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Opportunities for Productive Uses of Electricity in the Off-Grid Market

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***Abstract*— Increased demand for productive uses of energy is a driver of energy consumption. Low-income households in the off-grid market have a budget constraint. By understanding the energy priorities of low-income households in the off-grid market, utilities can develop innovative solutions for servicing the market. This paper builds on recent literature on productive uses of electricity for increased investment and pay back for micro-grid investment across the eight productive user categories that were developed in Rwanda. We ask: how can the range, success, and benefits of productive uses of energy be expanded in resource-constrained settings? To answer the research question, we address the need for supporting infrastructure of business development services, energy services bundling, and utility policy instruments that support productive use of energy. We created metrics for prioritizing productive uses of energy in the off-grid market. In the face of a budget constraint, low-income households that prioritize domestic over business and services uses of energy need integrated services that support the consumptive-productive-service link. Realistic cost-benefit analyses are needed. Solar irrigation as a small industry case in Rwanda can achieve at best a 3-year payback period if it can increase productivity by 54%. We offer recommendations to increase energy demand from productive uses of energy in the off-grid market: work with local cultural norms to support business development; develop realistic cost-benefit analyses based on local data, and partner with business training service providers.**

***Keywords*— productive use, off-grid market, utility policy, micro-grid investment, pay-back**

I. Introduction

Creation of profitable low-carbon transitions is the challenge confronted by key stakeholders in resource-constrained settings. Commercial energy entities and utilities must create energy demand in low-income regions. Previous studies suggest that utilities in resource-constrained settings can increase energy consumption by expanding the range of productive uses of energy for energy consumers [1, 2, 3]. The literature on productive uses of electricity outlines six broad elements that key stakeholders may wish to consider in sustainable value and inclusive business model as sustainable value creation, inclusive business model development, cost structures, infrastructure, socio-cultural acceptability, and enablers of appliance uptake [3]. However, energy consumers in the off-grid sector have a budget constraint and must prioritize energy needs. The paper seeks to support renewable policy focused on incentivizing low-income populations to set-up small industries that can payback micro-grid investment by the investors or utility companies. This paper contributes to the cost structures element of sustainable value creation and inclusive business model development [3]. It is important to understand how energy consumers prioritize energy needs when facing a budget constraint. The eight productive use categories of energy developed in Rwanda include public infrastructure, schools, health facilities, markets, administration offices, mining and quarry areas, industries, and small industries [3]. The objective of this paper is to support increased productive use of electricity in off-grid markets. We do this by formulating the service, policy, and information infrastructure that energy providers and government agencies can use to prioritize productive use of energy in off-grid markets. The research question answered is: how can the range, success, and benefits of productive uses of energy be expanded in resource-constrained settings? The next section summarizes literature findings on productive uses of energy in Rwanda followed by the methodology, results, discussion and conclusion.

II. Literature

Cost structures of productive uses of electricity have been determined from various perspectives. Productive uses of energy are categorized into primary, secondary, and tertiary sectors [1,3,4]. This paper considers the consumptive-productive-service link, a concept that maximizes multipurpose uses of technologies and appliances at the local level [1]. Examples of productive uses in the primary sector are mining and extraction of raw materials. In the secondary sector productive uses are shoe making, welding, bakery, and carpentry. The tertiary sector includes beauty salons, printing, and gastronomy services. Agriculture sector includes egg incubator for chick hatching, solar irrigation, and cold storage. Further categories in the agriculture sector include agriculture production, conservation, processing, livestock and poultry, and fishing and aquaculture [5].

Low-income consumers are interested in productive uses that promote economic development. Previous programs that gave loans failed because low-income households did not have collateral security [2]. Most new companies are reported to be out of business after one year. Utilities and energy providers

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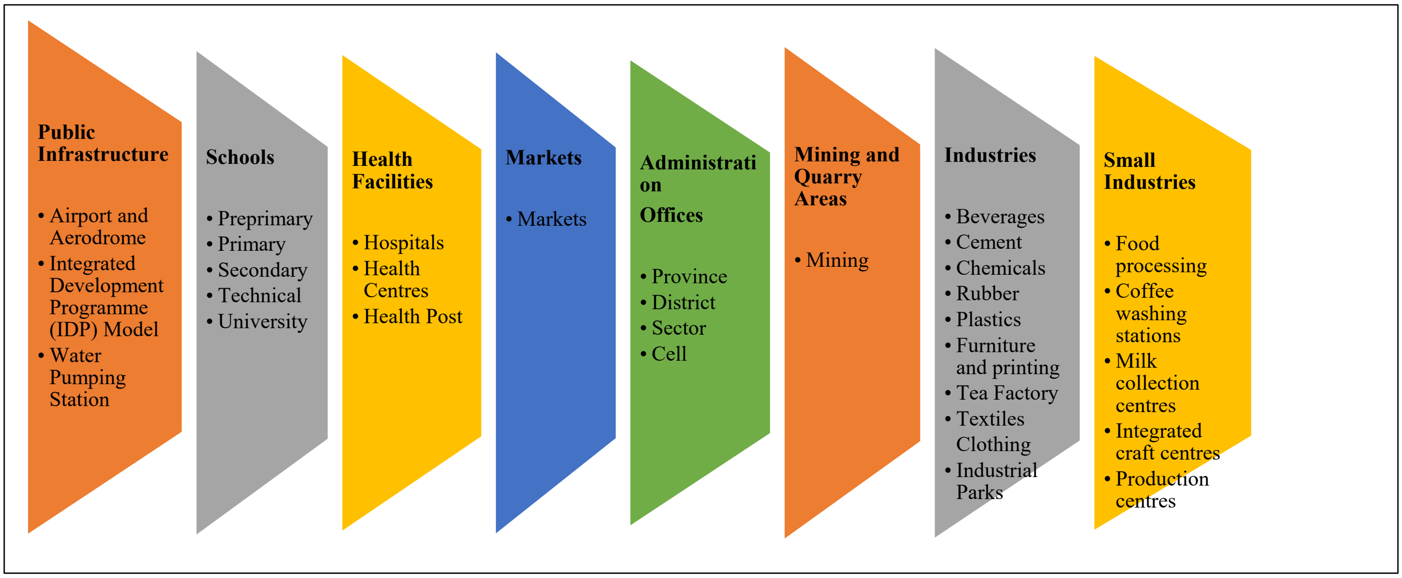

Fig. 1. Summary of productive user categories in Rwanda. Adapted from [3].

interested in electrification programs must incentivize productive uses and must find ways to support success of productive use ventures, both for societal benefit, and to maintain the demand for their energy services [2]. Fig. 1 illustrates that the eight productive use categories have been characterized as public infrastructure, schools, health facilities, markets, administration, mining and quarry, industries, and small industries [6].

The paper's framing using the sustainable value and inclusive business model element of cost structures is adapted in the cultural sense by forging a connection with the socio-cultural acceptability element. The framing of service infrastructures within local cultural norms in the Rwandan case supports productive uses of electricity. Relevant cultural norms include *Agakiriro* (translating to-becoming rich through business development); *Ubudehe* (translating to-a practice of mutual assistance to overcome socio-economic challenges) and *Imihigo (translating to-* a tradition of goal setting which can support business performance goals and accountability) [3].

In the off-grid market, utilities or energy companies support productive uses that are typically powered by renewable energy technologies. While low-income households are interested in productive uses of energy, they must prioritize domestic over businesses and services [1, 2, 3]. Also, mini-grid providers needed financial assistance to maintain the system. To survive, energy providers must create innovative strategies for servicing the off-grid market [7]. Even in the on-grid market, support for new power plants is increasingly contingent on the requirement that new projects must provide energy demand as well as energy supply.

III. Methodology

What should utilities do to create demand for productive uses? We develop a three-step approach: selected metrics and case studies from cooking, solar irrigation, and health facilities, and cultural norms in Rwanda. First, we draw on the literature on economic development, which supports the need for multiple service infrastructures, to spread risk and reduce the initial costs of equipment, particularly for business development in low-resourced communities [8]. Service infrastructures include business training and provision of financing. In addition, we include the framing of service infrastructures within local cultural norms.

Previous metrics used for evaluating success in the off-grid sector focus on increasing energy consumption [2]. We developed metrics for assisting utilities in prioritizing productive uses in the off-grid market. Fig. 2 illustrates six metrics used in the analysis: cost of productive uses, budget constraint, applicability in the off-grid market, demand, scope of expansion, and timeline.

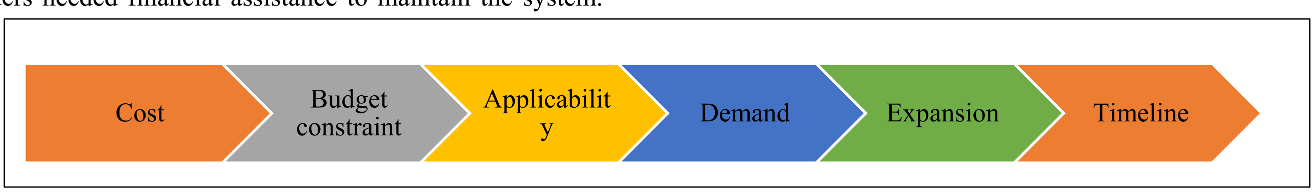

Fig. 2. Metrics for evaluating the challenges to productive uses of energy.

- **The cost of productive uses** is inclusive of equipment cost, installations, daily running costs, maintenance [1, 2, 3].
- **The income constraint** is income available for renewable energy after meeting household needs [1, 2, 3].
- **Applicability in the on-grid/off-grid market** concerns the importance of the technology for low-income households. This can be measured as the expected increase in production provided by electrification [1, 2, 3].
- **Demand** refers to the urgency in which the productive use is required [1, 2, 3].
- **Scope of expansion** concerns the potential for sustaining the demand for productive use [1, 2, 3].
- **Timeline** refers to the short-term and long-term potential for development of the productive use [1, 2, 3].

Second, we use three case studies: cooking, solar irrigation, and health facilities. We consider a case study of cooking which is key for the gastronomy industry [3], solar irrigation recognized to be one of the most cost-effective productive uses for East Africa [9] and Rwanda [3] and health facilities which have adopted last mile delivery facilities for health services in Rwanda. For the off-grid sector, we prioritize the suitable productive user category using the eight productive user categories in Rwanda.

Quantitatively, we use cost benefit analysis to evaluate opportunities for productive use. Cost benefit analysis can focus on the return on investment and pay-back period. Cost benefit analysis can also include metrics or additions that identify social or equity benefits of the productive use activity. For example, solar irrigation, in addition to providing near-term return on investment to the farmer, can provide the national benefit of increasing agricultural activity. Cold storage can also have near-term benefits for the farmer and supports the larger objective of value chain development for agricultural production, supporting transport to regional and even international markets. Business and economic efficiency are not the only broader benefits. Gender equity can be enhanced by women-owned businesses across all sectors; clothing production, gastronomy services and beauty salons are sub-sectors for which female ownership is especially high.

Third, we explore the energy cultures from Rwanda and pick three norms for integration: *Agakiriro*, *Ubudehe*, and *Imihigo* [3].

IV. RESULTS

The results report the prioritization of productive user categories; cooking, solar irrigation, and solar for health clinics as case studies, and integration of cultural norms. First, for the prioritization of productive user categories, emphasizing energy services provision, rather than providing electricity only, may enhance abilities for low-income households to make productive use of energy. Utilities can prioritize productive user categories with suitable metrics. Table 1 illustrates a sample evaluation that could be developed by an energy services provider. This example indicates that small industries is the productive user category with the most potential while administration may be one of the more challenging categories to flourish in this off-grid market.

Second, the three case studies are provided: cooking, solar irrigation, and solar for health clinics.

A. Cooking

We consider a case study of electric pressure cooking as a substitute for use of wood and charcoal for cooking. Electric cooking using pressure cookers can be more energy efficient. An objective is to reduce time and money costs of purchasing or collecting wood or charcoal biomass, to reduce pressure on forests, and to reduce health impacts of combustion. Implementation is seen as requiring policy for financing, either PAYGO, results-based-finance, and asset financing. Cooking technology is subsidized by the government of Rwanda at 45% for Ubudehe 3, at 70% for Ubudehe 2, and at 90% for Ubudehe 1, the lowest income class [9]. Electric cooking with a pressure cooker requires relatively high power, of more than 700W typically, for a short period of time. This necessitates either sufficient battery storage or sufficient size for a solar home system, or connection to the electric grid. Currently, less than 1% of Rwandan households use electricity for cooking. Widespread adoption, however, could add to higher grid power demands. With a population nearing 14 million people, an entire nation cooking with electricity, even very efficient electric pressure cookers, could result in a peak power demand on the order of 1 GW (1000 MW) for cooking alone. Current peak power supply in Rwanda is about 500 MW. Charcoal currently costs the equivalent of about $0.12/kg, which may be sufficient for 1 day of cooking. Other households gather fuelwood or grow their own. This suggests that electric cooking would need to cost less than about $0.12/day to compete with fuel wood or charcoal on cost. Cooking with electricity requires, for the most efficient applications, perhaps 800W for a minimum of 10 minutes to cook one meal. For three meals per day this would come to 0.4 kWh/day. For electricity costing less than $0.30 per kWh, electric pressure cooking in this scenario could cost less than use of fuel wood or charcoal. Women do most of the cooking. They may not be fully included in the decision-making regarding acquisition of electric cooking equipment. Moreover, household needs may overtake the willingness to pay for electricity for cooking, if other needs are more pressing. There is significant potential for subsidized electric cooking equipment to remain unused in lower income Ubudehe 1 households, due to perceived or real high costs compared to available alternatives. There is substantial experience with the introduction of new types of cooking equipment in households in Rwanda and other low-income countries. Continued use of old cooking equipment is common, with the new equipment used only some of the time, if at all. This suggests that cost-benefit analyses of electric pressure

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cookers and similar devices should clarify that the expected benefits will be a function of the utilization rate. The productive user categories in Rwanda do not have an explicit category for cooking, it is a cross-cutting intervention.

B. Irrigation

We consider a case study of solar irrigation, recognized to be one of the most cost-effective productive uses for East Africa [9]. The minimum capital cost *C* is $480, for the Sunculture Rainmaker, which can serve a 0.4 ha (1 acre) field. For growing maize, average productivity is 1.8 metric tons per hectare per season, with two growth seasons per year. The wholesale market price of maize in Rwanda is approximately $0.3/kg [10]. Optimistically, the price received by farmers may be $0.2/kg. For these conditions, the farmer would normally therefore receive $288 per year per hectare. Solar irrigation is reported to provide a 54% average increase in productivity [9]. If so, the benefit *B* in terms of additional annual income will be $156, or $78 every season. If the farmer does not have to take out a loan to make this investment, and has no alternative investments to consider, then a simple payback period, found by dividing the cost C by the annual benefits B gives $480/(146$/yr) = 3 years. This suggests a 3-year simple payback. However, if the farmer needs to take out a loan to buy the solar irrigation system, or if the farmer has other opportunities to use this money, the appropriate discount rate is greater than zero. Agricultural investment loans are available in Rwanda for 8% [11]. For a non-zero interest rate *r*, the number of seasons *N* needed to break even can be calculated by finding the number of seasons required for the net present value (*NPV*) of the project to reach zero.

$$NPV = -C + B\sum_{k=1}^{N}\frac{1}{(1+r)^k} \qquad (1)$$

If the interest rate *r* is 8%, or 0.08, the first integer value of *N* at which the *NPV* is positive is 9 seasons; with two seasons per year this is 4.5 years. Even with the 8% interest rate, this is still a good investment return, if the lifetime of the solar irrigation system is significantly greater than 4 years.

These results depend on achieving the average stated productivity gain of 54%. However, the reported range of productivity gains is 31% to 77%. If the solar irrigation system were used in a farm for with the productivity gain is 31%, then the simple payback time becomes 5 years and if the interest rate is 8% it takes 26 seasons – 13 years – to break even. Especially given the potential for the life of the system to be less than this, if the solar irrigation system can only achieve 31% productivity gain, it is not an advisable investment.

C. Health Services

We consider a third case study of electrification of rural health posts. Health posts can benefit from the provision of lighting. An estimated one billion people worldwide are served by health facilities with unreliable or no electricity. Costs for installation of solar lighting for health clinics can be expected to be fairly high as the locations are inherently remote, without multiple nearby installation opportunities to keep down costs. A minimal 1 kW system can be expected to cost at least $4 per watt, for a total of at least $4000. In addition to providing basic lighting, other electricity services can support healthcare. Many vaccines require refrigeration. Off-grid solar-powered refrigerators have been developed and deployed; the alternative is typically to have to deliver vaccines to the health facility daily. Using photovoltaics with battery storage, the system allows for refrigeration of vaccines and other applications. Initial cost is estimated to be $7300 for provision of 1875 kWh/yr. This is very similar in wattage to a system that would supply basic lighting; here the additional expense can be attributed to the refrigeration systems requirements. Some systems designed for health care facilities have larger capacity, on the order of 4 kW or more, allowing the sale of surplus power for uses such as refrigeration, water pumps, and battery charging. Of the three case studies, health care facilities are the only one for which electrification can also provide local residents and businesses with surplus power to generate income. However, in challenging rural health care settings, if electrification requires the clinic to also expand its operation to become both a health care clinic and a local electricity provider, additional and talented staff may be required to manage the system. More information on the successes and challenges of rural health clinic electrification would be helpful for future programs.

The case studies are summarized in Table 1. Working with potential customers to develop a realistic cost benefit scenario for their situation can support greater selectivity and provide successful experience for productive use. Transparent framing of the risks and potential of investments in equipment for productive use can draw on both *Agakirio* to communicate the potential, but also *Imihigo* to drive home the importance of careful calculations and projections, as well as *Ubudehe*, to draw on community support for investment capital and business support.

Third, for the cultural norms, utilities can work with potential customers to develop a realistic cost benefit scenario for their situation can support greater selectivity and provide successful experience for productive use. Transparent framing of the risks and potential of investments in equipment for productive use can draw on both *Agakirio* to communicate the potential, but also *Imihigo* to drive home the importance of careful calculations and projections, as well as *Ubudehe*, to draw on community support for investment capital and business support.

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TABLE 1: PRIORITIZING PRODUCTIVE USER CATEGORIES IN THE OFF-GRID MARKET

Service	Initial Cost ($)	Operating Costs	Context	Benefit	Income Constraint
Irrigation	1000	Maintenance	Off-grid	Increased food production	Loan or subsidy required.
Cooking	100	~ $1/day/HH	On-grid	Better health, time saved, less biomass harvesting	Subsidy required for cooker; HH may not be able to pay for electricity
Health Clinic Electrification	7000	Maintenance	Off-grid	Better health care, better maternity care	Full subsidy needed. Maintenance costs are a challenge

V. CONCLUSION

This paper has achieved its purpose to understand priorities of productive uses and developing innovative solutions for servicing the off-grid market. Energy consumers are hesitant to invest in equipment for productive use of electricity. From a strictly economic perspective, as illustrated with the case studies, consumers are right to be hesitant. However, even when the narrow economic calculation suggests that the investment is risky, there may be broader benefits of electrification that can increase productivity. In the case of agriculture, greater productivity increases food security and reduced reliance on exports. Public and private players in renewable energy are encouraged to consider both the business and development cases of new projects [12]. The study implications for sustainable value and inclusive business model are both for the cost structure and socio-cultural acceptability elements.

To increase adoption of technologies for productive use of electricity, utilities serving low-income markets must develop innovative ways to improve service provision in low-income contexts. Investments are required in small industries, as the cost of productive use, return on investment, applicability, demand, expansion, and needs are high. First, utility policy modelled around energy cultures can support small business development. Second, overlapping policy approaches that promote (1) grants for equipment and (2) training can improve uptake of productive uses under the *Agakiriro* programme. Framing business training in both the context of *Imihigo* and *Agakiro* can increase community support for mutual business success. *Ubudehe* can be structured to support successive small loans to local businesses to provide the capital for initial business investment

For the socio-cultural acceptability element, the cultural norm *Agakiriro* is crucial in promoting investments in small businesses [3]. Utility policy modelled around energy cultures can support small business development. First, utility policy modelled around energy cultures can support small business development. Second, overlapping policy approaches that promote (1) grants for equipment and (2) training can improve uptake of productive uses under the *Agakiriro* programme. Framing business training in both the context of *Imihigo* and *Agakirio* can increase community support for mutual business success. *Ubudehe* can be structured to support successive small loans to local businesses to provide the capital for initial business investment

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