SUSTAINABILITY, INCLUSIVENESS AND GOVERNANCE OF MINI-GRIDS IN AFRICA (SIGMA) RESEARCH PROJECT

SIGMA WORKING PAPER NO. 5

MINI-GRID SUSTAINABILITY FRAMEWORK AND ITS APPLICATION TO SELECTED MINI-GRIDS IN KENYA

ACKNOWLEDGEMENT

The activities reported in this report are funded by a Global Challenges Research Fund research grant (ES/T006684/1) from UKRI & BEIS. The Global Challenges Research Fund (GCRF) is part of the UK's official development assistance (ODA) and is managed by the Department for Business, Energy and Industrial Strategy.

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CITATION

The suggested citation for this report is:

Kausya, M., Nyumba, R., Onsongo, E., Kerr, D. & Bhattacharyya, S. (2024) Mini-Grid Sustainability Framework and Its Application to Selected Mini-Grids in Kenya. Sustainability, Inclusiveness and Governance of Mini-Grids in Africa (SIGMA) Project, Working Paper 5.

ABSTRACT

This paper presents an indicator-based framework for the sustainability analysis of mini-grids and applies this to a selection of mini-grids in Kenya. Although various frameworks exist, they have been criticised for lack of attention to long-term perspectives, high data needs, prescriptive nature of the attributes and limited user-friendliness. Considering that data availability is a major concern and that data available is qualitative in nature, this paper proposes a set of indicators and a scoring system that can be used with a broad qualitative understanding of the sustainability attributes of the mini-grids. The paper first presents the framework and the scoring system and applies this to the data gathered from the fieldwork in Kenya. The results indicate that the significant variation in sustainability performance of the mini-grids covered and the performance is relatively poor in social, institutional and environmental dimensions.

Keywords: sustainability indicators; mini-grids; qualitative data; performance comparison

CONTENTS

INTRODUCTION

The interest in mini-grids for electrification has grown in recent years, particularly after 2015 when the UN Sustainable Development Goals were launched. According to the Tracking SDG 7 report, the number of people connected to mini-grids has more than doubled to 11 million people in 2019, from 5 million in 2010 (IEA, IRENA, UNSD, World Bank, WHO, 2021)[1]. The World Bank however indicates that 47 million people across 134 countries are currently connected to 19,000 mini-grids (World Bank, 2019)[2]. It further suggests that 490 million people will be cost-effectively electrified by 210,000 mini-grids across the globe for the attainment of universal access by 2030.

While the mini-grid sector is growing, their desirability as a long-term solution is collectively determined by the ability of these technologies to support long-term prospects in technical, economic, social, environmental and governance terms. Depending on how they manage to negotiate these challenges, the long-term sustainability of mini-grids may either fall into what has been characterised as virtuous or vicious cycles. These cycles can emerge from different foundational perspectives; technical, socio-economic, governance/regulatory and environmental.

In our review of technical sustainability, we have presented the following definition of mini-grid sustainability (Bukari et al., 2023)[3]: *a mini-grid intervention to be sustainable if it is a technically feasible, safe and reliable option that meets the needs of the present generation and that of the future generations, economically viable and affordable, socially acceptable and leaves no one behind, environmentally sound and institutionally manageable*. Our review has also indicated various sustainability measurement frameworks developed by various authors (such as Ilskog and Kielstrom (2008),[4] Rahmann, et al., (2016)[5], Katre and Tozzi (2018)[6], Manali and Silveira (2015)[7] , etc.). The index-based approaches retained in these studies differ in their choice of indicators, their coverage and the weighting used for different dimensions.

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[1] IEA, IRENA, UNSD, World Bank, WHO, 2021, Tracking SDG7: The Energy Progress Report, World Bank, Washington DC (https://www.irena.org/publications/2021/Jun/Tracking-SDG-7-2021).

[2] World Bank (2019) 'Mini-grids for half a billion people: market outlook and handbook for decision makers', World Bank, Washington DC, available at https://openknowledge.worldbank.org/handle/10986/31926.

[3] Bukari, D ; Hatamimarbini, A ; Bhattacharyya, SC ; Kerr, D ; Baker, L ; Onsongo, E ; Sesan T , Sawe, E.N. and, Pueyo, A (2023) On the technical sustainability of mini-grids in developing countries: A comprehensive review of literature. Sustainability, Inclusiveness and Governance of Mini-Grids in Africa (SIGMA) Project, Working paper 2.

[4] Ilskog, E and B Kjellstrom, 2008, And they lived sustainably ever after? Assessment of rural electrification cases by means of indicators, Energy Policy, 36:2674-2684.

[5] Rahmann, C; O Nunez; F Valencia; S Arrechea; J Sager; D Kammen; 2016; Methodology for monitoring sustainable development of isolated mini-grids in rural communities, Sustainability, 8, 1163; doi:10.3390/su8111163.

[6] Katre, A. and A Tozzi, 2018, Assessing the sustainability of decentralised renewable energy system: A comprehensive framework with analytical methods, Sustainability, **2018**, 10, 1058; doi:10.3390/su10041058,

[7] Mainali, B and S. Silveira, 2015, Using a sustainability index to assess energy technologies for rural electrification, Renewable and Sustainable Energy Reviews, 41:1351-65.

However, several concerns and criticisms have been raised against the existing frameworks. These include:

1) Lack of attention to long-term perspectives: For example, the indicators do not consider the ability of the systems to meet future needs. The absence of any consideration for the future generations' ability to meet the needs goes against the basic requirement of a sustainable solution.
2) Information requirement: Many frameworks require a large volume of data which are either non-existent or difficult to obtain from the owners of mini-grids. Our fieldwork confirms that mini-grid owners/ operators are reluctant to share financial information. Quantitative data for social conditions are also not easily available and users of mini-grids can only offer qualitative views of the relevance and performance of mini-grids.
3) In addition, some frameworks have been criticised for the prescriptive nature of the attributes used. For example, there is often a presumption that a higher quantity of energy use is better, without realising that such an assumption can go against the environmental desirability of a solution and that the quality of the provision may be more important than quantity.
4) Concerns were also raised about redundancy of indicators, their ambiguity and fit for purpose.
5) User-friendliness of the frameworks has also been commented upon: frameworks are often complex, with stringent data requirements, or are opaque in their descriptors of sustainability dimensions.

The purpose of this report is to present a simple framework that captures the sustainability of mini-grids so that the idea can be applied to the data gathered from the fieldwork in the different countries covered by this project. The idea presented in the technical working paper is extended to include social, economic, institutional and environmental dimensions so that an overall picture of a mini-grid performance can be arrived at. Due to the qualitative nature of the data gathered, the framework would provide a perception of the sustainability performance of a given mini-grid at the time of the fieldwork and would allow a simple comparison across multiple mini-grids within a country and across countries.

FRAMEWORK DESIGN

Figure 1 presents the five dimensions of the framework proposed, namely technical, economic, social, institutional and environmental. Under each dimension, five indicators are being considered to capture the state of play of a mini-grid. These indicators will be assessed using a qualitative scale of low, medium and high level of compliance with a given indicator. A low level of performance will get a score of 1, the medium performance will be given 3 and strong performance will get a score of 5. The maximum score can be 125 and the lowest score can be 25. The details of the performance measures are presented in Table 1.

The technical indicators are similar to what has been proposed in Bukari et al. (2023). The economic indicators capture the affordability of the users, reliance on support (such as grants and subsidies), cost recoverability, integration of productive use of energy and the ability to support future expansion. The indicators for the social dimension include inclusivity, changes in terms of human drudgery, health and educational outcomes, and the level of community engagement. The indicators for the institutional dimension include local ownership, local capacity to manage the system, threat of grid extension, and availability of consumer and investor protection arrangements. Finally, the indicators for the environmental dimension include fossil fuel reduction, indoor air pollution reduction, improvements in air and water pollution and the level of recycling. These indicators follow from our extensive literature reviews and are measured in terms of their degree of contribution. A high value of 5 is used when the mini-grid is making or likely to make a strong contribution to the dimension whereas a low value of 1 is used when the mini-grid is making or likely to make limited or weak contribution. An intermediate value of 3 is used for other cases. Note that the qualitative description in table 1 reflects the nature of the indicator under consideration. For example, a mini-grid that heavily depends on subsidies or grants is considered to be weak in terms of economic sustainability and is given a score of 1. Cases should be examined carefully and scores assigned based on their performance in each sub-indicator.

The advantage of the framework is that it can be implemented using records of field visits where the researchers managed to gain a good understanding of the mini-grid operation at a given location, but where there was reluctance to share quantitative information due to confidentiality or other local reasons. The framework uses a simple scoring system to ensure its ease of application and all dimensions are given equal weights to allow equal importance to all factors.

Fig. 1: Framework for mini-grid sustainability assessment

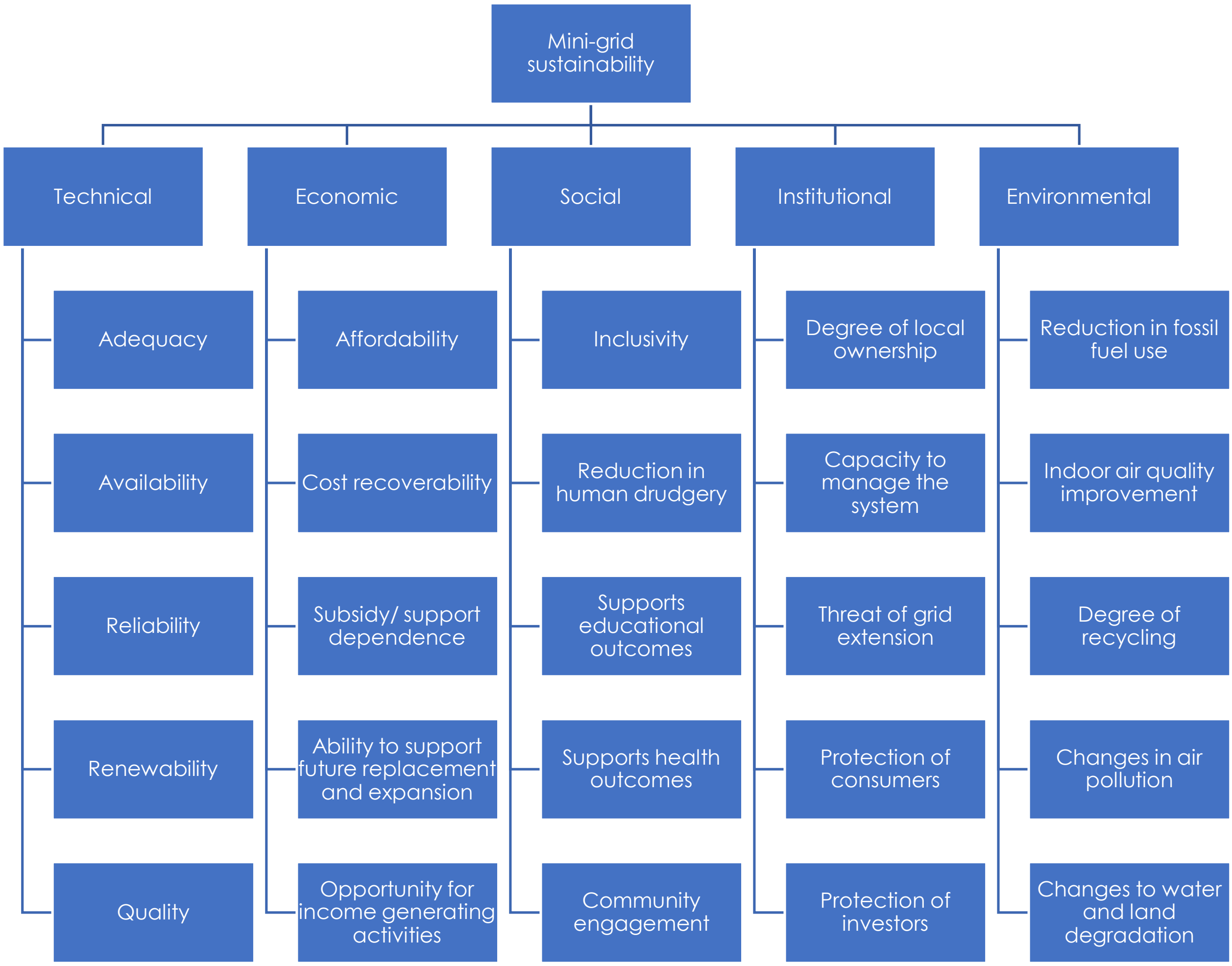


Table 1: Description of the framework components and measures

Dimension	Indicator	Measure capturing the indicator	Description of performance level		
			Low (1 point)	Medium (3 points)	High (5 points)
Technical	Adequacy 1 (50%)	How likely is the system to meet users' needs now?	Barely meets the demand	Regularly meeting the demand	Always meeting the demand
	Adequacy 2 (50%)	How likely is the system to meet the demand in the future?	Unlikely	Quite likely	Most likely
	Availability	Duration of supply: limited, fixed time or uninterrupted	Limited, short duration (2 -3 hours)	Fixed duration (6-8 hours)	Uninterrupted supply
	Reliability	How reliable is the supply?	Unreliable	Moderately reliable	Highly reliable
	Renewability	Share of renewable energy mix	Low mix (<20%)	Medium level (20-50%)	High (>50%
	Quality	Stable or unstable supply?	Unstable	Generally stable, with some fluctuations	Highly stable, with low levels of fluctuations
Economic	Affordability	Can users bear the tariff charges?	Weak (many reporting difficulty)	Generally affordable (few reporting difficulty)	Highly affordable (no complaints)
	Cost recoverability	Is the system recovering costs?	Inadequate (costs > income)	Breaking even or low margin	Generating sufficient profit margin
	Subsidy/support dependence	Degree of dependence on support	High dependence on capital and operating cost subsidies	Dependence on capital grant/ subsidy but covers operating costs	Low dependence on subsidies

	Ability to support future replacement/ expansion	Is the plant likely to support replacement and expansion?	Unable	Marginally able	Confidently able
	Income generating opportunities	To what extent has the project supported any economic activities?	No or very limited evidence	Modest level (with evidence of some regular activities)	High (supporting a wide range of activities)
Social	Inclusivity	Is the access reaching all potential users?	No, only who can afford to or are able to pay	Mostly, except those unwilling to join	All inclusive
	Reduction in human drudgery	Extent of reduction	Limited evidence	Modest evidence	Strong evidence
	Educational outcomes	Extent of improvement	Weak evidence	Moderate evidence	Strong evidence
	Health outcomes	Extent of improvement	Weak or no change	Some evidence of improvement	Strong evidence of improvement
	Community engagement	Level of engagement	Poor (hardly any consultation or participation)	Some consultation and participation	Strong, inclusive participation
Institutional	Degree of local ownership	Share of local ownership	No or very low local ownership (<20%)	Moderate level of local ownership (20-50%)	Majority local ownership (>50%)
	Local capacity to manage the system	Extent of local ability to manage the system	Poor evidence of any local capacity	Some evidence of local capacity	Strong evidence of local capacity
	Threat of grid extension	Extent of the threat and potential for stranded assets	Strong (imminent)	Some threat (in less than 5 years)	Limited or no threat
	Consumer protection	Procedures and capacity to protect consumers	None or poorly developed	Some protection available	Robust protection system

	Investor protection	Procedures and capacity to protect investors	No protection	Some protection	Strong, formalised protection
Environmental	Reduction in fossil fuel use	Extent of fossil fuel replacement	Low or no reduction	Moderate reduction (20-50%)	Strong reduction (>50%)
	Indoor air quality improvement	Degree of improvement	Low or no change	Moderate change	Significant improvement
	Changes in air pollution	Degree of improvement	Low or no change	Modest change	Strong change
	Degree of recycling	Extent of recycling	Low or no change	Some recycling evidence	Strong recycling measures embedded
	Changes to water pollution and land degradation	Level of improvement	Low or no change	Some evidence of improvement	Strong evidence of improvement
Overall	Overall score for the mini-grid				

APPLICATION TO THE MINI-GRIDS VISITED IN KENYA

The above framework was applied to the mini-grids visited in Kenya as part of the SIGMA fieldwork, and based on the information gathered from the sites, a qualitative evaluation was performed of the sustainability of these mini-grids. A separate report provides the details of the fieldwork through which data was collected (see Onsongo et al., 2023)[8]. Data for 15 mini-grids were used in this study to present an evaluation of their sustainability.

The details are presented in the Annex and the summary of the results by dimension is presented in table 2 (in descending order). The highest score is 78 (for Kalobeyei Settlement mini-grid) whereas the lowest score is 41 (Oloika plant). The lowest score is about 32% of the maximum possible score whereas the highest score is about 62% of the maximum possible score. The table also suggests that a majority of the mini-grids in the Kenyan sample lie between 50 to 60% of the maximum score. This implies that most of the plants are performing somewhere in between, and there is potential for significant improvement in terms of sustainability.

Table 2: Summary of sustainability evaluation of mini-grids in Kenya (for selected cases)

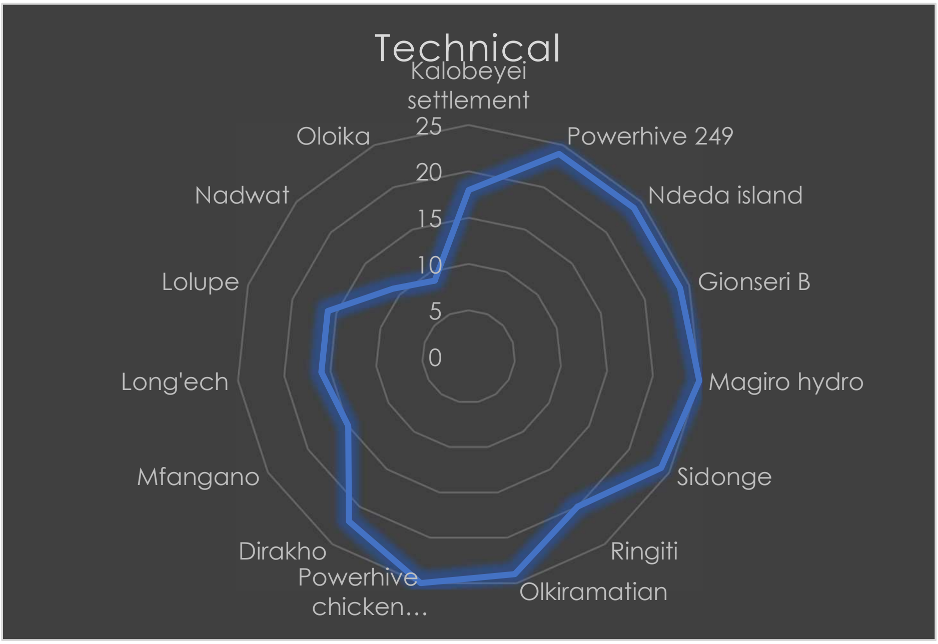
Plants	Technical	Economic	Social	Institutional	Environmental	Total
Kalobeyei settlement	18	21	13	15	11	78
Powerhive 249	24	15	15	11	11	76
Ndeda island	24	17	13	15	7	76
Gionseri B	24	15	15	11	11	76
Magiro hydro	25	15	15	11	9	75
Sidonge	24	17	17	11	5	74
Ringiti	20	15	15	15	7	72
Olkiramatian	24	17	11	13	7	72
Powerhive chicken slaughterhouse	25	17	5	19	5	71
Dirakho	22	15	15	13	5	70
Mfangano	15	15	15	19	5	69
Long'ech	16	15	9	17	5	62

[8] Onsongo, E., Okoko, A., Onjala, B., Nyumba, R. & Kausya, M. (2023) SIGMA Project: Kenya Fieldwork Report. SIGMA Fieldwork Report No.1, 2023

Lolupe	16	9	13	15	5	58
Nadwat	11	9	7	15	5	47
Oloika	9	7	9	11	5	41

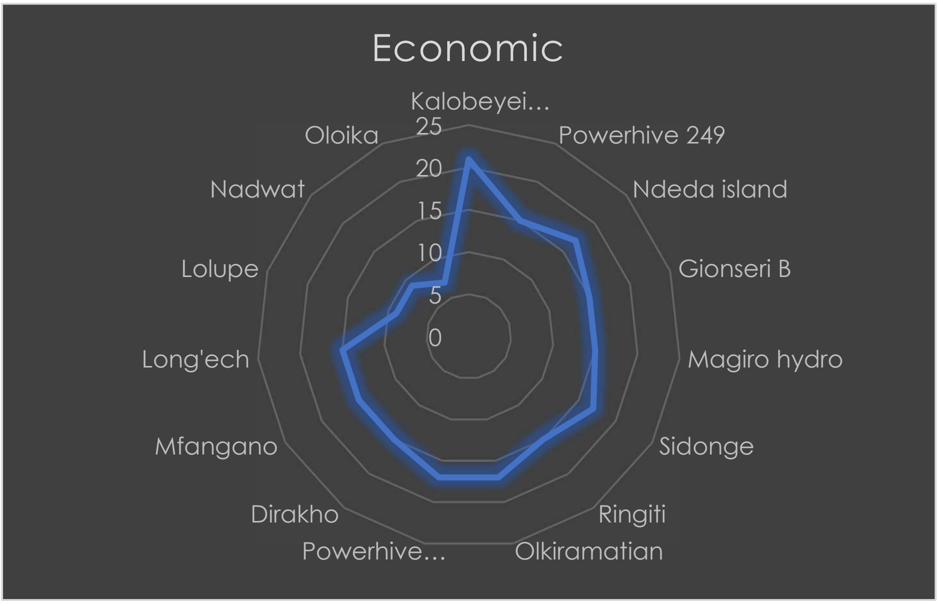
Figures 2 to 7 capture the comparative position for different plants for different dimensions. The scores are out of 25 for each dimension but it can be seen that most of the scores are much lower than the maximum possible score, except for the technical dimension. Several mini-grids are performing at the highest technical level of sustainability but some also have demonstrated poor performance.

Figure 2: Technical sustainability scores



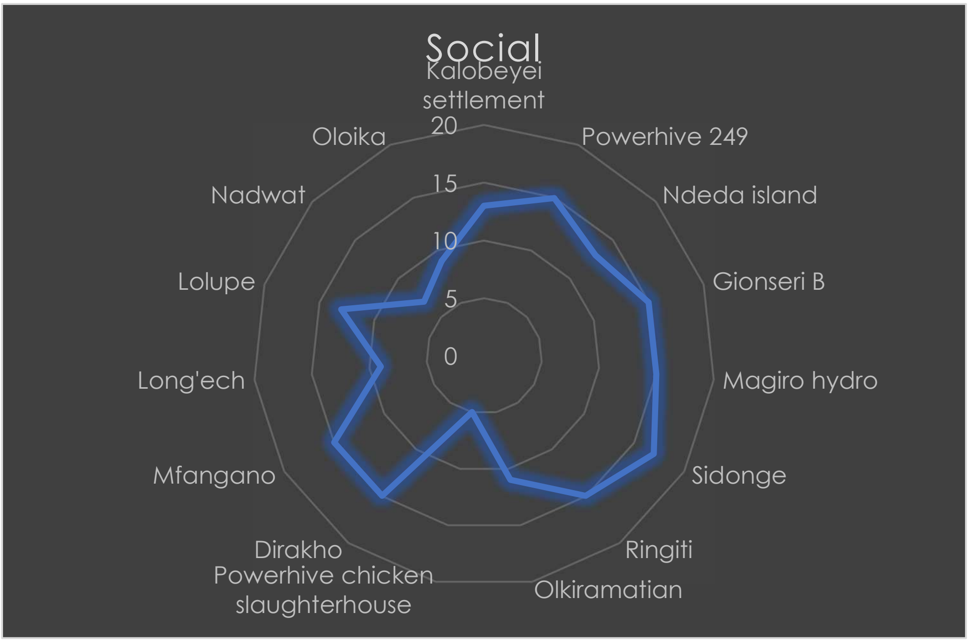
On the economic dimension, most of the plants have scored between 50 to 60% of the maximum score, suggesting the difficulties faced by mini-grids in economic terms. The dependence on subsidies, limited income generation opportunities, limited affordability and low cost recoverability are contributing to the low scores for this dimension.

Figure 3: Economic sustainability scores



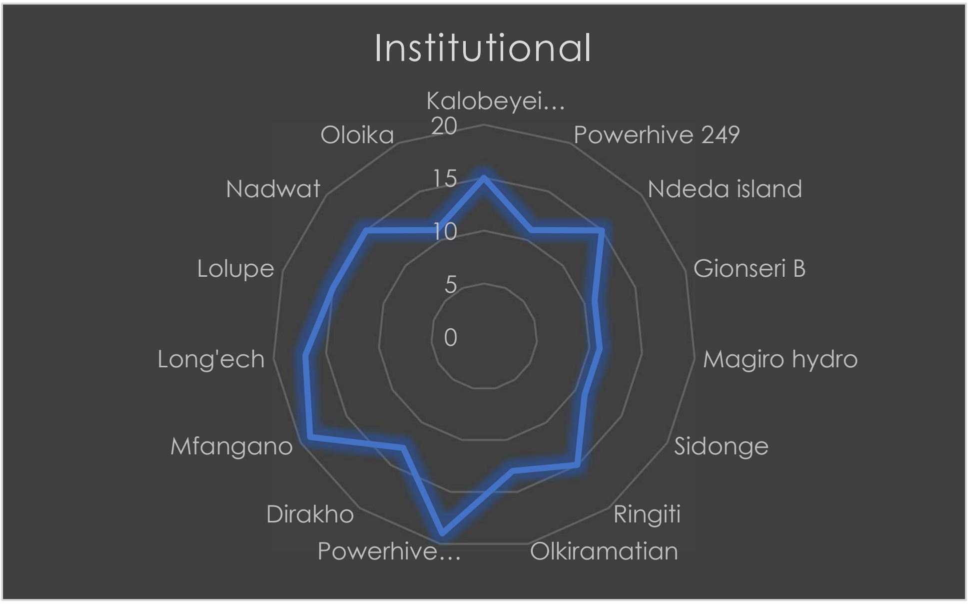
In the social dimension, the performance remains mediocre, with a majority of the plants scoring between 50 to 60% of the maximum possible score. A few plants are performing at a much lower level – indicating their limited contribution to inclusiveness, and other social outcomes.

Figure 4: Social sustainability scores



The scores for the institutional dimension vary widely. Only one plant has scored above 70% of the maximum, with six plants averaging a score of 60%. The majority of the plants have received scores in the 40% range. The rest have performed weakly and received lower scores. Limited local capacity, low consumer and investor protection arrangements and the threat of grid extension have contributed to the institutional weakness.

Figure 5: Institutional sustainability scores



Mini-grids relying on renewable energy technologies reduce fossil fuel dependence but the contribution of mini-grids to the environmental dimension can be limited due to limited use of electricity for cooking and heating purposes, where biomass use still remains high. The low scores in this dimension arise from these weaknesses.

Figure 6: Environmental sustainability scores

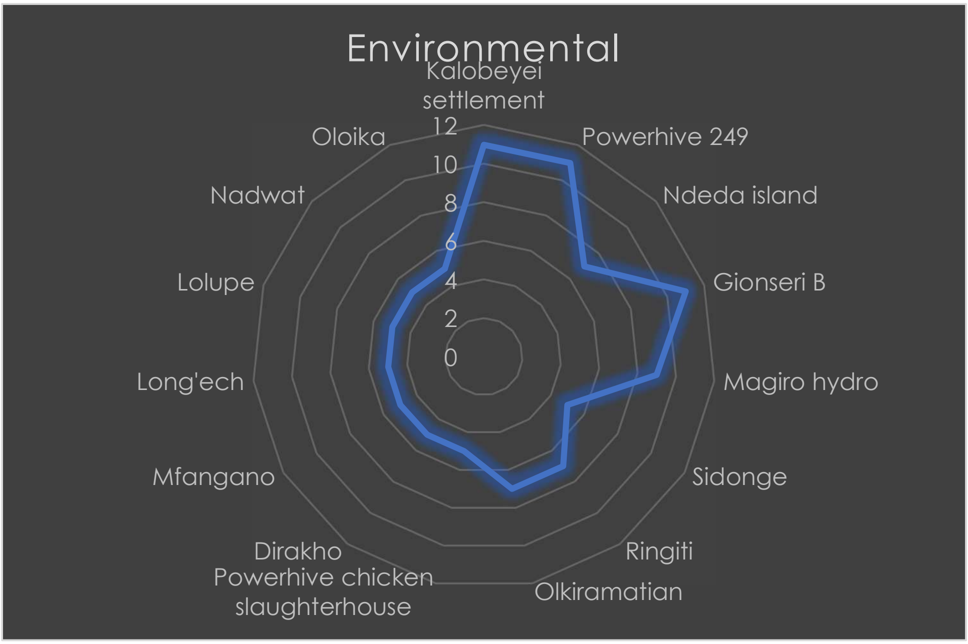
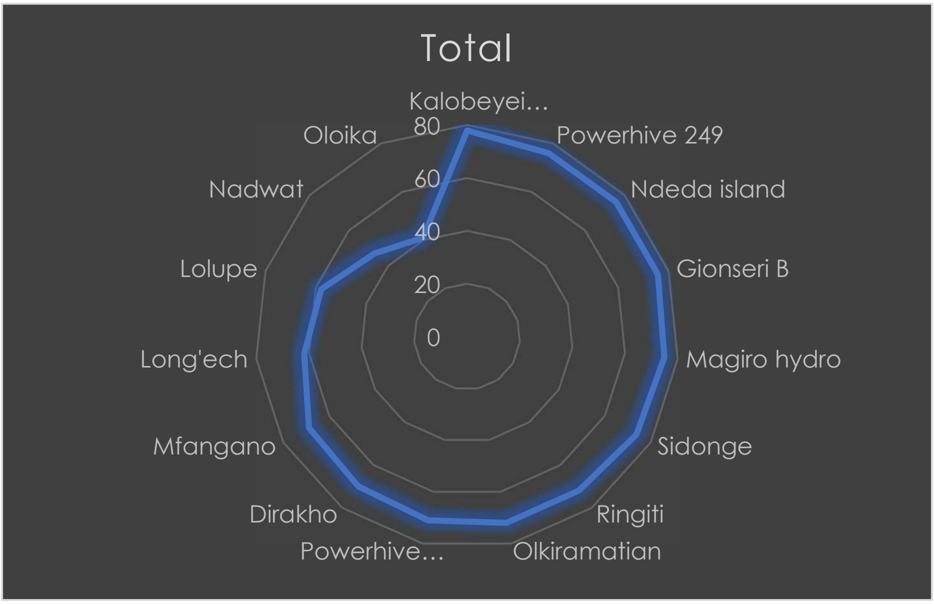


Figure 7: Total sustainability scores



DISCUSSION

Kalobeyei Settlement mini-grid, which is a solar mini-grid, has received the highest score in this study. This plant was commissioned by Renewvia, with support from EnDev, and offers electricity at rates comparable to those of the national utility, Kenya Power, thanks to substantial subsidies from donors. Following an expansion funded by the Kakuma Kalobeyei Challenge Fund (KKCF), a program facilitated by the International Finance Corporation (IFC), the mini-grid has now become the largest in East Africa, catering to nearly 2500 households, businesses, health facilities, schools, and international organizations located within the refugee settlement.

The lowest score went to the Oloika plant. The plant is not operating optimally due to technical issues, specifically battery failures and aging battery installations. The plant is currently operating without any storage, which implies no electricity at night when users need it most. The local cooperative managing the project has no relationship with the country administration and consequently, the plant is not benefitting from technical assistance from the government. The financial resource management remains weak and the initial benefits realised through the electrification process could not be sustained. This is an example of the sustainability challenges being faced by mini-grids promoted by international agencies.

The diesel – solar hybrid plant in Mfangano island (the Mfangano mini grid) deserves a special mention here. The plant is owned by the national utility company Kenya Power. The tariff charged is the same as what the rest of the country pays, which was way low compared to what other Solar PV mini-grids charge. The mini-grid boasts significant capacity, efficiently supplying electricity to the entire island. The mini grid serves the entire island supporting a variety of businesses, such as an ice making plant, fish farm, salons, barbershops, entertainment venues, and tourist hotels. The power is stable, reliable, and they rarely experience any outages unless there is delays in the delivery of the diesel to the island.

Community involvement during the construction phase was substantial, with local volunteers contributing their time and effort to assist in equipment off-loading. Moreover, the community played a pivotal role in determining the mini-grid's location. Operational and maintenance responsibilities are efficiently managed by dedicated Kenya Power staff stationed within the area. External assistance is only sought for major repair works like the repair of faulty transformers or destroyed power lines. Despite relying mainly on diesel, the mini-grid is supporting the local island community very strongly.

Similarly, the only hydro-based mini-grid in the sample (Magiro Mini-grid) coexists harmoniously with the main grid. The mini-grid reports no instances of conflict with Kenya Power. On the contrary, it is actively expanding its operations within the region. Their tariffs are low compared to other Solar PV mini grids, even cheaper than the Kenya Power tariffs. This affordability has positioned the mini-grid as the preferred electricity source for many households in the area. The electricity is stable, reliable, and the hydro plant has enough capacity, hence it is preferred by households over the Kenya Power electricity which unstable in that area. Most of the households use electricity from the Magiro mini-grid,and Kenya Power electricity serves as a backup.

The electricity provided by this mini-grid supports many kinds of end-use, and has been able to support a wide range of businesses, schools and other institutions. The founder and some HydroBox (the external investor) staff are based in the area, and they train interns from a nearby polytechnic to increase the local capacity. They heavily involved the community in the construction phase and some of the workers and the founder are from the area. This again shows the importance of active local engagement in the sustainability of mini-grids.

CONCLUSIONS

This paper has presented a simple indicator-based framework for sustainability evaluation of mini-grids. The evaluation using this framework can be performed using qualitative information gathered from the projects through field visits, stakeholder interactions and any secondary information available on the project. Five dimensions were identified for the sustainability analysis, namely technical, economic, social, institutional and environmental and each dimension has received equal weight. All dimensions are evaluated using five indicators, except for the technical dimension where 6 indicators have been used, with two indicators given equal weighting, keeping the overall distribution between dimensions the same.

A scoring system using a three-point scale has been developed to capture the low level, intermediate level and high level of sustainability. The maximum possible score for each dimension is 25 and the total maximum possible score is 125. The scoring system allows visualisation and comparison of performance across different plants at a given time.

The framework has been applied to 15 mini-grids visited by the team in Kenya. The application clearly captures the relative performance of mini-grids. The results indicate that high scoring mini-grids are all performing very well technically and they have supported economic activities well. These plants have also managed to offer affordable and somewhat inclusive supply. But there are weaknesses in institutional and environmental dimensions for most plants. Those receiving low scores have not ensured long-term technical performance and consequently, they have demonstrated weaknesses in terms of income generating activities, social outcomes as well as environmental and institutional performances.

Although the framework is easy to use and can capture the sustainability performance well, the scoring process remains inherently subjective. However, this is a criticism that remains true for any qualitative ranking methodology. As long as the methodology is used with care and is supported by evidence, the subjectivity is unlikely to affect the outcomes significantly.

Annex 1: Details of sustainability scores

			Mini-grids from Kenya														
Dimension	Indicator	Measure capturing the indicator	Oloika	Olkiramatian	Ndeda island	Ringiti	Mfangano	Powerhive chicken slaughterhouse	Powerhive 249	Gionseri B	Sidonge	Dirakho	Long'ech	Lolupe	Nadwat	Kalobeyei settlement	Magiro hydro
Technical	Adequacy 1 (50%)	How likely is the system to meet the needs now?	1	5	5	3	5	5	5	5	5	5	3	3	1	3	5
	Adequacy 2 (50%)	How likely is the system to meet the demand in the future	1	3	3	1	5	5	3	3	3	3	1	1	1	5	5
	Availability	Duration of supply: limited, fixed time or uninterrupted	1	5	5	5	3	5	5	5	5	5	3	3	3	3	5
	Reliability	How reliable is the supply?	1	5	5	5	3	5	5	5	5	3	3	3	1	3	5
	Renewability	Share of renewable energy mix	5	5	5	5	1	5	5	5	5	5	5	5	5	5	5
	Quality	Stable or unstable supply?	1	5	5	3	3	5	5	5	5	5	3	3	1	3	5
Economic	Affordability	Can users bear the tariff charges?	1	3	3	3	5	5	3	3	3	1	1	1	1	5	5
	Cost recoverability	Is the system recovering costs?	1	3	3	3	1	3	3	3	3	3	3	1	1	5	3
	Subsidy/ support dependence	Degree of dependence on support	1	3	3	3	1	1	3	3	3	3	3	1	1	1	1
	Ability to support future replacement/ expansion	Is the plant likely to support replacement and expansion?	3	5	5	3	3	3	3	3	5	5	3	3	3	5	3
	Income generating opportunities	To what extent has the project supported any economic activities?	1	3	3	3	5	5	3	3	3	3	5	3	3	5	3
Social	Inclusivity	Is the access reaching all potential users?	1	3	3	5	3	1	3	3	3	3	1	3	1	3	3
	Reduction in human drudgery	Extent of reduction	1	1	1	1	1	1	3	3	1	1	1	1	1	1	3
	Educational outcomes	Extent of improvement	1	1	3	3	3	1	3	3	5	3	3	3	1	3	3
	Health outcomes	Extent of improvement	3	3	3	3	3	1	1	1	3	3	1	3	1	3	3
	Community engagement	Level of engagement	3	3	3	3	5	1	5	5	5	5	3	3	3	3	3
Institutional	Degree of local ownership	Share of local ownership	3	1	1	1	3	1	1	1	1	1	5	5	5	1	3
	Local capacity to manage the system	Extent of local ability	1	1	3	3	3	3	3	3	3	3	1	1	1	3	3
	Threat of grid extension	Extent of the threat and potential for stranded asset	5	5	5	5	5	5	1	1	1	3	5	3	3	3	1
	Consumer protection	Procedures and capacity to protect	1	3	3	3	3	5	3	3	3	3	3	3	3	3	3
	Investor protection	Procedures and capacity to protect	1	3	3	3	5	5	3	3	3	3	3	3	3	5	1
Environmental	Reduction in fossil fuel use	Extent of fossil fuel replacement	1	3	3	3	1	1	3	3	1	1	1	1	1	3	3
	Indoor air quality improvement	Degree of improvement	1	1	1	1	1	1	3	3	1	1	1	1	1	3	1
	Changes in air pollution	Degree of improvement	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1
	Degree of recycling	Extent of recycling	1	1	1	1	1	1	3	3	1	1	1	1	1	1	3
	Changes to water pollution and land degradation	Level of improvement	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Technical			9	24	24	20	15	25	24	24	24	22	16	16	11	18	25
Economic			7	17	17	15	15	17	15	15	17	15	15	9	9	21	15
Social			9	11	13	15	15	5	15	15	17	15	9	13	7	13	15
Institutional			11	13	15	15	19	19	11	11	11	13	17	15	15	15	11
Environmental			5	7	7	7	5	5	11	11	5	5	5	5	5	11	9
Total			41	72	76	72	69	71	76	76	74	70	62	58	47	78	75