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# Abstract

Renewable energy systems are an increasingly popular way to generate electricity around the world. As wind and solar technologies gradually begin to supplant the use of fossil fuels as preferred means of energy production, new challenges are emerging which are unique to the experience of decentralized power generation. One such challenge is the development of effective monitoring technologies to relay diagnostic information from remote energy systems to data analysis centers. The ability to easily obtain, synthesize, and evaluate data pertaining to the behavior of a potentially vast number of individual power sources is of critical importance to the maintainability of the next generation of intelligent grid infrastructure. However, the application space of remote monitoring extends well beyond this.

This paper details the development and implementation of an open-source monitoring framework for remote solar energy systems. The necessity for such a framework to be open is much better understood when considered through the lens of the theoretical potential of remote monitoring technologies in developing countries. The United States and other industrialized nations in the so-called ‘first world’ are likely to be slow to seriously adopt renewable energy on account of the massive investment and infrastructural changes required for its integration into the existing electrical grid. In countries where grid infrastructure is generally inadequate or nonexistent, this barrier is far less of a concern, and renewable energy technologies are viewed much more as an enabling tool for progress than as a disruptive and expensive technological tangent. In this context as well, remote monitoring has a role to play.

Of course, renewable energy systems are nothing new in the developing world—they are just inaccessibly expensive to most individuals. Still, international charity organizations have been integrating renewable energy technologies such as solar power systems into their development projects for more than 40 years. In Sub-Saharan Africa in particular, most of these efforts have resulted in failure. Chief among the culprits responsible for these failures are the implementing organizations themselves, who almost pathologically fail to transfer the knowledge required to maintain renewable energy systems to local stakeholders. While a pervasive lack of access to technical training in most developing countries does not bode well for the success of future endeavors to promote electrification—rural or urban—it is arguable that remote monitoring systems would be of nontrivial assistance in such efforts. Of course, cost is still the greatest barrier to entry with respect to any given technology in the developing world. Therefore, *this* project revolves entirely around the use of open platforms and inexpensive, generic technologies to produce a viable remote monitoring framework for use in environments where the resources and general knowledge required to maintain renewable energy systems is particularly scarce.

# Introduction

Remote monitoring is not a new or unsolved problem. Therefore, the rationalization for pursuing this particular project requires some explanation and a description of the context in which the necessity for open-source remote monitoring arises. Furthermore, some vocabulary needs to be modified for specificity’s sake. Renewable energy systems encompass a vast range of technologies, but in particular this project is concerned with solar technology. Additionally, the results of this project, while arguably generalizable to any given solar application anywhere in the world, are specifically intended to demonstrate how remote monitoring can be made useful and affordable in developing countries. Finally, so as not to make callous generalizations about the homogeneity of the so-called ‘developing world’, the requirements for this project have been designed with the realities of poverty and underdevelopment specific to Sub-Saharan Africa in mind. The applicability of the results of this project in a different region or environment is left for others to decide.

## *1.1 Road Map*

In order to argue for the need for open-source alternatives in solar remote monitoring, it is important to demonstrate the unsatisfactory nature of the status quo. To do this, certain premises need to be established, in order.

1. By some mechanism, photovoltaic technology is a sufficiently common method of energy production in Sub-Saharan Africa, enough to the point where generalizations about its use can be made.
2. In most situations in Sub-Saharan Africa where solar power systems are implemented, these systems tend to fail as a result of poor maintenance.
3. While the proper maintenance of solar power systems requires regular to intermittent attention on the part of trained individuals, a significant portion of the maintenance process is an information technology problem.
4. An information technology solution in the form of a remote monitoring system can serve a critical role in providing system overseers with the information required to maintain solar power systems.
5. Existing solar remote monitoring systems are expensive, limited in their application, and proprietary for the most part.
6. Such a system should be available as an open-source technology because of the economic realities of poverty and underdevelopment in Sub-Saharan Africa.

Arguing for these premises will establish the proper context within which to discuss the requirements for this project and evaluate the results of this semester’s attempt at such an implementation. Thereafter, a discussion of future implementations, abstractions, and applications can be discussed in a productive way. The overall purpose of this thesis, much moreso than a description of an implementation or a celebration of achievement, is to serve as a proof of concept that solar remote monitoring is neither expensive nor particularly cumbersome to implement and thus warrants further investigation and development by the open source community. There are many applications for a system like this. Monitoring a solar power array is just one of the possibilities. Practically any device with measurable outputs running in a remote environment represents a potential future extension of this project. The hope, of course, is that others will be able to build upon this framework and use the results described here to cultivate their own applications. Advancements in this field can yield cheaper and more robust solutions to assist in both the maintenance and viability of remote solar power systems.

# Background and Literature Review

The first logical premise to establish in the defense of this thesis is the assertion that solar technology is a more or less commonplace method of energy production in Sub-Saharan Africa. The second is that most solar energy systems tend to fail as a result of misuse. Because these two premises are generally part of the same narrative when discussed in the context of development in Sub-Saharan Africa, they will be established in this section together through an in-depth analysis of three separate case studies. To begin, however, it deserves to be stated that when we consider the notion of solar power as common we are discussing the subset of people who actually have access to electricity, and thus generalizations drawn from studies of the utilization of solar energy systems are capable of only limited abstraction.

## *2.1 Solar Energy and International Development*

In 2002, the African Energy Research Policy Network (AFREPREN) published an article in Energy Policy magazine which estimated that roughly 68% of the inhabitants of Sub-Saharan Africa live in rural areas without access to grid-powered electricity. In the conventional interest of development and poverty reduction, the question of how to provide modern energy services to this enormous proportion of the population is of critical importance. As many African governments have proven incapable or unwilling to tackle this issue, the general consensus of the international development community at large has been to emphasize the dissemination of renewable energy technologies to rural areas. This focus on localized power generation has in turn led to the implementation of a variety of developmental programs involving the use of solar technology to provide generally inaccessible communities with electrical power for important infrastructure like schools and hospitals.

Now, short of making the problematic assertion that electricity is a solution to poverty, suffice it to say that the status quo has prompted many charity and non-governmental organizations (NGOs) to use solar energy systems in conjunction with their humanitarian development efforts. With this context in mind, arguments can be framed about best practices for sustainable development and the role of remote monitoring in renewable energy projects.

## *2.2 Solar Energy Case Studies—Popularity and Practicality*

How has solar technology fared as a solution to the pervasive and systemic lack of access to electricity in Sub-Saharan Africa? This is not a question which can be disputed on account of the maturity of the renewable energy approach. Rural development projects in Sub-Saharan Africa involving the use of photovoltaics for electricity generation have been underway since the 1960’s, and, therefore, the accumulated body of literature on this subject is vast. Upon examination of this literature, the most striking observation to consider is the general lack of theoretical disagreement among case studies. This is not to say that experience of every solar project or private initiative has been similar; rather, that they all seem to succeed or fail for similar reasons. In rudimentary terms, there has been a great diversity of contextual experiences with solar technology. In Zimbabwe, for example, the United Nations Development Program Global Environment Facility (UNDP-GEF) project from 1993-1997 seems to be the reigning example of overall failure, while the Nyimba Energy Service Company (ESCO) project in Zambia in 2000 and the Namibian government’s ongoing ‘Home Power!’ program appear to be shining arguments for the continued proliferation of solar technology.

Overall, these projects were both introduced into comparably poor rural communities, however, the character of each project’s implementation was markedly different, and the end results appear to reflect this. The experience of the UNDP-GEF project seems to have left the reputation of solar technology permanently scarred in some circles. Nevertheless, solar technology remains popular. In some ways, it appears that independent of the direction of the community of non-governmental organizations solar technology continues to find its way into the hands of those who can afford it. There are plenty of viable alternatives to solar technology as far as energy generation goes, and therefore the phenomenon of solar technology’s continued popularity is of particular interest to analyze and explain.

### *2.2.1 Solar is popular…*

Ray Holland, a member of the Intermediate Technology Development Group (ITDG), argued in an issue of IEEE Review in 1989 that the cost of solar technology needs to fall considerably before it can be used for applications in developing countries beyond communications, lighting, and water pumping. Today, 20 years later, this is still the primary barrier to the increased dissemination of solar technology. In spite of this, however, solar technology remains a popularly sought after and highly demanded commodity in Sub-Saharan Africa. The reason for this may be explained in part by the observation Holland makes that the over-consumption of electricity is generally not a problem for rural communities. The fact that solar technology can provide high-quality lighting and allows for the use of radios, small television sets, and cellular phones is enough to fuel the continued demand for panels and batteries. Mark Hankins and Robert J van der Plas, in their research for the World Bank's Energy Sector Management Assistance Program (ESMAP) in Kenya in 1998, concluded that between 75% and 90% of rural Kenyans *know* about solar technology. While not conclusive, they argued that the continued popularity of solar technology may be attributable to just that—its popularity. Absent readily available information about other sources of renewable energy such as wind turbines, efficient biomass combustion, and micro-hydroelectric generators (which are argued by some to be better suited for rural energy needs), it is probable that rural dwellers aspire to own solar panels because it is a symbol of relative social status and represents a step out of poverty.

### *2.2.2 …But should it be?*

Two researchers for AFREPREN, Stephen Karekezi and Waeni Kithyoma, conducted an evaluative study of renewable energy strategies for rural African communities in 2002. Their main criticism of contemporary approaches to energy generation on the part of international development organizations is actually the gross *over*-emphasis of solar technology. Karekezi and Kithyoma are keen to point out that solar systems are woefully inaccessible to the vast majority of rural communities. Citing the failure of previous micro-finance and subsidy-driven solar distribution programs, it is consistently estimated that around 80% of the rural poor in Sub-Saharan Africa cannot afford even the smallest 18W solar power systems, let alone keep up with service and maintenance fees. Putting relative costs into perspective, for a 40-50W solar power system, it is estimated that most rural households would have to pay on average 200% of their per capita GNP just to afford start-up and installation costs. In the United States, this percentage would amount to an average cost of $50,000 for the same system. Additionally, Karekezi and Kithyoma argue that home-based energy needs in Sub-Saharan Africa are 90% to 100% comprised of cooking and heating. As solar technology is generally limited to lighting and communication, it is hardly a viable or worthwhile investment for most rural families to purchase even a small solar power system.

However, Karekezi and Kithyoma do admit that solar technology can be employed to provide quality lighting and offset the need for fuel-burning light sources. In fact, solar is actually preferable to biomass in terms of lighting. Biomass applications produce low-quality light and require the continued purchase of fuels for combustion, whereas solar technology combined with high efficiency CFLs can perform for many years with relatively little maintenance. This also goes to directly offset a large proportion of the exposure to smoke particulates created by combustion lighting, (which is an altogether different public health crisis beyond the scope of this paper). It is not Karekezi and Kithyoma's purpose in their analysis to completely discredit the application of solar technology, as they do recognize the usefulness of the services it can provide insofar as lighting, entertainment and communication are concerned. They do, however, stress that solar is quite limited in its application and should not be at the forefront of renewable energy strategies for rural development.

### *2.2.3 The UNDP-GEF Project*

The analysis of Karekezi and Kithyoma is important as an African perspective on current energy paradigms. While it is clear they are opposed to the dominance of solar technology in rural development strategies, it is important to consider the context from which they draw their criticisms. One of the major case studies that exemplifies the failure of development projects involving solar technologies is the UNDP-GEF program in Zimbabwe from 1993-1997. The GEF project was one of the largest efforts in history by the UNDP to proliferate the use of solar technology, and the fact that its results are so widely criticized deserves examination. In a May 2000 article of Energy Policy magazine, Tim Jackson, Tinashe Nhete, and Yacob Mulugetta published a comprehensive article on the lessons of the GEF project. Jackson and Mulugetta are researchers from the University of Surrey Center for Environmental Strategy (UK), and Nhete is an ITDG member from Harare, Zimbabwe.

The main criticisms Jackson, Nhete, and Mulugetta cite, overall, are the lack of rural stakeholders in the projects’ success, and the lack of post-project commitment by the UNDP. In a nutshell, the project was a donor-driven program to install 10,000 environmentally friendly solar systems in Zimbabwe’s rural areas over the five-year period between 1993 and 1997. From the very outset it can be argued that the project was overly ambitious and attempted to address the concerns of too many incompatible interests. In the report on the project released by the UNDP in May 2004, the mission statement includes the achievement of the UN Millennium Development Goals, the satisfaction of environmentalist concerns regarding greenhouse gas emissions, the alleviation of rural poverty in Zimbabwe, and the creation of new markets for local solar companies. In the attempt to satisfy all of these goals at once, the GEF project spread itself very thin and failed to do much beyond meeting donor funding deadlines. In the *Energy Policy* article, the GEF goal of reducing global carbon emissions by installing environmentally friendly technologies in rural areas of Zimbabwe is correctly likened to “using a sledgehammer to crack a nut.” It is an ostensibly ridiculous assumption to say that rural communities in Sub-Saharan Africa have an even measurable impact on global carbon emissions, and it is an act of blatant hypocrisy to impose upon them such limitations as a prerequisite for development aid.

### *2.2.4 Critical Implementation Failures*

Despite the wrong-headedness of the GEF project from the outset, critical failures were made during the project’s implementation which undermined the likelihood that the systems put in place would remain functional for much longer than the project itself. While some of the solar power systems were donated to rural communities, the majority of them were sold through micro-financing schemes. In this respect, the most common problem facing the proliferation of solar technology was again brought to bear. Only 20% of rural households in Zimbabwe could afford even the smallest solar system offered to them by the GEF project. In this respect, the locally affluent became the primary benefactors of the project rather than the rural poor. Moreover, emphasis on spurring private sector solar industries was given priority over the transmission of knowledge to the owners of solar power systems. In turn, local solar technology suppliers and businesses were the only resource rural communities had when they experienced system failures as a result of misuse.

On its head, this is not an entirely unworkable situation. Technical knowledge of solar system design and implementation is a marketable skill and should be allowed to seek professional outlets. The problem arises, however, when the owners of solar power systems have *no* understanding of how they work and must pay local technicians for even the most minor causes of concern. Over time, it was found that a majority of people misused their systems without realizing why, and were then burdened by the increased costs of maintenance and repair.

### *2.2.5 The Problem of Maintenance: Battery Care*

The most common problem was the routine overuse of batteries. Solar power system owners were not educated on the basic principles of battery care, and were not aware of their system’s limitations. Thus, they routinely left electrical loads on until their battery bank fully discharged and their appliances cut off. (Solving this problem is one of the primary goals of the remote monitoring system described in this paper.) Then, without knowing the consequences of consistently over-discharging batteries, this practice was repeated until the battery electrolyte was depleted and could no longer hold charge. While this is the eventual fate of any rechargeable battery, understanding safe discharge limits can double or triple battery longevity. If solar owners were taught simply that they should only leave their lights and appliances on for a certain amount of time so as to prevent their batteries from completely discharging before allowing them to recharge, it is likely that many of the GEF systems would have lasted much longer. The way the GEF project was conducted and the overemphasis placed on the role of local technicians led to many systems failing far before they should have. Many solar power system owners then replaced their failed batteries with cheaper and more affordable car batteries, which, unfortunately, are not designed for the charge cycling of a solar power system, have fewer amp-hours, and, in turn, would end up failing soon after. A robust understanding of the mathematics involved here is useful, but not necessary to solve such problems. Much of the failure of the GEF project to create lasting improvements in rural communities is hinged on the fact that they did not transmit even the most basic knowledge of solar power system ownership to the project's benefactors.

### *2.2.6 The Problem of Maintenance: Local Technical Support*

Part of the reason the importance of a basic understanding of solar power system maintenance and care seems to have been overlooked by the GEF project was that it was hoped this void would be filled by the growth of local businesses and technicians. In the interest of time, perhaps, this was wishful thinking on the part of the GEF project planning staff. It also appears that another casualty of the GEF projects’ donor-imposed time constraints was the formation of a stakeholder community. No local or international NGOs, rural authorities, or patrons of any sort were procured prior to the full fledged implementation of the project, much to the dismay of observers in Zimbabwe and elsewhere. The GEF project, it seems, was constrained so tightly by its five-year commitment to install 10,000 solar power systems that it forgot most everything else and left the responsibility of repairs, maintenance and education up to unproven and, essentially, *undesignated* local actors.

### *2.2.7 The Pitfalls of Scope*

Another unfortunate complication of the GEF project was that its immense scope had the unintended consequence of undermining the long term viability of local solar technology businesses. The introduction of the raw equipment for over 10,000 PV systems into the local market dramatically distorted the prices of system components. The parallel market which formed in the midst of the GEF installations also took a toll on the ability of registered PV businesses to function. Cheaply made amorphous silicon panels from South Africa made their way into Zimbabwe and began to compete with the more expensive multi-crystalline silicon panels supplied by the UNDP. Panel theft also became a problem. PV panels are valuable commodities and are easily removed from rooftops as a result of the necessity that they are open and exposed. The primary targets of theft were women, the elderly, and the disabled. The resultant fear of criminals and the loss of such a large investment made some potential buyers of solar power systems turn the opportunity down. This, combined with the onslaught of economic downturn in Zimbabwe, drove many of the newly formed solar power companies out of business in a relatively short period of time. In 1997, there were roughly 60 registered solar companies to service 10,000 new customers as a result of the GEF project. By 2000, there remained only 15. Of the businesses that survived, the vast majority of them had been in business prior to the GEF project. Today, with inflation rates in Zimbabwe above 1 million percent, it is doubtful that even the strongest of these solar businesses still exists.

### *2.2.8 The Lack of Follow-Up*

Unfortunately, there is no post-project data on either the GEF project systems or the businesses it tried to create. The reason for this, while hardly surprising given the circumstances, was that the UNDP had not planned on making any post-project assessments and instead assumed that this data would be collected by local solar energy companies. As over 75% of the businesses created by the GEF project failed within three years, there is today no data on the performance of *any* of the 10,000 installed systems.

The experience of the GEF project tarnished much of the popular support among some NGOs for similar endeavors. However, it deserves to be stated that the GEF project was poorly executed and failed in a rather predictable manner. The tiger’s share of the blame in this instance is to be laid at the feet of the UNDP for their almost inspired incompetence and their treatment of communities of interest in the project moreso as a commodity in service of an environmentalist publicity stunt than as the intended benefactors of a serious and rigorously researched effort at promoting sustainable rural electrification. Fortunately, while the GEF project may be sadly representative of the general experience of NGO projects involving solar energy systems, other projects have been much more successful, despite being faced by similar challenges. Nevertheless, the GEF case study is instructive.

### *2.2.9 Glimmers of Hope: The Nyimba ESCO Project*

The failure of the UNDP-GEF project is humbling, but nevertheless deserves to be countered with examples from smaller, but more effective development efforts involving solar energy systems. One such example of a successful solar energy program was implemented by the Nyimba Energy Service Company (ESCO) in Nyimba, Zambia in 2000. In this case, the introduction of solar technology had a positive impact on the lives of people in rural communities, particularly with regards to educational prospects. Mathias Gustavsson and Anders Ellegaard, two researchers from Goteborg University in Sweden, reviewed the progress of this ESCO project in a 2004 article of *Renewable Energy* magazine.

An ‘ESCO project’ is a new type of technology-dissemination program which has been employed in a variety of contexts and communities around the world with considerable success. The Nyimba ESCO project operates 100 individual solar home systems in rural communities near the town of Nyimba. The general philosophy of the Nyimba ESCO project is that expensive technology such as a solar power system is beyond the purchasing capability of most rural dwellers and should therefore be given as a service package, whereby clients enter into a contract providing them with the installation of a 50W solar home system in exchange for a monthly service fee of 25,000 Zambian Kwacha, or the equivalent of U.S. $6.85. This service fee covers any problems that may arise during the time clients use their solar home system, including the replacement of parts if they are damaged. The contractual system is composed of a 96 Ah deep cycle battery and charger, a 12V, 50W PV panel, and four 7W CFLs for lighting, including fixtures. As the combined wattage of the CFLs is only 28W, clients are encouraged to buy their own appliances to make use of the rest of their solar home system’s capacity. This is intended to endow clients with a sense of ownership in the maintenance of their solar home system; of course, most of the need for technical expertise is accounted for through monthly servicing fees.

### *2.2.10 Poverty and Servicing*

The unique facet of the Nyimba ESCO project compared to other case studies from Sub-Saharan Africa is the fact that people who would not be able to afford a solar home system are given the opportunity to use one for a small monthly fee. In practice, however, this fee was still a barrier for many households. The results of Gustavsson-Ellegaard study found that 90% of the households with solar home systems contain at least one formally employed person. The division in incomes is again made clear here, as it was found that between 10% and 15% of households with solar home systems find it extremely difficult to pay their fees. Nevertheless, it was found that around 50% of clients did attempt to expand and maximize the use of their solar home systems, some of whom even managed to purchase and install inverters to run an appliances requiring alternating current (AC) power. Overall, however, most households acquiring a solar home system felt that the primary benefit of solar technology is the availability of quality lighting at night.

### *2.2.11 The Benefits of Solar Technology*

The benefits of quality light manifested themselves quite vividly qua the experience of the Nyimba ESCO project. The Gustavsson-Ellegaard study found that nearly 60% of clients claimed they could not read at night prior to having a solar home system, and 50% believed that children were the primary benefactors. Around 89% of households with a solar home system claimed that their children used the available light at night to study, whereas only 42% of households without a solar home system could claim that their children attempt to study at night. Interestingly, it was found that children would study together at night in houses with solar home systems. Furthermore, teachers began to use the advantage of having dependable light at night to teach classes. Extremely poor children who cannot afford schooling and who must work to support their families during the day were able to benefit from classes taught at night. This was also found to be the case in Namibia, and thus it points to the educational promise that PV lighting may hold indirectly for rural communities in Sub-Saharan Africa.

The ability to expand one’s active day was cited as another benefit of having a solar home system. Twenty percent of businesses owners claimed they could expand their working hours after dark with the aid of dependable lighting. Beyond this, the desire to own a television set was repeated in the Gustavsson-Ellegaard study as greater than the desire to have a solar-powered water pump. This seems to point to a consistently exhibited desire on the part of rural communities to have access to appliances and commodities that allow for entertainment and increased communication with the outside world. As one teacher in Nyimba was paraphrased as saying, “Our lifestyle changes; it is like we moved from the rural area to the town. We now have light in the evenings and we can play music.”

### *2.2.12 The Recurring Problem: Battery Maintenance*

Still, amid this apparent success in Zambia, some of the pitfalls of the UNDP-GEF project were also found to exist. A general lack of knowledge among clients absent the support of technicians seemed to lead to the overuse and failure of batteries. Also, economic conditions in some rural communities have resulted in an increase in service fees and, as was the case in the Nyimba ESCO project, some solar home system contracts had to be terminated. This is representative of the recurring problem of solar technology—it is generally inaccessible to the poor majority of rural communities.

### *2.2.13 Glimmers of Hope: The Namibian Home Power! Program*

Throughout this discussion of the various experiences in Sub-Saharan Africa with solar energy, it deserves reiteration that development projects in this context tend to succeed or fail for similar reasons. Another successful solar energy program worth mentioning is the Namibian governmental ‘Home Power!’ program.

Njeri Wamukonya, a researcher for the United Nations Environmental Program Collaborating Centre on Energy and Environment in Denmark, prepared an evaluation of the Namibian government's post-independence efforts to gradually expand the electrical grid to all parts of the country. To date this has been an enormous endeavor, and thus the Namibian government has launched a low-interest rate loan program called Home Power! through which rural and semi-rural communities can purchase home solar power systems. The program provides applicants with a solar home system installation to be paid back over a maximum of five years at a 5% interest rate.

The experience of Namibia has been similar to that of the rest of Sub-Saharan Africa in the sense that, again, only a minority of rural households seem to be able to afford even the smallest PV systems, and therefore localized elites tend to gain more from the dissemination of solar technology than do the rural poor. In fact, the Home Power! program does not grant installations to applicants who do not make enough money to afford the systems.

*2.2.14 Stakeholder Cultivation and Knowledge Transfer*

The Namibian government has committed itself to the development of its grid infrastructure and popular electrification in a way that NGO and donor-led programs simply cannot sustain for any considerable length of time. Furthermore, the Home Power! program, in contrast to the UNDP-GEF debacle, is a long term effort and does not have deadlines to install a specific number of PV systems into random rural communities. Home Power! involves the contracting of local suppliers to install systems properly in client’s houses and emphasizes the transfer of knowledge regarding maintenance and installation between technicians and clients. This is a responsible action on the part of the Namibian government to attempt to prevent its installments from being wasted on account of misuse. There are national radio programs, advertisements, and TV commercials in Namibia intended to educate citizens on the proper use and limitations of their PV systems. This kindles local businesses, encourages proper usage of PV systems, and promotes the technology around the country.

An interesting note about the Namibian Home Power! program is that recipients of solar home systems, by virtue of the fact that they understand exactly what their system can and cannot be used for, report almost universally that their welfare improves after installation. Kerosene lamp and paraffin candle use decreases because of the availability of quality of light, however, fuel wood consumption does not decrease, mainly because it cannot be used for cooking. (Interestingly, households with off-grid power do not have to deal with blackouts and actually have more consistent lighting than do their counterparts in urban areas!) The primary benefits of quality lighting and solar technology are reported as the ability to read at night, listen to radio, and in some instances watch television. Above solar water pumping or any other appliance, surveys indicate that the first things people with solar arrays desire to run are television sets. This allows people to watch news and keep updated with national affairs, watch sports, and in general provides a greater sense of connectedness with the outside world. Such additions to rural people’s daily lives, while primarily aesthetic in nature, are widely reported as marked improvements over life without electricity at all.

Sustainability is an ironic topic in the field of humanitarian development projects because it is so often emphasized in theory but almost always bungled in practice. Consider the espoused benefits of renewable energy systems versus the practicality of their application: Right off the bat, solar energy falls flat on its face as a sensible investment for poor and rural communities because it is astronomically expensive given the economic returns it can yield through income-generating activities. In most situations it is simply a material impossibility to afford. Thus, in the vast majority of cases where solar technology actually finds its way into the hands of otherwise underdeveloped and impoverished communities in Sub-Saharan Africa, it is only through the work of international charity organizations. As a result of this dependency, the sustainability of development projects involving solar power systems is tenuous. Solar energy may provide a theoretical source of clean, renewable, and essentially ‘free’ electricity, but its initial cost is so high that it necessitates external intervention.

Moreover, one of the major problems with the introduction of expensive and potentially complicated technology into underdeveloped communities is the concept of cost after installation. Once a new piece of infrastructure is in place, a permanent maintenance cost has also been introduced. For example, if a solar array is installed on the roof of a school, somebody has to look after it. That person's time and skill-set are going to cost money, furthermore, because the maintenance of a stand-alone solar array requires specialized training and knowledge of electrical power systems. But how can an already impoverished community afford such expenses? And where does the knowledge come from?