Social Impacts of Mini-grids: Towards an Evaluation Methodology

Aran Eales[1], Luke Walley[2], Hannah Buckland[1], Damien Frame[1], Scott Strachan[1]
University of Strathclyde[1], Carbon Trust[2]
Aran.eales@strath.ac.uk

The level of investment in mini-grids is limited by a lack of understanding of their social impacts. A paucity of published data exists on the issue, presenting a need for mature, better-integrated monitoring and evaluation methodologies. Such social impact focussed data would provide a critical evidence base for supporting claims of the beneficial effects of mini-grids on the communities they serve. This paper provides a literature review exploring the existing knowledgebase on the social impacts of mini-grids, what methodologies are used to evaluate them, and the extent to which social impact monitoring and evaluation is currently carried out. It finds that although there is a general acceptance of the benefits of rural electrification through mini-grids, it is not often based on empirically measured evidence of mini-grid impact on the general wellbeing or social development of the communities they serve. Existing studies tend to focus more on measuring technical and economic performance of installed systems. Recommendations for a best practice methodology for evaluating the social impact of mini-grids is presented, which will be applied and tested in a variety of development contexts to gain valuable data to inform the sector.

I. Introduction

Meeting the challenge of the United Nations Sustainable Energy for All (SE4All) initiative in providing energy access to the 589 million people in Africa currently living without it by 2030 [1] demands new and innovative solutions for rural electrification. SE4All has significantly progressed the development of mini-grids as a solution for rural (and peri-urban) areas unlikely to receive grid connection in the near future. Mini-grids are thus emerging as a third alternative to rural electrification, coming between the option of large-scale national grid extension and stand-alone solutions such as pico-solar products and solar home systems [2]. Mini-grids can also effectively serve communities close to the grid in more developed countries such as South Africa. In such cases, 'grid-tied' or 'interconnected' mini-grids can deliver high-quality service while reducing load on the grid [3]. With such promise and potential, there has been substantial interest in implementing mini-grids in developing countries, particularly in Sub-Saharan Africa. The International Energy Agency estimates that mini-grids will be the best solution for over a third of the global population currently living without electricity access [4].

Although barriers for widespread deployment of mini-grids in developing countries are reducing, the focus for key stakeholders has been largely technological to date. Business models have also been explored extensively [5], as well as different financing mechanisms and potential for national and international interventions. There remains, however, a lack of understanding of the real social impacts of mini-grids on the community and customers they serve, due in part to the cost of collecting such data. Measuring quantitative use of system factors requires expensive metering, whilst measuring qualitative factors, such as the effect on education or community health, requires resource intensive data collection methods, such as surveys, interviews and focus group discussions. Challenges exist for collecting quantifiable data in a uniform manner that will ensure an accurate and consistent representation of these impacts to be measured across different sites and projects. Regardless, understanding and measuring how communities interact with, and are affected by mini-grids will allow better comparison with alternatives for investment when making decisions on options for sustainable electrification.

Energy underpins all of the 17 Sustainable Development Goals (SDGs) set out by the United Nations [6]. Given the potential for mini-grids as a tool within the energy sector for working towards the SDG targets, the purpose of this paper is to gain insight on quantifying the holistic impact of mini-grids within the context of the SDGs, particularly with regards to the anticipated impacts at the design stage.

In Sections II and III observations and discussion points are drawn from academic and industry literature, which are used as a basis for developing key recommendations on a methodology for evaluating the social impact of mini-grids in Section IV. Conclusions are presented in Section V.

II. Literature Review

The literature review is comprised of three sections: key academic papers explaining the social value of electrification, a discussion of current methodologies used to evaluate mini-grid electrification, and selected industry reports with recent minigrid evaluations from the field. Relevant search terms including "*mini-grids, social impact,* and *evaluation methodologies*" were utilised in search engines. The selection reflects what was encountered by the Authors and is by no means exhaustive. However, seminal works are included and common methodologies employed in the evaluation of mini-grid impact are represented in the review.

A. Social Value of Electrification for Development

Electricity can improve quality of life by increasing the level of health, education, welfare, and technology [7]. Rural electrification in particular, defined as the percentage of the rural population with access to electricity, has been found to be a crucial part of socio-economic development [8]; responsible for increasing youth literacy rates and improvement in health care through upgraded facilities [9]

[10]. It has also been found to enhance employment, especially among women [11], by enabling income generating activities, and advancing rural productivity [12]. The United Nations Development Programme states that on a national scale, per capita electricity service is highly correlated with improvements to the Human Development Index, showing extremely strong marginal diminishing benefits [13].

In their short communication regarding the social value of mid-scale energy in Africa, Miller et al. define the social value of energy "*in terms of the total value derived by an individual or community from the use of energy, including economic and other forms of value, less any risks or burdens that accompany energy production, transmission, and consumption*" [14]. They suggest a need to consider social value of energy alongside cost comparisons in designing projects to reduce energy poverty. They state that mid-level energy initiatives (such as mini-grids) have potential for higher levels of impact, but social value considerations are frequently omitted with a tendency to exclusively focus on electricity supply. Assessing the social value of electrification ensures that community energy systems create a positive feedback loop enabling growth and delivering value by avoiding system disrepair and disuse. In their conclusion, Miller et al. stress the need for greater emphasis on key innovations in energy system design, which include "*evaluations of the social value of energy services*; *successful community engagement in the prioritisation of social value provision; and user-centred design of high-value energy service delivery that achieves effective integration of social and technical elements*."

[15] confirms this view of combining a technical outlook with a sociological one during system design in their study of how technology integration affects remote communities. Their argument is based on the idea that social factors are often key in explaining system failures (alongside technical causes of system failures). Understanding social factors and their role played in system failures improves prospects of future prevention. They propose that technology adoption cannot be considered successful until verifiable evidence of perceived benefits are actually delivered to recipient communities. Furthermore, the change that these systems can effect in rural communities can only occur when users become independent in managing and maintaining newly introduced energy systems. The success of such projects is threatened by a lack of understanding of the lifestyles and habits of the community members. The paper concludes by suggesting that exploring social habits, cultural attitudes, and the networks of social relationships and behaviours clears the path for a more precise explanation of unsuccessful design and adoption of electrification technologies. This, in turn, translates into a socio-technical solution that is more likely to result in the success of such programmes.

[16] Engages ethnographically with local communities benefitting or expected to benefit from renewable energy projects in Africa to investigate reasons for failure. It finds that despite differences in culture and understanding, reasons for project failure are found to be similar across different countries and have mainly social roots such as: political agenda, stakeholder co-operation, public acceptance & inclusion. This further supports arguments that social factors and impacts require more attention in the mini-grid sector.

[17] identified competing approaches to renewable energy system deployment: some are socially orientated, while others have a commercial objective "*to create a market for electricity services*". The different approaches to the engagement in rural electrification reflect different levels of ambition and expectation, and it is most certainly easier to evaluate a project with a main objective to "*create a market*", as opposed to a project with a social dimension intended to serve as a "*prerequisite for poverty reduction*".

Finally, a 2016 paper by Trotter [18] contributes to a growing body of socio-politically oriented literature on electrification in developing countries, which conducts econometric and case-example analyses to show a strong positive association between democracy and rural electrification in sub-Saharan Africa between 1990 and 2010. Engaging with local and national politics through democracy is considered a clear indicator of positive social progress, and evidence of electrification affecting such a criterion should be carefully considered when exploring its social impact.

B. Monitoring Social Impacts of Mini-grids: Methods, Frameworks and Results

Despite a large number of rural electrification projects being implemented in developing countries, there are few published in-depth evaluations of the effects of these projects on sustainable development [17]. Technological performance monitoring frameworks for mini-grids exist [19], but rarely involve a comprehensive methodology that considers the full range of potential impacts; with societal impact factors being a notable omission from most.

Practical Action's Poor People's Energy Outlook (PPEO) [20] outlines a framework for observing and evaluating the social value of energy projects at a local level through an ecosystem approach that encompasses the SE4All Global Tracking Framework [21]. This is achieved by specifying the community energy services as well as recording the existing social and entrepreneurial activities; recognising the externality impacts of certain energy uses that are detrimental to the community; and identifying the essential nature of key influencing parameters such as social capacity, policy and financing frameworks. Essentially, the PPEO recognises the need for socio-technical design, refuting the common dogma that techno-economic challenges such as increasing system energy output and customer consumption while reducing costs through efficient design are separated from social aspects of capacity building, policy and regulatory assessment and advocacy and low income tariff structures.

[17] presents a method for the evaluation of rural electrification projects that covers five dimensions of sustainability: technical, economic, social/ethical,

environmental, and institutional. The methodology uses indicators to help create a better understanding of how a specific project contributes to sustainable development. [22] utilised this framework to measure the sustainability of mini-grids in Peru and Nepal. Fieldwork was conducted in three case study sites using a variety of evaluative methods, including semi-structured interviews with users and managers, transect walks, photographic evidence, and observations. Villagers' perspectives were triangulated against the results of semi-structured interviews held with the implementing agencies, enabling different levels of analysis to be embedded in each case study. A series of 43 sustainability indicators were developed for evaluating the grids; categorised into the five themes of sustainability indicators presented in [17]. They state that in an ideal scenario, sustainability indicators should be designed in consultation with project stakeholders such as users, government, local electricity service providers, project workers, financing bodies, etc.; yet frequently practicalities can limit the opportunity for such wide stakeholder engagement. The social and ethical indicators used in the study are outlined in Table I.

As well as evaluating welfare benefits, foundations were identified to ensure such benefits could take place: community mobilisation, productive uses, and a supportive enabling environment. The enabling environment included access to financing, technical support and supply parts, and establishing favourable institutional, technical and regulatory frameworks. The work of [22] not only provides an indicator framework to evaluate the effect of sustainable welfare benefits created by renewable energy mini-grids, but also gives welcome recommendations on interventions for increased positive social impact. As expected, a key focus within the indicators is put on education, healthcare, and gender; with a notable element of equality also highlighted.

TABLE I
SOCIAL AND ETHICAL SUSTAINABILITY INDICATORS

Sustainability Dimension	Social and Ethical Development
Key Variables	• Improved service availability • Credit facilities • Equal distribution
Indicators	A. Electricity is used in schools B. Education has improved due to electricity C. Electricity is used in health centre D. Healthcare has improved due to electricity E. Electricity is used in community centre F. Existence of street lights G. Improved telecommunications due to electricity H. Women's burdens have reduced due to electricity I. Micro-credit (or alternative) possibilities are available for electricity services connection and tariff payment where necessary J. All households who want it have access to electricity service

[12] conducted a detailed case study analysis of a micro-grid in rural Kenya to quantify the effect on social and business services in the village. They recorded a 20-70% growth in the income levels of local workers in small and micro enterprises, resulting from a 100-200% increase in productivity per worker from using electric equipment. Additionally, access to electricity improved the social and business services provided by the village infrastructure such as schools, markets, and water pumps, as well as boosting agricultural productivity. Teachers and parents interviewed all agreed that academic performance had measurably improved, although no quantitative figures are presented. Anecdotal explanations suggests electrification benefits came initially from automated water pumping, freeing up 2-3 hours for each student to study rather than carrying water manually. Financial savings were also made in switching from kerosene to electric lighting, with additional benefits identified through ICT use and offering vocational courses, impacting examination scores and employability, and increase in teacher retention with access to lighting and television for the staff. In general, increased productivity and growth in revenues was found to achieve significant social and economic benefits for rural communities.

[23] conducted a preliminary literature review of the benefits and risks presented to communities by photovoltaic hybrid mini-grid systems. They found that the most commonly identified benefits are those that are easiest to measure: reduced cost and provision of improved electrical services. Other benefits, such as the social or environmental benefits, are less commonly measured, but are frequently claimed. The major risks identified included incorrect system sizing due to load uncertainty, challenges related to community integration, inappropriate business models and risks associated with geographical isolation. For all of these types of risks, associated mitigation strategies were also identified in the literature.

C. *Practitioner Experiences of Measuring Social, Economic and Technical Impact of Mini-grids*

An evaluation of 20 mini-grids in Africa and Asia [24], considered a number of parameters including service level, number of connections, demand per connection, type, capacity and capital cost of technology. Financial parameters included sponsor type, payment method and mechanism, tariff, business model, profitability, financing, payback and perceived risk. Financial insights include mini-grid payback of the mini-grids varying between 1 and 12 years, with an average of 6.2 years. The mini-grids surveyed had an average per capita demand of 2.5–30 kWh/month. The key (and only) social impact statistic provided in this report is that two of the nine Distributed Energy Service Companies had a 23% disconnection rate after 5 months and a 10% disconnection rate after 50 months, while the other seven had no disconnections. This illustrates the satisfactory service provision and affordability of these systems, but does not provide any information on how positive the impact on the local communities was, or how it could be improved.

Early insights into solar PV mini-grid operations in rural Kenya are described in [25] providing a wealth of information on social impact. Generally, demand for mini-grid electricity in Kenya is strong and growing, and surveyed consumers cited economic growth, increased security and health benefits as primary drivers for this demand growth. Although most consumers had a low consumption of <250 Wh/day, through a pre-pay model, the majority of customers kept their accounts constantly in credit. Mini-grid consumers shifted almost entirely away from fossil fuels, with kerosene and disposable battery use decreasing from 86% to 4% and diesel generator use reducing from 10% to 0%. The unmeasured impacts of this transition include reductions in greenhouse gas emissions, local air pollution and safety risks, as well as improved health through lower incidence of serious respiratory problems [26]. Pre-installation survey estimates of energy use compared with actual consumption revealed an average of 15% overestimation of anticipated demand. Customers with greater disparity between expected and actual consumption were in general less satisfied. It was also found that the customers consuming the highest 10% of energy had a five-fold higher Average Revenue Per User than the remaining 90%, and generated 40% of total revenue. Electricity use causing economic inequality in a community is thus a potential area for investigation.

Appliance use was highlighted in [25] as both a key driver and barrier to mini-grid demand, with (44%) of customers surveys stating appliance availability as a barrier to energy use. When access to appliances was not a challenge, 51% of customers connected new appliances, the majority of these used to improve businesses and generate additional income. 80% of surveyed customers indicated an intention to purchase or lease additional appliances in the future.

The Rockefeller Foundation [27] conducted an evaluation of the impact of rural electrification in Uttar Pradesh and Bihar, India. The Foundation utilised a model that provides electricity through mini-grids for lighting and business use. The study found that 80% of the overall customer base were of low-medium economic status, while 90% of domestic customers were in low wealth groups. 33% relied on seasonal or vulnerable livelihood sources (labour, small businesses), while 36% had agricultural livelihoods. The theme of productive use was strongly emphasised, and although 80% were residential customers, 7% were productive use customers such as fuel stations, grain mills and irrigation pumps. An additional 13% of the customer base was medium-load, e.g. computer centres, photocopy units, photo studios, and pharmacies. Users with productive loads increased significantly from 0 to 2979 in 2 years, contrasted to lighting customers which only increased from 158 to 573. Micro-enterprises in general have benefitted from the mini-grid with 60% of owners reporting improved lighting conditions, increased appliance ownership and ease in business operations.

III. Discussion

While electricity access clearly has a positive impact on education, health, employment, and gender equality, the review highlights a need for a robust means of assessing the extent of any social value and impact derived specifically from mini-grid energy provision. The reviewed evaluations of mini-grids were conducted through field visits, surveys and informal interviews, using a variety of metrics to quantify technical, economic and social performance and impact of each scheme. Social impacts specifically included effects on schools, health, security, and income generating activities. Productive uses of energy were highlighted as key to improving the socio-economic conditions of the recipient community.

Within the industry literature a substantial lack of information was found concerning mini-grid impact, with few reports containing qualitative analysis of mini-grid performance or effects. Most are intended as progress reviews to inform future investment in the sector and as a result tend to focus on technical and financial aspects of installations. Such techno-economic data on energy systems is often commercially sensitive, perhaps more so than measured social impacts, which could explain the dearth of available literature. The lack of social impact reporting relative to that of technical and financial data, illustrates the need for a greater consideration of the social interactions with rural energy systems by developers and financers. Given that the SDGs are ultimately concerned with the reduction of poverty and increased quality of human life, a greater focus on assessing the impact of rural electrification through mini-grids on human development is required. Making measurable positive social impact an explicit goal is seen as more challenging than measuring the technical and economic impact, as it can require added costs and skillsets beyond the engineering and business capacity of many project developers.

However, social impact and profitability are not intrinsically at odds with each other. Measuring and improving the social impact of mini-grids will increase the value derived to customers: rural communities living in energy poverty. This can affect the willingness to pay for services and further increase the financial viability of business models. Additionally, many mini-grids are often donor funded, with social development indicators stated as requirements to demonstrate the social return on investment from aid agencies or charities. Furthermore, sharing social impact information can also ultimately help to improve the quality of mini-grid implementation internationally through adaptions and innovation in mini-grid business models for base of the pyramid customers.

One reason for the lack of evidence and focused studies on social impact is hinted at in [17], that it has proven easier to evaluate a project's success on its economic return on investment rather than its social return on the same investment. Despite the objective of most mini-grid projects being poverty reduction, often consideration is given only to the economic bottom line. Finally, it should be stressed that an attribution gap in the long-term impacts (particularly of the qualitative factors discussed in this paper) does exist and that a causal relationship is sometimes difficult to attribute to an energy intervention (and also costly to conduct longitudinal studies of the social impacts of energy interventions).

IV. Recommendations for a Methodology for Assessing the Social Impact of Mini-grids

Given the evidence outlined above, and considering the complex relationship between rural electrification and social impact, there is an identified need for bespoke and specific studies examining the social impacts of mini-grids. Based on such a premise, this section sets out recommendations for development of a methodology to evaluate the social impact of mini-grids. The full list of recommendations from the literature review is shown in Table II.

TABLE II:
RECOMMENDATIONS TAKEN FROM THE LITERATURE REVIEW

Literature Finding and Recommendation	Comments
A lack of technological data collected on operating mini-grids: ***Meters should be installed in all systems***	Meters enable system optimisation and design; especially demand-supply balancing, per capita consumption and growth trends. Without proper usage data, it is hard to quantitatively assess the development impact of an energy system.
A lack of data on the social impacts of operating mini-grids: ***Regular surveys should be carried out***	Better understanding of social dynamics will have a significant effect on the uptake and utility of mini-grids in rural communities. Further evidence is also still required to substantiate the asserted social impacts of rural electrification via mini-grids.
Collected data tends to be from point of operation: ***Social and technical baseline studies should be carried out***	Without baseline studies conducted before construction, it is challenging to accurately assess the impact of an intervention. This will therefore be critical to generating reliable data with which to make the development case for mini-grids.

An effective evaluation strategy ensures that accurate and reliable data is collected, synthesised and analysed into useful and insightful information, which is then related to knowledge which is applied to a concrete situation in order to establish and lessons for decisions. [28] contains a detailed best practice guide for international development project monitoring and evaluation, including choosing appropriate methods, differentiating between qualitative and quantitative data, consulting individuals or groups, and discussions on participatory evaluation strategies. [29] includes an impact evaluation framework based on sustainable livelihoods containing best practices for investigating social and human capital for energy projects in development context.

Value could be gained from utilising such frameworks to devise an extensive academic evaluative methodology, once utilised allowing impactful insight to be drawn into social changes caused by minigrid electrification. This academic evaluation is recommended as timely and well needed research, however conducting such in-depth studies will likely be costly and unaffordable to most practitioners. A pragmatic approach is therefore proposed here: to define an evaluation strategy that balances the need to capture useful qualitative and quantitative data, whilst utilising methods that require modest resources, producing a positive cost benefit ratio to practitioners.

Social impact quantification is intended for use in conjunction with a suitable technological performance monitoring. Only by combining the results of both social impact and technological performance can the full success of a scheme be determined. Following the justification of a desire for low cost and useful methodology, only three data collection techniques are proposed, namely: quantitative, continuous data collection of energy use utilising installed metering and remote monitoring technologies; customer surveys conducted through enumerators, telephone interviews, or SMS based frameworks; and proxy indicators obtained from census data, previous studies, or other desk based research. Allowing for multiple data collection methods assists with data triangulation and enhanced validation of collected data. An indicative list of the indicators that should, where possible, be taken into consideration when evaluating a mini-grid are outlined in Table III, segregated into social, economic and technical categories, with a suggested data collection method for each.

TABLE III
INDICATORS FOR CONSIDERATION AND DATA COLLECTION METHODS

S= Surveys, M=Metering, P=proxy
Social Quality of life (S) Gender equality (S,P) Social capacity, community structures and dynamics(S,P) Social infrastructure (existence of community-based organisations) (S,P) Health and sanitation (S,P) Education and literacy (child and adult) (S,P,) Time savings (i.e. collecting water or firewood) (S) Access to electricity services for all households that want it (S,M) Unexpected impacts of electricity such as entrenching inequality, or secondary negative impacts (S) Democracy and political engagement (S,P) Observations on poverty reduction and wider social development (S,P)
Economic Income-generating and entrepreneurship opportunities(S,P) Household income and expenditure(S,P) Number, type and distribution of jobs and employment rate (S,P) The availability of micro-credit (or alternative) possibilities for electricity service connection and tariff payment where necessary (S,P)
Technical Time-step, average and seasonal consumption by customer segment (M) Number of households/customers connected to the system (M) Supply and demand patterns, both daily and seasonal (M) Appliances connected: type, number of appliances, hours used (S,M) Number of schools electrified; services offered to those schools (S,M) Presence and number of street lights (M) Improvements to telecommunications due to electricity access (S,M) Number of health centres served (M) Use of other fuels, e.g., kerosene, firewood and paraffin (S) Number of community centres served (M)

Additional recommendations include the use of regular surveys carried out with users to understand social dynamic interaction with installed technology and for baseline studies to be carried out, to allow for useful longitudinal studies. Furthermore, it is proposed that social impact of energy provision via minigrids should be quantified within the context of different SDGs.

V. Conclusions

The literature review has examined both academic papers and industrial reports to explore the extent to which social impacts of mini-grids are being researched and quantified in the sector as a whole. It was found that there exists a paucity of recorded evidence of the impact mini-grids have on the general wellbeing or social infrastructure of the communities they serve, with studies more focused on measuring technical and economic performance of installed systems.

Evidence of impacts on education, health, and gender equality have been identified, with productive uses emphasised as powerful economic drivers with potential to boost local economies and provide additional employment. Social indicators are rarely examined and tend only to be a sub-section of a wider evaluation of mini-grid parameters, with technical and economic performance being the primary focus of the majority of reports.

Methodologies for conducting an evaluation have been reviewed, most utilising a mixture of electronic data logged for consumption and associated income patterns, with site visits, household surveys and informal interviews used to set a baseline and conduct regular reviews. Although some frameworks for assessing project sustainability have been proposed [22], a unified methodology for measuring the direct social impact of a mini-grid initiative has yet to emerge.

Social impact focussed monitoring and evaluation data would provide a critical evidence base for supporting claims of the beneficial impacts of mini-grids. Recommendations for a methodology to quantify such social impacts has been presented, with qualitative and quantitative indicators outlined. The proposed methodology will be developed in detail and utilised to assess the social impacts of existing mini-grids in Africa through performing an ongoing evaluation of existing mini-grids, analysed in combination with their technical performance. The methodology and evaluation results will be shared widely amongst industry and academia to promote dialogue and inform development of the sector as a whole.

Acknowledgment

This work was completed with funding from the Scottish Government and Global Challenges Research Funding awarded through the Scottish Funding Council.

References

[1] SE4All, “SE4All Africa Hub - Supporting Sustainable Energy for All in Africa,” 2017.

[2] Alliance for Rural Electrification, “Rural Electrification with Renewable Energy: Technologies, quality standards and business models,” 2011.

[3] Carbon Trust, “Integrating off-grid solutions into South Africa’s electrification programme,” 2017.

[4] IRENA, *Innovation Outlook: Renewable Mini-Grids*. 2016.

[5] J. Knuckles, “Business models for mini-grid electricity in base of the pyramid markets,” *Energy Sustain. Dev.*, vol. 31, pp. 67–82, 2016.

[6] United Nations, “Sustainable development goals - United Nations,” 2015.

[7] F. S. Javadi *et al.*, “Global policy of rural electrification,” *Renew. Sustain. Energy Rev.*, vol. 19, pp. 402–416, Mar. 2013.

[8] P. Cook, “Infrastructure, rural electrification and development,” *Energy Sustain. Dev.*, vol. 15, no. 3, pp. 304–313, Sep. 2011.

[9] M. Kanagawa and T. Nakata, “Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries,” *Energy Policy*, vol. 36, no. 6, pp. 2016–2029, Jun. 2008.

[10] P. Mulder and J. Tembe, “Rural electrification in an imperfect world: A case study from Mozambique,” 2008.

[11] T. Dinkelman, “The Effects of Rural Electrification on Employment: New Evidence from South Africa,” *Am. Econ. Rev.*, vol. 101, no. 7, pp. 3078–3108, Dec. 2011.

[12] C. Kirubi, A. Jacobson, D. M. Kammen, and A. Mills, “Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya,” *World Dev.*, vol. 37, no. 7, pp. 1208–1221, 2009.

[13] UNDP, “Human Development Report 2007/2008.”

[14] C. A. Miller, C. Altamirano-Allende, N. Johnson, and M. Agyemang, “The social value of mid-scale energy in Africa: Redefining value and redesigning energy to reduce poverty,” *Energy Res. Soc. Sci.*, vol. 5, pp. 67–69, 2015.

[15] V. G. García and M. M. Bartolomé, “Rural electrification systems based on renewable energy: The social dimensions of an innovative technology,” *Technol. Soc.*, vol. 32, no. 4, pp. 303–311, 2010.

[16] E. C. X. Ikejemba, P. B. Mpuan, P. C. Schuur, and J. Van Hillegersberg, “The empirical reality & sustainable management failures of renewable energy projects in Sub-Saharan Africa (part 1 of 2),” *Renew. Energy*, vol. 102, pp. 234–240, Mar. 2017.

[17] E. Ilskog, “Indicators for assessment of rural electrification—An approach for the comparison of apples and pears,” *Energy Policy*, vol. 36, no. 7, pp. 2665–2673, Jul. 2008.

[18] P. A. Trotter, “Rural electrification, electrification inequality and democratic institutions in sub-Saharan Africa,” *Energy Sustain. Dev.*, vol. 34, pp. 111–129, 2016.

[19] I. Baring-Gould, K. Burman, M. Singh, S. Esterly, R. Mutiso, and C. Mcgregor, “Quality Assurance Framework for Mini-Grids,” 2016.

[20] Practical Action, “Poor Peoples Energy Outlook 2014.”

[21] SE4All, “Global Tracking Framework,” 2017.

[22] A. Yadoo and H. Cruickshank, “The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya,” *Energy Policy*, vol. 42, pp. 591–602, 2012.

[23] J. Hazelton, A. Bruce, and I. MacGill, “A review of the potential benefits and risks of photovoltaic hybrid mini-grid systems,” *Renew. Energy*, vol. 67, pp. 222–229, 2014.

[24] World Bank, “OPERATIONAL AND FINANCIAL PERFORMANCE OF MINI-GRID DESCOS,” 2017.

[25] C. Blodgett, E. Moder, L. Kickham, and H. Leaf, “VULCAN IMPACT INVESTING,” 2016.

[26] R. P. Chilcott, “Health Protection Agency Compendium of Chemical Hazards: Kerosene (Fuel Oil),” 2006.

[27] Rockefeller Foundation, “Understanding the Impact of Rural Electrification in Uttar Pradesh and Bihar, India:,” 2017.

[28] O. of E. S. International Fund for Agricultural Development, *Methods for Monitoring and Evaluation | Better Evaluation*. 2002.

[29] E. Colombo, F. Romeo, L. Mattarolo, J. Barbieri, and M. Morazzo, “An impact evaluation framework based on sustainable livelihoods for energy development projects: an application to Ethiopia,” *Energy Res. Soc. Sci.*, vol. 39, pp. 78–92, May 2018.