PROJECT 'MUMUNI SINGANI':

A BLUEPRINT FOR CLEAN ENERGY PROVISION AND SUSTAINABLE DEVELOPMENT IN RURAL ZAMBIA.

The Integrated Infrastructure and Services Concept (IISC)

IMPRINT

Authors:
Susann Stritzke, Tonny Kukeera
Smith School of Enterprise and the Environment / University of Oxford

With a special contribution from
Youth Development Organisation Zambia (YDO)

Project Principal Investigator:
Aoife Haney

Photos:
Susann Stritzke

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1 Executive Summary

Over 95% of the population in rural Zambia have no access to the electrical grid. Distributed energy solutions such as solar mini-grids are considered to be the least-cost solutions for many rural areas in sub-Saharan Africa as grid extension is economically not feasible.

A number of solar PV mini-grid solutions have been installed across rural Zambia but they face substantial challenges. They are not economically sustainable and the energy generated cannot be fully utilized. One reason for these problems is a mismatch between community energy needs, affordability, and the design of the energy system. A second reason is the isolated implementation of an energy solution without considering the complex socioeconomic context of the rural settings. To date, developers and communities in Zambia and across SSA face a substantial challenge to develop sustainable off-grid solutions which are financially viable and facilitate long-term socioeconomic development in communities [1].

The research project 'Mumuni-Singani' aims to tackle these challenges by developing a blueprint for a renewable energy (RE) project that addresses rural community energy needs in Zambia other sub-Saharan African countries.

The concept is based on substantial community research and has been developed in partnership with local NGOs and private sector companies from the RE sector. It aims to overcome the sustainability challenges by converting the predominant isolated approach of only providing electricity, towards an 'Integrated Infrastructure and Services Concept (IISC)' for rural communities.

The IISC is based on data evaluation for three pilot sites in the Southern Province of Zambia. It is designed to tackle the interdependent challenges of rural communities by applying a holistic approach. The IISC integrates the provision of clean energy through solar PV mini-grids, the support of its productive use by the inclusion of the local value chain of goods, especially in the agricultural sector, clean cooking, irrigation solutions and economic re-forestation solutions. Hence, IISC aims to support to stabilize and increase local income and resilience to climate change.

As a blueprint for implementation, the concept incorporates the inclusion of local communities and their representatives to ensure service solutions that are tailored to the needs, potentials, and market conditions of these communities. The cooperation with Women-Self Help groups as key enablers and beneficiaries of such a project would enhance gender equality and -inclusion in rural communities.

The provision of clean energy to local clinics as part of the concept will improve the service quality of these institutions and enable them to enhance their economic basis for future investments. The integrated service concept also aims to reach the 'last mile' of clean energy supply by incorporating mobile battery solutions which will enhance the outreach of clean energy as well as its sustainability by optimizing the utilization of the power generated by the solar PV mini-grids.

2 Acknowledgements

The research for project 'Mumuni Singani' was performed through a collaboration between researchers from the University of Oxford, the University of Zambia, Youth Development Organisation Zambia (YDO)and Buffalo Energy Zambia. The research for the Mumuni project would not have been possible without the dedicated field research support from Partner Siabutuba and Lindiwe Habanyama from YDO.

The authors also acknowledge the work of research for project 'RISE'[1] which was conducted by an international team of researchers from the University of Cape Town and the University of Oxford as key data generated by the project helped to develop the IISC.

Special thanks for supporting the projects go to the leaders of the Women Self-Help Groups in Singani District represented by Mrs Loveness Mungamelo, Chiefs Cooma and Chief Njawa for facilitating the research as well as the communities of Siachimputi, Njawa, Pangwe, Chooye and Sianvula for the warm welcome and enthusiasm to support the project. We would also thank the private sector and institutional stakeholders including the Ministry of Zambia for providing information and participating in the surveys.

The support of the Economic and Social Research Council (ESRC) and the Global Challenges Research Fund (GCRF) for both projects is gratefully acknowledged.

[1] https://www.smithschool.ox.ac.uk/research/rise-renewable-energy-innovation-scale/

3 Introduction

Project 'Mumuni Singani' stands for 'Light in Singani' in Tonga, the local language spoken in the research area.

95% of the population in rural Zambia lack electricity access. Oxford University research suggests 10-15% of these people operate small solar home systems (SHS) as an unreliable energy source (component failures) or small diesel generators with high running costs (approx. 70-80 USct/kWh). Electricity supplied from these sources is too limited for productive use or scaling business.

Fossil energy use for lighting and cooking amplifies deforestation at an average annual rate of 0.91% and the prevalence of respiratory diseases which are currently the number one cause of mortality in the region, especially among children and women. Absent electrification of rural clinics and schools results in poor health services and education, limiting future prospects for generations.

Consequently, over 95% of the people in the area want to change the source of energy, almost 100% want to use it productively mainly for cooling, services and lighting. Long distances to the electrical grid and limited national infrastructure investment erase the feasibility of grid connections.

Decentralised renewable energy solutions including solar PV mini-grids (MGs) are the preferred electrification solution for rural communities but despite 90% willingness to pay more for better electricity access (average ZMW 113 per month), affordability is low. 80% of rural households earn less than USD 80 per month on an intermittent basis. They are mostly small-hold farmers depending on seasonal rainfalls being negatively affected by droughts. Similar challenges have been identified for most rural communities across SSA but limited community engagement during RE project development restricts awareness of rural energy needs. Consequently, most MGs are not financially sustainable, energy generated cannot be fully utilized and projects cannot generate the anticipated positive development impacts.

Through the holistic approach of the IISC, developed by the partners based on substantial research, combining the installation of PV MGs with income stabilization measures and community engagement, the complex challenges of rural communities are directly addressed through irrigation, sustainable farming, clean cooking, the provision of appliances a local value chain approach and training measures to ensure energy affordability and MG sustainability. Mobile Power Hubs charged by the MGs further increase the utilization of the energy. They can provide access for households not directly connected to the MG who are usually left out in conventional approaches having to rely on more costly SHS.

4 Data collection and research approach

- **The report is based on comprehensive empirical data of two research projects**
- **The data is comprised of rural household surveys from Uganda and Zambia, multi-level stakeholder interviews, site-visits and focus group discussions**
- **Research was conducted in cooperation with local partners**

Focus group discussion, Southern Province Zambia, 2019

Empirical data. The findings presented in this report compile a synthesis of empirical data collected through the University of Oxford research projects 'RISE – Renewable Innovative and Scalable Electrification'[2] and 'Mumuni-Singani. The projects applied a mixed-method approach of detailed household surveys, qualitative interviews, focus group discussions and on-site physical data collection (Zambia).

Household surveys. The household surveys were rolled out in two different stages for each research project. For 'RISE', the surveys which focused on general socio-economic conditions, general energy needs and demands including cooking were comprised of 106 questions which were developed and performed in rural Uganda and Zambia (N = 1016) to understand local energy needs. Based on the findings and implications of this first round, the surveys in round two ('Mumuni project') included 54 questions and were focused on gaining a deeper understanding of some of the data collected in round one as well as gaining insights on the potential value chain opportunities for the productive use of energy and were rolled out in two rural communities in the Southern Province of Zambia. The surveys in both rounds were translated into local languages and administered through local NGOs who are aware of the socio-cultural contexts and specifics in the respective rural communities and who have been trained by the research teams. For Zambia, the survey rounds were flanked by site visits and focus group discussions in five rural communities in the Southern Province of Zambia. The focus group discussions included representatives from various stakeholder groups within rural communities such as members of local women self-help groups (SHGs), cooperatives and parent-teacher associations (PTAs), local businesses as well as public representatives such as councillors, health workers and school staff. The site visits included the collection of physical

[2] University of Oxford, 2018 – 2020: https://www.smithschool.ox.ac.uk/research/rise-renewable-energy-innovation-scale/publications.html

data such as population density, local infrastructure, the water and agricultural situation, buildings, existing social or economic groups and their specific energy needs, the conditions with regard to education (schools) and health services (local clinics) as well as environmental observations especially with regard to soil erosion and deforestation. All site visits and group discussions were supported by local NGOs who also advised on the procedures and largely performed in local language (mainly Tonga) and translated for the researchers.

Qualitative interviews. The findings of the qualitative interviews 45 with public sector stakeholders (policy-makers, local leaders, donor organisations and NGOs) and off-grid energy companies, mainly in Uganda, Zambia, Tanzania and the UK interviews have been further verified and specified in the follow-on project with a specific focus on RE project development in rural Zambia.

Case studies. The empirical data collection was complemented by a comprehensive review of MG case studies in a developing context with regard to the financial and operational sustainability of these energy solutions in various regional contexts, mainly Africa and Asia.
The main purpose of the synthesized data evaluation from both research projects is to gain a comprehensive understanding of rural household energy needs, demand and their socio-economic situation in relation to the impact of potential off-grid RE project development with a specific focus on solar PV mini-grids and the development of an infrastructure concept approach that matches a rural community ecosystem and overcomes the most common challenges for the sustainability of solar PV mini-grids in Zambia which is regionally scalable in sub-Saharan Africa.

Ethical review. The process of empirical data collection followed the strict field-research rules and guidelines of the University of Oxford and was subject to ethical approval of the Central University Research Ethics Committee (CUREC).

5 The sustainability of off-grid systems

- **Although mini-grids are considered as the more suitable option for the productive use of energy compared to Solar-Home-systems (SHS), many MGs face serious challenges in terms of energy-uptake and overall sustainability.**
- **MG projects are often implemented with a pure focus on the energy system itself without sufficiently integrating socio-economic determinants of the rural community.**

Mini-grids in rural Zambia. Mini-grids provide energy connections to households that are located further away from the main electrical grid. In Zambia, they are usually owned and operated by private sector companies in collaboration with cooperatives. The size of these systems and the number of connections can vary and lies roughly between 8 kWp and 60 kWp of installed capacity in Zambia. It and can either be a hybrid system of diesel and solar PV for example or based on a single energy source such as hydropower or solar PV, normally in combination with a battery system for energy storage. MGs are usually considered to be more suitable for productive uses of energy than solar home systems (SHS) which are usually sized between 10 Wp and 250 Wp installed capacity [2,3].

Financing and sustainability mini-grids. The majority of RE mini-grid projects in Zambia have been financed through a blend of donor-funded grants of 50, 70 or in some cases even 100% of the total initial investment and private sector investment and [4,5] to mitigate some of the financial risks associated with the operation of MGs in rural areas. Although the importance of decentralised RE MGs for enhancing access to clean energy and the demonstrated positive impacts on rural livelihoods has been recognised, the sustainable operation of these systems remains challenging - especially if the systems are required to operate in a market environment that requires cost-reflective energy tariffs like in Zambia. Financial sustainability of an MG in this context is understood with regard to the initial investment costs or capital expenses (CAPEX), and the operating expenses (OPEX) of the system over its lifespan. In the ideal case, the minimum financial sustainability of an MG means that the non-grant financed share of the CAPEX and the OPEX over the lifespan of the asset would be retrieved by its revenue.

Operation of mini-grids. The sustainability of a mini-grid is directly tied to the utilisation of the energy generated by the system and the recovery of operating costs through steady cash flow and revenue. While technical parameters such as outages or maintenance issues can have some impact on electricity generation, the financial viability of a system is mainly determined by the community context presented in
Figure 1.

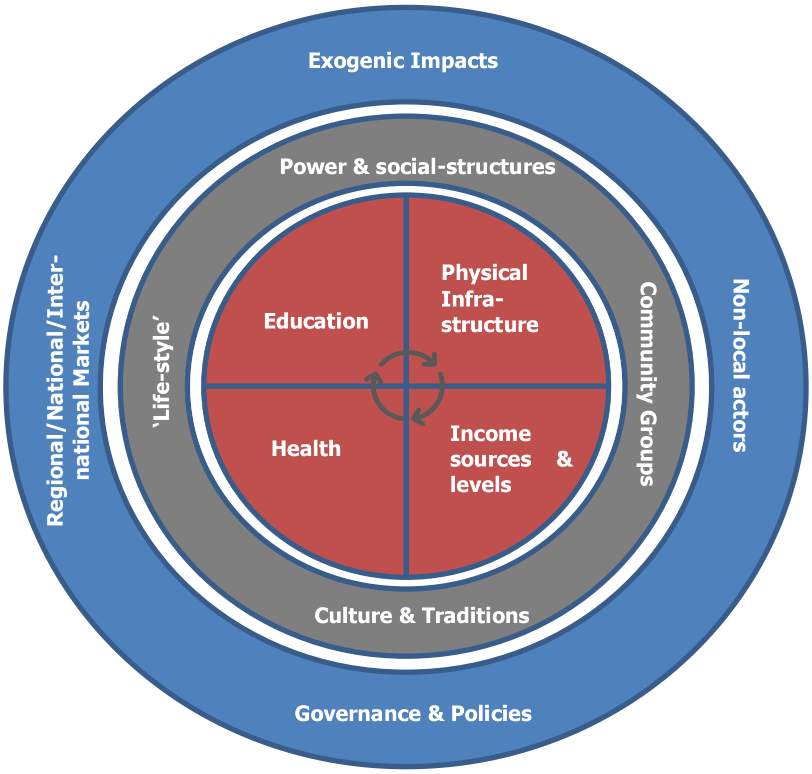

Figure 1 Community Ecosystem: suggested model of interrelated components and meta-level determinants [1]

6 Community Ecosystems as determinants of infrastructure solutions: Rural Household Data Analysis

- **This socio-economic environment of rural communities in SSA establishes complex demands and creates opportunities that are substantial for the sustainability of the infrastructure solution such as solar PV mini-grids**
- **Community survey data illustrates a high demand for electricity and it's productive use but reveals affordability gaps as well training needs to enable added value creation through clean energy use**

Community ecosystem. The literature review and the evaluation of case studies presented in the previous chapter reveals that the development of energy systems for rural communities is often 'top-down' [6].

Complex challenges. The empirical research data illustrates the complex and interrelated socio-economic challenges for rural communities in Uganda and Zambia which can be transferred to many similar settings across sub-Saharan Africa. The potential implementation of energy systems, such as off-grid solar PV mini-grids, as well as other infrastructure solutions needs to be considered within the context of these interrelated challenges which are illustrated in Figure 2 for the case of rural Zambia and the wider socio-economic environment as they directly influence the operations of infrastructure solutions.

Low income levels. The data shown in Figure 3 illustrates, that over 80% of the respondents in Zambia are self-subsistence farmers. They are highly dependent on seasonal rainfalls and average household income levels are low of with around USD25 (K500)[3] which translate into monthly household spending levels of around USD20 per month. over 95% of the respondents in both countries generate their income through some form of self-employment and levels of forms of wage labour are very low.

[3] Currency conversion rates of 03/2021. s

Figure 2 - Socio-economic challenges of rural communities in Zambia

Intermittent income. As a consequence of being self-subsistence farmers who rely on seasonal rainfalls, the majority of the respondents reported that income is highly intermittent as shown in Figure 4. The causes of income fluctuation have been evaluated in more detail and are mainly related to the absence of irrigation solutions and low degrees of agri-processing which leads to an oversupply of produce in some months which leads to decreasing market prices. Due to the high dependency of small-scale farming and the growing of maize as the main cash-crop in Southern Zambia, most respondents can only generate a one-off annual income (around 50%) or, if they are able to cultivate other products such as vegetables, operate small businesses or are engaged in live-stock rearing reported no or low income between 2 to 3 months of the year, mainly between December to February. Droughts as a result of climate change exacerbate these difficulties and threaten food security in the region. While irrigation solutions can be an approach towards extending the growing season for vegetables which enhances income and the diversity of products, on-site visits revealed, that the feasibility of implementing irrigation through additional boreholes is limited in some locations and would threaten the overall water supply due to low groundwater levels. Consequently, water harvesting and storage options should be part of a solution.

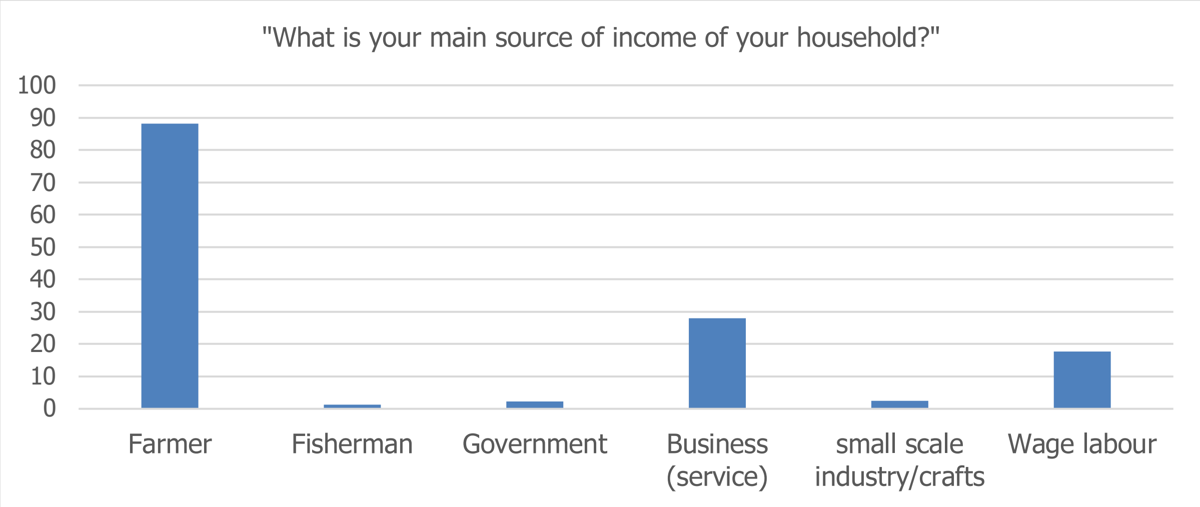

Figure 3 – Main source of income; N=550; Responses in %; Data from project ‚RISE'; Multiple responses possible

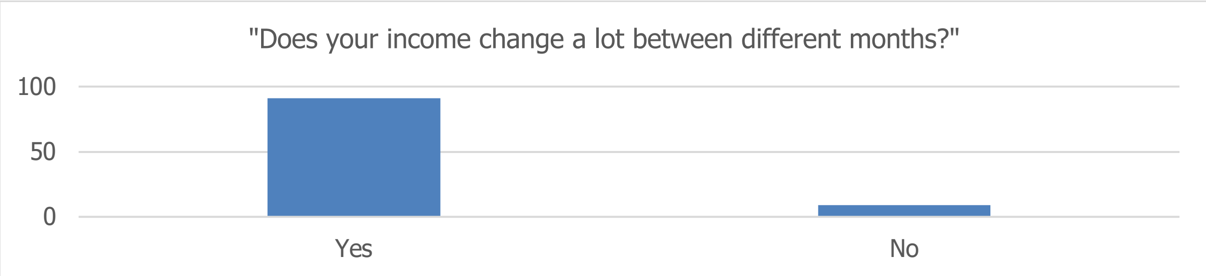

Figure 4: Income Intermittency; N=550; Responses in %; Data from project ‚RISE'; Multiple responses possible

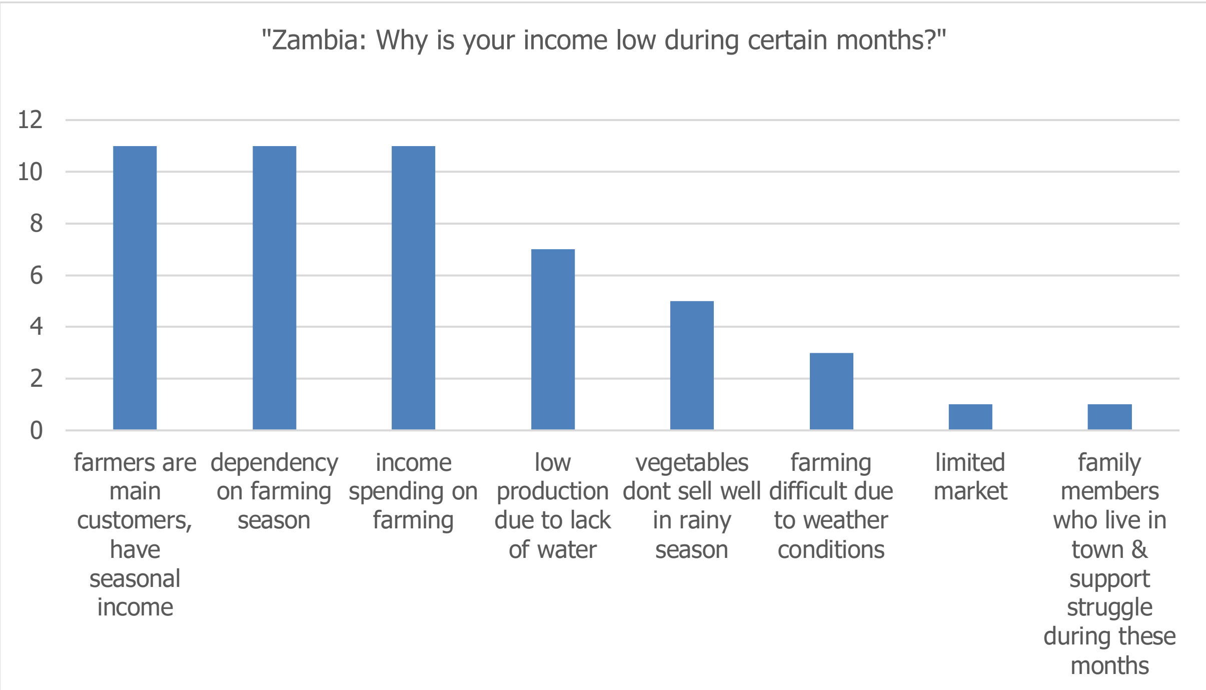

Figure 5: Reasons for low income; village level – Southern Zambia; N= 50; Numeric responses; Data from Project 'Mumuni Singani'; Southern Province Zambia

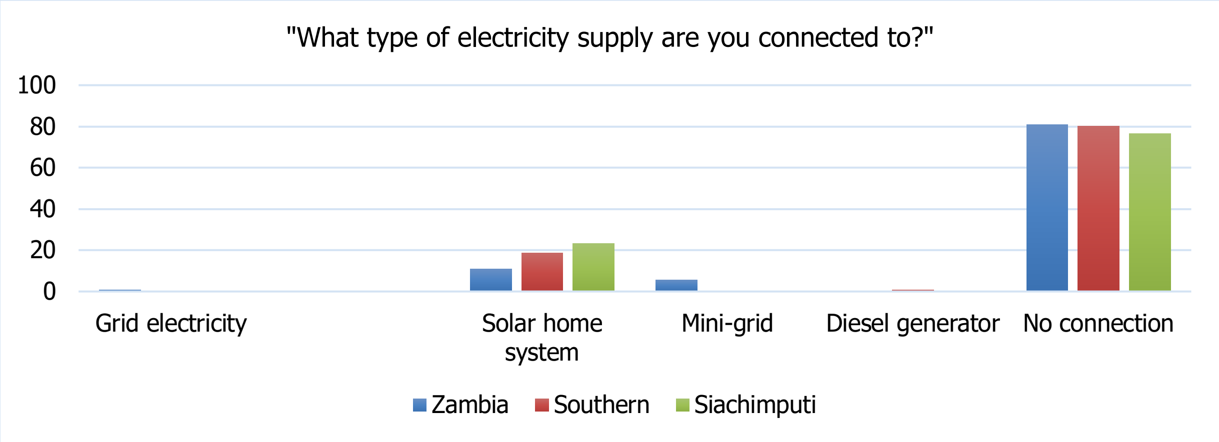

Figure 6: Electricity supply in Zambia; Responses in %; N=550; Data from Project 'RISE'

No/low access to electricity. Figure 6 and 7 show the number and type of connections in Zambia on national -, provincial – and community levels. The most dominant source of energy for those respondents claiming to have energy access are solar home systems (SHS). A further analysis of community-level data on energy connections in the Southern Province of Zambia presented in Figure 7 illustrates, that the majority of respondents relies on portable solar panels or SHS. With regard to financing the surveys revealed that over 90% of these appliances have been obtained as a one-off purchase. 'Pay-as-you-go' (PAYGO) or Rent-to-Own (RTO) financing models are of limited prevalence in the communities surveys and respondents have stated limited availability of these purchasing models. The most common type of connections in both countries (SHS and solar-panels) only permit productive use of energy due on a very limited scale due to the capacity of these installations[4] which corresponds with the data on energy use presented in Figure 8. The data indicates similar energy usage patterns for Uganda and Zambia with energy being mostly used for lighting and charging devices.

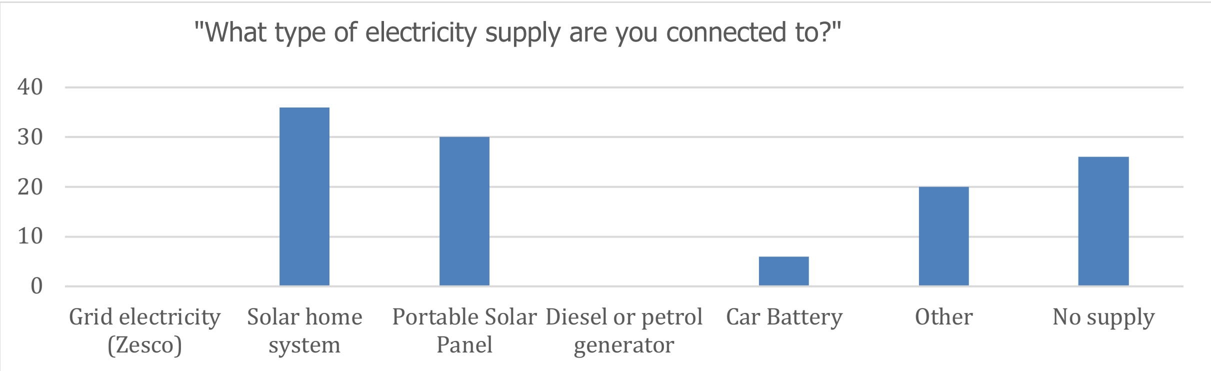

Figure 7 Type of electricity supply – granular data from Zambian community level; N= 50; numeric responses; multiple responses possible

[4] See foe example: I. Nygaard, U.E. Hansen, T.H. Larsen, D. Palit, C. Muchunku, Off-grid Access to Electricity Innovation Challenge, Accel. Clean Energy Revolut. - Perspect. Innov. Challenges. DTU Int. Energy Rep. 2018. (2018) 47–54. https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=NP. [8]

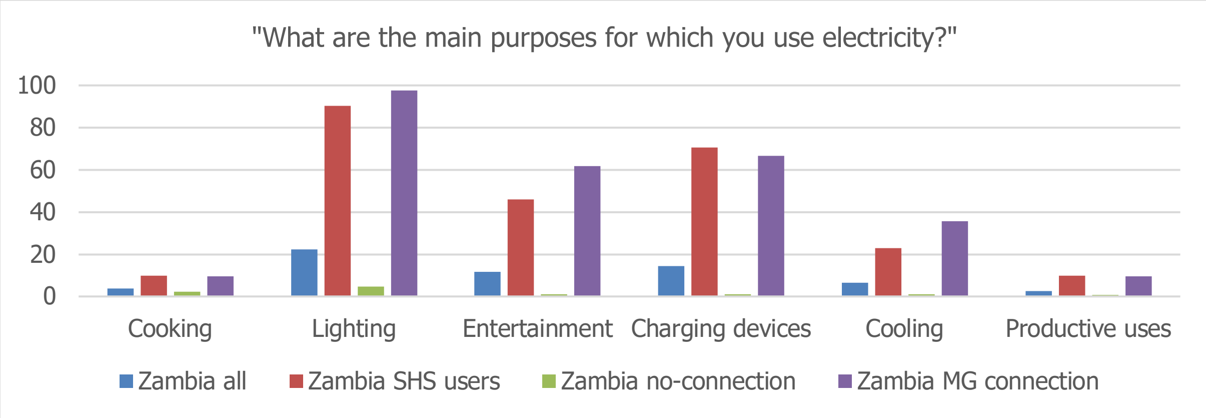

Figure 8 - Energy usage patterns; responses in %; multiple responses possible, combined data from Project Rise (N=550) & *Mumuni Singani (N=50)

Great demand for improved energy access. The surveys have also revealed that a great demand for improved energy supply (98%), willingness to pay for an upgraded electricity supply as well as the intention to use energy productively (over 90%) as Figure 9 shows. However, if asked for what type of activities the productive use of energy would be focused on, Figure 10 reveals a strong tendency towards local services provision which itself would be strongly dependent on the income of expected customers which in turn is very volatile. Hence the data suggests, that in order to support the uptake of the productive use of energy, training measures and local market – and value chain assessments can help to introduce productive uses that creates added-value and helps to overcome seasonal dependency.

The provision of clean energy must be flanked by measures to stabilise and increase local income. The data presented in this section and recent research shows, that low and intermittent income poses a significant challenge in terms of energy affordability which also threatens the financial viability of decentralised RE systems.[1] Consequently, the implementation of a local clean energy solution such a solar mini-grid must include measures that help to overcome income challenges and enable the productive use of energy as substantial part of the project development itself.

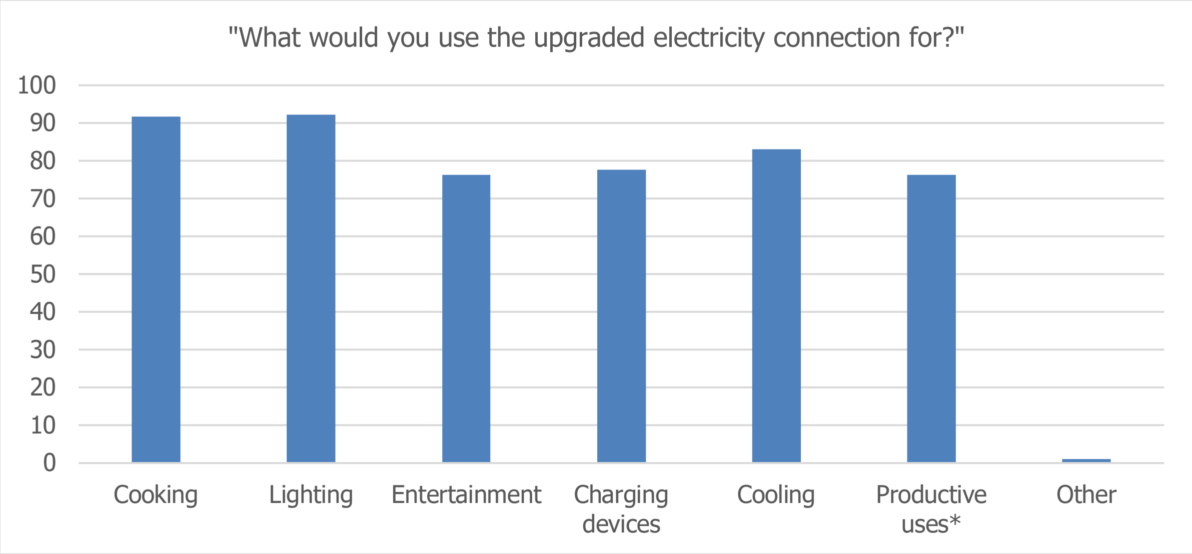

Figure 9 - Desired energy use; responses in %; multiple responses possible, combined data from Project Rise (N=550) & *Mumuni Singani (N=50)

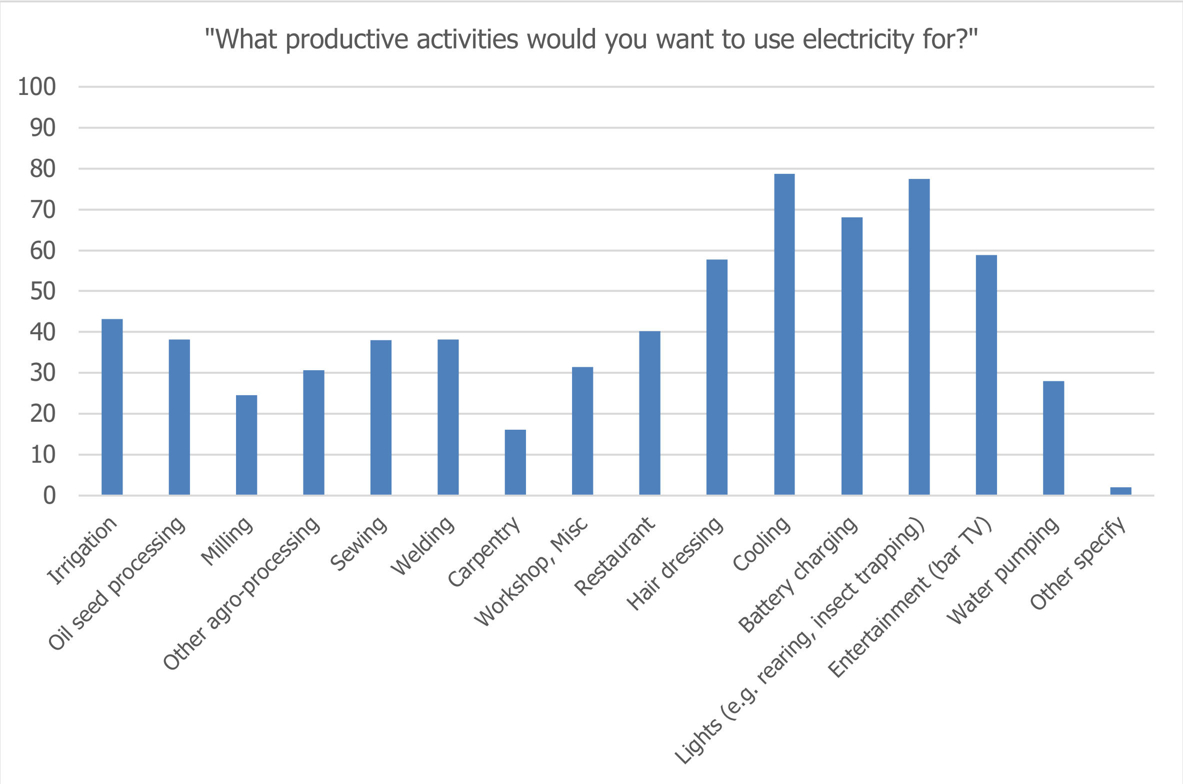

Figure 10 - Desired productive energy use in Zambia; responses in %; multiple responses possible, combined data from Project Rise (N=550) & *Mumuni Singani (N=50)

7 Insight: the local community perspective

The socio-economic structures and dynamics of communities in rural Zambia – a perspective shared by Youth Development Organisation Zambia (YDO), the local implementation partner for project 'Mumuni Singani'

As at 2016, Zambia's population was estimated at 15.9 million of which 57.9 percent was rural-based. While the larger percentage of the population lives in rural areas, the country has had huge development deficits in rural areas, especially in key sectors that can help facilitate growth and development. Rural areas continue to have poor road networks and poor delivery of social services, limited access to electricity with the majority of the population working in the informal agriculture sector, characterized by low productivity.

The underdevelopment of rural areas is attributed to among other factors having a highly centralized system of development delivery which tends to disadvantage rural areas. Also, the fiscal architecture does not allow for direct receipts of resources for development of deprived rural areas. Despite the reported high economic growth in the last 10 years, poverty has remained persistently high at 76.6 percent in rural areas, compared to 23.4 percent in urban areas. The disparity shows that in Zambia, poverty has a rural dimension and the economic gains of the country largely benefit the urban areas.

Although the country recorded steady economic growth during the period 1990-2015, poverty remained the greatest challenge to national development. Poverty trends suggest that overall income poverty prevalence was reduced between 1991 and 2015 by 24.6 percent, although an increase was observed in the late 1990s. The reduction in poverty was more significant in urban areas, where it declined by 25.6 percent, from 49 percent in 1991 to 23.4 percent in 2015. Income poverty in rural areas decreased from 88 to 76.6 percent. The percentage distribution of the population by level of poverty in 2015 showed that 40.8 percent of the population was extremely poor while 13.6 percent was moderately poor. The proportion of the non-poor was 45.6 percent. With the 2015 projected national population at 15.9 million, this meant that 8.5 million people lived in poverty, with 3.5 million of those living in extreme poverty. It is clear that economic growth did not translate into significant poverty reduction, especially in rural areas.

It has been observed that the pattern of economic growth in Zambia is highly unequal and has not increased the incomes of the poor rapidly enough to lift them out of poverty. This is mainly for three reasons: first, economic growth has historically been concentrated in capital-intensive industries such as construction, mining and transport. The second reason is related to the geographical component of growth, where urban areas have gained more than rural areas.
The third reason is related to the structure of the economy; economic growth in the country has not been associated with labor-intensive sectors in which the poor tend to work, such as agriculture.

Because of high levels of poverty, communities are trying all sorts of economic coping mechanisms to just provide for their families. Social conflict and malnutrition is on the increase and different stakeholders have come on board to try and make a contribution to reversing the trend of poverty. Unfortunately, due to weak sustainability of these interventions, no significant positive impact is recorded on the communities. Some of the daily struggles communities are dealing with are related to accessing food, accessing health and education services, water and energy (fire wood) as well as long distances to market to sell their farm produce for household income The high levels of poverty have resulted in many social problems such as Children's rights abuses, increased teenage pregnancies and early marriages among school going girls leading to increased school dropouts, petty crime among youths, increased HIV prevalence has been blamed on poverty as some girls resorted to transactional sex (while it is also true that HIV and AIDS is both a cause and effect of poverty), increased poverty and weak public social protection systems has resulted in many children leaving on streets and streetisim phenomenon is emerging even rural areas where this was least expected. The number of Children scavenging in dumpsites is increasingly seen.. The number of vulnerable households has also been on the rise and comprises people with limited access to essential services that are necessary for human survival such as health, education, water and sanitation. In addition, poor nutrition, which in part is a function of food insecurity in poor households, further erodes the human capital potential. This reinforces the intergenerational transfer of poverty and keeps these households trapped in a vicious cycle of poverty. Vulnerable groups currently include: female-headed households, child-headed households, persons with disabilities, orphaned children, and the chronically ill and elderly people.

There are several power systems and structures that exist at community all concerned with the wellbeing of the community and their daily social-economic struggles. Apart from local Governance structures such as Ward Development Committees, there are structures such as Village Agriculture Committees, Parents and Teachers Committees, Community Welfare Assistance Committees-C-WACS , Religious organisations and NGOs are also part of the community efforts through different community based initiatives all aimed improving the welfare of the community.
In order to make a different, Youth Development Organisation (YDO) with financial help from KinderNotHilfe introduced a Self Help Group (SHG) concept. YDO is currently working with

over 1,300 poorest women in communities in Choma, Kazungula and Pemba Districts by facilitating the formation of Self-Help Groups (SHGs) and Cluster Level Associations-CLAs. The SHG approach has been used successfully across Africa for decades, helping women to empower themselves financially, socially and politically, and enabling them to provide a better quality of life for their children. In partnership with KinderNotHilfe (KNH), YDO has established over 100 SHGs in Choma, Kazungula and Pemba Districts. The SHG is a perfect platform where apart from doing business, learning and supporting each other, Community Facilitators (CFs) engage the women in various social economic and political issues which affect women including HIV and AIDS, child marriages, Violence Against Women and Girls (VAWG) drug and alcohol abuse and participation and how these vices negatively impact on them. The rural women SHGs are a perfect platform and present an opportunity to introduce new community based development ideas as women are receptive to new ideas and willing to try new things.
Women and Youths are easy to mobilise for community development action as opposed to men. Working with local organisation who are present in the community can be cost effective. With over 17 years of working in rural communities and working with poor communities, YDO has learnt that there is need to implement long term social-economic interventions if poverty among the rural poor community was to reduce.

Covid19 pandemic has exacerbated the poverty situation in Zambia. The local and poor community members especially women have had the great deal of covid19 impact as they depend on urban areas for domestic supplies and commodities. Unfortunately the ever increasing cost of commodities due to poor performance of the Kwacha and restrictions on imports due covid19/has made economic coping mechanisms for poor communities unsustainable. In 2020 national budget cycle, Government put in place a number of covid19 economic empowerment programs but nothing of such was deliberately channeled to rural communities. Lack or weak social protection services by Government in the face of covid19 impact is increasing the social and economic vulnerability of rural communities especially women and children. Zambian Health Authorities have reported that covid19 is not going away any time soon, therefore, there is great need to design economic empowerment programmes and activities for women and children cannot be over emphasized as these are the worst hit by the impact of covid19.

Youth Development Organisation was founded and registered in 1997 to give Zambian Youths an opportunity to address and effectively participate in some of the Socio-Economic, Democratic Governance and Youth Participation as well as Environment and climate justice issues affecting them and their communities. YDO is one of the most active, consistent and effective Youth-focused organisations in Zambia. Its ultimate goal is to empower young people, helping them to achieve their potential and shape a better future for Zambia.

https://www.ydozambia.org.zm

8 Recent approaches to increase energy access in Zambia and the context for the IISC

Low rural electrification rate. The rural electrification rate in Zambia stands currently at around 6 per cent. The 'Rural Electrification Masterplan' (REMP) adopted in 2008 identified 1,217 Regional Growth Centres to be electrified by 2030. Due to limitations in national infrastructure investment capacity and remoteness of most of these clusters, rural electrification has largely been outsourced to the private sector in Zambia supported by foreign donor initiatives. Through the 'Beyond the Grid Fund Zambia' around 148,000 off-grid connections, mainly through SHS with connection sizes between 5 to 50W (Tier 1 & 2) have been established by private sector companies in rural Zambia since 2017.[5] However, the size of the connections indicates a limited productive use of energy which is key to sustainable rural development.[6]

The roll-out of MGs in Zambia is still challenging. To date, approximately five to seven solar PV mini-grids have been implemented in Zambia mainly by private companies with significant financial support from foreign donors. An in-depth evaluation of the mini-grids in Zambia with an operation period of +3 years (Mpanta/Sinda) performed by the Universities of Zambia and Oxford reveals significant ongoing technical and financial problems and they do not currently operate financially sustainably.[1] Yet, the number of established RE companies providing sustainable MG solutions in Zambia remains relatively low despite a significant market potential identified by the REMP and supported by low rural electrification rates. These companies largely operate independently from each other: when decentralized energy solutions are provided by a company (SHS, MG), users often lack access to qualitative and affordable appliances to utilize the energy provided due to the remoteness of their location. Limited community engagement during the project stages limit awareness of energy solutions, technical requirements, user options etc. which combined with high levels of rural illiteracy (50-60%) and language barriers (local languages of rural population, English of the developers) further hampers the off-take of decentralized energy solutions, especially solar PV MGs.[7]

[5] https://www.bgfz.org
[6] https://www.smithschool.ox.ac.uk/publications/reports/Smith-School-RISE-Report-final.pdf

9 The Integrated Infrastructure and Services Concept (IISC)

Concept development based on empirical data in collaboration with communities. Based on rural community surveys and site-visit data, the IISC has been developed in cooperation with local and international stakeholders and is taking a community perspective on energy project implementation.
Consequently, the IISC directly addresses the key socio-economic challenges and their interdependencies to enable communities to (1) access clean energy, (2) obtain appliances that can be operated with the energy, to (3) afford clean energy by creating added value through its productive us and business activities and (4) impact the community environment to strengthen their resilience to climate change and limit threats to their economic and social well-being through a coordinated multi-partner approach.

Local partner inclusion. This approach, which is presented in Figure 1, includes the communities at all stages and is facilitated through the cooperation with a partner (LOCAL NGO/PARTNER) that is experienced in working with rural communities and speaks their language.

Value chain approach and support of productive energy use. The value chain approach presented in Figure 2 is developed in cooperation with the community and based on their needs ensuring the optimal utilization of the energy generated from the project and its sustainable long-term operation, generating an immediate significant short-term impact as well as triggering long-term socio-economic development for the community by diversifying economic activities and stabilizing income generation. The tier-based tariff system prioritizes productive use incentivizing the use of energy. A HOMER LCOE simulation (see example in Table 1) based on actual demand and resources avoids oversizing of the system. The concept integrates innovative technologies: road-testing MobilePoWer Hubs as part of IISC and the implementation of an SMS-based consumer information system. It combines the provision of energy and community services into a holistic approach that enhances the effectiveness and impact of each component: The energy produced by the solar PV mini-grid can be utilized and becomes affordable through the integration of sustainable farming, agri-processing and irrigation solutions. Training, especially for Women SHGs and consumer information will help consumers to understand the services provided, enhance their value chain and increase their income. This also entails business development support on a consultative basis. Aggregate power consumption measurements, as well as data about consumption patterns of individual appliances, will be collected using e-monitors and electricity meters, installed on the selected households in the off-grid community (see Figure 3). This will be used by the disaggregation algorithm to generate the disaggregated appliances-wise energy consumption data. Based on this data together with historical consumption data, energy price information data and other usage data, a decision would be taken whether to alert the user through an SMS or shed specific loads, depending on the grid conditions. Mobile Power battery hubs connect remote consumers and contribute to the revenue of the MG.

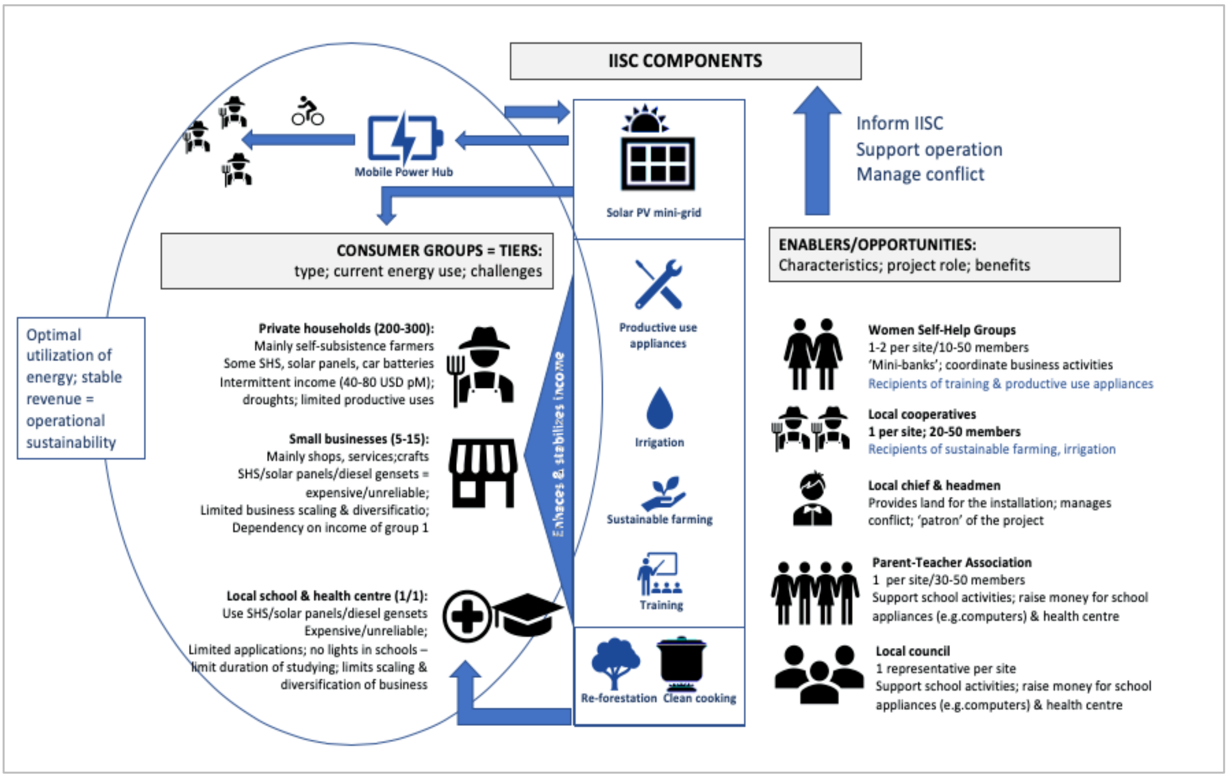

Figure 11: IISC Business Model & key components

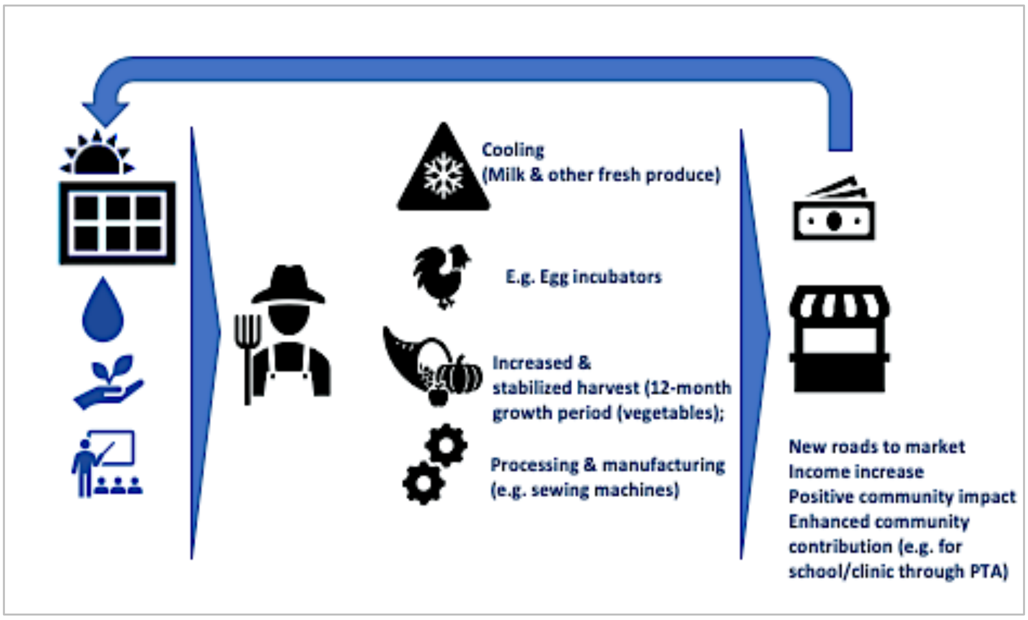

Figure 12 IISC Value chain increase

10 The IISC Model – development of the model and basic assumptions

The necessity of developing an integrated concept for decentralised energy-access systems. The scientific analysis of solar PV off-grid/mini-grid solutions that have been installed in sub-Saharan Africa including Zambia shows that most of these projects are not economically or environmentally sustainable. Reasons for this are a mismatch between community needs and affordability on the one hand and the design of the energy projects on the other. To date, most projects are not designed in a way that connects energy access to other development goals.

Data-driven approach. The basic assumption of the IISC is, that the community ecosystem determines the features of decentralised energy systems [1]. The IISC has consequently been developed on the basis of community data collected between 2018 until 2021 at five sites in Southern Zambia. The specific locations for IISC data collection and potential project implementation have been mapped out using GIS geospatial data and through suggestions provided by the local Chiefs. The selection of the specific projects sites was informed by: (1) urgency to provide clean energy and other infrastructure solutions to enhance food security and economic diversification due to the ongoing drought; (2) established local footprint of the project partners and network of successful Women-Self Help groups (SHGs) as potential off-takers of energy projects; (3) high levels of community support and (4) positive socio-economic prospects related to the provision of clean energy.

The lack of clean energy supply has severe impacts on rural communities. The rural areas of the Southern Province in Zambia share a number of central features with other rural communities across sub-Saharan Africa and which were the starting point of the development of the IISC. These are generally low energy access and income levels, high dependency on self-subsistent farming, the usage of firewood and charcoal which results in high levels of deforestation and respiratory diseases, limited of clean water supply, the dependency on seasonal rainfall patterns and a lack of irrigation systems, a low diversity in crops and unsustainable farming methods, high illiteracy levels as well as unelectrified clinics and schools with low service levels. Simultaneously, rural communities display a great demand for energy, especially for its productive use, but very limited access to reliable energy.

The lack of clean energy supply has severe consequences for the people in the area: (a) Health: lung infections and pneumonia are the main causes of morbidity in the area. (b) Education: local schools and clinics have either no electrical power source at all or rely on small solar installations, which cannot fulfil basic needs of power supply or they run small diesel gen-sets which are expensive and polluting. This directly affects the quality of services these institutions have to supply to an already disadvantaged community, which suffers high levels of illiteracy, especially among women. (c) Economy: The lack of power stalls socio-economic development as local investment (e.g. in machinery and appliances) is automatically limited due to the absence of a reliable and affordable power source.

Rural community challenges require an integrated, innovative approach. To overcome these interdependent challenges and provide for a sustainable operation model for clean energy solutions, an intervention is required that is based on a value chain approach and systematically addresses challenges on rural level which is developed in cooperation with the community and based on their needs. This ensures the optimal utilization of the energy generated from an off-grid project and its sustainable long-term operation, has the potential to generate an immediate significant short-term impact as well as triggering long-term socio-economic development for the community by diversifying economic activities and stabilizing income generation. Agri-processing and selling agricultural products in the market is hampered and a lot of products go to waste due to the absence of cooling or processing options and the needed diversification of economic activities cannot be achieved. The region also suffers from an ongoing drought which has severe health and economic effects as clean water supply becomes further limited and effective irrigation systems are largely absent. The complexity and interdependence of these challenges require a holistic project approach that goes beyond the sole provision of electricity to ensure the sustainable operation of the energy system and to facilitate long-term socioeconomic development in the communities.

Scalability. While the approach has been developed through research from the University of Oxford in cooperation with Local Project Developer, Youth Development Organisation and other partners, it requires to be road-tested to generate practical learning lessons for the scalability of the concept and the cooperation, multi-partner approach which is a new paradigm which provides great potential for the partners involved to access new markets and customers in Zambia and other SSA countries and to enhance the sustainability of their offered services (energy/irrigation/appliances/agriculture etc.) which not only benefits their business models but also enhances the long-term socioeconomic growth of the communities.

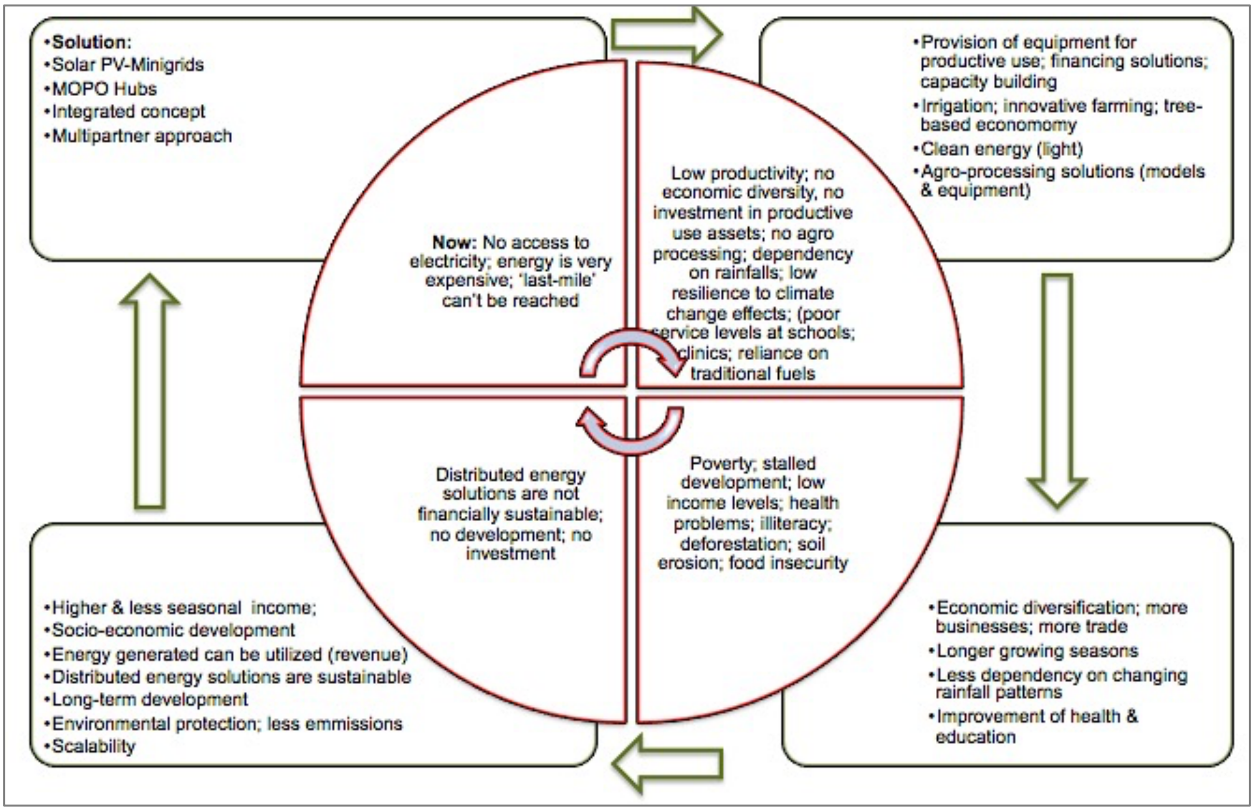

Figure 13 - The IISC Basic Logic Model - Challenges & Solutions

11 Concept Components

11.1 Clean Energy: Solar PV-system (example)

Solar PV mini-grids as the source for clean energy provision. Mini-grids are basically small electricity grids providing electricity to a village, island, building complex etc. The basic technical set-up is electricity generation (which could be solar or a hybrid of solar and diesel Genset), distribution, and consumer as shown in Figure 14. The electricity generation system of each of the three mini-grids in Mumuni is based on solar photovoltaic (PV) panels with a total power of around 30kW.

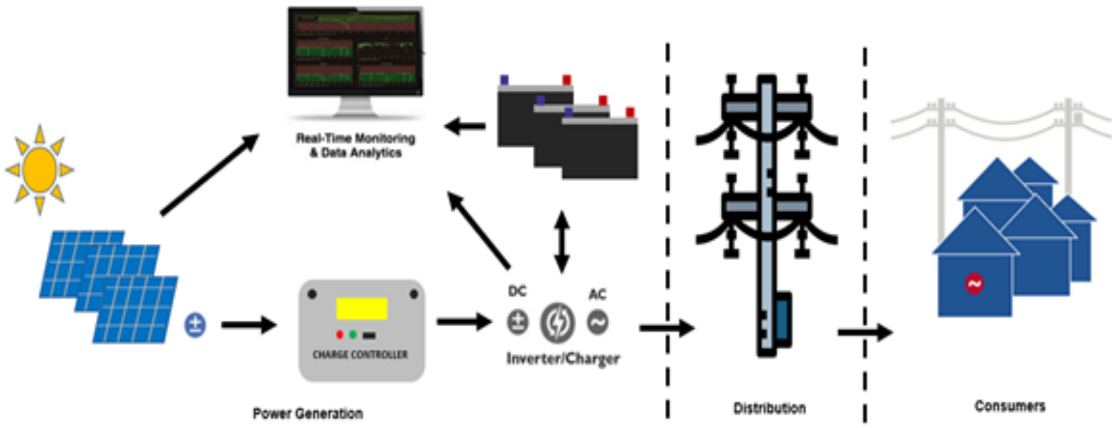

Figure 14 - Basic technical set up of a mini-grid

Productive use of energy as a primary focus. Powering business activities in the local community is an important part of electrifying rural areas and building sustainable and self-reliant households. To enable the success of small businesses in communities, schemes such as tier-based tariffing which make electricity affordable are employed. This not only makes electricity cheaper but also incentivizes and prioritizes the electrification of small businesses - ranging from retail shops and phone charging, barbershops, and agricultural post-harvest technologies such as maize milling machines, refrigerators and drying equipment – which are very critical in creating and building resilience in communities. Powering local health centres and schools is another important part of building sustainable communities. In addition to extending access to essential services (education and health services), it galvanizes community members' involvement in the electrification processes and participation in the development activities of their villages.

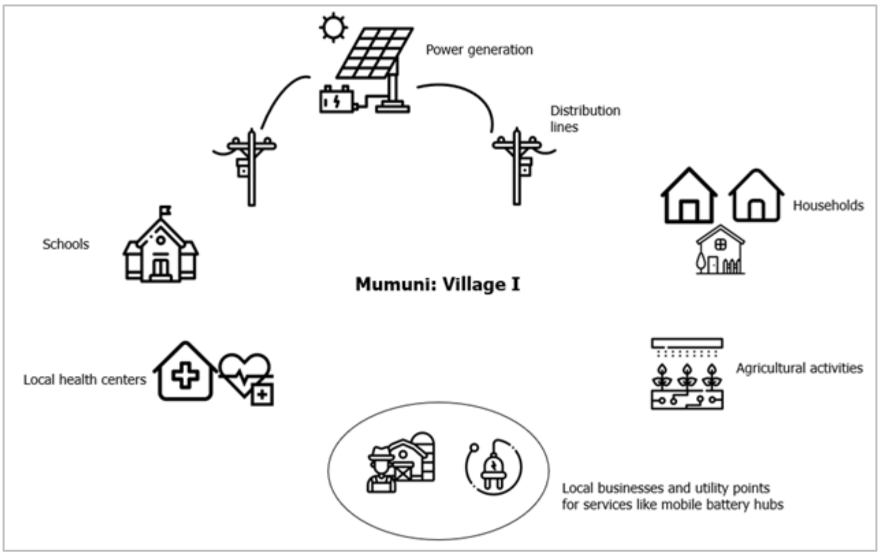

Figure 15 Minigrid ecosystem set up.

Sizing of the system. The detailed sizing of the RE MGs as a key component of the IISC including the technical configuration number and type of connections will be developed site-specific based on a HOMER (Hybrid Optimization Model for Multiple Energy Resources) simulation. On average it can be estimated that 200 to 300 households can be connected to the IISC mini-grid providing clean energy to about 7 members per household. The mini-grid would apply a 3-tiered tariff system for businesses, private households and public service institutions (schools/hospitals). As the main focus of the concept is the provision of clean energy for income generation and productive uses, the energy supply of businesses and service institutions will be prioritised during the planning process.

Tariff scheme and sustainability. Typically, in terms of overall project cost, more than 85% of the overall capital investment comprises hardware, whereas 4-5% are allocated to service, labour and miscellaneous costs respectively. It should be noted that the most important cost components are the PV modules and inverters. Together, they represent more than 70% of the total investment costs and are therefore important drivers of the project's electricity generation costs.

A significant challenge for mini-grids in Zambia and other developing countries is the recovery of the operating costs through the revenues generated by the mini-grid [1]. Local energy tariffs and local affordability due to low and seasonal income are often not aligned and as the data evaluation for IISC shows, the sites evaluated are no exceptions. Although a tariff cannot be fixed in the IISC layout as it depends on the actual implementation costs and financing model, in the case of implementation, the IISC requires a substantial due diligence process between local income and tariffs charged. A tariff subsidy for productive uses of energy that is limited in time could help to trigger productive energy use and income growth in the early phase of the MG. However, this must be aligned with the energy regulatory framework which currently requires cost-reflective tariffs in Zambia for example.

11.2 Irrigation through rainwater harvesting

Irrigation supported by a rainwater harvesting system

The absence of irrigation limits local income opportunities. The majority of the people in rural Zambia are self-subsistence farmers with a high dependency on seasonal rainfalls. With the changing climate patterns, finding sustainable ways that empower farmers to practice agriculture throughout the different seasons of the year is very crucial. Unlike some communities, Mumuni experiences two seasons, wet and dry. The wet season is characterised by huge amounts of rainfall in the last through the first quarter of the subsequent year, with the heaviest downpours in January and December. The rest of the year is very dry and normally characterized by poor agricultural productivity, and poor earnings among the majority of the community members. This is further reflected in the poor electricity payment patterns by consumers which is a common trend among most communities in SSA off-grid serviced areas. Additionally, school time for students is normally interrupted by the lack of water as they travel reasonable distances to get water from the local wells. Hence, to ensure that households can consistently earn throughout the year, as well as supporting education and other household activities, access to water for both agriculture and domestic use is key.

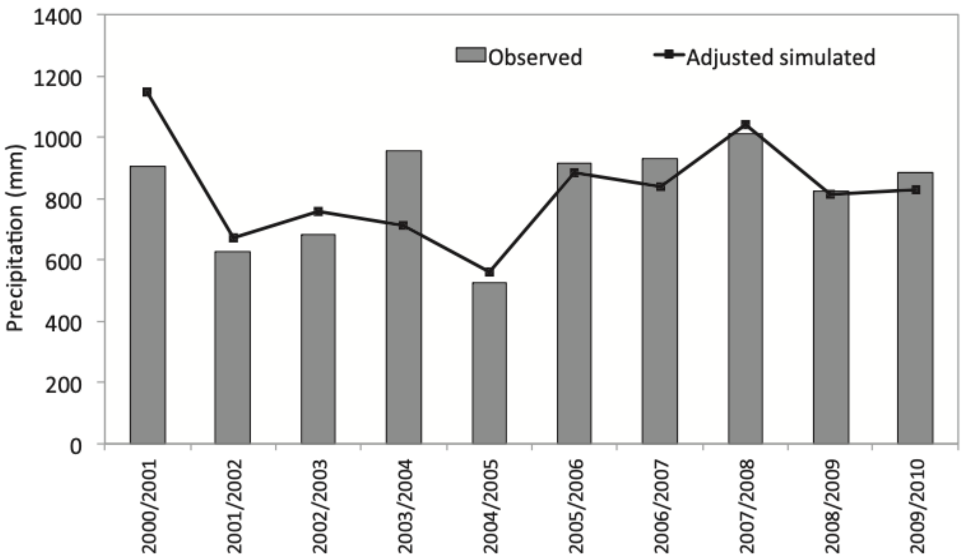

Figure 16 – Annual observed and simulated precipitation from 2000 to 2010 at Choma national meteorological station.[7]

[7] https://weather-and-climate.com/average-monthly-precipitation-Rainfall,choma,Zambia

Rainwater harvesting as a possible solution. Site visits have revealed, that the extension of water access for agricultural uses through boreholes is challenging for the communities as it would further challenge the supply of drinking water due to low levels of groundwater. Consequently, a rainwater harvesting system could be a feasible alternative to provide water for agricultural uses and to extend and diversify opportunities for growing crops (mainly maize) and vegetables (tomatoes, beans etc.) which can be sold in local markets. Due to the two precipitation quarters of the year, we conceptualize a system of water access based on water harvesting. This majorly relies on the readily available catchment presented by the large harvesting surface areas, the corrugated roofs of the 3 school buildings, totalling about 534 square meters. Wrap-around gutters are connected to allow for maximization and redirection of rainwater to the storage tank. Using locally available materials, an innovative sizable tank is designed based on mainly two factors, 1) the average amount of water to be stored and 2) the community population which ultimately determines the overall amount of water consumed by households. The area receives an estimate of 825 mm of rainfall annually and the drought months where community irrigation would be required are late May to mid-October (approximately 5 months). A total amount of 440 cubic meters (440,000 litres) of water could potentially be harvested and stored.

Example Water Harvesting Modelling based on Site data from Singani		
3 School buildings with total roof surface of 534m2		
Average rainfall:	805mm pA	
Oct - April/mid May	5	months
Irrigation: late May - mid Oct = 5 months	150	days
10-yr average rainfall: 825mm	825	ltr per sqm
Total potential storage: 825mmx534m2 =	440	m2
Average supply per day dry season (150days)	2937	ltr per day

Table 1 – Calculation example rainwater harvesting

Summary of steps for setting up the water harvesting system:

a. Determining the water harvesting potential

This is the product of the surface area available also known as the catchment, typically the roof, and the annual precipitation of the location. Surface types affect the harvest potential i.e., different surfaces have varying surface coefficients with corrugated roofs offering the highest runoff factors – approximately 0.9.

b. Determining storage size

Storage size depends on the population, water use and site e.g., for Mumuni, agriculture and domestic uses, and a population of close to 300 households. Such factors are important to avoid over/under-sizing the storage tank. Sizing of the storage also includes determination of the cost components to carefully balance investment and benefit.

Figure 17 - Example for rainwater harvesting system in Zimbabwe by Sowtech[8]

c. Determining layout

This is determined in such a way that water collection surfaces are maximized. Different options can be explored i.e., i) Single tank fed by gutters surrounding the catchment, i) spread out option, where more than one storage tank is spread around the catchment area; ii) Cluster tank option, where different tanks are placed close to each other.

d. Determining pump-size

Pump sizing is dependent on the flow rate and total dynamic head which is the height over which water has to be raised i.e., for an underground tank, the height estimate would be the difference in the head from the lowest point of water level in the tank to outlet of the pump, including friction losses in the pipework. For irrigation purposes, the discharge rate to be applied is determined by computing the irrigation water requirement which is a function of the crop type and the effective rainfall in a given period.
Based on the flow rate and the total dynamic head, an appropriate pump is selected. It is advisable to perform a quick survey of the pump brands available on the local market. This helps to ensure access to spare parts in case of any mechanical breakdown.

Business Models and mode of supply

Ultimately the water is meant to support the community in both economic activities especially agriculture and domestic consumption. Different business models could be designed around these two main modes of consumption. In principle, for such water systems in low-income drought-prone areas, it is recommended that high productive crop species with a low water requirement, for example, vegetables, be cultivated. This not only ensures maximum utilization of water but also farmers' income and economic productivity at large.

[8] https://www.sowtech.com/irhprojectfeedbackreport-feb2020-final.pdf

For agricultural purposes, two forms of water supply and rationing can be pursued; i) using watering cans and ii) using a DC pump powered by the mini-grid. For both forms, it is very important to factor in the size of gardens and the water requirement of the particular crops in order to ensure adequate water supply throughout the crop seasons. Charges can be levied on the quantity and size of cans/buckets. Further discussions about issues such as mode of delivery of water to community gardens i.e., whether one prefers a piping system or manual carriage, and pricing can be opened to include different stakeholders in the community.

11.3 Supply of Productive Appliances

Focus on productive use of energy but access to appliances is limited. The key component of the IISC is the focus on income generation to increase energy affordability and trigger socio-economic growth and benefits in the community. The community surveys and site visits have revealed that access to productive use appliances is very limited due to poor infrastructure and low accessibility of markets as well as the lack of supply of quality goods. Limited income patterns and low private equity result in the inability of many potential users to directly buy appliances.

The implementation of 'Rent-to-Own' schemes is necessary. The supported provision of quality appliances under a flexible financing scheme is necessary to ensure the productive use of electricity and mitigates the risk of payment default for the supplier. Profits generated from the scheme will enable project implementers to de-risk and invest in future similar projects. The provision of appliances is a cornerstone of the IISC to stabilise and diversify income.

A value-chain approach is the basis of providing access to appliances. The community surveys presented in section 6 have revealed, that over 90% of the respondents are interested in using electricity productively but the surveys have also indicated the need for support in terms of financing and access to appliances. As the target communities are rural farming communities, the basis for developing a 'rent-to-own' appliance concept as part of the IISC must be focused on local agri-value chains and developed in cooperation with local businesses, cooperatives and Women Self-Help-Groups. Although the community surveys pointed towards a great interest in using energy for services, a focus on creating added value through agri-processing, manufacturing and other small businesses with the aim to stabilize income over the year is preferable as the service sector largely depends on the seasonal farming income. This might also require training efforts to maximise the positive socio-economic impact of productive energy use. Over 95% of respondents in rural areas are interested in training activities with the greatest demand in training for improved farming methods (90%), business management (50%) and food processing (35%) being the top three topics with this regard.

A projection for expected profits should be done for each appliance. Community members have stated great demand for cooling devices, milling applications, sewing machines or egg incubators. In order to prepare the implementation of an appliance financing and promotion scheme as part of the IISC, a projection of expected revenues and profits generated through the device in relation to local market conditions can help the successful implementation. While cooling systems for example can expand the lifespan of certain products or improve their 'consumption quality', in the case of cold drinks, for example, cooling is relatively energy-intensive and adds costs to the cooled products which need to be retrieved from the selling process. An example of an added-value projection is presented in Table 2 for the case of egg-incubators. The calculation shows a potential profit margin of 34% which could be a benchmark for similar equations for other appliances too. For these projections it is important, however, to realistically assess local market conditions and eventual transport costs as some products might not be sold locally but need to be transported to nearby towns.

VARIABLES	VALUES	UNITS
Size of incubator	100	eggs
Power rating of incubator	100	Watts (W)
Capital Cost	122	$
Amount of power consumed per day	2.4	kWh/day
Operational hours	24	hours/day
Operational days per month	21	days
Tariff	0.90	$/kWh
Cost of power	45	$/month
Avg. Expenses per month (including electricity)	83	$/month
Avg. Revenue of sales per month	125	$/month
Net profit	**42**	**$/month**
Profit Margin	**34%**	
Simple payback	**3**	**months**

Table 2 Example business case for egg incubation[9]

[9] https://www.energy4impact.org/file/2039/download?token=8ardN8he

11.4 Consumer Information system

The consumer information system is meant to promote community engagement and energy awareness among the community members as well as optimise the mini-grid infrastructure. It ensures two-way communication between the mini-grid infrastructure and the electricity consumers. The system feeds off the monitoring system and periodically notifies consumers through a short message service (SMS) (see Figure 19). Because mini-grids provide finite electricity, end users i.e., businesses, households and schools are constrained by the amount of electricity available at certain times during operation. This is worsened by the highly consuming, poor energy-efficient appliances in many households. A consumer information system helps to mitigate these challenges and build energy-conscious communities. By monitoring and availing consumption information to end-users through SMS alerts, the system points consumers to cheap and energy-saving opportunities, which are readily available at specific times of solar mini-grid operations. This not only helps to maintain min-grid stability and blackouts prevention due to overloading but also the sustainable use of mini-grid infrastructures.

Figure 18 represents the information system set-up. The SMS consumption and information alert can rely on either a smart meter or and smart devices which are installed at energy usage points e.g., for households and businesses, at the metering points, to collect consumption data and store it in the cloud. The consumption information is processed and interpreted into simple and practical terms in the local languages for understanding and to allow for a bigger impact in usage behaviours.

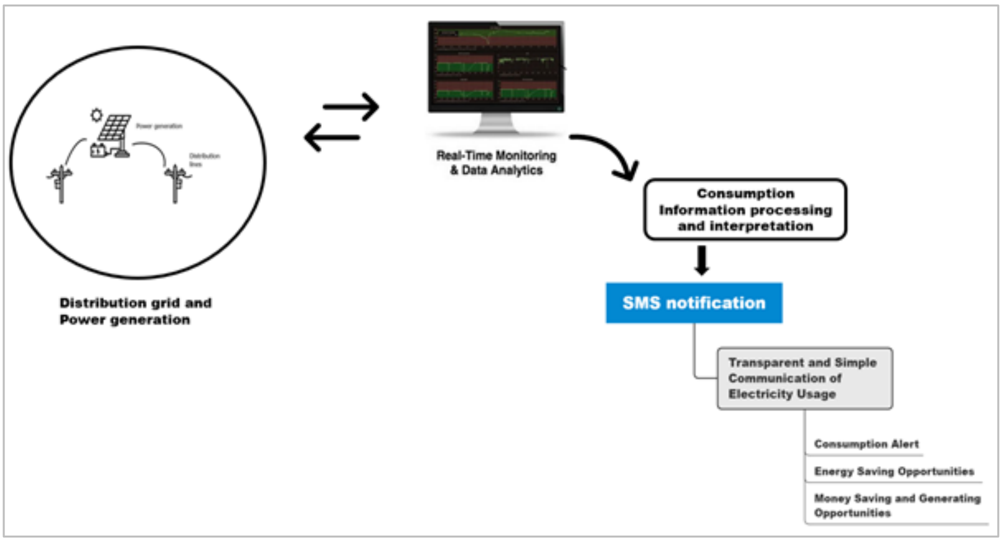

Figure 18 - Consumer Information system setup

Overall, the system helps to reduce the cost of mini-grid infrastructure by improving the efficiency of energy use and load management. It also lays a foundation for new markets and the estimation of future demand by tracking consumption patterns. For the broader picture, there is generally a paucity of appliance information throughout the off-grid supply chain, for instance, product manufacturers have insufficient market intelligence to advance appropriate products that satisfy consumer needs. Measures that promote user information access pave ways for alleviating such challenges for the long term.

12 IISC: Anticipated Benefits

Access to electricity: The IISC is focused on providing access to clean and reliable energy through solar PV mini-grids and Mobile Power hubs.

Business models, energy affordability, sustainability of MGs & investment: The value chain approach including the provision of productive appliances through an innovative financial model will enhance incomes and affordability of energy. This approach aims to solve the current sustainability dilemma of rural MGs through enhancing their profitability which attracts future investment in the rural energy market.

Renewable energy and energy efficiency: The clean energy component of the IISC will replace fossil-fuel-based energy sources (kerosene/diesel) and promote clean cooking solutions. This will reduce carbon emissions as well as the high levels of deforestation and leads to improved health due to limiting the exposure to toxic fumes.

Policy implications: Current rural electrification strategies are mostly solely focused on the provision of electricity and are disconnected from community needs. Promoting the optimised IISC pilots can induce a strategic shift in energy policy-making and project development among central decision-makers, increase community engagement and improve rural electrification projects.

Health & education: The IISC includes the provision of clean energy local schools and clinics. The availability of energy will enable both institutions to organize additional funding and equipment to improve the service quality and will have a positive impact on health services and education.

Energy-food nexus & resilience to climate change: The project incorporates the WEF Nexus by including irrigation/water harvesting and productive use of energy appliances supported by sustainable farming concepts through multi-partner cooperation. The concept direct addresses the problem of food insecurity due to droughts and provides long-term sustainable development in the agri-/food-sector. It aims to mitigate the effects of climate change in the communities, reduces carbon emissions and will introduce reforestation measures.

Equality and women empowerment: The focus on Women SHGs as a key component for RE development through training increases their socioeconomic basis which supports gender equality and community development. Since many of these SHGs are also carers of orphans and vulnerable children, these groups also directly benefit from the projects.

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