Renewable Energy in the Third World:

a Holistic approach and solutions to Africa's Energy Problem

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Introduction

William Kamkwamba stood on stage in Lilongwe, Tanzania, for the TED (Technology, Entertainment, and Design) conference in 2007. Despite being introduced to the internet for the first time hours before, he was in the process of giving a talk to hundreds of leading scientists, designers and entrepreneurs about his windmill, or "electric wind" machine (Kamkwamba and Mealer). Limited educational opportunities and almost complete isolation from the outside world combined to cause William to be nervous and trip over his words. In response to one of many probing questions about the process he used, William responded with, "… I try, and I made it" (Kamkwamba and Mealer). While this statement could be described as embarrassing or grammatically incorrect, it is actually an adequate window in the current energy situation in Africa at the present time. The innocence and simplicity of the statement allow a brief glimpse into the childhood years of most Africans, even in recent years. The statement also embodies the work ethic and ingenuity of many Africans, especially those given the right tools and opportunities to succeed. In another capacity, the statement also implies that many in Africa try, but don't make it, and many have lost hope and no longer try at all. It is just as Wangari Maathai says, "principled and visionary leaders are still too few in number; and while the world increasingly recognizes that Africa will be hit hard by climate change, the transfer of 'green' technology from industrialized nations to the continent is slow, and forests in Africa continue to shrink" (Maathai). As a visionary leader on the African continent, William Kamkwamba has come to understand that a holistic solution is the most effective way to solve any problem. The more difficult a problem, the more pieces, perspectives, and people are needed to come together to succeed. This principle is not only embodied in William's experience, but is also the most effective way to take on the energy challenges facing Africa at this very moment.

African communities are hungry for power. Rural communities are especially in need, due to lack of proximity to their government and many profit-driven traders and companies, among other reasons. Existing solutions and power grids only reach so far; political corruption and a general lack of infrastructure both effectively cap the amount of progress that can be achieved. The purpose of this paper is to effectively understand, compare, and communicate two solutions to this problem: wind turbines and micro-hydro systems. Both solutions tap renewable energy sources and provide unique solutions to pieces of the problem presented, to be categorized and compared in the following contexts: social, economic, and engineering. The first and arguably most important category, the social context, is important for laying the

framework for any quantitative solutions. Additionally, it is also essential to understanding the interpersonal element within the problem presented. Due to the heavy influences of past culture in the present African lifestyle, social considerations are increasingly important in other major issues facing African countries right now as well, including: political corruption, persistent health problems, and economic growth (Maathai). While overlooking any of the three subcategories has the potential to be a grave mistake, it is far too common to see the social element overlooked in problems and solutions like these. Economic analysis will also be presented, as is the case with any business venture or long term sustainable solution to any problem. It is important to consider who has the money and power in the current African setting, and more importantly, what they want to do with it. The engineering perspective is needed when actually implementing any solution presented. It encompasses training communities to use and maintain the solution effectively; guidance and assistance during the building phase, as well as follow up visits to increase independent creative thinking, among others. These categories have been chosen so as to achieve a well-rounded, "holistic," perspective on this topic. The two solutions to be presented are not necessarily mutually exclusive; the most efficient and effective solution may combine certain elements of both. It is also of some importance to note that this paper is only effective to the point of being written without a hands-on perspective into this problem; having "boots on the ground" would be a substantially relevant to this perspective's applicability.

Before continuing in the three subcategories of comparison, it may be beneficial to briefly touch on the two proposed methods of renewable energy gathering. Wind turbines are towers that use large rotating blades to capture kinetic energy from the wind and transfer it into mechanical energy. Likewise, micro-hydro systems follow a similar idea, excepting that now water is the driving force behind the supply of kinetic energy. In the micro-hydro scenario, water is rerouted from a stream or river, given extra velocity, pushed through a micro-hydro station to generate power, and then inserted back into the stream or river ("Practical Action"). Some micro-hydro plants are placed directly in the middle of an existing stream or river in order to increase water usage and thus power output, however this usually has an increased detrimental effect on the surrounding environment.

Social Context

Without being able to call oneself "African," it is difficult to fully grasp the magnitude of social implications on any solutions contributing to lasting progressive change on the continent of Africa. After many hundreds of years of colonization, many African countries gained independence in the mid twentieth century. To address the monumental challenges that faced the continent, many African countries came together to form the Organization for African Unity (OAU), which is now known as the African Union (AU). Their goals were to decolonize the entire continent, to promote unity, and to effect economic and social development in order to rid Africa of ignorance, disease, and poverty (Maathai). Even now, the established AU goals are lofty, but effectively highlight problem areas that are common throughout the entire continent.

Simply providing a one dimensional solution to any African problem is similar to neglecting whole parts of these societal issues, which almost assuredly portrays ignorance. So before the solution to current energy demand is addressed, it is important to understand and appreciate how the above problems are already being approached (or not approached).

The peoples of Africa are typically associated with the idea of being backward. Indeed, in many ways, this is true, however; as with most things, the situation is more complex than this one word descriptor. Africa has, and still does, face a mountain of problems. In the 2007/2008 UN Human Development Report, all of the twenty two lowest ranked countries- in terms of life expectancy at birth; adult literacy rates; combined gross enrollment ratio for primary, secondary, and tertiary education; GDP per capita; life expectancy index; education index; and GDP- were from sub-Saharan Africa (Maathai). As in William Kamkwamba's case, a large family and low income from farming meant that when it came time for William to attend secondary school, there was no money for him to do so (Kamkwamba and Mealer). This is all too common among African families, and is aggravated by the fact that 65 percent of Africans continue to rely on subsistence agriculture (Maathai). While farming and agriculture is important for survival, it is greatly subject to the fickle seasonal weather patterns and governmental regulation. It also does not need to be taught in a classroom setting because families are able to enlist their children to help in the fields from a very young age, teaching them what they already know without diversifying their understanding of farming practices. The benefits of education are too numerous to mention here, but in direct relation to farming, children might learn best farming practices to make existing farms more efficient, new crops to provide higher yield and profits, etc. Because the farming techniques that are passed down through families are rarely best practices, the food and extra income provided is rarely enough for many luxuries, and sometimes not enough for necessities (like school). In one example, Maathai talks about a local farmer in Yaoundé, Cameroon. The woman plowing her hillside field does it in a manner that is parallel to the slope direction of the hill, allowing the rainwater to wash away all her planted seeds during the rainy season. (Maathai) This reduces her harvest considerably, and could be easily avoided had she been given a chance to have better education. Although many of the social problems in the above list seem diverse, many of them can be solved with an improved opportunity for education to the common man. Through education, AIDS awareness can be spread, limiting this terrible disease and repairing broken families as well. Education has direct influence on adult literacy rates and the education index, and an indirect effect on GDP per capita by allowing for better paying jobs.

Education plays a direct role in the application of a local energy solution in any rural African community. In order for either a wind or water solution to be sustainable, the locals must take ownership and responsibility for it. This means that they know how it works, inside and out, and are able to clean it, maintain it, fix it, and more. Asking a local town to do this for either solution without a fore knowledge of basic physics or math would be next to impossible. So, a holistic solution makes sure that there is an education system in place that can sustain a

renewable energy resource system. If this is not viable, educating a few locals with the intention that they teach others is also a possibility. Ideally, either system would not only spark local economic growth and independence, but also a desire for increased learning in both the old and young.

Many African countries are still reeling from the effects of colonialism, particularly manifest in the corruption and bias exhibited by many government officials throughout the continent. This problem has been addressed over the past few decades to some extent; however, it is still a major issue for many countries in Africa today. Corruption, and occasional politically instigated violence, was initiated by the many injustices performed on the African people during the period of colonialism. It is not uncommon for African voters to makes their decisions simply based on tribal allegiances, and for them to expect their elected officials to do the same while in office (Maathai). To some extent this is fine, but when bribes and promotions enter the picture, things start to go downhill quickly. The worst element involved with this problem is that the seeming "quick fix" is actually much more detrimental in the long run. Maathai puts it this way- "By exposing their own greed and selfishness, the people are easily bought, exploited, and victimized, thereby working against their own interests." While corruption is more obvious in governmental positions of power and authority, the nature has become so ingrained that even the populace has become accustomed to the way it is (passive) or complicit in their behavior. In response to both educational opportunities and widespread corruption, Maathai responds with a call to what could be described as a "revolution in ethics":

"The aim here is not education, per se: it is not as if the leadership in Africa hasn't had its share of highly educated individuals. The point is to recognize that, just as one develops new technologies and expands the potential for breakthroughs in computer science and engineering through technical colleges, so advances in leadership and the application of values must receive similar impetus" (Maathai).

In William Kamkwamba's childhood, he witnessed his town's "chief," or leader, ask for acknowledgement and assistance from the president of Malawi during a drought and famine in the country. At the time, the president was not willing to acknowledge his own inability to solve the current food shortage problem, and consequently had the chief beaten for speaking out about it. The chief never fully recovered from the severe beating and died not many years later (Kamkwamba and Mealer). As a young man, William respected his chief for speaking out about the problem (as did many others), but all were reminded of who carried the power then and what they wanted, and didn't want, to do with it.

When addressing any energy solution, preparing for government involvement or intervention is almost inevitable. Until sub-Saharan government structures start becoming more balanced and protective of local citizen's rights (or giving them more), any energy solution could be cheated or bribed out of the local community's hands. Those who know how to maintain the solution could commandeer it for their own selfish purposes, causing the rest of their community

to suffer. Until a revolution of ethics occurs, both of these scenarios and others are potential outcomes to an otherwise positive solution. If possible, putting up social barriers to this type of corruption is ideal- not just for the maintaining of the solution, but also for the sustained independence of the local people.

Even while Africa has and is facing many hardships, it is robust and strong. Many Africans over the past few decades have shown extraordinary virtue and courage in the face of hardship, including: Nelson Mandela, Julius Nyerere, and more recently, William Kamkwamba. Many others have stood in the face of corruption and non-democratic behavior, but have lost their political position and social clout for doing so, of which Wangari Maathai is one (Maathai). Africans have just as much potential to be smart, honest, ingenious and successful as Americans or Europeans if only they can be given the right encouragement and opportunity. It is important when suggesting a solution to any of their problems that the solution reflects the knowledge that they desire to grow, learn and succeed just as much as the next person on planet earth. It is also important that the recommended solution encourages Africans to invest in other Africans, and not simply to use the recommended energy solution as a bridge to receive an education off continent and never return to Africa.

The above discussion points highlight the importance of understanding social context before moving forward with quantitative discussion, but an interactive personal relationship with any community being considered is ideal. One very effective way to incorporate the community into the solution, as opposed to the problem, is to set up an action plan (Walker). This would be a plan that outlines what actions will be taken, what resources will be used, the people responsible for taking the actions, and the expected timeline of completion of each of the actions (Walker). The community could be responsible for terrain mapping, generating local discussion, teaching others, providing suggestions and comments, manual labor and more. The action plan would effectively let the community know that there are things they can be doing in relation to this new technology, instead of simply reaping the benefits from it. It would also increase their responsibility for the project as a whole, and decrease the overall time needed to accomplish the project.

Considering social implications first when suggesting a solution of this nature may be easy to overlook, but has the potential to be a catalyst for ethic revolution among the people of Africa. It provides a way for a renewable energy source to become a source of personal and national pride as well, reminding each individual that they have what it takes to succeed in the world of tomorrow, and that the long term benefits of ethical choices always outweigh corrupt short term decisions.

Economic Analysis

Considering the nature of income of most Africans, it might be a natural reaction to assume that most Africans are unable to purchase any kind of renewable energy device, and

wouldn't want to even if they were financially capable. In reality, the opposite is true (Doyle 24-26). Modern energy products such as solar systems, wind generators, improved stoves, kerosene, batteries, and electric lamps are all hot on the market in many African countries right now (Doyle 24-26). In fact, companies bringing supply to the demand for these products are jumping up all over, especially because the prospects for expanding electric grids across Africa does not look promising in the near future (Doyle 24-26). And while the buying power of some Africans is staying stagnant, for others it is rising- especially in rural areas (Doyle 24-26). Armed with this knowledge, it is not as much of a stretch to assume that a more substantial investment on a small community scale renewable energy project is within reach as well.

Unfortunately, prices are being driven up by financially inefficient delivery chains and informal trade customs that are both typical in sub-Saharan African countries. Delivery chain's inefficiencies are largely due to a lack of infrastructure and upkeep of public roads, which ties into political corruption via the misuse of public taxes. War and political volatility also heavily affect the market prices of such items, due to this area of product being such a sensitive one at the current time (Doyle 24-26). Improving delivery options is projected to be a huge market driver, despite otherwise large price volatility (Doyle 24-26).

In the case where either the windmill or micro-hydro station would be built by the local community, one of the first problems the community would face after compiling the money would be gaining access to the right high-value energy equipment. Fortunately, more and more "hire purchase" stores are opening up across Eastern and Southern Africa, which have the potential to carry necessary items (high-value energy equipment) for future wind turbines and micro-hydro stations (Doyle 24-26). It is projected that these stores and high-value energy equipment distributors would be able to coordinate in the near future regarding making more environmentally friendly products available to the public at cheaper prices (Doyle 24-26). Because of average overall proximity to these distribution and selling points is decreasing, rural villages will soon be able to purchase the same products for cheaper. Currently, Kenya has diversified the most in Eastern Africa, in both "hire purchase" stores and petrol station networks, whereas Uganda and Ethiopia have not grown as much (Doyle 24-26). The growth of both of these networks is key to the spread of availability of renewable energy options to rural towns and villages of Africa. Another problem that the community would face would be attaining the foreknowledge required to build a wind turbine or micro-hydro system. While some information can be gleaned from local libraries, this is not always an option (Kamkwamba and Mealer). The basic structure of a wind turbine is a bit simpler to replicate when considering crude working designs of both solutions, thus making the wind turbine the cheaper option of the two in simpler designs. When considering more complex designs of each, both energy solutions are going to have a similar price tag. Going through an outside private company would likely cost more initially, but it would have a longer lifetime and the process would likely incorporate more specific learning and training for the community.

It is also possible for the existing urban markets for these products to act as proxy sites for their rural counter parts (Doyle 24-26). A good example of this is when those from rural areas take a visit to family and friends in the city (happens about four to five times a year). When they are in the city, these visitors usually take the time to buy things that they need or want that they are not able to access out where they live, including the higher value energy equipment (Doyle 24-26). This allows for sellers of high-value energy equipment to better judge and react to market changes, as well as know where is best to set up their next most profitable rural shop. This information could also be used to determine which rural towns are most in need of a new renewable energy system, and which ones are most likely to pay for it or want it.

Economically speaking, another large unknown is the demand on power at any given time in a specific town, region or country. To model this, Professor Sendegeya of Makerere University in Kampala, Uganda, used the Monte Carlo simulation (Sendegeya). The Monte Carlo simulation is a type of statistical modeling that receives a number of uncertainty inputs in order to model phenomena. His findings showed that "the consumer's price sensitivity has a significant impact on the economic performance of isolated power systems" (Sendegeya). In other words, as the local village is more reactive to the changes in price for power, the less economically viable the renewable energy system. Based on this statement, it is safe to say that the poorer the community, the less likely the renewable energy system will survive economically. Part of the simulation was to test the difference between an altruistic system vs. profit maximizing system, and it was concluded by Professor Sendegeya that a profit maximizing operator would increase the reliability of the machine (Sendegeya). It was also determined that in order to provide better results, data pertaining to market behavior and consumer behavior is very important. Without it, it is difficult to determine more on how well a renewable energy system would fair economically in a specific set of parameters.

In the ideal scenario, the rural town that intended to bring the renewable energy source platform near to them would take full responsibility for a set of economic steps. Firstly, they would seek any available outside consulting assistance, the more immediately available and free the better. An example of this is the Energy Through Enterprise Company, which issues grants (that include entrepreneurial training, business proposal writing materials, and increased access to equipment) to budding entrepreneurial companies and individuals (Singer). Even as the community (or individual representing the community) should be seeking outside help, they need also to be taking active steps towards mapping out what they want- with terrain mapping, estimation of power needed, and measurement of potential renewable energy sources to be tapped. This type of community action would actively show any potential investors that the community is committed to the success of the project, and is worth any investment risk. Taking care of the above active steps will also eliminate steps that need to be taken care of by any outside company or assistance. Whether the renewable energy platform is footed mostly by the community or an outside company, it is essential that at least one (preferable multiple, for accountability within the structure) of the local villagers learns how to manage the mathematical

and engineering aspects of the renewable energy platform. This will secure the correct upkeep and management of revenue soon to be secured from the platform. This is also necessary so they may dispel any rumors among those less educated that are started regarding the platform being anything other than a provider of power and scientific item. Also, the community should come together to have a group discussion to outline realistic and unrealistic expectations regarding the new addition to the town. This is important in that everyone gets an equal share and understanding of how to better their daily activities with this new option available to them. Although not necessary, it may be of some long term benefit for someone who is capable in the village to take data on energy use of the community based on current market variables (like the prices of gas, electricity, etc.) and other variables (like weather, political stability, etc.). This data could be used to better predict the market in the future, which would be very beneficial in manipulating power output from the platform in order to best meet the community's desires during times of greater need (Sendegeya).

Engineering Perspective

Within the previous two sections, very little if any discrimination has been established between the two solutions to be presented in this paper: wind turbine for harvesting wind energy, and a micro-hydro station for harvesting energy from moving bodies of water. Taking a calculated, engineering perspective is absolutely essential before making binding decisions with regards to this process. Without an engineering perspective and grasp on the situation before, during and after, things are bound for failure.

One of the first considerations before erecting a wind turbine is assessing whether or not there is wind to power it. According to a report compiled by Rodolfo Pallabazzer in 1997, the country of Uganda does not benefit from having a good amount of wind to use as a resource. This wind strength was assessed by erecting ten meter towers in eleven locations around the country, and each measured the wind speed in meters per second at one hour intervals (Pallabazzer, and Sebbit 41-49). Immediately upon analyzing the data collected by these towers, it became obvious that only two of the eleven sites were suitable for attempting to use a wind turbine as primary power supply for the surrounding area (Pallabazzer, and Sebbit 41-49). This decision was based on prior knowledge of parameters that dictated high outputs in other wind turbines- moderate to high average wind speeds as well as low to moderate variability in those high speeds. Once sites have been determined that are suitable for a wind turbine, it is necessary to determine what

support and materials are nearby. Is there a company who will do the work for a fee, or do the locals need to be educated on the construction and maintenance? It is also important to note what kind of wind turbine is being built, whether of a more homemade variety as William Kamkwamba did or a more industrial type. These questions greatly change cost, time frame of construction, and power output, among other things, and thus are pivotal to answer well before plans are in motion. Locating and transporting the necessary pieces of a wind turbine can be an engineering challenge in and of itself. Will there be a need to recruit extra man power from surrounding villages? Who will be trained on the inner workings of the nacelle (gear box, motor, etc.) and who will be responsible for routine maintenance? How will these people be trained?

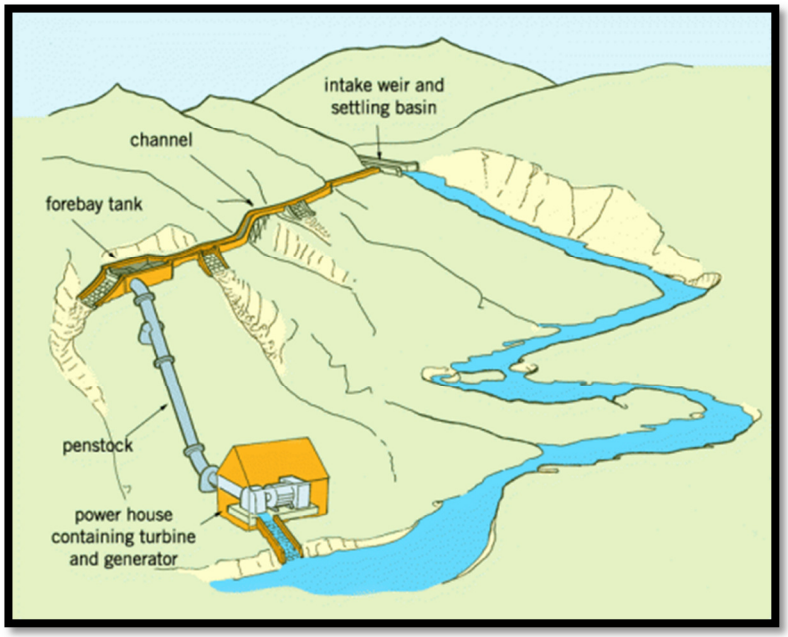
Early in his article, Pallabazzer actually makes the recommendation that, within the scope of micro electric generation, tapping the hydraulic resources of Uganda would be more powerful than tapping wind energy resources for the same. Similarly, wind energy resources are recommended for local water pumping, due to its irregularity (Pallabazzer, and Sebbit 41-49). In fact, studies on both of these are soon to be initiated by the largest state university in Uganda- "the Faculty of Technology of the Makerere University is moving to study the feasibility of autonomous power systems from two renewable energy sources: water and wind" (Pallabazzer, and Sebbit 41-49). Indeed, the renewable energy potential in both of these is large, and if used properly in Uganda and other countries throughout sub-Saharan Africa, could cause dramatic social and economic change.

As an alternative to wind turbine placement, micro hydro stations are also an effective gatherer of renewable energy in the third world community setting. They are placed near a moving body of water, like a stream or river, and are strategically positioned so as to harness a maximum velocity from some form of falling water ("Practical Action"). Micro-hydros are in essence a type of miniature dam, and while dams are not uncommon across sub-Saharan Africa, micro-hydros have not gained as much momentum as their larger counterparts.

Multiple large dams have been erected in the past few decades, and provide large portions of overall energy production in many of the countries they are located. The large dams have been gaining attention over the past few years due to their handle a variety of society benefiting tasks besides power generation, including flood control, water supply control, and irrigation supply control (Bishop). Kafue Gorge Lower Independent Power Project is one such dam, located in Zambia, and produces 750 MW (Bishop). This amount contributes to 25% of the country's supply of electricity (Bishop). Bujagali hydroelectric power project is another such dam, located on the Victoria Nile River in Uganda. It is expected to be finished in 2011 and produce 250 MW, which will double the nation's energy capacity (Bishop). On the African continent currently, over 7500 MW in large dam projects is currently being built (Bishop). Large dams may seem like a more efficient choice when looking for renewable energy from bodies of water; however, they do come with their share of problems. Large dams throughout Africa need to be upheld to strict regulations and codes, otherwise they are prone to environmental and social hazards (Bishop). Also, because one structure contributes to such a

large part of the nation's power, dams are typically hotspots for corruption- since they are so pivotal to the nation's economic and social well-being they can easily be wielded in exchange for increased political clout (Pascal). Finally, because the transmission of energy is limited by distance, they do very little for the rural community that this paper is focusing on (Bishop).

Luckily, there is an alternative. Micro-hydros not only have the potential to provide enough energy to satisfy the local community they are intended for, but they also have the potential to provide much needed jobs (Bishop). They also solve the problem of energy travel distance to rural communities, as they are usually located onsite, and provide the amount of power needed for that community (while any extra has the potential to be sold for a profit to the main power grid). As previously stated, a micro-hydro station is either situated in the middle of a moving body of water, or near a moving body of water, in order to harness the kinetic energy of any water that is falling ("Practical Action"). They harness the energy in a very similar way to wind turbines- the continual forced turning of a set of blades, which is connected to a rotating shaft and electrical generator to produce electrical current. While the two systems are very similar in nature, micro-hydro systems require a bit more housing around gears and electrical units due to the proximity to water. Even so, parts can be homemade and assembled with little outside assistance if necessary (Pascal). A typical cost for a micro-hydro system runs somewhere around $15,000, but is worth much more than that to a community (Pascal).



Conclusion

When considering a holistic perspective, both wind turbines and micro-hydro systems seem like viable options for solving a good chunk of Africa's energy needs. In many ways, they are very similar. They both have comparable costs, similar mechanics, and produce similar results for the communities they are in. Both solutions provide independence and responsibility for otherwise government dependent rural communities, teaching them about cutting edge technology used around the world as well as inspiring them to learn and grow beyond their sheltered lives in their small communities (Pascal). Depending on a community's location in relation to distribution centers for high cost energy products, the overall cost of creating either solution might increase. As stated above with regard to wind turbines, neither solution should be

placed simply out of need- both research and planning are needed before either is implanted so as to maximize the amount of energy made available to the community. So depending on the country or region in question, the answer to the African energy problem should shift to coincide with the local natural resources of wind, water, or both. For example, due to a greater number of moving bodies of water in Uganda, it would be logical to implement micro-hydro stations across the country, assuming this was also more cost-effective than wind turbines and socially viable/acceptable. However, in order to supplement this energy source, wind energy might also be provided for secondary tasks, such as pumping water from wells. This solution might be flipped in Malawi, seeing as William Kamkwamba has shown in his book that there is an abundance of wind waiting to be tapped there. It may be true that only one of the two solutions may be viable at one time; however, if the first solution holds there may be enough economic growth in the area to allow for a supplementary solution. Wind and water energy both have the potential to be great electricity producers for those struggling without power in sub-Saharan Africa, but the true lesson is learned when a holistic approach is applied- people first, problem second. Perceiving, understanding, and listening before acting will always be more important than the flawless implementation of the most efficient, inspired solution.

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