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Improving Risk Management for Utility PV-Battery-Diesel Mini-grid Projects in Sabah, Malaysia

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Abstract

This paper examines the deployment of PV-Battery-Diesel hybrid mini-grids for rural electrification in the Malaysian state of Sabah. The region has seen a high uptake of these types of systems through a government sponsored and utility operated electrification program, the primary drivers being improved energy access to remote areas and reducing their diesel fuel dependence. As this undertaking involves the deployment of complex technology in remote, tropical environments, an encompassing risk management framework is described, used to assess the deployment of these systems to date, and make recommendations for improvement. The framework examines risk across three spheres – performance risk, commercial risk and programmatic risk. Within the performance sphere it is evident that while energy services are being effectively delivered by the systems, current deficiencies in monitoring and asset management capabilities are hampering the utility's ability to effectively operate the systems and realise the intended reduction in operating costs. In the commercial sphere, it is apparent that the initial design and construction phase with its high reliance on external contractors raises difficulties as they have only a very limited contractual stake in the ongoing performance of the systems. Finally in the programmatic sphere, evidence points to a lack of regulation and standardisation to effectively govern and control the deployment of these systems, and a tariff setting that makes it impossible to recover costs, so support for these systems will be subject to political will. Despite the challenges identified, the Sabah PV-diesel mini-grid systems are relatively new, and this type of system certainly shows promise for large scale and programmatic application to achieve remote electrification with renewable energy. This work provides recommendations that could help optimize and improve the deployment of these systems, a serious alternative to traditional diesel mini-grids and central grid extension in Sabah and beyond.

1. Introduction

As part of the Sustainable Energy for All (SE4ALL) initiative, the United Nations hopes to achieve both universal energy access and a doubling in the share of renewable energy (RE) in the global energy mix by the year 2024 (International Energy Agency (IEA) and the World Bank, 2015). In achieving these ambitious targets, 'clean energy mini-grids' are expected to play a key role, having been identified as a flagship High Impact Opportunity within the initiative. A RE mini-grid is a standalone local power system that manages local energy supply and demand via a distribution network, powered by RE in combination with other generation sources and storage. It is not a new technology, but has recently captured growing commercial and research interest, as renewable energy becomes increasingly cost effective, and technological advances - such as demand side management, energy efficient appliances, battery storage and smart grid developments - facilitate renewable integration and improve the proposition of decentralised generation more generally. In many remote applications, RE mini-grids are already the most cost-effective electrification option, and can provide a more sustainable and secure energy service than grid extension or diesel only mini-grids (Van Leeuwen, 2013).

In order for mini-grid technology to grow to meet its slated role in the SE4ALL program, private sector investment will be essential. Mini-grids require much larger investments than solar home systems, but still are not large enough, certainly at individual project level, to access conventional large public infrastructure finance. Therefore, a significant barrier to scale up is attracting sufficient investment. Generally, rural electrification and renewable energy are both considered high risk propositions, and the combination of the two are thus far proving unappetising to the private sector and investment community (Waissbein et al., 2013; Bardouille, 2012). Perceived risk is further increased because, despite a growing number of pilot RE mini-grid systems around the world, there remains a lack of data and published experience from operating projects. It is therefore important to examine these operating experiences to better understand RE mini-grid risks, and how these can be mitigated or managed.

In this paper we present a novel risk framework specifically designed for this task, and apply it to assessing risk in a number of utility scale solar mini-grid systems that are currently in operation in Malaysian Borneo. PV-Battery-Diesel mini-grids have been deployed there to deliver high quality electrical energy access at more than 20 remote sites. The systems range in size from less than 100kW to multi-MW generation capacities, and vary in PV penetration, with systems designed to have annualised contributions of between 30 to 70%. This investigation assesses risk by analysing operational data from three sites as well as conducting risk-orientated interviews with project stakeholders. Insights are given into the current risk proposition of this technology and recommendations for how risks might be better managed to attract private interest are provided.

2. Electrification in Malaysia

Malaysia's national electrification rate of 99.3% is extremely high in comparison to targeted SE4ALL efforts in African, other Asian and Island nations (see for instance South Sudan at 5.1%, Papua New Guinea at 18.1% and the Solomon Islands at 22.8%) (World Bank, 2015). However, as shown in Figure 1, the national figure does not reflect the historical contrast in development between the populous Peninsular Malaysia and the Malaysian Borneo states of Sarawak and Sabah. Low economic development in the latter areas has meant that the RE mini-grid projects studied here serve Malaysia's poorest and face common challenges in relation to developing local capacity, logistics in supply and delivery, and ongoing maintenance (see, for instance (Furst, 2010)). As the government targets a uniform electrification rate of 99.9% by 2020, it is expected decentralised energy projects will be further supported, complementing on-grid extension to reach the very remote populations who thus far remain without electricity services.

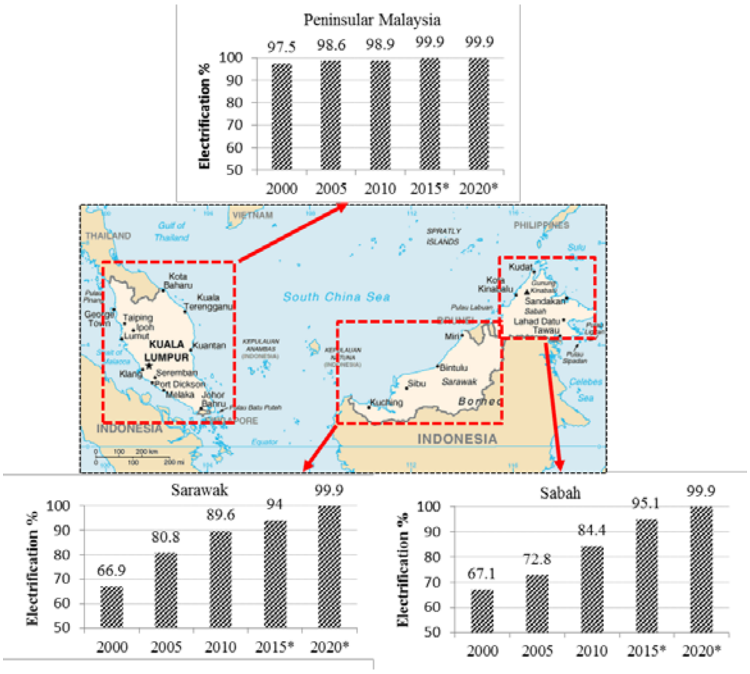

Figure 1 - Rural Electrification Progress and Targets by Region (Source: 2000, 2005, 2010 data (Mekhilef et al., 2012); 2015*, 2020* (Economic Planning Unit, 2015) where * indicates estimates; Map (Wikipedia Commons, n.d.))

Progress in closing the gap has already come a long way and Sabah now has a large number of operating utility and community run RE mini-grid systems which are often overlooked in the global reviews undertaken of this technology - for instance Werner & Breyer, (2012) and Innovation Energie Développement (2012). Nationally the renewable energy sector is maturing quickly due to on-grid FIT measures – and past deployment policy schemes which have provided some lessons for policy design (Sovacool & Drupady, 2011). Sabah provides a case study where the political will, availability of funds and technological capabilities have allowed the pursuit of the RE mini-grid development. It is evident the country has been an emergent leader in pursuing the mini-grid path, and while some barriers have been overcome, current systems and hence possible future developments are also now facing growing challenges. The application of a risk analysis framework presented here can explore the range of issues, from the risk of equipment failure, to the risk of stranded assets in regions where the main grid continues to expand.

3. Research design

3.1. Methodology

This research presented is based on a combination of literature review and interviews, as well as site visits, end user surveys and SCADA data analysis carried out in 2014/2015. The case study method was chosen as there has been a lack of specific evidence and particulars on how renewable energy mini-grids are deployed in Malaysia, and globally very few reports of how these systems operate and perform (also noted by Schnitzer et al., 2014). In the literature review, publications covering rural electrification and mini-grids in Malaysia were identified and reviewed for two purposes: i) to better understand the specific context of rural electrification to inform development of the conceptual framework and ii) to then compile prior studies on mini-grid deployment, and any associated modelling, in Malaysia. As mini-grid research is expanding quickly, international summary reports were also included as they often cover a broader range of issues than academic publications alone. Also, in two instances, the UNF (Schnitzer et al., 2014) and IEA PVPS (Jacquin et al., 2011), the work resulted in some specific case studies and lessons on Malaysia which were valuable contributions.

Interviews were conducted with 30 stakeholders, selected due to their involvement in rural electrification, renewable energy or mini-grid deployment specifically. These interviews included stakeholders from government, utility, industry and NGOs. Not all respondents had detailed knowledge of the projects; they were, instead, involved in facilitating processes such as policy development and implementation, and supply chain links. Multi-stakeholder interview design was based on process and recommendations from Painuly's (2001) interviews on a related topic of barriers to Renewable Energy integration. To accommodate the differing tiers of involvement, two different interviews focussing on different issues were developed. 'High level' interviews were used to garner the organisations' involvement and perception of deployment risks. 'Developer Specific' interviews were undertaken for stakeholders who had good working knowledge of the projects, and in some form had had exposure to project risks. The results of the high level and developer specific interviews are used to describe the deployment models in the paper, while inductive methods were further used by the investigators to establish perceptions of risks and benefits of deployment. Furthermore, surveys were conducted with the end user in order to understand levels of service delivery and their overall satisfaction.

3.2. Risk and the Assessment Framework

In its broadest sense, risk can be is defined as "an undesirable implication of uncertainty" (Chapman & Cooper, 1983). The consideration of risk is vital part of any decision making, and increasingly society has sought to understand the occurrence and consequence of risks, in the hope of being able to better manage uncertainty. In this work, we define risk to be *uncertainty that impacts RE mini-grid program outcomes in a positive or negative way*. Inclusion of positive impacts may seem at odds with the common understanding of risk but is done so deliberately to represent uncertainty in its fullest sense. While the definition is broad enough to encompass the host of issues that will affect projects, admittedly it is also unwieldly. In order best explore the risks associated with the projects, we introduce a conceptual framework based on this definition, with which we can present and analyse the interactions of a tiered risk analysis structure.

Bhattacharyya & Dey (2007) noted that there were few existing applications of risk management in the rural electrification literature, and developed a framework to explore an ambitious electrification program India was undertaking nationally at the time. They noted that project management's risk paradigm provides a good analytical framework to deal with complexities. For the proposed model in India they analysed risk across three levels – national, state and site - through the familiar modes of risk *identification*, risk *mapping* and risk *mitigation* using secondary sources and a specialist survey.

Resulting from an initial literature review of the risks associated with RE mini-grid deployment, a multi-tiered risk typology framework was previously presented by the authors in (Hazelton et al., 2014). While this preliminary framework can help categorise and appropriately identify where risk management opportunities exist – at site, state and national levels – it can now be improved to capture the interactions between stakeholders. This is important as risk mitigation often depends on the extent to which risk is transferred between or retained by stakeholders. Considering rural electrification as a project rather than program was also seen as a limitation of the previous framework, as it does not reflect the ongoing nature of energy service delivery, or the implications of scale or programmatic learning. The preliminary framework has therefore been improved, by using a similar three tiered risk categorisation, but highlighting stakeholder interaction (influence) and taking a programmatic view of project risks, as shown in Figure 2 below.

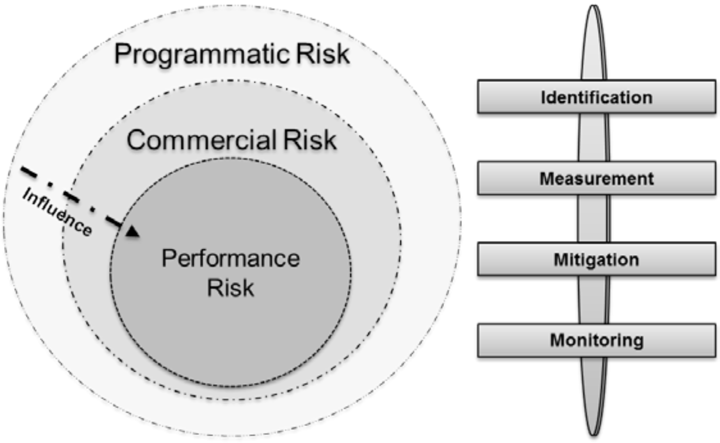

Figure 2 – Chosen Risk Analysis Framework for RE mini-grid technology in rural electrification (based on (Prengel, 2004; Bhattacharyya & Dey, 2007)

In the inner-most sphere, *Performance Risk* relates to the variation of system operation from the expected. In the case of RE mini-grids the key indicators used are reliability and financial viability. These indicators of success were proposed by Schnitzer et al. (2014), as the critical factors for project sustainability, based on observations of virtuous and vicious cycles. *Commercial Risk* relates to uncertainty in terms of the delegation of particular risks as well as commercial influences affecting the financial viability of the mini-grid system. *Programmatic Risk* relates to the legal, regulatory and political influences that will affect the programs. For each layer it is necessary to apply a traditional risk management lens – Identification, Measurement, Mitigation and Monitoring.

4. Deployment and Status of Mini-grids in Sabah

The research identified three delivery models used for RE mini-grid systems in Sabah. While this paper focuses on the utility electrification program, further information about the deployment of small scale school systems and a community micro hydro are also available in the literature (Mahmud, 2011; National Audit Department Malaysia, 2012; Schnitzer et al., 2014).

4.1. Deployment within the BELB/Utility Electrification Programs

Under the Rural Electrification Program - Bekalan Elektrik Luar Bandar (BELB) - the process of site selection is carried out by Ministry of Rural and Regional Development (KKLW) on the basis of community applications. The criterion for mini-grid selection is firstly based on planned grid extensions – a PV/diesel mini-grid will be targeted if the communities will not be connected within seven years by a conventional grid. KKLW will then visit the community to count the number of houses that can be connected, and then estimate the load by multiplying the houses by 8kWh/day (it was apparent that the responsibility for load estimation is often out sourced to the contractor). KKLW also dictate the guidelines as to the renewable energy percentage[1] such as 70% PV/battery to 30% diesel, or 50% PV/battery to 50% diesel, depending on the site. This decision is based on the remoteness of the site, with the objective to reduce diesel dependence to the most remote places where ongoing fuel delivery is expensive and logistically challenging. While, formally, the utility Sabah Electricity Sdn Bhd (SESB) should be engaged during these initial design points, interviews with stakeholders highlighted that this is commonly not the case. Once the major design points are settled – i.e. the load and the renewable fraction – KKLW pass this information into a tender process or direct negotiations with a suitable company. The contractor essentially operates as a project manager and subcontracts out work into typically three subcontractor categories – Civil works, Mechanical and Electrical, and the Solar/Battery system designer.

SESB will give some feedback in term of design and requirements. KKLW will appoint a contractor to model and design the system and undertake it's construction and commissioning, and the contractor will appoint a Civil and Structure (C&S) and Mechanical and Electrical (M&E) consultant. The consultant will submit the design to SESB. SESB are only responsible on material specification and building design, while KKLW are responsible for approving the RE System design.

The system is then constructed by the third party and their subcontractors (typically over one to two years) appointed by KKLW, and the final commissioning work is supervised by SESB/KKLW, to confirm that the site system operates as expected.

The Site is operated by SESB, but under a full subcontractor warranty for any breakdown in the first two years. After that time, full maintenance responsibility is transferred to SESB, which will look after the site until decommissioning, or ideally integration with their grid connected networks. There is a design warranty offered by the contractor, however, this only covers issues relating to the primary design criteria so are unlikely to be cause for retroactive claims. Figure 3 summarises these complex arrangements between participants. Tariffs, equal to that in the grid connected towns of Sabah, are collected by SESB usually in person by officers of SESB.

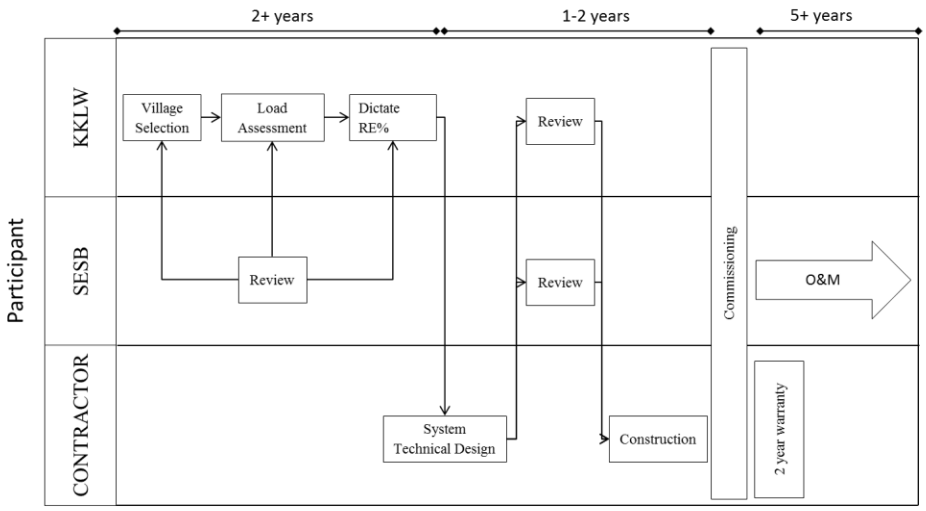

Figure 3 – Deployment responsibilities in PV-Diesel mini-grid roll out

[1] Renewable energy percentage in this case refers to the annual energy contribution in Wh terms, i.e. for a 70% RE to 30% Diesel system, 70% of the annual MWh comes from Renewable Energy (PV) and 30% comes from Diesel.

4.2. Current status and operation

Information regarding the current status of BELB systems was collected for this study from SESB internal documentation and confirmed by KKLW. There have been, in total, 24 mini-grids deployed through the BELB, some funded directly by KKLW (budget allocation from the ministry of finance), and others funded by a trust fund set up from operating profits of the on-grid utility businesses (with the majority of money coming from Peninsular Malaysia electricity customers).

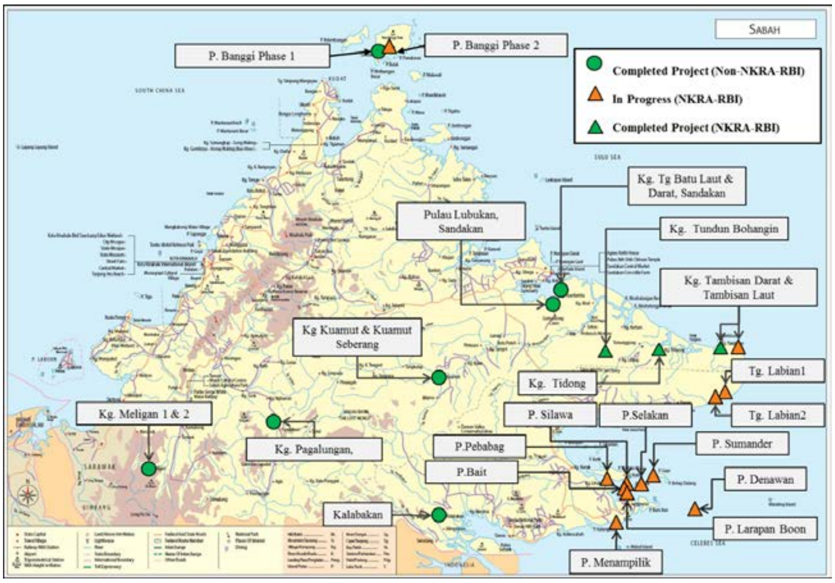

Figure 4 - PV Hybrid Installations under the BELB program in Sabah(Combined from SESB (2014) and Govt. Map (Malaysia Travel Guide, 2015))

Table 1- Installed Systems, Households Served and Component Configurations

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

5. Risk Management and Recommendations

This section summarizes some of the key findings of the research, using the framework as previously defined.

5.1. Performance Risk

It was evident from the field visits how little performance monitoring currently takes place and this indicates a capacity gap in managing and improving performance. Throughout the research there was difficulty accessing operational data from the projects because there is no regular monitoring or analysis undertaken by SESB. The systems were originally designed to have a web interface accessible to monitor and download operational data, but this was out of service due to satellite problems at each of the three sites visited. At Pulau Banggi the site operated 24/7 by a rotating roster of staff members so failures could be reset and addressed with relatively short downtime. At Tanjung Labian there was no locally based staff so technicians would have to be notified of the outage by end users and then dispatched from Lahad Datu. This of course resulted in significantly more delay in resuming supply.

SCADA Data was able to be collected first hand from servers on site, and there was evidence of some data loss due to limited storage on the server and no regimented data warehousing. In terms of reliability, the systems had high levels of user satisfaction (85%), outages were reported as uncommon and there was generally less than 1 significant black out per week according to the available data.

Financial viability was defined as one of the key success indicators of performance, with one of the major objectives of the systems being to save fuel. Detailed cost data was not available at the time of the research, although modelling based on available information will be presented in future work to fully assess the financial viability. In relation to the tracking of diesel savings, it was noted that it was difficult to benchmark given load growth due to expanding energy access, and the imperfect quantification of diesel consumption. SESB can only track usage by keeping count of the complete refill of diesel tanks on the island. This had only happened once at the time of the site visit, which means sufficient data had not been gathered to understand the savings.

From the available SCADA data, the design point of 70% RE to 30% diesel was not met at Pulau Banggi (36.7% RE to 63.3% Diesel was achieved), due to low solar yield and non-optimal control system constraints. Battery State Of Charge (SOC) readings were shown to be consistently inaccurate, which impacted the control system by frequently running the diesels to charge the batteries overnight, forgoing solar in the daytime. RE penetration did, however, exceed the 70% target at Tanjung Labian 1, reaching 85.4% for the 11 months with which data was available. This is in part due to localised conflict driving down demand and growth in the area. This was reported as an exceptional case, as substantial demand growth was regularly witnessed elsewhere.

At the needs assessment phase, load growth seems to be the single biggest design challenge in regard to rural electrification, for mini-grids both in Sabah and globally (Hazelton et al., 2014). The current static approach used by KKLW has on multiple occasions led to design objectives not being met. There are evident opportunities to improve the methodology applied by KKLW, or alternatively, for better management of community loads or direct load limiting. Risks related to load growth have been less significant, and hence received less attention for traditional diesel only systems as they are relatively easily upgradable, increasing capacity with larger or multiple gensets, although importantly the battery will experience increased cycling frequency of discharge levels.

5.2. Commercial Risk

Mapping of risk exposure for mini-grids was developed based on similar work from Prengel (2004) on renewable energy CDM project risk, and discussed and modified following feedback from the survey participants (Figure 5).

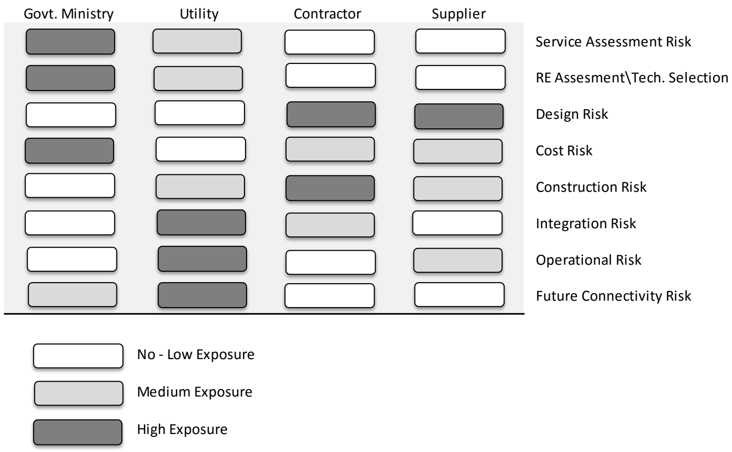

Figure 5 – Distribution of Risk (adapted from Prengel, based upon interviews)

It is evident from Figure 5 that with short warranty periods, operational risks are borne largely by the government and utility. As noted previously, involvement of the eventual owner/operator SESB was low through the design and construction phases. This resulted in a deficiency in engagement at handover and documentation processes, making the utility dependent on ongoing contractor support out of warranty. While the contractor staff were skilled system operators and well placed to collect failure information and troubleshoot problems, they would invariably leave the community after commissioning, and a village chief expressed his dissatisfaction with the training of the local SESB staff. While the exact contractual setup was commercial in confidence, the value of the five year design warranty is questionable, given the design criteria are proposed by KKLW, and then the accepted tender signed off by KKLW. It seems unlikely that a claim on these design warranties would be undertaken.

5.3. Programmatic Risk

With the majority of interviewed stakeholders, discussions on programmatic risk focused on the tariff structure, which is viewed as an unsustainable subsidy of energy costs for consumers. This is the case in Sabah state-wide, for on-grid systems as well as off grid. For off grid systems the cost of generation is higher however, so the subsidy required to reach an even state wide tariff is larger (Suruhanjaya Tenaga, 2014).

There might be a case for raising the tariff to improve service provision. 40% of end user respondents expressed willingness to pay more if service could be improved. The prevalence of personal generators in off-grid sites also indicates willingness to pay more for reliability. Ongoing support for capex intensive RE projects will depend not on a sustainable business case but the political will to increase RE share, which is not currently on a firm footing. The current Economic Planning Unit (EPU) plan to reach 99.9% electrification may help contribute to this goal, as it flags a decentralized approach, but this competes with other priorities, such as higher SAIDI and SAIFI value for on-grid supply. There is also the programmatic risk of central grid extension to decentralised sites– at which point there is interconnection of the mini-grid systems to the national grid, and the risk of stranded assets – this scenario has already affected one of the systems in central Sabah where the PV hybrid system was actually decommissioned.

It was also evident from utility interviews that there are few regulations and lack of standards for this scale of system – this regulatory role could well be filled by SEDA and the MPVIA, but their concerns have been traditionally peninsular based and focusing on the introduction of the on-grid FIT program.

6. Conclusion

RE mini-grids are set to play a large role in delivering energy access to the world's rural communities, and service delivery in Malaysia has shown that wide scale deployment is possible. In this work, an improved framework was used as a lens to assess risk in Malaysian mini grid programs across programmatic, commercial and performance spheres. Within the performance sphere it is important that operators are able to effectively monitor, operate and understand the technology in order to realize the intended reduced operating costs. In the commercial sphere it is apparent that in the Malaysian case study, the initial design and construction phase has a high dependence on the contractor, who contractual has minimal stake on the ongoing performance of the system. Finally in the programmatic sphere, evidence points to a lack of regulation and standardization to effectively govern and control the deployment of these systems, and a tariff setting that makes it impossible to recover costs, so that support for these systems are at risk of changing political priorities. While the Malaysian mini grid systems are relatively new, the technology has shown promise for large scale and programmatic remote electrification with renewable energy. This work points to recommendations that could help optimise and improve the ability for these systems to be prove themselves as a serious alternative to traditional diesel mini-grids and central grid extension.

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