Rural Electrification in sub-Saharan Africa: A Tier-Study of Electrification Mechanisms and their Practicality

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Abstract

There has been a plethora of papers produced regarding rural electrification. However, few relate different methods of electrification to each other, given different socio-economic and geo-political environments. The Millennium Development Goals, established in 2000, prove that there is a collective desire for global electrification. I studied three methods of rural electrification, national grid expansion, micro-grid implementation, and mimic solutions, and their practicality in different areas. There is no single formula for electrification. Rather, these three mechanisms act as different tiers, and countries and communities can choose what, specifically, works given their economic and environmental situation.

JEL codes: Q01, Q02, Q40

Keywords: National Grid Expansion, Micro-grids, Mimic Solutions,

Introduction

In 2000, representatives from 189 countries across the globe met at the United Nations Summit and agreed upon the Millennium Development Goals; a set of targets for every country in the world to meet by 2015. The seven objectives spanned across numerous social and economic platforms, and were mostly targeted towards developing countries. These goals were measurable, for example, "Goal 1: Reducing the poverty rate by half by 2015 compared to its level in 1990" (Easterly 2009). Unfortunately, sub-Saharan Africa, a collection of countries in which the goals were most focused, did not fare so well. In 2007, the UN declared that, "sub-Saharan Africa is not on track to achieve any of the goals" (Easterly 2009). The World Bank declared, in 2009, that it will invest $930 billion in Africa over the span of 10 years. It went on to state that 50 percent of these development dollars would go towards power infrastructure (Bernard 2010). However, the methods for attaining this goal were never specified.

1.6 billion people across the world do not have access to electricity (Dinkelman 2011). Rural electrification was never explicitly mentioned in the list of Millennium Development Goals, but I argue that it is a mechanism that can be used to attain the desired objectives. One of the goals is focused on primary education. A study conducted by the World Bank in the Philippines showed that students from electrified households were about two years ahead, academically, when compared to their same-age peers from non-electrified households (Kirubi 2009). Two of the other goals focus on decreasing the rate of maternal mortality and child mortality. Another study, from Mali, shows that television access increases the amount of completed pre-natal visits by pregnant women (Kirubi 2009). Televisions can disseminate valuable information on a national scale. Companies and governmental agencies can run programs advertising the beneficial health effects of visiting a pre-natal professional often during pregnancy, or techniques to prevent HIV contact - the topic of another Millennium Development Goals. In this paper, I will discuss three different approaches for rural electrification: national grid expansion, the implementation of micro-grids, and small, off-grid, projects that mimic the benefits created from electrification. I

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study case studies in South Africa, for national grid expansion, Senegal and Kenya, for micro-grid projects, and Malawi for mimic solutions.

These three styles are vastly different, and each possess different barriers. Expanding the national grid is a lofty goal. The African continent is known for its eclectic environment and lack of infrastructure, especially in rural areas. The three main factors that are considered before grid expansion ensues are, proximity to existing power lines or sources, population density, and terrain (Dinkelman 2011). It is costly for utility companies to build new infrastructure to allow for the passage of electricity, especially if the land is uneven. For national grid expansion to succeed, proven governmental determination through subsidies or incentive programs is essential as well as having an already established national utilities company.

The implementation of micro-grids also poses numerous problems. Mostly, the companies that provide the micro-grid technology and installation are privatized. Without governmental assistance, they are responsible for much of the costs associated with their projects. Average connection costs can total anywhere from $50 to $250 per family, per year. The average income in Africa is less than $2 dollars a day (Bernard 2010). Thus, any family level investment in electricity would represent a significant investment. Electricity, with its ability to power televisions, radios, and other entertainment devices, is seen as a luxury good instead of a tool to be used for income generation, so the willingness to pay is lower than it should be (Bernard 2010). Micro-grids are generally cheaper to install then expanding the national grid, but the private utility companies are smaller and have fewer resources than national utility companies that are contracted by the government.

Another way to address the issue of low rural electrification rates is through the dissemination of smaller products that mimic some of the positive effects of electricity, like solar-powered LED lanterns. Clearly, a large detractor from this project is that it does not actually produce electricity, so consumers will not be able to use the lanterns for income-generating projects. However, extra light during the night time can generate large benefits towards education. And, these products are generally much cheaper than the costs associated with connecting a house to the national grid, or establishing a micro-grid. This permits these technologies to be widely accessible, allowing them to act as a transition technology, between no electricity and connection.

These three mechanisms, mimic solutions, micro-grids, and expanding the national grid, can be viewed as individual tiers that eventually build to complete electrification of a country. National wealth should not be excluded in this discussion as it provides relevant information pertaining to infrastructure capacity and development. According to the World Bank, Malawi, in 2015, had a GDP of $6.4 billion. Kenya, in 2015, had a GDP of $63.4 billion. And South Africa, during the same period, had a GDP of $314.5 billion (World Bank). Based on GDP alone, it is ridiculous to think Malawi could afford to expand the national grid as aggressively as South Africa did in the 1990s. However, the success of the specific implementation mechanisms, in each of the studied countries, shows a strong sentiment of optimism for future capacity. After the LED success in Malawi, the government has granted the free import of solar lantern technologies, indicating future growth. Likewise, after the success of the MEP project in Mpeketoni, Kenya's national utilities company took control of the program and expanded services to neighboring regions, indicating rural electrification is a national priority. So, even though these mechanisms are different, they represent various stages of electrical capacity development. It is reasonable to say that relatively poorer countries start with mimic solutions until their methods and benefits are proven. The next logical stage is micro-grids. Finally, with a unified national agenda, national expansion, through the connection of established micro-grids, is feasible.

South Africa: Grid Expansion, on a National Scale

Hailed as the greatest success story in Africa pertaining to rural electrification, the case for electrical expansion in South Africa is particularly interesting. From 1990 to 2007, Eskom, South Africa's national utilities giant was able to provide electricity to an additional five million households. Unfortunately for the rest of sub-Saharan Africa, this massive expansion seems hardly replicable. The "Electricity for All" campaign, funded by Eskom and initiated by the state, was a founding pillar of the new government created through the end of the apartheid in 1994. At this point, South Africa was legally divided by race, with black South Africans suffering the unjust rule, socially, politically, and economically. A 1996 census survey showed that 58 percent of the population had access to electricity. 78 percent of homes in rural areas reported using wood fuel for cooking, and 74 percent used candles for their dominant source of lighting. Electricity was, often, only one input on an extensive list of energy sources, including kerosene, candles, and biofuels, for families in rural areas. 14 percent of the population, also the richest same 14 percent, used electricity as their sole energy input (Davis 1998). This coverage was constant in large cities and suburbs, which contain a high density of white and wealthy inhabitants. In less covered areas, 97 percent of non-urban white homes were electrified, while only 25 percent of non-urban black homes were (Bekker 2008). Decreasing the economic divide, between white south Africans and black South Africans, through electrifying homes was one of the first ways theorized to deal with inequality. In the 1950s, the African National Congress (ANC) created a Freedom Charter explaining their agenda in their fight against apartheid. In this charter, they created a list of basic needs that were to be included in their fight for equal political rights. These needs included the importance of owning a home to socioeconomic status. Equal home ownership standards, on par with the wealthy white population of South Africa, included the luxury of electricity in the home. When apartheid ended, the ANC, who championed electricity expansion as one of their key platforms, was able to initiate a program called the National Electricity Program (NEP).

Eskom, South Africa's dominant national utility company, already had the infrastructure and market positioning when the plan to expand electricity to rural areas was announced; the company even provided the capital to fund the program from 1995 to 2000. In 1996, Eskom incorporated and the state began funding the program through the treasury. The government also brought electricity to the poorest households through the Free Basic Electricity (FBE) program, which allowed for the free use of 50kWh/month. These inclusive models of financing, coupled with the importance of electrical expansion to the government, provided the perfect atmosphere for the ambitious program. 470,000 homes were connected, by Eskom, from 1993 to 2003 (Bekker 2008). In the KwaZulu-Natal region of South Africa, which holds 20 percent of the country's total population, the importance of electrification in terms of employment particularly had drastic effects on the female population. In a community where over 50 percent of households are headed by women, electrification allowed for more efficient cooking and lighting, which granted women the opportunity to seek additional income generation projects. During this time, more than 15,000 women joined the workforce, representing an increase of 9.5 percent (Dinkelman 2011). The increase in female employment directly addresses the Millennium Development Goal focusing on gender equality.

It would be naive to use the undisputable accomplishment of rural electrification in South Africa as a model for future sub-Saharan electrical development. The unified political sphere that resulted from the end of apartheid, the goal of facing issues of inequality through rural electrification, and a national utility company with the infrastructure of Eskom are all factors that converged to make the National Electricity Program a reality. South Africa was divided by race and socioeconomic level, which clarified the immense inequality facing the country. When apartheid ended, the next logical step for an equal society was national electrification. And, South Africa could call upon the utilities giant, Eskom, for assistance. These factors occurred independently from one-another, and their convergence is impossible to replicate. Nevertheless, the metrics, pertaining to female employment and reduced inequality, can be used to advocate for similar programs in other sub-Saharan African countries.

Senegal and Kenya: Feasibility Analysis and Implemented Microgrids

Senegal, a country in North Africa, in 2006, had only 16 percent of its rural population connected to electricity, compared with 76 of the urban population (Thiam 2010). This was problematic as the total population was split evenly between rural and urban households. In 1998, the government of Senegal decided to implement strategies to increase rural access to electricity. With the help of the World Bank, Senegal broke up the main monopoly that controlled the utility sector (SENELEC) and created an agency with rural electricity as its main mission (Thiam 2010). In 2010, a feasibility analysis was conducted in the country pertaining to the costs and benefits of three different electrification methods: off-grid solar, off-grid wind, or national grid expansion. This analysis was to act as a set of recommendations for the Senegalese government in their pursuit of national electrification.

Senegal, like many other African countries, is dependent on foreign oil imports. However, its geographic-location provides a wealth of natural resources. Due to its proximity to the equator, the country has access to 3000 hours of direct sunlight per year. The northern, coastal region generates a lot of wind power. In 2006, 40 percent of the energy consumed was created through biomass; urban areas used charcoal, and rural areas burned wood (Thiam 2010). The feasibility analysis projects the viability of using off-grid renewable energy in contrast to national grid expansion in the pursuit of connecting rural communities.

A large component of the feasibility analysis was the cost associated with the different methods of electricity production. When calculating costs, it is essential to include explicit costs, such as fixed costs associated with implementing a project, as well as implicit costs, such as maintenance and education surrounding that same project. For example, an explicit cost could be the cost of installing the turbine, and an implicit cost could be fixing the turbine after a storm. It is also important to consider externalities, which are, relatively, much more difficult to calculate. In the case of installing a wind turbine, a positive externality could be the reduction of carbon emissions that normally result from the burning of fossil fuels, which can lead to respiratory problems. Other externalities include the gain in additional hours of light, which can have positive benefits to childhood education. Generally, renewable technologies have a higher fixed cost, but require lower operating costs (Thiam 2010). The heavy cost of solar panels and wind turbines is also decreasing due to increased supply and improved efficiency. After calculating total costs and regional demand, the analysts found that off-grid solar is the most viable option currently for Senegal, followed by off-grid wind. Expanding the national diesel-grid, with a complex terrain and inconsistent population densities, proved too costly to be cost-effective. It is essential for governments that wish to implement aggressive rural electrification programs to first do their research. Using feasibility analyses is a good way to do this.

Researchers have mathematically theorized that microgrids can act as a cost-efficient solution to bring electricity to rural areas in Senegal. Kenya, a country in eastern Africa, has already introduced policies and programs to bring microgrids to rural communities. The government has incentivized energy production by allowing private companies under 3MW to operate without heavy government regulation. The Mpeketoni Electricity Project (MEP), an effort to create diesel powered microgrids in the region of Mpeketoni, in the Lamu District of Kenya, began in 1994. The total cost of installation was $40,000 and the affected community agreed to pay 30 percent, with the government subsidizing the rest (Kirubi 2009). The electricity was hardly consistent, with power outages sometime ranging numerous days, but, the benefits that resulted were astounding.

The main advantages resulting from the MEP were apparent in agriculture. Mpeketoni is largely an agricultural society; in 1972 every family was given 20 acres of land to cultivate. Before the implementation of the microgrid, few tractors contracted from Witu, which is 100km away, were available to use in tilling and clearing agricultural plots. The owners of these diesel-powered tractors were afraid of their tractors breaking down in Mpeketoni. However, the electrification of the community allowed for the use of electric welding tools that drastically sped up repairs, giving renters a sense of security. Community members recall only two tractors for contract in 1988, and over a dozen in 1994. Electricity also introduced cold-storage technology, which allowed farmers to transport their produce farther distances to market (Kirubi 2009).

Entrepreneurial endeavors, referred to as small and micro enterprises (SMEs) such as tailoring or carpentry, accounted for 90 percent of new job creation in Kenya in 2003 and totaled 30 percent of GDP (Kirubi 2009). These ventures benefitted greatly from the prevalence of electricity; productivity per artisan increased from 100 to 200 percent when compared to pre-electric productivity. The quality of the goods increased, and revenue for

the small businesses that created them increased by 20 to 80 percent. A notable example is shown in the case of a tailor, who, with the introduction of an electric sewing machine, can produce more goods of higher quality. Using a charcoal iron, a worker can iron an average suit jacket in one and half hours. With an electric iron, he can iron a suit jacket in thirty minutes, giving him more time to generate income through ironing additional clothing or other endeavors (Kirubi 2009).

Access to electricity increased incomes and productivity, but also created benefits for the community. Kenya, like the United States, mandates that all students who wish to continue their education at a university take a standardized test, which largely determines their path. This test favors students that live in wealthy urban communities with prestigious education systems. Mpeketoni Secondary School used 50 percent of the total electricity produced through the MEP (Kirubi 2009). Electricity allowed schools to stay open later and gave teachers access to educational resources through the internet, thus lessening the gap between students in urban settings and rural settings. Mpeketoni is one of the few rural communities in Kenya that has created a polytechnic institute to further train students in computer science. Electricity was used to pump water to educational facilities, decreasing the risk of water-borne illnesses such as cholera. Electrification brought banks and post offices to Mpeketoni, which led to the availability of capital to expand businesses. With the success of the MEP, a Rural Electrification Agency was formed by the Kenyan government, in 2006. In 2007, the Kenya Power and Lighting Company, Kenya's national utilities company took over the MEP and expanded electricity to adjacent rural communities (Kirubi 2009).

Malawi: Mimic Solutions

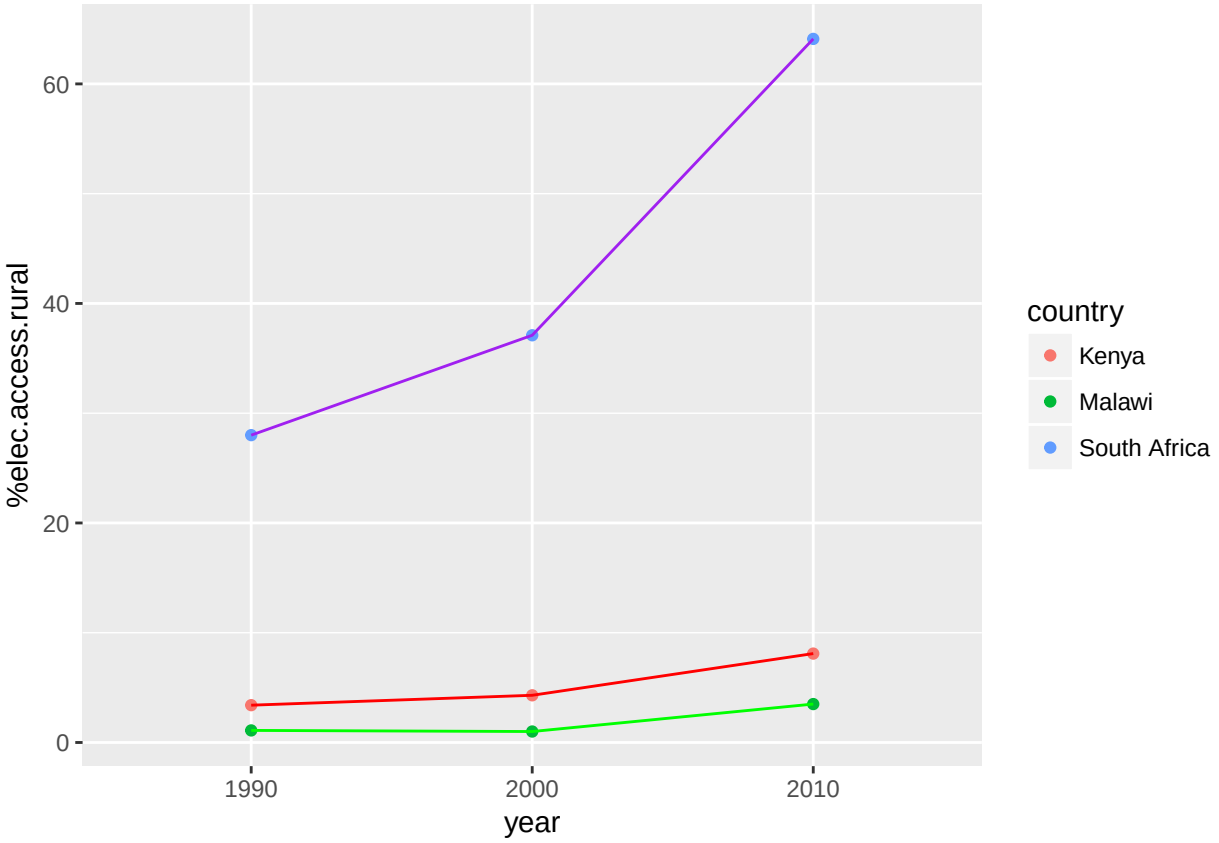
The Zomba district of Malawi, in 2004, attempted to find a market solution for rural electrification. Zomba received funding through the Millennium Villages Project, an organization that established "Millennium Villages" to increase rural productivity (Adkins 2010). This organization was founded in 2004, and had 80 villages in 2010, serving 400,000 people. The Millennium Villages Project located and trained wholesalers across sub-Saharan Africa, sold them Light Emitting Diode (LED) lighting units, and allowed them to sell the units to the public as part of their businesses. These businesses created different payment plans, allowing households to pay immediately in-full or overtime given the inconsistent nature of incomes in sub-Saharan Africa. LEDs provide a large array of benefits. They are sold for around $25 each, which pales in comparison to the $350 it takes to connect a home to the national grid, which only 5 percent of Malawi's population has opted for. One LED unit provides nearly 50,000 hours of clean light. Malawian households have reported spending 25 percent of their income on conventional lighting fuels such as kerosene or wood (Adkins 2010). These conventional fuels require time to collect, and cause an array of health problems, specifically respiratory issues.

After the program began, the households in Zomba, both with and without LED units, were surveyed regarding their experiences. The respondents claimed to spend 19.7 percent of their income on lighting, which was predominantly used to illuminate family dinners and children's studying, 30.9 percent and 11.1 percent, respectively (Adkins 2010). Households that purchased LED units drastically reduced their kerosene usage, from 98.2 percent of total energy to 53.7 percent. Respondents also reduced their weekly expenditures on kerosene, from $.61 before purchase to $.09 after purchase (Adkins 2010). The increase in nightly light availability, from 2.7 hours per night with kerosene to 4.4 hours per night with LEDs was a main factor that prompted every single respondent to answer "yes" when asked if the implementation of LED units increased their quality of life (Adkins 2010).

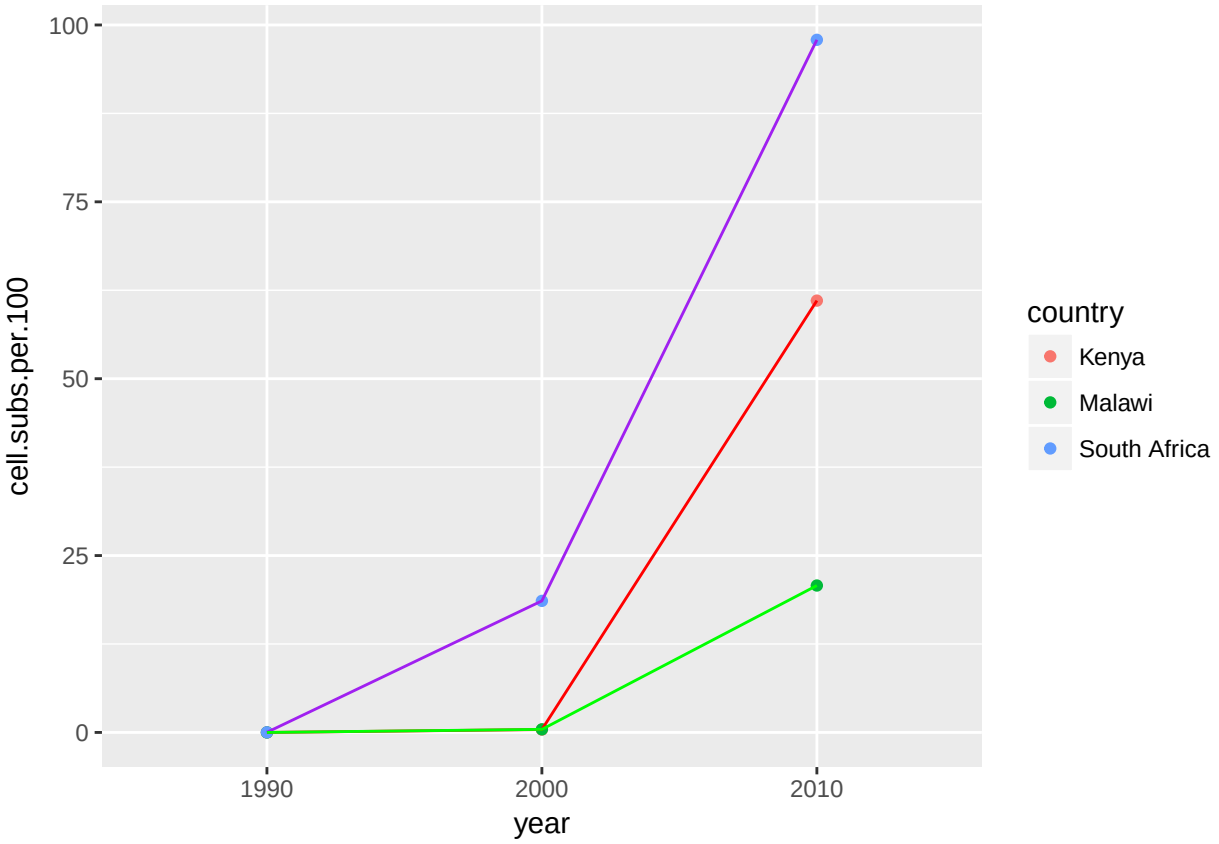
The success of the LED program has led to the formation of the Opportunity Bank of Malawi and lending circles to credit households, allowing more people to have access to this technology. Also, as an incentive program, the government of Malawi has granted free import status to solar lanterns (Adkins 2010). LEDs mimic the benefits of rural electrification without actually providing mechanical electricity. Light is one of the largest advantages of electricity and LEDs provide a cheap method of illumination.

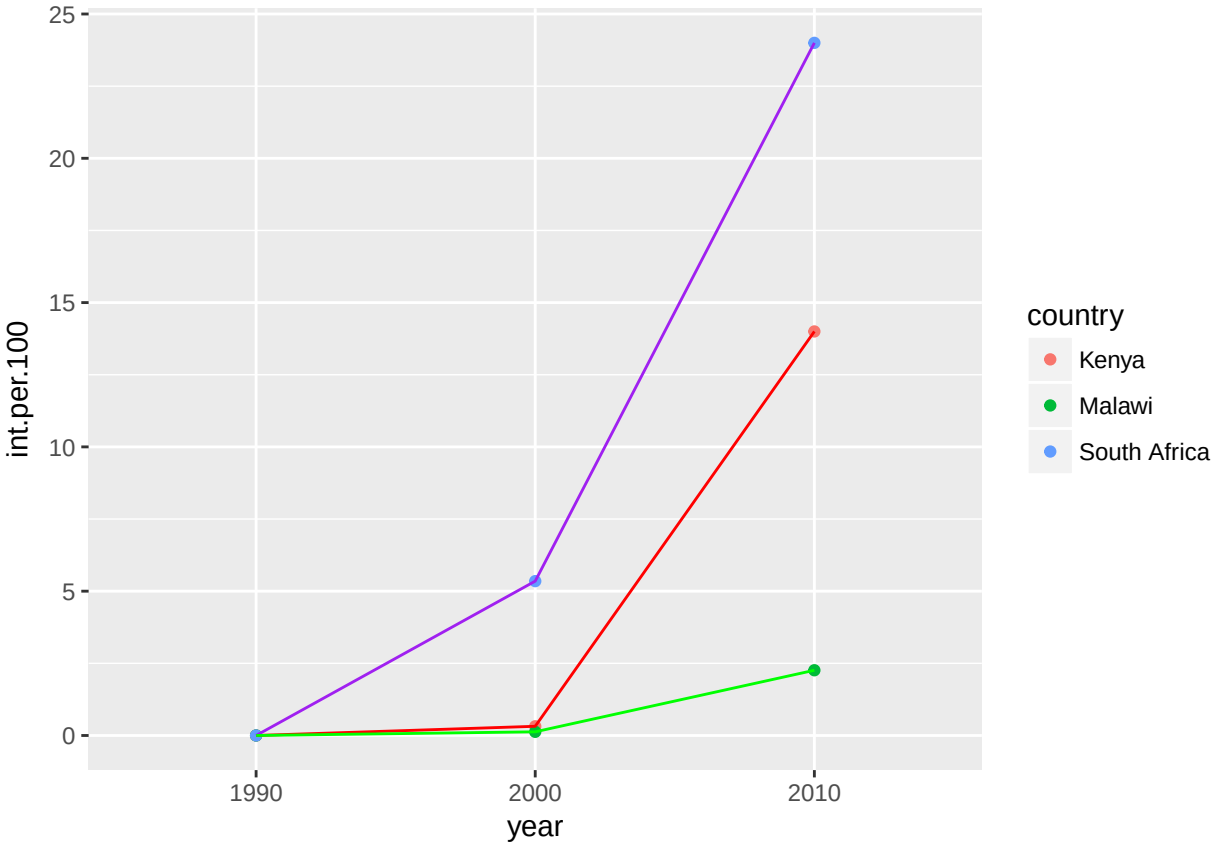
Discussion and Inference

With the acceptance of the Millennium Development Goals in 2000, and the relationship between the objectives delineated in the agreement and electricity, it is clear that there is a global prerogative for electrification. The graph below, created with data from the World Bank, shows the percent of the rural population with access to electricity for each of the countries I studied from 1990 to 2010.



Clearly, South Africa was able to install a much larger capacity during this time period, as a result of their national expansion campaign and their comprehensive infrastructure systems. Even with smaller micro-grid and mimic solutions, Kenya and Malawi were able to increase the proportion of households in rural areas with electrical access. The World Bank provides data on the amount of cellular subscriptions and internet use in developing countries. The increased availability of electricity prompted the rise in cellular subscriptions and internet access for the affected countries. Cell phone subscriptions and internet access pose important benefits in the form of income generation, mobile banking, and globalization.





The three forms of electrical generation discussed in this project can be viewed as different tiers. The first tier, mimic solutions, represents generally lower-income countries without an established electrical infrastructure and without a national agenda or funding. This mimic solution does not actually provide the utilities of electricity, but can replicate some of the benefits, such as lighting. However, the benefits of these solutions should not be ignored as they pave the way for a more extensive system. Secondly, micro-grids, are normally seen in countries with more extensive infrastructure and policy incentives, and can often be coupled with renewable energy resources, such as wind or solar. This solution poses more tangible benefits, such as the dissemination of healthcare agendas to the public through the television advertisements, educational benefits through longer hours of school operation, and income-generation schemes for individuals. Finally, and most elusive, is the expansion of the national grid. This is, comparably, much more difficult to attain and requires a national policy agenda, installed and established infrastructure, and financing. But, as seen in South Africa, if done correctly, this method has the potential to create tangible change in a society, especially in terms of equality. There is no singular formula for rural electricity acquisition. Different electrification schemes are more appropriate for different countries depending on the size, infrastructure, and geo-political climate. These methods are then able to interact, incrementing through the different tiers, to create sustainable electrification expansion.

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