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Appliance Ownership and Aspirations among Electric Grid and Home Solar Households in Rural Kenya†

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Universal energy access has emerged as a major policy goal in sub-Saharan Africa. However, there are active debates about the extent to which energy access should be driven by investments in large-scale infrastructure, such as grid connections, or small-scale decentralized solutions, such as solar lanterns and solar home systems. Recently, both the US Agency for International Development (USAID) and the UK Department for International Development (DFID) have announced high profile energy initiatives—similarly named Power Africa and Energy Africa, respectively—targeting the 70 percent of sub-Saharan Africans who are believed to be living off the electric grid. At the heart of both policies is a focus on expanding the market for solar lanterns and solar home systems, which we refer to collectively as "home solar."

Several factors have contributed to the enthusiasm for home solar. With energy-related emissions of greenhouse gases accounting for over three-quarters of global emissions, politicians, donors, and nongovernmental organizations have been quick to highlight the renewable nature of the technology, particularly in developing countries that are still building out their electricity systems. In addition, recent innovations have increased the affordability of home solar by reducing solar prices and decreasing the power requirements for a variety of end uses (e.g., connectivity and computing through smartphones and tablets). Furthermore, by integrating mobile money payment technologies into their products, companies such as M-KOPA in Kenya have addressed the financing challenge and are providing poor, rural households with previously unaffordable home solar systems that can be paid for gradually over time.[1]

Not everyone, however, shares this enthusiasm for home solar. On the cost side, Deichmann et al. (2011) propose that decentralized renewable energy will be the lowest cost option for just a minority of households in Africa, even when taking into consideration the likely reductions in costs over the next 20 years. On the demand side, a recent household survey in Tanzania, conducted by the Center for Global Development, revealed that nearly 90 percent of households who already had "access to electricity outside of the national grid, such as solar power" still wanted a connection to the national grid.[2] Writing at The Breakthrough Institute, Caine et al. (2014, p. 17) caution that, "whatever the short-term benefit, a narrow focus on household energy and the advocacy of small-scale energy sources like solar home systems can, in fact, make it more difficult to meet the soaring increase in energy demand associated with

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[1] In addition to these factors, Jacobsen (2007) points to the private sector appeal of home solar, noting how decentralized solar first emerged during the late-1980s and 1990s, a period in which mainstream development policies emphasized economic liberalization, privatization, and market-based approaches to service provision.

[2] See Benjamin Leo, *Center for Global Development* (blog), October 23, 2015, "Why is DfID Pushing Solar-Only When Africans Say They Want On-Grid Electricity?" http://www.cgdev.org/blog/dfid-solar-only-approach-rural-electricity-africans-want-on-grid.

moving out of extreme poverty." Broadly, policymakers have begun to move away from binary definitions of energy access to recognize variation in the service levels provided by home solar and grid connections with different levels of reliability (see, e.g., ESMAP 2015).

While there is a small but growing research literature on the economic impacts of electrification (see, e.g., Barron and Torero 2015), there is minimal data and evidence on how electricity is consumed in the developing world, and how electricity use relates to the type of energy supplied. In this paper, we summarize the results of a recent household appliance survey conducted in Western Kenya to provide descriptive evidence on how rural households with and without grid connections, and those with home solar systems, compare in terms of the appliances they own and the appliances they aspire to own.

Our data indicate that home solar users own quite different appliances compared to grid-connected households, and suggest that home solar does not satisfy the full range of household energy needs, given current appliance technologies. We also document planned expansions in centralized electricity generating capacity in a number of sub-Saharan African countries, including Kenya. We find that the environmental advantages of decentralized solar are likely to be relatively small in countries like Kenya, where a large proportion of existing and planned grid electricity is generated without fossil fuels. This paper is organized as follows: Section I describes the data and setting, Section II presents the results, and Section III concludes.

I. Data and Setting

We analyze household survey data collected between February and August 2014 from 2,504 rural households in 150 communities in Busia and Siaya, two counties that are broadly representative of rural Kenya in terms of electrification rates and economic development. Our sample consists of 2,289 households that are not connected to the grid and 215 households that are connected to the grid. In each community, field enumerators sampled 15 unconnected households, and up to four connected households wherever possible, using a comprehensive census of residential structures conducted in 2013. At the time of the census, community electrification rates were low, averaging 5 percent for rural households. The sampling procedure—which is described in detail in Lee, Miguel, and Wolfram (2016)—ensured that the data are largely representative of the rural population in Western Kenya.

We collected data on the different types of energy used in each household. In our setting, home solar penetration is low despite low grid electrification rates. For unconnected households, the most common primary sources of energy are kerosene (92.4 percent), solar lanterns (3.6 percent), and solar home systems (2.2 percent). Only 8.7 percent of unconnected households use either a solar lantern or a solar home system as a primary or secondary source of energy.[3]

Based on this data, we divide our sample into three categories: (i) households that are connected to the national electric grid ($n = 215$); (ii) households that are not connected to the grid but use home solar systems (i.e., solar lanterns or solar home systems) ($n = 198$); and (iii) households that are not connected to the grid and rely primarily on kerosene energy ($n = 2{,}091$).

There is a wide range of products in the home solar market. Solar lanterns, which typically cost \$10 to \$100, offer less than 10 watts of power and are limited to lighting and mobile charging services. In contrast, solar home systems, which cost anywhere from \$75 to \$2,000, offer up to 1,000 watts of power and can power televisions, fans, and limited motive and heating power. The most popular solar home system in Kenya, M-KOPA, currently costs over \$200 and provides an 8 watt panel, two LED bulbs, an LED flashlight, a rechargeable radio, and mobile charging adaptors.[4] In comparison, residential grid connections support the full range of potential applications. Higher-end systems, accommodating the use of high-wattage appliances, are rare in Western Kenya and none of the households in our sample have such a system. In our data, the mean price paid for solar lanterns and solar home systems is \$54.27 and \$234.37, respectively.[5] Most of the systems documented are used solely to power low-wattage appliances.

[3] Households were asked to identify their "main" (primary) and "other" (secondary) sources of lighting energy.

[4] Based on Alstone, Gershenson, and Kammen (2015) and M-KOPA (http://www.m-kopa.com/products/).

[5] Mean prices paid for solar lanterns and solar home systems are based on 113 and 51 responses, respectively.

For this reason, we group solar lanterns and solar home systems together in our analysis.

We asked household respondents to list all of the electrical appliances they own. We then asked respondents to name the appliances that they would ideally purchase next. After compiling a list of all owned and desired appliances, we divide the list into two categories based on typical required wattages.[6] We define low-wattage appliances, such as mobile phones and radios, as those that can be powered using the most common solar lanterns and basic solar home systems found in the study region. High-wattage appliances are defined as those that require either higher-end solar home systems (which again are largely nonexistent in our setting) or connections to the electric grid. Using these data, we present comparisons below across the three categories of households defined above in order to better understand how households compare in terms of appliance ownership and aspirations.

II. Patterns of Electrical Appliance Ownership and Aspirations

Three patterns emerge in our data. First, home solar households have higher living standards than kerosene households, but differences in appliance ownership are not large. In online Appendix Table A1, we summarize the key differences in observed characteristics between kerosene and home solar households. Both types are similar in that the majority of household respondents are primarily farmers by occupation, but home solar users are characterized by higher socioeconomic status across most measures: they are more educated, politically aware, have bank accounts, and live in households characterized by high quality walls (made of brick, cement, or stone, rather than the typical mud walls), more land, and assets. These higher living standards, however, do not translate into meaningful differences in appliance ownership.

In Figure 1, we present a summary of the appliance ownership survey data, grouping appliances into low-wattage (panel A) and high-wattage appliances (panel B). Horizontal bars indicate the proportion of households in each category that own (dark gray) and desire

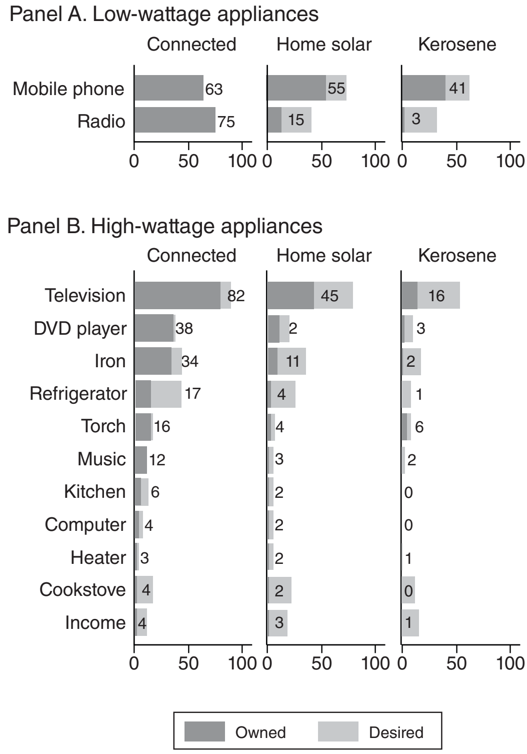

FIGURE 1. ELECTRICAL APPLIANCE OWNERSHIP IN RURAL KENYA

Notes: The number next to each bar indicates the proportion of households that own the appliance. See online Appendix Note A1 for additional details.

(light gray) each appliance type. Connected households clearly own the most appliances, which is expected given that both connectivity and asset ownership are positively correlated with income. The difference between home solar and kerosene households, however, is far more muted; neither type of household owns many appliances. With the exception of mobile phones and televisions, ownership levels for all appliances fall below 6 percent and 15 percent for kerosene and home solar users, respectively.[7]

[6] We assume that nearly all households with grid connections or home solar devices have electric lighting.

[7] A number of households own appliances that they appear unable to use regularly. For example, 16 percent of kerosene households own televisions, which may be powered with car batteries. Electric iron ownership is likely to be largely "aspirational" among home solar consumers, as conventional irons require over 1,000 watts of power, far more than the 8 watts that the most common home solar systems in Kenya can accommodate.

Second, both home solar and kerosene households reveal a strong desire to own high-wattage appliances. The most desired appliances for kerosene users include televisions (39 percent) and irons (16 percent). Similarly, home solar users desire televisions (37 percent), irons (26 percent), and refrigerators (24 percent). Many of the most commonly desired appliances can only realistically be powered with connections to the electric grid, pointing to the limitations of the home solar systems commonly available in Kenya.

Third, despite having access to electric lighting, both connected and home solar households continue to purchase nontrivial amounts of kerosene. In online Appendix Figure A2, we summarize monthly spending for non-charcoal energy sources for each household category.[8] As expected, connected households have the largest total energy budget, spending \$15.68 per month on average. In comparison, kerosene and home solar users spend \$5.42 and \$6.53 per month, respectively. Surprisingly, all three types of households spend a similar amount on kerosene, ranging from \$3.66 for connected households to \$3.90 for kerosene households.

Although mean kerosene spending is similar, there are substantial differences in the proportion of households reporting zero spending on kerosene. For example, 33.4 percent of connected households reported that they did not spend any money on kerosene over the past seven days, compared to 23.7 percent and 2.5 percent of home solar and kerosene households, respectively. These figures suggest that a large proportion of home solar users—and even connected households—are unable to completely eliminate their use of kerosene.[9] For connected households, these spending patterns may indicate underlying problems with the grid, such as blackouts and other forms of poor reliability, highlighting the need for an increased focus on improving the service quality of the electric grid. For home solar households, these patterns suggest that the current range of solar products do not provide sufficient lighting points within the home and must be complemented with kerosene lanterns.

III. Discussion and Conclusion

Solar lanterns and solar home systems are often framed as an important step up the "modern electricity service ladder" (see, e.g., Alstone, Gershenson, and Kammen 2015). The findings in our data are consistent with this description. Relative to kerosene, home solar users benefit from improvements in basic energy applications, such as lighting and mobile phone charging. Once households have access to these basic end uses, however, the appliances that they aspire to own next tend to require high wattage levels that cannot be accommodated by most home solar systems. Since the power supplied by these systems does not scale with demand, home solar is not a substitute for grid power. Unless there is a dramatic reduction in the price of high-wattage systems, it is unlikely that households will be able to "leapfrog" the electric grid in the same way that mobile phones allowed people to leapfrog fixed line telecommunications. Of course, decentralized solar may remain the most attractive option for a small number of isolated rural communities located far away from the national power grid.

Home solar still has the potential advantage of being cleaner than fossil fuel based energy alternatives. To evaluate their possible environmental advantages in Kenya and other countries, we document existing and planned sources of centralized electricity generating capacity in the region. In Figure 2A, we plot installed capacity, and the proportion of nonfossil fuel generation, for the top ten producers of electricity in sub-Saharan Africa (SSA) and ten newly industrialized countries (NICs) from other regions. Relative to the SSA countries, the NICs have much higher levels of installed capacity. However, the SSA countries generate power that is, on average, half as carbon-intensive as the NICs. In the NICs, nonfossil fuel capacity is 29.4 percent compared to 64.6 percent in the SSA countries.[10]

[8] We asked connected households for the amount of the last monthly electricity bill. For kerosene and other sources of energy, we asked for the total amount spent over the past seven days and then estimated monthly amounts.

[9] Note that very few households report using kerosene to cook. Only 0.4 percent and 3.1 percent of unconnected households list kerosene as their primary and secondary source of cooking energy, respectively. In comparison, 94 percent of unconnected households list collected firewood as their primary source of cooking energy.

[10] Figures 2A and 2B summarize plant capacities, while environmental emissions will be proportional to the energy produced by different types of plants. Unfortunately, we are unable to obtain predictions of plant capacity factors, although it is not a priori clear that the share of nonfossil

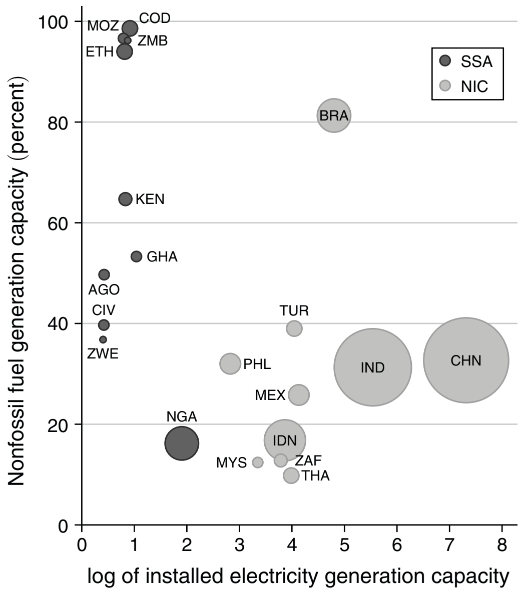

FIGURE 2A. CURRENT INSTALLED CAPACITY

Notes: Average nonfossil fuel generation capacity is 64.6 and 29.4 percent for SSA countries and NICs, respectively. Markers are scaled by population.

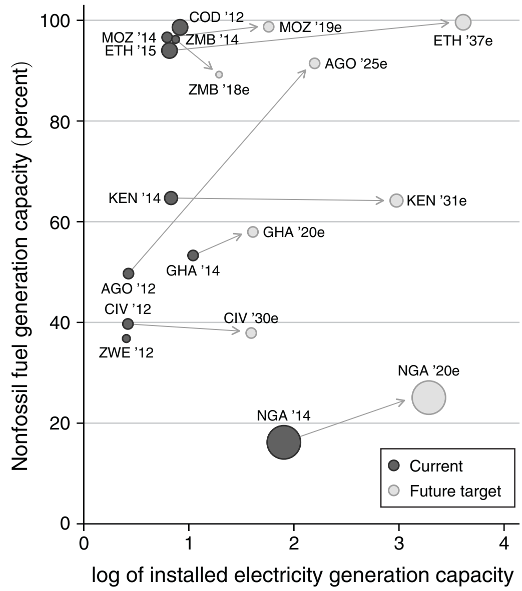

FIGURE 2B. FUTURE INSTALLED CAPACITY

Note: See online Appendix Note 2 for details on data sources for Figures 2A and 2B.

In the future, countries in sub-Saharan Africa will continue to expand centralized electricity generating capacity to serve industrial, commercial, and urban customers. This will happen regardless of the proportion of rural households that adopts home solar. In the SSA countries that we examine, a large share of these capacity additions will feature nonfossil fuel technologies. Online Appendix Table A1 summarizes current and future installed capacity in Kenya, where several geothermal and wind projects are already under development. Over the next 15 years, installed capacity is expected to increase dramatically from 2,295 MW to 19,620 MW. Still, the proportion of nonfossil fuel sources will remain constant, at roughly 64 percent.

In Figure 2B, we plot current and future installed capacity targets for the ten SSA countries, based on publicly available sources. Almost all of the countries plan to increase installed capacity while maintaining or even increasing the share of power derived from non-fossil fuel sources. As countries move to further decarbonize their national grids, the potential environmental advantages of home solar will decline.

The energy infrastructure choices that Kenya and other African countries make over the next decade will have major implications for both their economic development and global climate change. Focusing on home solar alone is unlikely to promote economic development. As Kremer and Willis (2016) point out, investment choices today will impact the economics (and the politics) of future energy infrastructure investments. In order to understand the economic implications of different approaches to addressing energy poverty, more research is needed on household energy demand in low-income countries, and how improvements in the governance and service quality of electric utilities will influence this demand.

fuel production would be lower or higher than the share of nonfossil fuel capacity based on capacity factors of similar types of plants in other countries.

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