COST-BENEFIT ASSESSMENT FRAMEWORK FOR PV MINI-GRIDS

Mikaila Thwaites[1], Michael Tuckwell[1], Lyndon Frearson[1], Paul Rodden[1], Anna Bruce[2]

[1] CAT Projects, South Stuart Highway, PO Box 8044, Alice Springs NT 0871, Australia; Phone: +61 (0)8 8959 6240; Email: mikaila.thwaites@catprojects.com.au
[2] The University of New South Wales, Sydney, Australia

ABSTRACT: The primary goal of this research is to better understand the cost structures of delivering Renewable Energy (RE) based mini-grid projects. The research has revealed a significant lack of clarity and consistency in the RE mini-grid cost literature, and a lack of appreciation of the impact that delivery mechanisms, service outcomes and other technical aspects have on costs.

The RE mini-grid sector is growing and attracting interest from public and private sector investors. However, the ability of investors and other key decision makers to evaluate proposals is limited by this lack of consistency in the presentation of mini-grid project costs, and by insufficient qualifying details provided. With many investors new to the sector, this obscurity results in slow approval processes and high risk premiums, stymying the sector's further development.

It is proposed that a standardised framework for presenting and qualifying costs of RE mini-grids will address this critical issue. The framework would include a standardised set of cost heads, and set of required qualifying information.

This paper proposes as an example, a preliminary cost framework for PV based mini-grids. A literature review and case studies are provided to support the proposition of the need for and usefulness of the framework.

Keywords: Developing Countries, Mini-grid, Economic Analysis, PV System, Energy Access, Villages

1 INTRODUCTION

A Renewable Energy (RE) mini-grid comprises one or multiple RE generators connected to an independent low-voltage Alternating Current (AC) Power Distribution Network (PDN), distributing electricity to a localized community. RE mini-grids are generally installed with either fossil fuel generators or battery storage to provide power when RE resource is not available. This paper focuses on Photovoltaic (PV) mini-grids with battery storage and the potential for diesel generator back-up.

Systems described as mini-grids in the literature vary considerably in terms of service model deployed, with models ranging from pure 'substitution' systems[1], which provided basic lighting services as a replacement to existing lower quality energy services, to 'surplus' models that provide additional energy for productive end uses (existing and potential). Delivery mechanisms can also vary considerably; systems may be owned and managed by the community, by utilities, by private entities [1]; systems may be installed as isolated, one-off projects while others are designed and installed as part of larger delivery programs with attributable cost sharing and cost savings [2] [3].

These variables and more have a significant impact on cost and the service outcomes delivered to customers, which is not adequately defined by industry or captured in publically available literature. The cost of implementing mini-grids is often estimated using benchmark dollar per watt peak ($/Wp) figures, and the benefits of mini-grids are generally compared in relation to their levelised cost of electricity (LCOE) or dollar per kilowatt-hour ($/kWh) cost. These simple cost metrics are insufficient for capturing and comparing the relative costs and benefits of different options and the many variables that affect these. Further, there is considerable obscurity and inconsistency in the literature in relation to the cost components that are included in $/Wp and $/kWh calculations. Some cost sets include only key hardware items [4] [5] [6] while others include all hardware and engineering costs [7], and in some cases it is not clear what is included [8] [9].

This lack of consistency in cost presentation, and insufficiency in details provided of the service model, delivery mechanism and technical parameters adopted limits the ability of investors and other key decision makers to impartially evaluate apparently competing models (of both technologies and delivery models). With most banks and other private investors still new to this sector, this obscurity inevitably results in difficulties in finding willing investors, slow approval processes and high risk premiums, stymying the sector's further growth.

It is proposed that a standardised framework for presenting and qualifying all costs associated with mini-grids is required to address this critical issue. This cost framework would be used by project developers to ensure that all costs and relevant project characteristics are taken into account in their proposals, and by investors to evaluate and assess the relative merits of proposals. The framework would include a standardised set of cost heads against which all costs should be accounted, and a set of qualifying information that must be provided which address the identified variables affecting these costs.

2 CURRENT STATUS OF MINI-GRID COST LITERATURE

A literature review has been completed on papers which present and analyse cost figures for PV and PV-diesel mini-grids. Most papers use the LCOE ($/kWh) as the primary measure of assessing and comparing mini-grids and other off-grid electricity supply technologies. Some papers quote an LCOE for mini-grids or potential range for LCOE with minimal reference to any of the assumptions underlying the figures presented [10] [1].

In papers which calculated LCOEs, each used a

[1] The terms surplus and substitution are defined by Frearson and Tuckwell in *The future of mini-grids: from low cost to high value* [2].

different format and method for presenting, accounting for and estimating the costs of mini-grid implementation. Capital costs ranged between $4.70[2]/W [7] to $11.20/W [9]. Some papers presented itemised breakdowns of most cost components [7], some grouped hardware or Balance of System (BOS) costs without clearly detailing what had been included [11] [4] [5], while others used dollar per watt figures to estimate the total installed cost [8] [9]. Some papers only provided itemised cost breakdowns but did not provide a value for the total installed cost [12] [13]. Papers that provided cost breakdowns invariably included a different set of cost components. Some included staff and other soft costs [7] [12], while others only included hardware [4] [8] [5] [14] [15]. Some papers only included the generating and storage equipment in the hardware costs [15] [12], while others included distribution, wiring and other enabling equipment [4] [5] [14] [13].

The costs associated ongoing with mini-grid management and Operation and Maintenance (O&M) are similarly difficult to ascertain from the literature, and generally lack, as before, any qualifying information as to delivery mechanism, service outcomes and technical design parameters. Estimations for these costs ranged from $20/year [15] to $2625/year [14], often with little reference to what O&M services entail. Some papers estimated O&M costs using percentages of total capital costs [4] [7] [9], with resulting costs between $100 and $200 per year. Some papers have assumed fixed yearly values for O&M: [8] assumes $50/year for a PV and battery system, [14] assumes $2624.95/year for an Annual Maintenance Contract. [11] has considered a combination of fixed ($/year) and variable ($/kWh) costs for O&M costs. The only paper found to consider the cost of mini-grid ownership and management was [14].

The lack of clarity and consistency in the available mini-grid cost literature makes it difficult to ascertain the actual costs of mini-grid implementation. For the RE mini-grid industry to continue to grow, comprehensive cost structures of mini-grid projects must be understood and documented, and the relationship of cost with the delivery mechanism, technical design parameters and service outcomes delivered, properly defined and appreciated.

3 STANDARDISED COST FRAMEWORK

A standardised cost framework is proposed to increase the consistency, clarity and completeness of cost figures presented for RE mini-grid implementation. The framework would include a standardised set of cost heads against which all costs should be accounted, and a set of qualifying information which address key variables identified that affect costs.

The key purpose of the framework is to offer a tool for ensuring that all costs and relevant project characteristics are accounted for. This is important for project planners to ensure that they plan and account for all costs. It is also important for prospective investors as a means of providing the information required for undertaking due-diligence on prospective investments and making informed and impartial evaluations of proposals. Further, if literature adopts the framework and cost figures are published according to a common set of cost heads with qualifying information, then useful information can be gleaned on the actual cost of implementing mini-grids. The wider industry could then start to establish useful benchmark estimates.

3.1 Proposed Framework for PV and PV-diesel mini-grids

A preliminary cost framework has been developed for solar PV and PV-diesel hybrid mini-grids using literature reviews, three case studies and interviews with mini-grid practitioners. This framework is presented with a view to (i) receiving industry review and feedback that can inform its further development, and the development of frameworks for other RE mini-grid technologies; and (ii) the adoption of these throughout the industry.

3.1.1 Costs

Table 1 outlines the proposed set of cost heads for the framework. The list was developed using cost databases for previously implemented PV and PV-diesel mini-grids and interviews with mini-grid practitioners who have worked in the design of programs, and the design, implementation and maintenance of mini-grid projects[3].

Costs are divided into Project Development Costs, CapEx and OpEx costs.

Where any cost components are not included, this should be clearly stated, and the reason for their exclusion.

Table 1: Proposed set of cost heads for PV and PV-diesel mini-grids

Project Development Costs	
Project management costs	e.g. project design, initial community consultation, finance mobilization; project conception costs could also be included if financing is sought to reimburse these
Technical design costs	Engineering design
Capacity building/training costs	e.g. capacity building and training within village, government, suppliers etc. following initial community consultation
Other Project Development Costs	e.g. project overheads during project development
CapEx	
Solar PV Array	PV modules
	Array frame and mounting
	Other PV costs e.g. lightning protection, marshalling box, DC cabling, DC isolator
Power Conditioning Unit (PCU)	Inverter
	Other PCU costs e.g. remote communication hardware
	Battery cells

[2] All cost figures have been converted to USD using 2013 exchange rates to allow for comparison.

[3] In this paper a program refers to a large scale deployment of mini-grid systems over several years, while a project refers to a one-off design and implementation of one or a couple of mini-grid systems.

Battery Storage Systems	Other battery costs e.g. connectors, stands, distiller, battery isolator switch
Diesel Generator	Diesel generator
	Other generator costs e.g. generator switchboard
Fencing and Gates	Compound fencing and gates
System Housing	Power house including all construction materials
PDN	Poles - if overhead cabling
	Main supply cable
	Service wires
	Consumer switchboards and wiring
	Other PDN costs e.g. concrete, bracketing, support wires
DSM	DSM costs (if applicable)
Internal building wiring	Internal consumer wiring costs
Other hardware costs	Other Costs e.g. safety gear, replacement parts, distribution switchboard
Implementation Costs	Cost of labour for installation
	Transport/Freight costs
	Taxes
	Other installation costs
OpEx	
System Management	Administration e.g. organization of O&M, fuel supply
	Other System Management and Administration costs
Operation and Maintenance	Fuel costs
	Replacement of key hardware
	Consumables excluding replacement of key hardware e.g. filters, oil etc.
	Contracted annual maintenance costs (from third party service provider)
	Local operator remuneration
	Other Operation and Maintenance costs
Capacity building/training	Technical support and training of local technical staff
	Managerial support and training of local management entity e.g. committee, co-op
	Other Capacity building/training costs

3.1.2 Qualifying information

The following set of proposed qualifying information was identified through a literature review of sustainability frameworks and industry best practices [3], and through the case studies and interviews. This qualifying information would be provided in addition to general details of the context and system. The case studies provide examples of how this qualifying information may be used to understand costs.

Service outcomes: Total kWp and kWh capacity are important components of the service outcomes, however, additional information is required to put these into context. The service model of substitution or surplus [2] should be specified, and any capacity to expand the system explained. The hours of availability, reliability and flexibility of use [3] for each consumer should also be specified. Importantly, any demand or supply control management systems [16] [17] implemented to ensure this availability and the equitable distribution of power should be described. In the absence of reliable diesel back-up, details of the battery bank capacity and design days of autonomy are also important details to understand the reliability of the system [18].

Delivery Mechanism: The delivery mechanism relates to the scale of a project, ownership and management structures; it also relates to the procedures carried out to design and implement the project. With regard to scale, is the project implementing as an isolated system or is it a part of a large scale coordinated deployment program [2]? If it is the latter, then details of the program structure should be outlined, including standardisation of systems and procedures to reduce costs [3].

Ownership and management of systems is also important: will the system be owned by a community, private or public company or organisation [1]? Will the system be managed as an isolated entity or as part of a cluster of systems [2]? Importantly, a detailed plan and budget for the operation, maintenance and management of the system should be developed to ensure the long term viability of the project [19]. The procedures carried out to design and implement the project are also important to understand as these can be linked to the sustainability of the project [19] [20]. Do procedures carried out align with industry best practices and sustainability frameworks? (e.g. The International Energy Agency’s (IEA’s) Task 11: Social, Economic and Organisational Framework for Sustainable Operation of PV Hybrid Systems within Mini-Grids (Task 11) [19] and Task 9: PV for Rural Electrification in Developing Countries – Programme Design, Planning and Implementation (Task 9) [20].

Technical design parameters: The capacity of PV generators, inverters, batteries and any diesel generators are important aspects of this, however again, further information is required. The standards to which the system and all its components have been designed is important to specify as this impacts on the safety and quality of the system [21]. The design life expected from the system and all components should be outlined as this determines their replacement costs over the life of the system. Details of the battery bank design are particularly important in this regard as battery replacement costs can be a significant lifetime cost [1] and their life is critically dependent on cycling patterns and daily Depth of Discharge (DoD) [18]. Any energy management systems in place to protect batteries are therefore important [1] and should also be described.

4 CASE STUDIES

Three case studies have been completed using the proposed framework of costs and variables to describe and analyse the costs of previously implemented mini-grids. The first of these is a large scale mini-grid program that operated in remote rural Australia for the past ten years, installing and maintaining close to 200

PV mini-grid systems with an average capacity of 20kW. The second project involved the implementation of two 9.6kW PV mini-grids in two remote Indian villages in 2009-11. The third PV mini-grid project was a 15kW system implemented in a Cambodian Village in 2011.

Comprehensive descriptions of each of these case studies including outlines of the preparation, design, implementation and Monitoring and Evaluation (M&E) phases (as defined in The IEA's Task 9 [20]) of each program may be found in Cost Structures of Sustainable Mini-grid Programs [3].

4.1 Australian Mini-Grid Program

4.1.1 Context

This mini-grid program operated in remote Australian Indigenous communities throughout central and northern Australia. Some sites for mini-grid installation and maintenance were extremely remote and so mobilisation costs were high, and some communities were only accessible during the dry season. For the purposes of this case study, the costs of one mini-grid system installed close to the town centre of Alice Springs in 2012 will be presented and discussed.

4.1.2 Service Outcomes

All mini-grids implemented through this program were designed to supply a guaranteed quantum of energy (kWh) to each household. This quantum would be agreed upon during community engagement process, which included a full analysis of all existing loads and livelihood aspirations in the community. 24 hour supply was guaranteed to each household with 99% reliability through Demand side Management (DSM) units. These DSM units would cut off non-critical loads when supply was low and continue to supply power to critical loads. These DSM units also ensured equitable distribution of power to each household.

4.1.3 Delivery Mechanism

PV mini-grids were installed and maintained through a centrally managed, large scale deployment program. The program was government funded with fees collected from some communities depending on the Regional Authority. In the 2012 case study system, power was delivered to each household through pre-payment meters which required households to pay for each kWh of electricity before they consumed it.

All mini-grids were owned by the community, but managed by a team of up to 25 technical and community engagement workers, based in Alice Springs, providing ongoing support, M&E and maintenance services.

The program used standardised design tools and procedures to streamline design, procurement and approval processes. Significantly, there was a large focus on community engagement through all processes, including initial consultation, design, installation and commissioning and ongoing M&E.

4.1.4 Technical Design Parameters

All designs and installations were completed in accordance with relevant Australian Standards. The overall system design life was 20 years. Batteries were designed with a daily DoD of 30% and days of autonomy, 3-5 depending on the system's location (tropical or arid). The battery design is one that is common to all systems in the program, and expected lifetimes of ~10 years are being realised with minimal replacements to date. The 2012 case study had a PV capacity of 11.4kW with a 144kWh (C_{100}) battery bank.

4.2 Indian Mini-Grid

4.2.1 Context

This project involved the design and installation of 2 PV mini-grids in two remote communities in India, one in West Bengal, and one in Orissa.

4.2.2 Service Outcomes

Both mini-grids were designed to supply a guaranteed quantum of energy (Wh) to each household. This quantum was agreed upon during community engagement process, which included a full analysis of all existing loads and livelihood aspirations in the community. Both systems were designed using a surplus model, with the potential for 20% growth in demand, in accordance with expectations for community and demand growth. 24 hour supply was guaranteed to each household with 99% reliability through DSM units, ensuring equitable distribution of power to each household.

4.2.3 Delivery Mechanism

The project was funded by the Australian government, with 2 full-time Australian staff developing and implementing the project over 2 years. Both systems were community owned and the project involved the setting up of a village cooperative and village energy council to manage systems. Maintenance services are delivered through 5 year Annual Maintenance Contracts (AMCs) with fixed costs for services.

This project also had a significant focus on community engagement through all processes, including initial consultation, design, installation and commissioning and ongoing M&E. Many stakeholders, including government bodies and local NGOs were included in the project's development.

4.2.4 Technical Design Parameters

Both mini-grids had 9.35kW PV arrays. Daily demand is 23kWh with battery banks designed accordingly with a daily DoD of 25% and 2 days of full autonomy. All designs and installations were completed in accordance with relevant International Standards. The overall system design life was 20 years. The batteries were expected to have a lifetime of approximately 8-10 years.

4.3 Cambodian mini-grid

4.3.1 Context

This project was implemented as a pilot project for PV mini-grids, by a private company, which designs and installs mini-grids predominantly using diesel and biomass technologies.

4.3.2 Service Outcomes

The mini-grid was designed to deliver 5 hours of light to 80 households. There was no energy management system in place to ensure that energy was equitably distributed, that a set kWh would be delivered to each household or that energy could be reliably accessed for 5 hours.

4.3.3 Delivery Mechanism

The project was designed and installed by the CEO of the Cambodian mini-grid company, an electrician. Tariffs are collected per kWh of energy consumed. There is a guard employed full-time to guard the PV array, and one accounts person is employed to manage tariff collection.

4.3.4 Technical Design Parameters

The PV array is 15 kW, and battery bank 67.2kWh. There is battery protection in place to limit the DoD to 70%. No indication of expected DoD was given. The PDN was designed in accordance with all relevant standards.

4.4 Project Development Costs

The Project Development Costs were the most difficult to define category within the cost figures provided and interviews undertaken. As outlined in Table 1, the Project Development Costs refer to the 'soft' costs that are incurred once, usually during the planning phase; these were identified to include conducting needs assessments, stakeholder consultation, assessment of national policy objectives etc., as well as technical design [20]. The importance of these steps is stressed in the sustainability literature [20], and by practitioners [3]. However, these costs can be substantial and the extent to which these costs should be included in the assessment of proposals or calculation of mini-grid implementation costs will depend on whether the project developer is seeking to recover any of these funds as part of the finance being sought.

The Australian and Indian mini-grid programs both involved substantial project development work, with extensive needs assessments, stakeholder consultation including work with government bodies, local NGOs, and the communities where mini-grids would be implemented, in order to design projects that would best meet community needs and align with national policy objectives [3]. The approaches taken were aligned with the IEA's recommended steps for the implementation of off-grid PV [20]. For the Australian mini-grid program, the cost of this project development was $1.63 million over 1.5 years and for the Indian mini-grid project it was $1.35 million over 2 years. The developers of these projects indicated that the costs incurred related to project management, process development and standardisation, technical design and capacity building, although they could not provide accurate estimations of how the development cost figures provided should be divided into these categories. No detail of project development work or costs were provided for the Cambodian mini-grid project.

4.5 Capital Costs

$/W installed figures are commonly used to estimate/describe the capital cost of installing PV systems, both grid connected and off-grid [4] [5] [15] [22]. This index has been used to express the Capital Costs for the case studies; however it is argued that this measure has limited usefulness in the context of mini-grids, given the vast range of variables that affect costs.

The following graph illustrates the hardware and implementation costs in $/Wp for the three mini-grid projects. Notes on cost components included:

- India: All PV costs, including modules, frames, BOS are grouped together;
- Cambodia: These costs do not include installation or powerhouse costs.

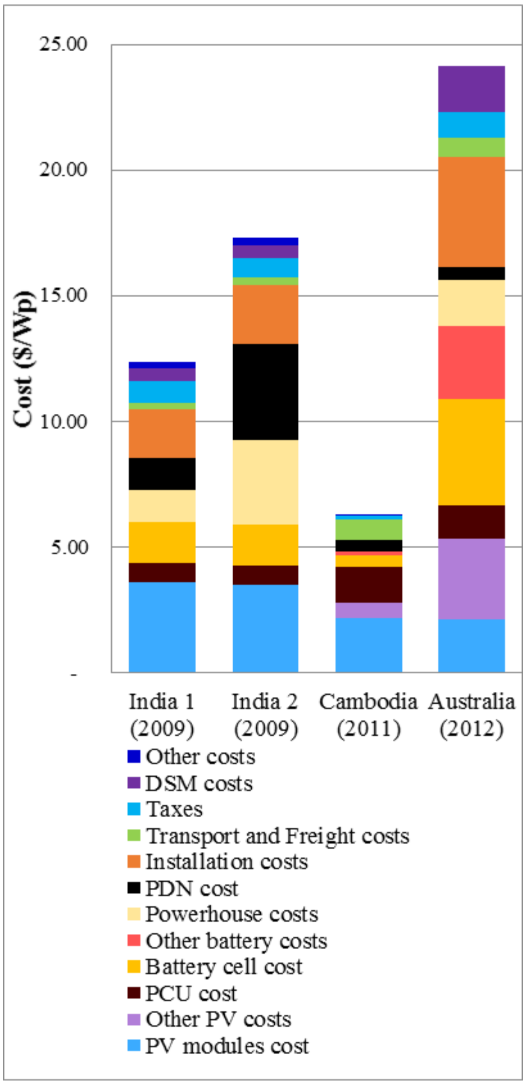

Figure 1: Itemized capital cost breakdown of mini-grids in India, Cambodia and Australia

From the graph in Figure 1, it is clear that the Cambodian mini-grid project has substantially lower capital costs than the other projects, however, this can only be a preliminary comparison - understanding the costs that have been accounted for and the qualifying information provided make the reasons for this clear.

Firstly, considering the relative size of powerhouse and installation costs for the other three mini-grids, it is clear that omitting these costs substantially reduces the $/Wp cost. Secondly, battery costs are minimal in this project while they form approximately a third of the cost of installing the Australian mini-grid system. With additional qualifying information, this difference can be understood: battery banks in Australia were designed to provide 24 hour supply to power a range of electric appliances with a daily DoD of 20%-30% to maximize battery lifetime; batteries in the Cambodian mini-grid system were designed to provide 4-5 hours of light with an estimated DoD of 70% and so would be expected to have substantially reduced lifetime and higher replacement costs.

Other differences that should be considered between the case studies include the following: Labour costs in Australia are higher and so installation costs are higher. The PDN costs in the second India project are higher because the village is more dispersed and so the PDN required is longer. The powerhouse costs for the first Indian mini-grid system are lower because the village supplied free labour for its installation. The PV costs for the Indian mini-grids appear higher because they were installed at an earlier date, and all PV related costs have been grouped together.

4.6 Operational Costs

The ongoing Project Costs were easiest to obtain from the Australian mini-grid project because the clustered management of the various systems meant that all cost figures were centrally managed and stored. Comprehensive and accurate figures could not be obtained for the other case studies.

Total annual cost was $3.8m over 200 systems; the breakdown of these costs is outlined in Figure 2. Again, a detailed breakdown of costs into the different cost heads and qualifying information can be used to better interpret the total annual cost of running the mini-grid program. The level of service delivered to customers through the program was high, with service quality requirements on par with standard urban supply: annual maintenance visits by 1-2 qualified electricians, additional maintenance visits if required to ensure electricity is always available, and community engagement visits at least once a year to ensure consumer understanding and proper use. The delivery method of a government funded program, with 245 systems managed under the program and up to 25 staff employed at a given time, meant that there were management costs associated with government liaison and staff management. These costs may not be incurred in a smaller project with different funding structure or delivery method.

4.7 Case Study Findings

These case studies have demonstrated some of the variables that exist within PV mini-grid projects and how these may impact on costs. The qualifying information proposed in the preliminary cost framework for PV and PV-diesel mini-grids has been useful for contextualizing and comparing the costs of systems with different delivery mechanisms, service outcomes and technical design parameters. More case studies and cost figures are required to draw conclusions on the expected costs of mini-grid implementation and for any analysis to be conducted on the impact of the different variables affecting costs.

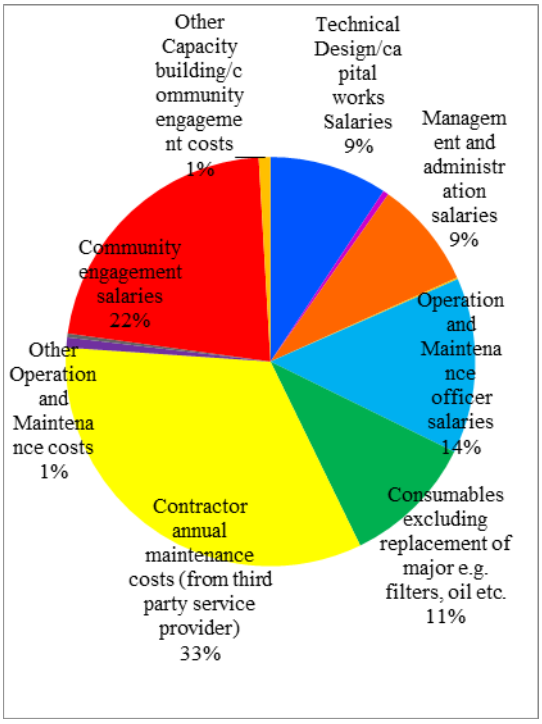

Figure 2: Itemized cost breakdown of Annual Operating Costs of Australian mini-grid program in 2012-13

5 CONCLUSION

A standardised cost framework is proposed to increase the consistency, clarity and completeness of cost figures presented for RE mini-grid projects. The framework would include a standardised set of cost heads against which all costs should be accounted, and a set of qualifying information which address key variables identified that affect costs.

It is expected that the framework will act as a useful tool for ensuring that all costs and relevant project characteristics are accounted for. This is important for project planners and prospective investors as it will allow for standard due-diligence processes to be carried out and informed and impartial evaluation of proposals to be made. Further, if researchers and industry adopt the framework and cost figures are published according to a common set of cost heads and qualifying information, then useful information can be gleaned on the actual cost of implementing mini-grids. The wider industry could then start to establish useful benchmark estimates for the various costs associated with implementing mini-grids.

A preliminary cost framework has been developed and presented for solar PV and PV-diesel hybrid mini-grids. Case studies of costs for three projects have demonstrated how this framework may be used to understand and contextualize cost figures. This framework is presented with a view to receiving industry review and feedback that can inform its further development and ultimate adoption throughout the industry.

6 REFERENCES

[1] ARE, "Hybrid Mini-Grids for Rural Electrification: Lessons Learned," Alliance for Rural Electrification, Burssels, 2006.

[2] L. Frearson and M. Tuckwell, "The future of mini-grids: from low cost to high value," ADB Technical Assistance-7512 REG: Empowering the Poor through Increasing Access to Energy - final report, Manila, 2013.

[3] M. Thwaites, "Cost Structures of Sustainable Mini-grid Programs," The University of New South Wales, Sydney, 2013.

[4] M. Nouni, S. Mullick and T. Kandpal, "Photovoltaic projects for decentralized power supply in India: A financial evaluation," *Energy Policy 34,* pp. 3727-3738, 2005.

[5] M. R. Nouni, S. Mullick and T. Kandpal, "Providing electricity access to remote areas in India: Niche areas for decentralized electricity supply," *Renewable Energy,* pp. 430-434, 2009.

[6] C. Breyer, C. Werner, S. Rolland and P. Adelmann, "Off-Grid Photovoltaic Applications in Regions of Low Electrification: High Demand, Fast Financial Amortization and Large Market Potential," Hamburg, 2011.

[7] L. Qoaider and D. Steinbrecht, "Photovoltaic systems: A cost competitive option to supply energy to off-grid agricultural communities in arid regions," *Applied Energy,* p. 427–435, 2010.

[8] S. Shaahid and I. El-Amin, "Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia—A way forward for sustainable development," *Renewable and Sustainable Energy Reviews,* pp. 1-9, 2008.

[9] S. Mahapatra and S. Dasappa, "Rural electrification: Optimising the choice between decentralised renewable energy sources and grid extension," *Energy for Sustainable Development,* p. 146–154, 2012.

[10] P. Bertheau, P. Blechinger, C. Cader and C. Breyer, "Geographic, technological and economic analysis of isolated diesel grids to assess the upgrading potential with renewable energies A case study of Tanzania," Berlin, 2013.

[11] ESMAP, "Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies," The World Bank Group, Washington, DC, 2007.

[12] G. R. T. Esteves and A. N. A. Lima, "Energy Supply on Amazon Remote Communities in Brazil: A Study Case for the Communities of Terra Nova, Mourão and São Sebastião," in *Micro Perspectives for Decentralised Energy Supply,* Berlin, 2013.

[13] P. E. Carajal, "Standardization of photovoltaic mini-grids for electrification of isolated communities in Amazonas-Brazil," in *Micro Perspectives for Decentralized Energy Supply*, Berlin, 2013.

[14] A. Chaurey and T. Kandpal, "A techno-economic comparison of rural electrification based on solar home systems and PV microgrids," *Energy Policy,* pp. 3118-3129, 2010.

[15] M. M. Kumar and R. Banerjee, "Analysis of isolated power systems for village electrification," *Energy for Sustainable Development,* p. 213–222, 2010.

[16] F. Katiraei, R. Iravani, N. Hatziargyiou and A. Dimeas, "Microgrids Management," *IEEE power and energy magazine,* vol. may/june 2008, pp. 54-65, 2008.

[17] N. Kanoksing and W. Tayati, "Economics of Demand Side Management and Hybrid Renewable Energy Systems for a Remote Village Electrification in Northern Thailand," *Chiang Mai University,* N.D..

[18] GSES, "Stand Alone Power Supply Systems Design and Installation Training Manual," Global Sustainable Energy Solutions, Ulladulla, undated.

[19] IEA, "Task 11: Social, Economic and Organisational Framework for Sustainable Operation of PV Hybrid Systems within Mini-Grids," International Energy Agency, 2011b.

[20] IEA, "Task 9: PV for Rural Electrification in Developing Countries – Programme Design, Planning and Implementation," International Energy Agency, Paris, 2003.

[21] A. R. Inversin, "Mini-Grid Design Manual," Energy Secor Management Assistance Programme (ESMAP), 2000.

[22] T. Singh, "Amendment in the bench mark cost for “Off-grid and Decentralized Solar Applications Programme” being implemented under the Jawaharlal Nehru," Government of India. Ministry of New & Renewable Energy, New Delhi, 2013.

[23] D. Waddle, "Principles of Successful Expansion of Rural Electrification Programs," Pacific Energy Summit, Hanoi, 2012.

[24] J. Cust, A. Singh and K. Neuhoff, "Rural Electrification in India: Economic and Institutional aspects of Renewables," 2007.