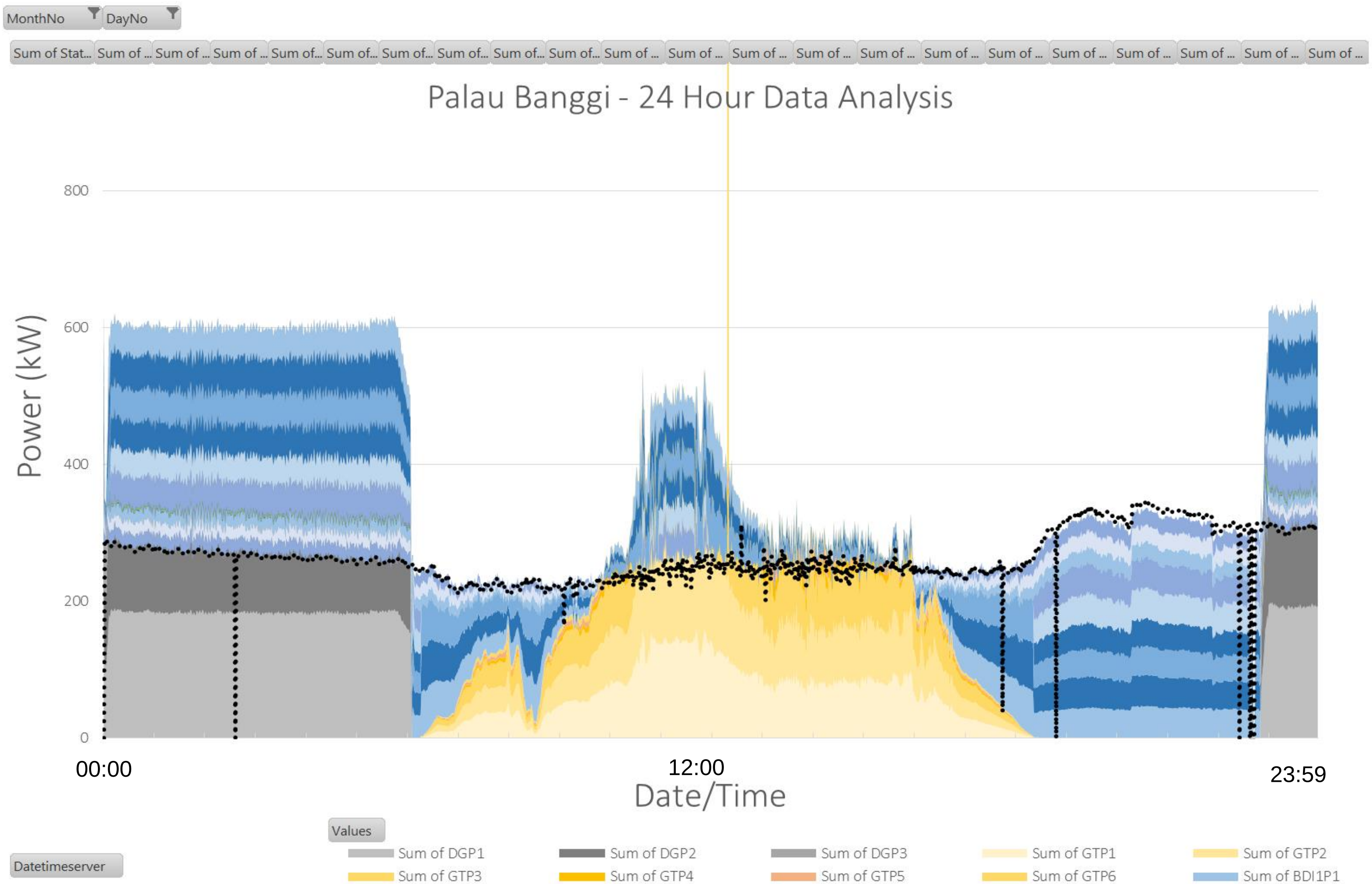




Case Study: Sabah, Malaysia



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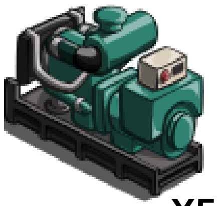

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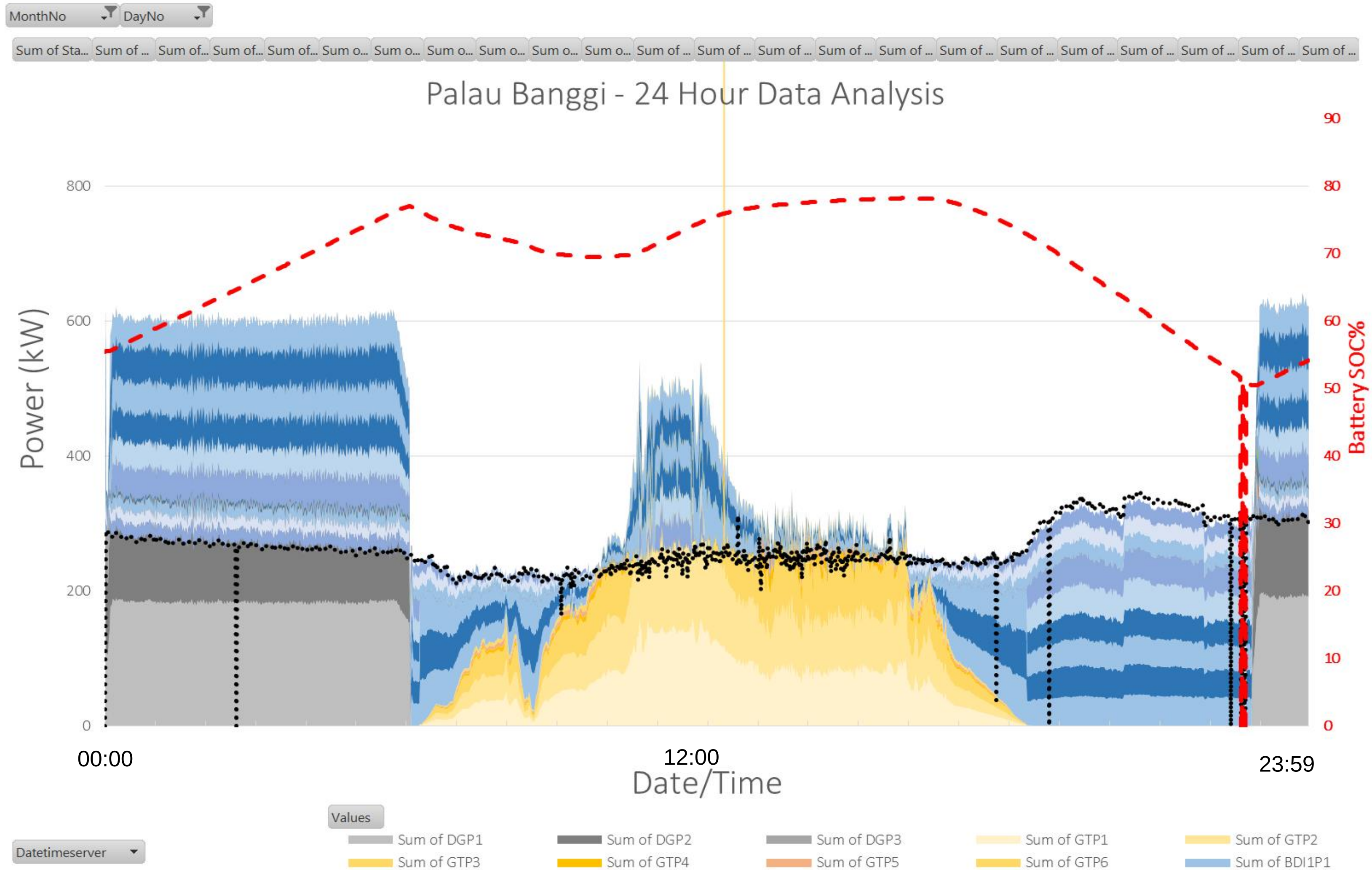
Case Study: Sabah, Malaysia



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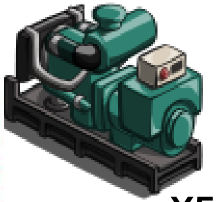

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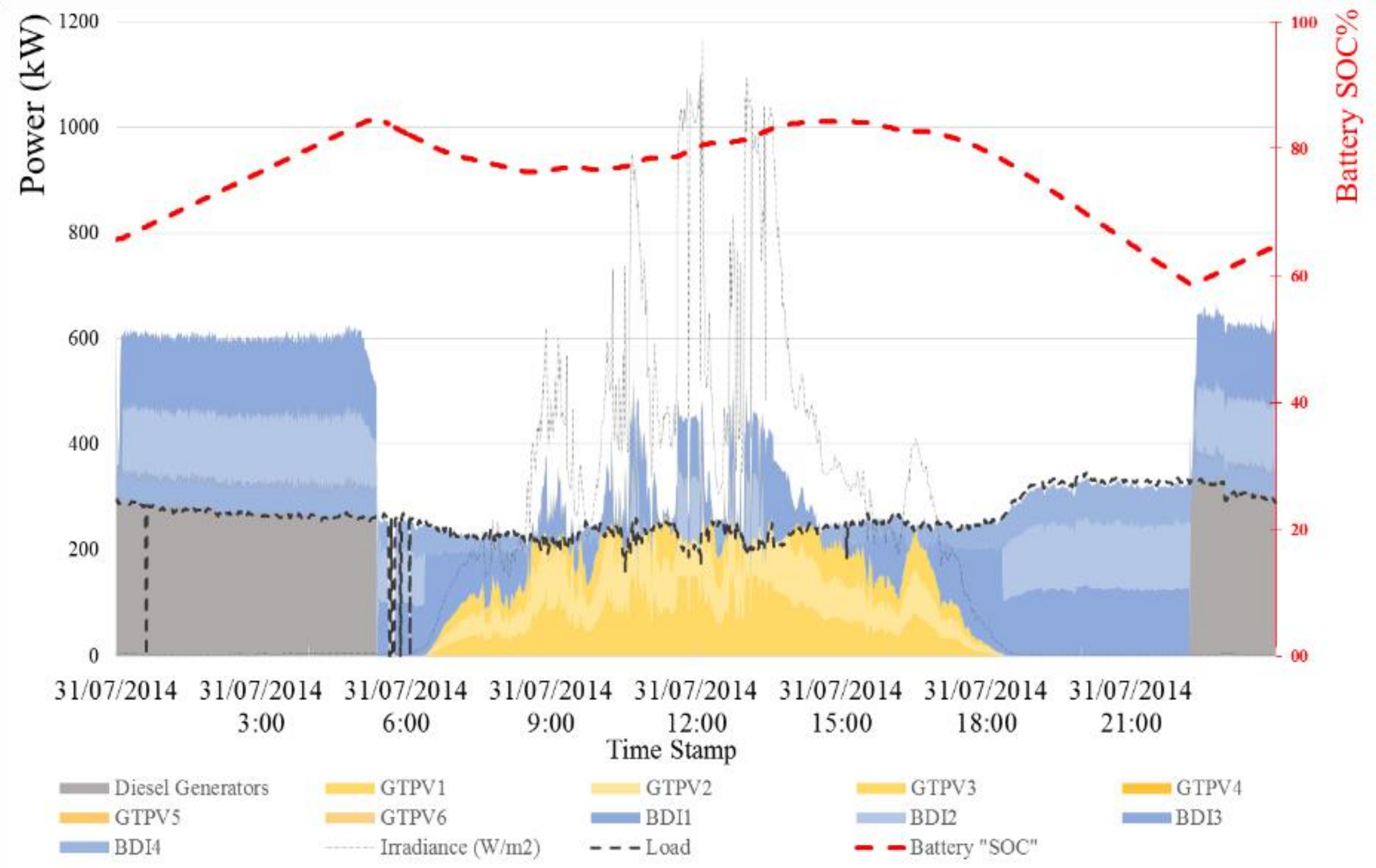
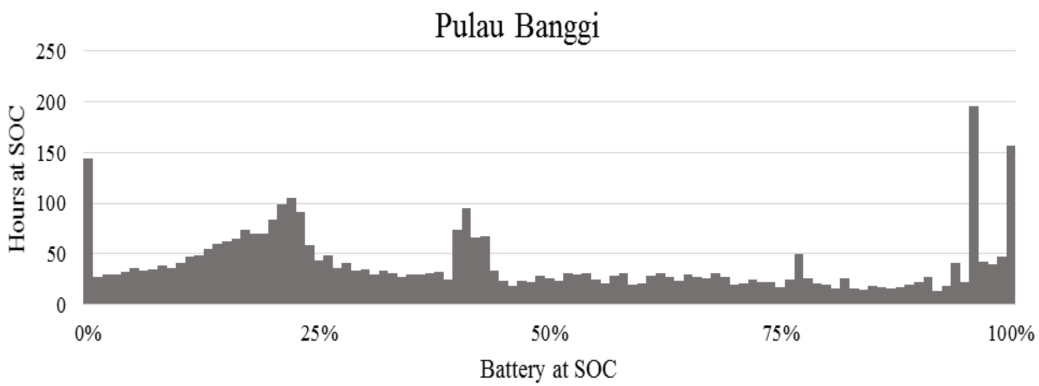
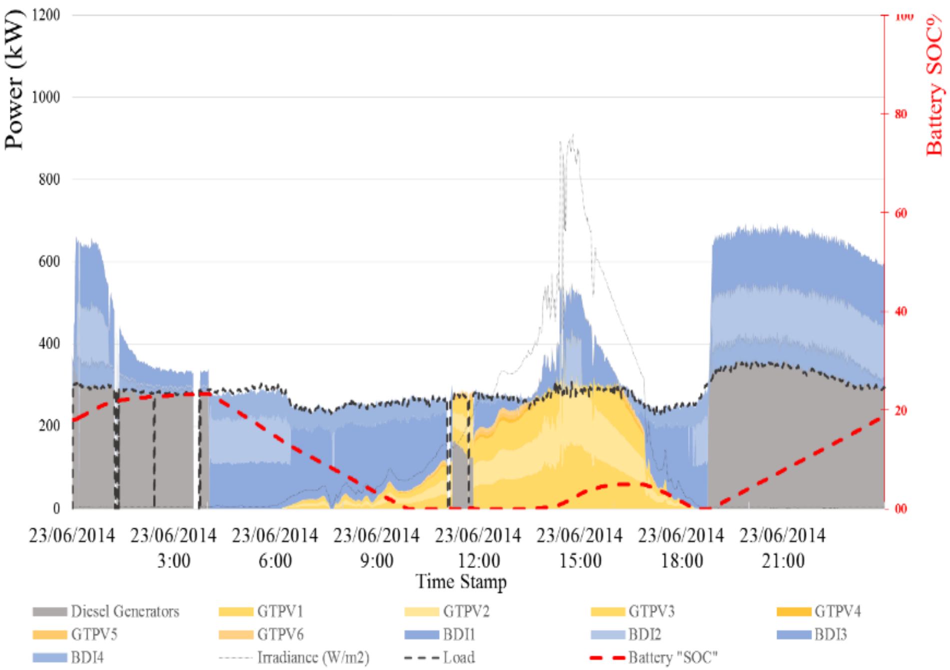
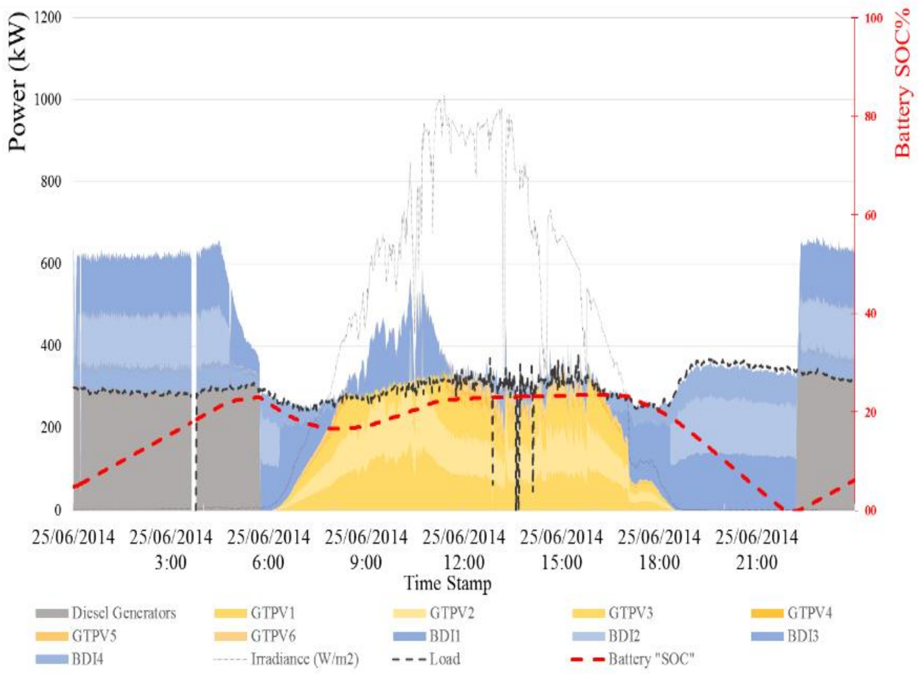


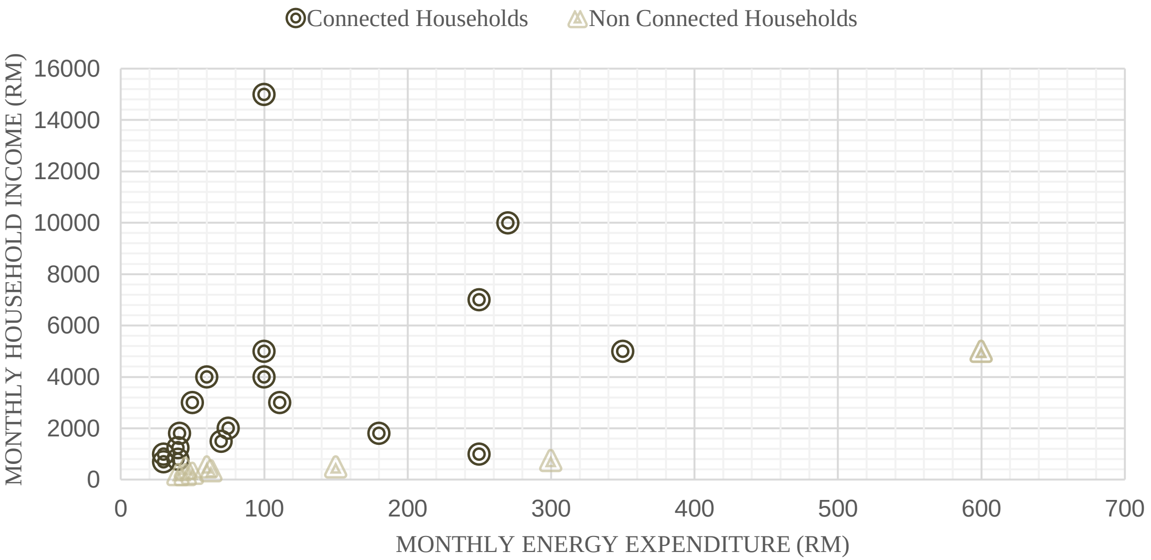
Case Study: Sabah, Malaysia

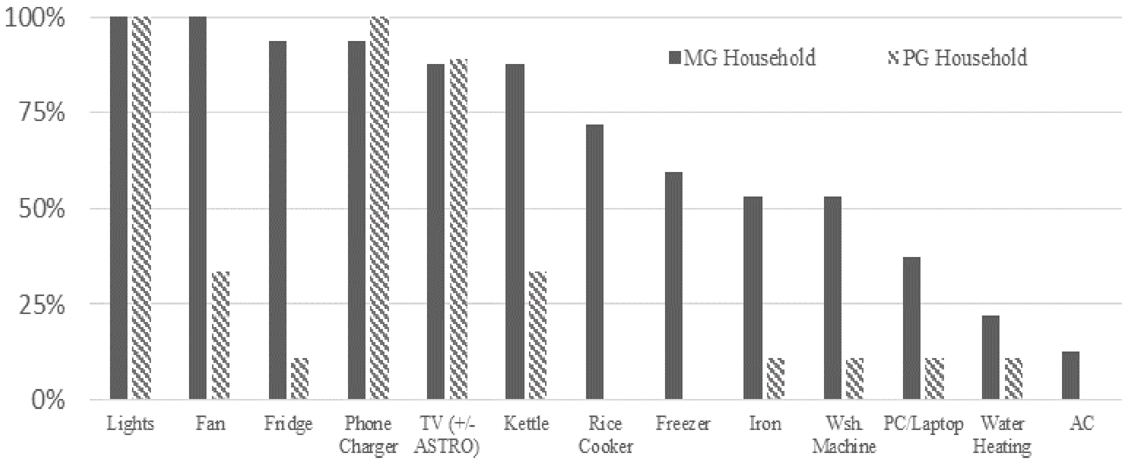






Case Study: Sabah, Malaysia





Sabah – Findings and Discussion

Performance Risk

Summary of Findings:

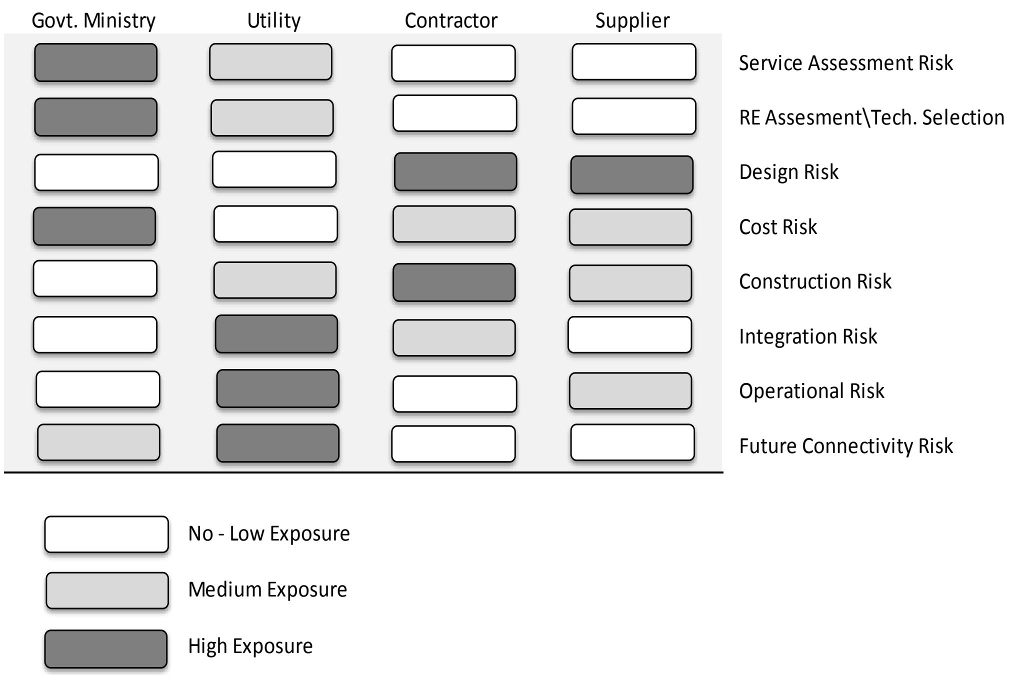
- Performance to the RE fraction design point varied substantially, some underperformed (36.7% vs. targeted 70%) while others outperformed (85.4% vs targeted 70%), but to date these indices aren't monitored or reported.
- Other indicators such as Battery SOC were problematic for the control system to 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

Commercial Risk

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.



Sabah – Findings and Discussion

Programmatic Risk

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

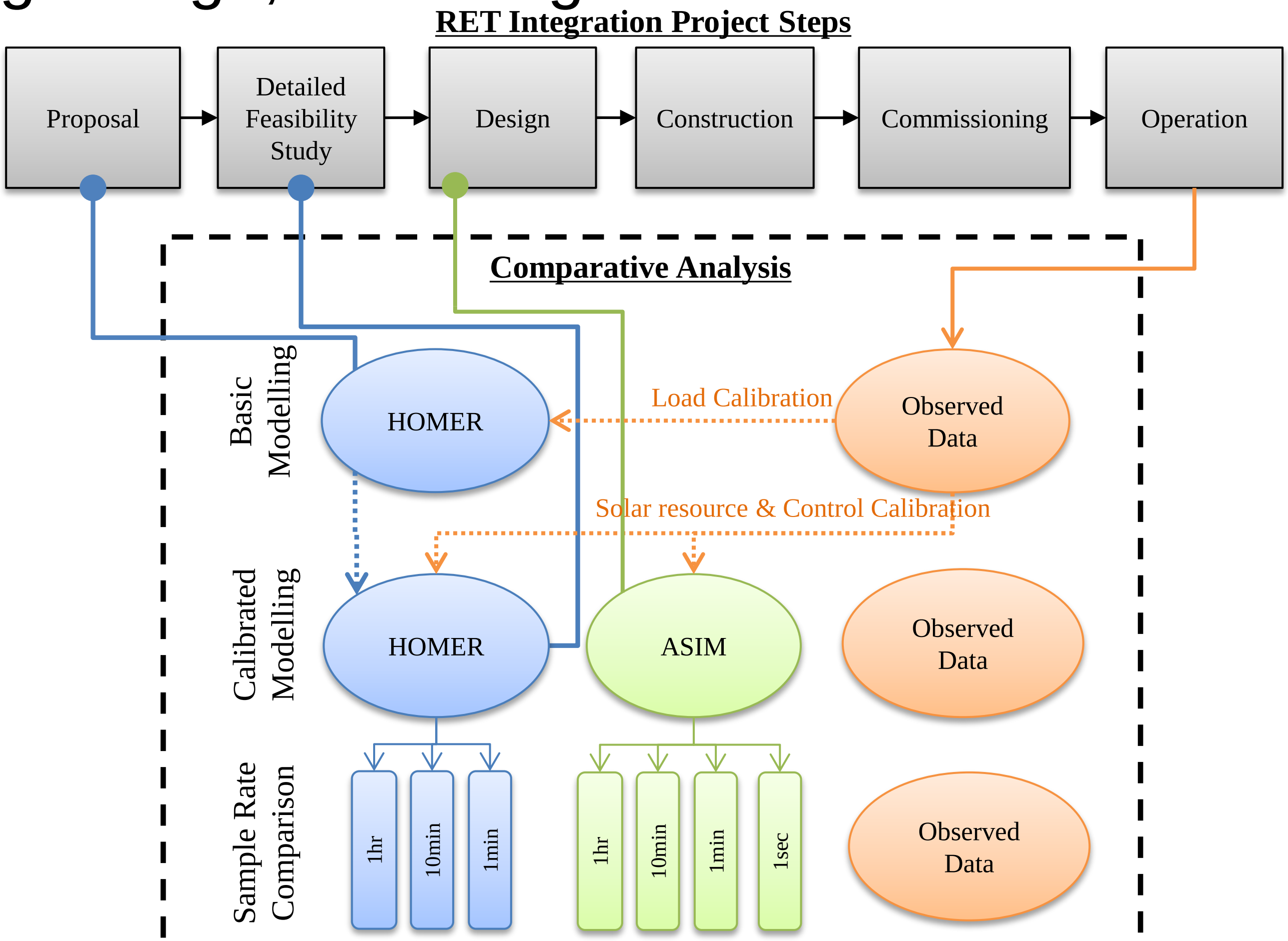
Demand Side	Resource	System Performance
- Annual Demand - Load Profiles - Interday/Timestep Variability - Load Distribution Curves - Load Step Changes - Load Factor (dmd side) - Coincidence/Diversity Factors - Load Growth +/-	- Peak sun Hours - Clearness Index - Hourly Resource Profiles - Probability Of Exceedance	- Annual RE % (kWh) - Annual DG % (kWh) - Peak RE % (kW) - Battery SOC Dist. - Fuel Consumption - Capacity Factor - Normalised PV Yield - Relative PV yield - Run hours/ Starts - Operating Range Distributions - Measured Fuel Curves - Specific Fuel Consumption (FC_{DG}, FC_{sys}, FC_{DPV}) - Ramp Rates (load and PV induced)
Commercial/Contractual	**Programmatic/Service based**	**Economic**
- Time based Availability - Energy based Availability - Take or Pay minimums .. And any of the above system measures.	- New connections - Operating Reserves - SAIDI - SAIFI - Reserve capacity	- LCOE - NPV - IRR (retrofit) - VAR

- Applying Each to the Case Studies

- Reflection on usefulness

- Addressing challenges in application

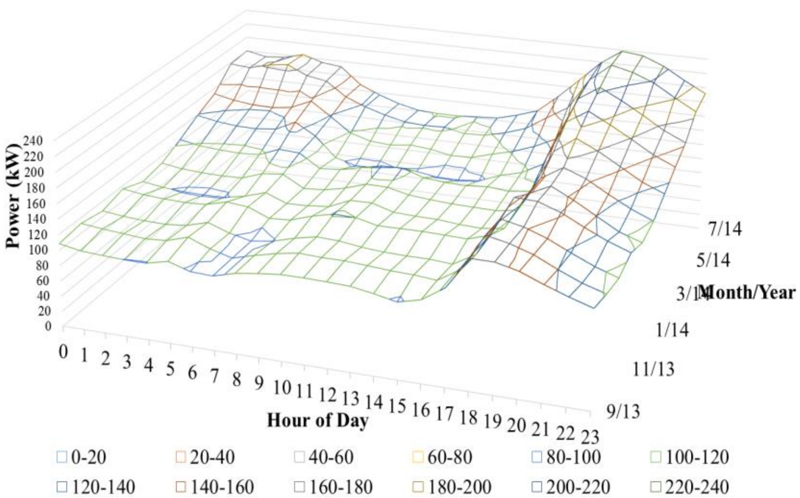
Improving Design, Modelling and Performance Measures

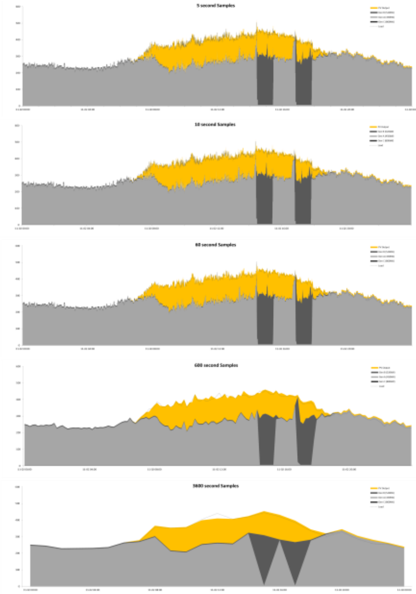


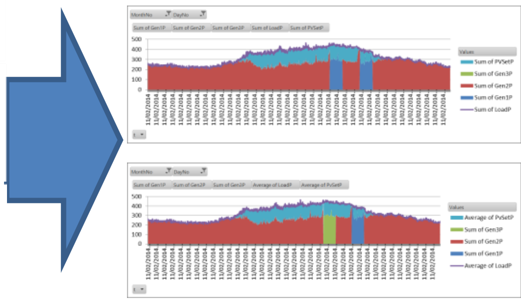
Metrics of Comparison:

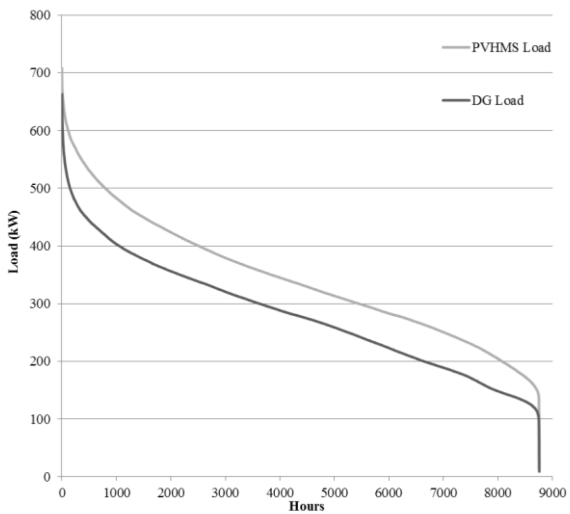
- RE % (Annual kWh and Peak kW)
- Generator Run hours
- Generator Starts
- Generator Operating Ranges
- ~Fuel Reduction (L) compared to Diesel Only Case
- ~NPC ($) and ~LCOE ($)

Improving Design, Modelling and Performance Measures

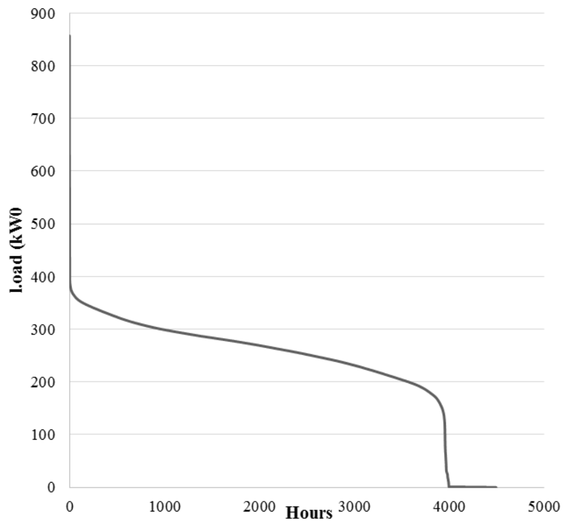




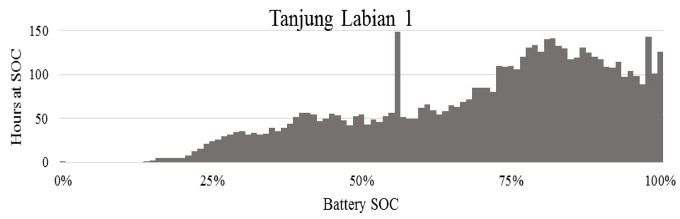


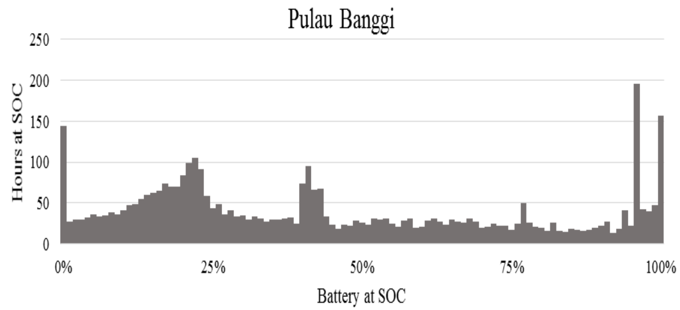


Ti Tree



Pulau Banggi





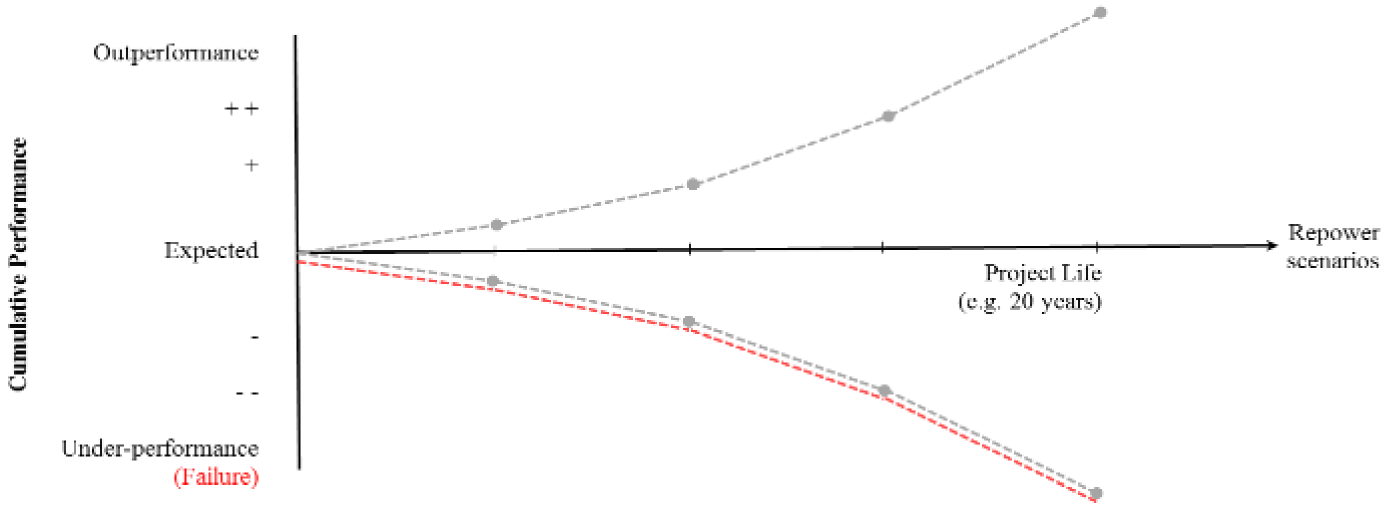
Improving Design, Modelling and Performance Measures

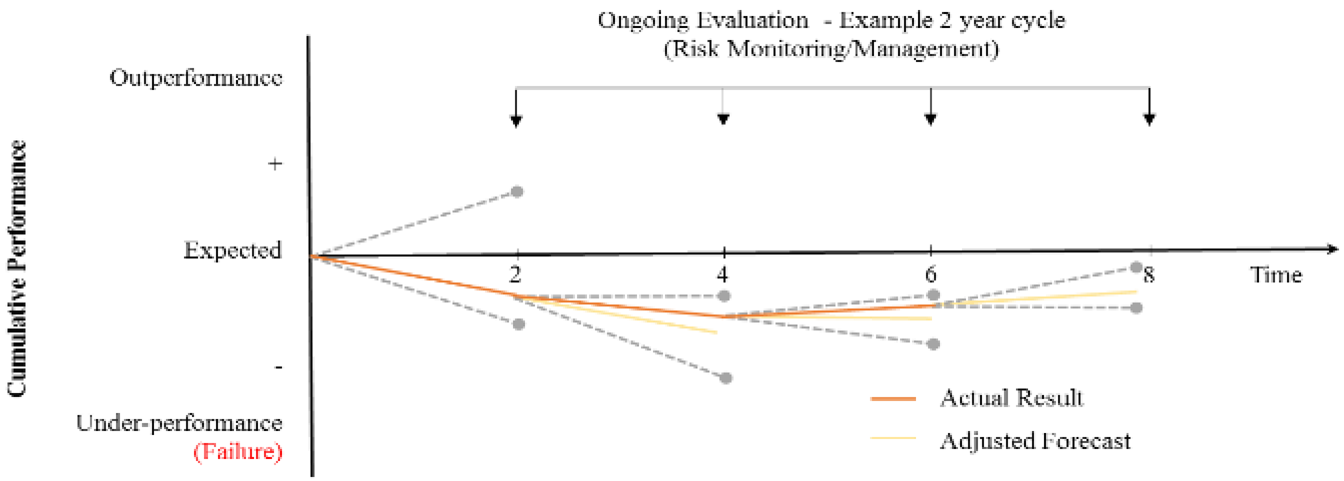
Metric	Ti Tree	Kalkarindji	Pulau Banggi	TL 1
PSH	5.61	5.15	5.14	5.68
PV generation (kWh)	542,000	527,000	~798,000	~1,334,000
PV Capacity (kWp)	324	402	1,130.88	1,223.40
Normalised PV Yield Y_N (kWh/kWp)	1,672	1,310	705	1,090
Total PSH_τ	2048	1882	874	1383
Relative PV Yield (Y_R)	82%	70%	36%	52%
Capacity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

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.

Recommendations





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.

Acknowledgements