ENVIRONMENT AND DEVELOPMENT

The Energy-Poverty-Climate Nexus

Community-level carbon abatement curves highlight opportunities for increased access to clean, efficient energy for the poor.

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Close to two-thirds of the world's poorest people live in rural areas (*1*). Eradication of rural poverty depends on increased access to goods, services, and information, targets detailed in the United Nations Millennium Development Goals. However, alleviating poverty is hindered by two interlinked phenomena: lack of access to improved energy services and worsening environmental shocks due to climate change. Mitigating climate change, increasing energy access, and alleviating rural poverty can all be complementary, their overlap defining an energy-poverty-climate nexus. We describe interventions in a rural Nicaraguan community to show that energy services can be provided in cost-effective manners, offering the potential to address aspects of rural poverty while also transitioning away from fossil fuel dependence.

The Energy-Poverty-Climate Nexus

Increased access to energy services alone will not eradicate poverty, but it can have immediate effects (*2*, *3*). More than 1.5 billion people live without access to electricity, another billion only have access to unreliable electricity, and close to half the global population depends on traditional biomass fuels for cooking and heating (*4*). Energy poverty results in unmet basic needs and depressed economic and educational opportunities that are particularly pervasive among women, children, and minorities (*5*, *6*). Electricity catalyzes rural economic activity (*7*–*10*) and increases the quality of services available to meet basic business and domestic needs through improved lighting, labor-saving devices, and access to information through TV, radio, and cellular telephones (*11*). Provision of high-quality public lighting can increase security and improve delivery of health and education services (*7*, *11*).

Environmental shocks related to climate change will first and most severely affect vulnerable, poor populations, many living in rural areas (*1*, *12*). Improving delivery of affordable, reliable energy services to rural communities is critical for helping them develop human and economic capacity to adapt in the face of a changing climate.

Greenhouse gas emissions in industrialized countries are dominated by electricity generation and transportation, whereas the majority of emissions from the world's poorest countries come from agriculture and changes in land use (*1*). However, with 1.5 billion people without access to electricity, combustion-related emissions from the rural power sector are expected to grow. Because of low capital costs and a large network of suppliers, diesel generators are often the technology of choice in rural areas, without sufficient consideration of the volatility of fuel prices, resulting in expensive generation costs (*9*, *13*).

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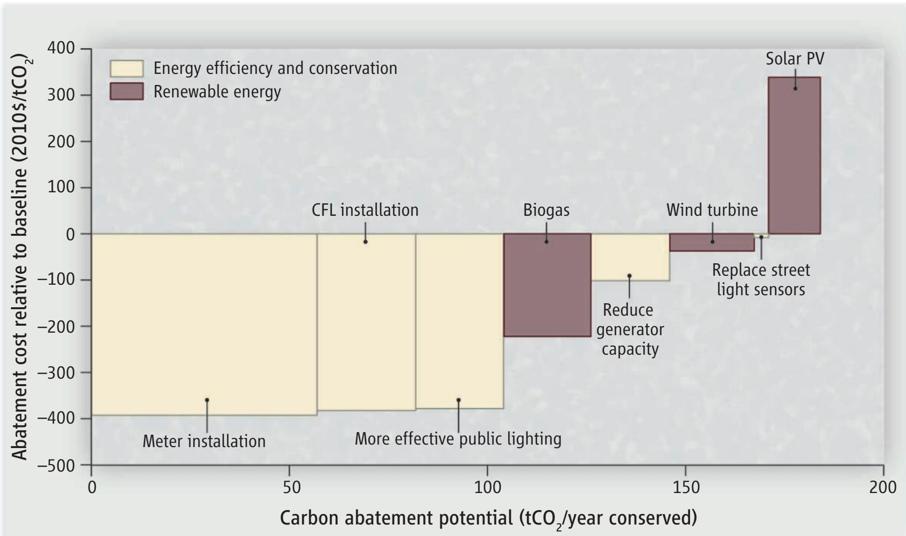
Given the relationships outlined above, every dollar spent on the transition to more efficient low-carbon energy systems in rural areas has the potential to produce greater human development, savings, and carbon mitigation returns than in more industrialized areas (if economies of scale do not dominate). However, debates about climate change and vulnerability have been slow to highlight the energy-poverty-climate nexus. This has been due, in part, to the lack of meaningful metrics needed to stimulate social, economic, and technical innovation in this sector.

Marginal Abatement Cost Curves

A marginal abatement cost (MAC) curve typically shows the annual carbon abatement potential for an intervention, and the cost per quantity of carbon emissions abated, relative to the emission costs for a baseline case (*14*, *15*). A community-level MAC curve derived from ongoing research on the Atlantic coast of Nicaragua demonstrates that low-carbon rural energy services can be delivered at cost savings in cases where communities use diesel-powered generation, isolated from the national grid (microgrids).

The rural communities of Orinoco and Marshall Point share a diesel microgrid serving 172 households. In partnership with the Nicaraguan government and a local nongov-



MAC curve of the electricity sector for Orinoco and Marshall Point. Abatement cost is with respect to a baseline diesel carbon price of $397 per metric ton of CO_2 (tCO_2). (Negative cost indicates savings.) Abatement potential is due to the reduction of diesel use, relative to each previous measure. Multiplying abatement potential and abatement cost gives total annual costs relative to baseline, assuming that the previous measure was implemented. Only the most economic technologies appropriate for the community resources, capacity, and grid sophistication are included. See SOM for details.

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ernment organization, several energy efficiency measures were implemented in 2009 [see the supporting online material (SOM)]. Based on this work, we developed a MAC curve for the electricity sector of these communities (see the figure). The first two efficiency measures in the curve [installation of meters and compact fluorescent lights (CFLs)] were actually implemented, whereas impacts of subsequent measures are based on estimations (SOM).

With the price of diesel fuel at US$1.06 per liter, the generation cost for each additional unit of electricity in the village (its marginal generation cost) is $0.54 per kilowatt-hour (kWh) (SOM), compared with costs on the order of $0.10 per kWh in the national grid (*16*). This difference in generation costs creates the potential for greater savings available from mitigation in diesel microgrids (although the total capacity for carbon abatement is considerably less than in the national grid). The majority of the abatement measures in the figure can be achieved at negative costs relative to the diesel baseline (i.e., costs are outweighed by savings).

There are a number of ways an intervention's impact on poverty can be assessed. For this study, we quantify the potential for increase in availability of energy and reduction in household consumption, which can translate to reduced expenditures without decreasing the quality of energy service. Future work could explore how interventions create jobs and increase earnings and how benefits are distributed by using inequality metrics such as the Gini coefficient or Kuznets ratios.

Decreasing Consumption

The installation of electricity meters allowed accurate billing of household consumption, instead of using unmetered, fixed tariffs. This resulted in a 28% decrease in daily energy consumption, which could translate into household savings. The relatively greater reduction in daytime load suggests that meter installation resulted in reduction of less-valued energy services (e.g., lights being left on during the day).

To increase lighting efficiency, every household was given the option to replace two incandescent bulbs with CFLs, resulting in an additional 17% drop in daily consumption and the potential for additional household savings. The large demand response due to metering and efficient lighting was the result of both behavioral changes and a market intervention (*17*, *18*).

The combination of the meter and CFL installations led to an increased availability of 84 liters of diesel per day. The daily operation of the microgrid was increased by 2 hours, providing households the opportunity to invest in additional electricity use (*19*). In the month following the two measures, 37% of the households in Orinoco received lower electricity bills. However, benefits to the poorest households were mitigated due to a regressive tariff structure in which the smallest consumers pay a fixed rate (SOM).

The MAC curve also highlights estimated benefits of replacing a portion of diesel fuel with biogas. The biogas can be produced locally through anaerobic digestion of animal dung and agricultural residues. This introduces the opportunity for a large part of the gross carbon abatement cost to be captured within the community through local, low-carbon fuel production, rather than paying for imported fossil fuel. Although community-scale biogas systems have had mixed success, often depending on the model of ownership, they highlight opportunities for implementing sustainable biofuel systems with current technology (*20*).

Suite of Tools for Poverty-Climate Analysis

Although this MAC curve focused on carbon abatement in the electricity sector, similar curves can be created for different rural energy services such as cooking and transportation, as well as agriculture. For example, 57% of households use charcoal for cooking, with the majority having unimproved stoves. More efficient stoves would mitigate black carbon emissions, lessening impacts on climate and also respiratory harm most prominent among women and children (*21*, *22*).

Using MAC curves in conjunction with a clear understanding of how various measures will support community development goals ensures that climate change dollars also address the most pressing challenges of the poorest communities. However, MAC curves must be part of a suite of analytic tools for understanding various poverty-climate nexuses. For example, investment in agro-ecological farming practices may not necessarily appear favorable in a MAC curve but will likely be critical in the agricultural-poverty-climate nexus (*23*).

Integration of development agendas into climate change frameworks has been limited, in part, by a lack of both easy-to-understand metrics and systems-level planning tools necessary for prioritizing the allocation of limited capital. Using one such tool, MAC curves, it is apparent that increasing access to energy services can reduce carbon emissions and monetary expenditures, with great potential to affect development and reduce poverty. Continued development of methods of analysis, and interventions based on those analyses, is needed to allow us to reduce poverty while also confronting climate change.

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Supporting Online Material

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