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Sustainable Energy Is Key to Achieving Global Development Goals

Sustainable energy—the ability to have access to adequate and affordable supplies of safe and reliable energy sources—is inextricably linked to nearly every major development challenge the world faces today. The more than 1 billion people living without electricity confront limits in opportunities. Without electricity, women spend hours fetching water, clinics cannot store vaccines, schoolchildren cannot study after dark, and people face constraints in their choices of business activities. The almost 3 billion people lacking access to clean and affordable fuels and stoves for cooking and heating are exposed to dangerous levels of indoor air pollution—exposure that each year leads to nearly 4 million premature deaths.

Achieving sustainable energy is possible, but countries need to take concrete steps toward prioritizing energy efficiency, reducing regulatory distortions, and investing in clean, renewable energy sources. Ensuring access to affordable, reliable, sustainable, and modern energy for all is among the 17 Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly in 2015. Known as SDG7, this goal interacts with many of the other SDGs, including improving livelihoods, providing more secure living conditions, enhancing access to development opportunities for women, and reducing environmental harms.

The World Bank has been an important source of financing and advice to improve the efficiency and sustainability of energy supplies in developing countries. Its research on sustainable energy, as envisaged in SDG7, is aimed at supporting technical assistance and lending as well as informing public debate on the adoption of effective policies and approaches. This issue features papers highlighting both challenges and opportunities for developing countries in advancing sustainable energy objectives.

One study, examining electricity sector reform in 88 developing countries over a 25-year period, finds that in most of those countries reforms were only partially implemented. It concludes that countries' economic and political characteristics have much to do with their uptake of reforms. Another study finds that rural electrification in Bangladesh has aided such key development outcomes as higher household incomes, greater well-being for women and children, and lower use of kerosene. Other studies highlight the importance of clean, renewable energy sources, including solar and hydropower, for improving health, reducing greenhouse gas emissions, and sustaining economic growth.

Research offers ample evidence that better regulatory frameworks, more efficient energy pricing, and effective incentive structures for clean energy adoption are critical for improving sustainable energy. Achieving all these requires strong political will, increased investment, and greater involvement by all stakeholders. Yearly investment in sustainable energy infrastructure needs to triple, from around $400 billion today to $1.25 trillion by 2030.

Countries must step up. Without sustainable energy, the world may fall short of its development goals.

IN THIS ISSUE

Charting the Diffusion of Power Sector Reforms across the Developing World

After rapid diffusion in 1995–2005, the spread of power sector reforms across the developing world slowed significantly in the following decade

Some 25 years have elapsed since international financial institutions espoused a package of reform measures that became known as the Washington Consensus. In the power sector, similar to other utility industries, this package encompassed the establishment of autonomous regulatory entities, the vertical and horizontal unbundling of integrated national monopoly utilities, private sector participation in generation and distribution, and eventually the introduction of competition in power generation and even retail services. A paper by Foster, Witte, Banerjee, and Moreno provides a much more detailed characterization of the content, timing, and sequencing of power sector reform measures than has previously been possible, covering 88 developing countries over the period 1990–2015. (The paper takes a descriptive approach, as other studies have already undertaken broad evaluations of the impact of such reform.)

Overall, power sector reform in the developing world lags far behind what was implemented in the developed world during the same period. Unbundling of power utilities is twice as common in developed as in developing countries, while creation of wholesale power markets is 10 times as likely. Nonetheless, full power sector reform has not been universal even in developed countries.

Following rapid diffusion during the decade 1995–2005, the spread of power sector reforms across the developing world slowed significantly in the subsequent decade (2005–15). By 2015 only about 25 percent of developing countries had been able to adopt the full package of Washington Consensus reforms in the power sector, often over a period of many years. At the same time, as many as 40 percent of developing countries have a power sector that remains largely unreformed. The other 35 percent find themselves at an intermediate stage, having adopted some elements of the reform package but with little sign of continuing reform momentum.

In a number of developing countries published policy commitments to power sector reform could not subsequently be implemented because of political opposition. As a result, reforms were only selectively adopted, often according to ease of implementation. By far the most common reforms were the introduction of independent power projects and the creation of regulatory entities; each of these reforms was adopted by about 70 percent of developing countries, perhaps because neither represented a major challenge to vested interests in the sector. On the other hand, privatization of distribution utilities was undertaken by only 44 percent of developing countries and proved more difficult, with about 20 countries experiencing reversals of some 40 private transactions for power distribution.

Partial reform is sometimes associated with incoherence. For example, about half the developing countries that created regulatory entities did so without introducing the private sector participation in power distribution that originally motivated the creation of the regulator.

Country characteristics such as geographic region, income group, power system size, and attributes of the political system seem to have had a statistically significant influence on the uptake of reform. One of the largest influences has been system size: developing countries with installed capacity of more than 10 gigawatts went twice as far with power sector reform as did those with capacity of less than 1 gigawatt. Similarly, developing countries in the middle-income bracket, and those with relatively competitive political systems, went much further with the reform process. Geographic region was also an important driver, with Latin America and the Caribbean standing out as the pioneering region for power sector reform and the Middle East and North Africa as well as Sub-Saharan Africa lagging behind and introducing more limited reforms.

Moreover, the vast majority of developing countries remaining at the early stages of reform fall into one of the categories that have historically found power sector reform challenging to implement: fragile states, small systems, low income bracket, or weak rule of law. Many of these countries are in Sub-Saharan Africa. Indeed, there is not a single large, stable, middle-income country in this group of countries at the early stages of reform.

These patterns in the uptake of power sector reform already tell an illuminating story. They illustrate that the full package of Washington Consensus reforms in the sector has proved challenging to implement in its entirety in a developing country environment and, though undoubtedly much more widespread in developed countries, still remains far from universal even in that group.

Vivien Foster, Samantha Witte, Sudeshna Ghosh Banerjee, and Alejandro Moreno. 2017. "Charting the Diffusion of Power Sector Reforms across the Developing World." Policy Research Working Paper 8235, World Bank, Washington, DC.

How Much Do Rural Households Benefit from Electrification? Evidence from Bangladesh

The benefits of rural electrification depend critically on the quality of electricity supply—and are fully realized only over the long term

Bringing electricity to rural areas has been widely recognized as a key driver in reducing poverty and boosting economic development. Not surprisingly then, rural electrification has ranked high on the agendas of governments, nongovernmental organizations, and international development agencies. This underscores the importance of accurately understanding its benefits. Estimates vary widely across studies. While many studies find substantial benefits of electrification, some suggest that these benefits may be overstated.

Using data from Bangladesh, a recent study by Samad and Zhang offers explanations as to why the findings have not been conclusive. First, the study shows that the benefits of being connected depend on the reliability of electricity supply. Poor quality of supply could constrain and even discourage the productive use of electricity by households and businesses. Second, the study demonstrates that how long a household has been connected to electricity matters. While some basic benefits such as more efficient lighting can be achieved almost immediately, other development benefits accrue only over the long run. The study is based on data from a two-round panel survey in rural Bangladesh, carried out in 2005 and 2010 and covering 7,018 households.

One complication in identifying the causal relationship between electrification and household welfare is that grid expansion and households' decision to adopt electricity may not be random. For example, the government may target electrification projects to areas that are more easily accessible and have greater growth potential. And when electricity becomes available in a village, better-off households are more likely to obtain grid connections first. To deal with the selection bias, the authors use a two-stage propensity-score-weighted fixed-effects model. They first estimate a household's probability of being connected to the grid (propensity score) based on a range of household and village characteristics observed in the base year. They then assign to each household a weight proportional to the propensity score so that households that look more similar to connected households in the base year receive more weight. Finally, to estimate benefits of grid electrification, the authors compare changes over time within households that were connected to the grid in 2010 with changes within households that were not connected.

Findings suggest that the length of daily power outages has a strong negative impact on almost all development outcomes considered. For example, a one-hour increase in daily power outages for a household is associated with a 5.9 percent increase in kerosene consumption and a 0.3 percent reduction in annual income. In addition, the benefits of electrification increase over time, though at a declining rate. For example, each additional year of being connected to the grid is associated with a 7.8 percent reduction in kerosene consumption and a 1 percent increase in annual income or expenditure. And where supply is reliable, estimates show, electrification brings substantial benefits, increasing income by 17 percent and expenditure by 12 percent.

The study also finds that women and girls are likely to benefit more from rural electrification than men and boys do. After households gain access to electricity, girls' daily study time increases by about 30 minutes on average, while women's labor force participation increases by 2.3 percentage points. In contrast, no statistically significant effects are observed for boys' study time or men's labor force participation. In addition, gaining access to electricity improves women's empowerment (as measured by decision-making abilities).

Finally, using a quantile regression approach, the study finds that higher-income households benefit more from electrification than lower-income households during the time span covered by the evaluation. Richer households are typically early adopters of electricity and can afford a wider range of electrical appliances that could allow more productive use of electricity. Since the marginal return to electrification declines over time, however, poorer households that are connected to the grid may later catch up.

Accounting for income growth alone, the study estimates that the total potential benefits from achieving universal access to electricity while also improving reliability could reach $2.3 billion a year in Bangladesh. It emphasizes that merely providing connections is not enough to spur economic growth, especially where the quality of electricity supply is poor. This issue has attracted growing interest—as reflected, for example, in the Multi-Tier Framework, a tool for monitoring and evaluating energy access developed by the Energy Sector Management Assistance Program (ESMAP) at the World Bank in consultation with multiple development partners. The framework goes beyond the binary measure of connection (yes/no) to also include attributes of electricity service and use such as reliability, quality, and capacity—issues that need to be addressed in any discussion of electricity access and its benefits. Overall, the study's findings suggest that achieving long-term and inclusive benefits from electrification requires sustained efforts, attention to the quality of service, and complementary policies to encourage the productive use of electricity, particularly among poorer households.

Hussain Samad and Fan Zhang. 2017. "*Heterogeneous Effects of Rural Electrification: Evidence from Bangladesh.*" *Policy Research Working Paper* 8102, *World Bank, Washington,* DC.

Forecasting Electricity Demand in Developing Countries: Is There a Better Way?

Forecasting electricity demand is particularly challenging in developing countries. A recent paper evaluates a new approach

Power cannot be easily stored. So underestimating demand for electricity leads to supply shortages and forced power outages, which have detrimental effects on productivity and economic growth. But overestimating demand may lead to overinvestment in generation capacity and, ultimately, to higher electricity prices because utilities typically need to recover their investment costs to maintain financial viability.

Accurate forecasts of electricity demand are thus critical in designing least-cost generation plans for the power sector and in carrying out investment appraisals of power generation projects. They also matter in designing national greenhouse gas mitigation strategies, because electricity generated from fossil fuels is an important source of greenhouse gas emissions.

But forecasting electricity demand is difficult because it involves a range of uncertainties, including population growth, changing technology, economic conditions, and prevailing weather conditions (and the timing of those conditions). It can be particularly challenging in developing countries, where data are often elusive, political influences are often brought to bear, and historical electricity demand can be more volatile because of macroeconomic or political instability.

As a result of these problems, in developing countries demand forecasting often receives less technical attention than other elements of power sector analysis. Indeed, policy makers and energy practitioners often rely on crude electricity demand forecasts based on simple heuristic measures. According to a recent paper by Steinbuks, conversations with World Bank specialists suggest that among these "rules of thumb," the two most popular are these: Electricity demand grows at some predetermined constant growth rate. And electricity demand is proportional to the GDP growth forecast. Unsurprisingly, these heuristic measures often yield very inaccurate projections of electricity demand.

The paper argues that rather than depending on ad hoc predictions, energy practitioners in developing countries can rely on time-series econometric forecasting models, which yield much more accurate forecasts of electricity demand for the near decade (that is, over a 1- to 10-year horizon). These models are particularly useful for the needs of developing countries because they are less data-intensive than microeconometric studies and they are straightforward to implement in most of the popular statistical software packages (such as MATLAB, R, and Stata). They are also useful for validating long-term computational energy models with a forecast horizon of 30–50 years. Time-series econometric models are thus important decision support tools for investment planning by national governments of developing countries as well as by utilities, international institutions, and private electricity generation companies.

To demonstrate this point, the paper assesses the accuracy of a set of the most popular time-series econometric methods in forecasting electricity production—which, because of the nonstorability and limited tradability of electricity, is a close and frequently the only available proxy for unobserved electricity demand (or total final consumption) in many developing countries.

Drawing on the time-series econometrics literature, the author first develops an econometric framework for forecasting electricity production. He then obtains a number of out-of-sample electricity production forecasts resulting from different econometric methods and model specifications based on historical time series for 106 developing countries over the period 1960–2012. Finally, the author evaluates the accuracy of these competing electricity production forecasts and also compares them with the predictions based on heuristic methods.

The results show that the best-performing time-series methods yield highly accurate forecasts of electricity production in the majority of developing countries. These forecasts also prove to have much smaller errors than the predictions of two heuristic models that assume that electricity production grows at an exogenous rate or is proportional to real GDP growth.

But the quality of the time-series econometric forecasts diminishes for countries and regions where rapid economic and structural transformation makes it difficult to establish stable historical production trends. These include low-income countries, countries in Sub-Saharan Africa, countries with poor electricity access, and those with small electricity generation systems. For these countries in particular, more accurate forecasts could be produced through the collection of higher-quality (ideally disaggregated) data and a more rigorous forecasting approach using a combination of microeconometric and computational modeling methods.

Another important direction for future research on forecasting electricity demand in developing countries would involve more accurate prediction of structural shifts. These include, for low-income countries, the transition from more primitive forms of energy (fuelwood, kerosene) toward electricity and, for middle-income countries, the use of more electricity-intensive appliances.

Jevgenijs Steinbuks. 2017. *"Assessing the Accuracy of Electricity Demand Forecasts in Developing Countries." Policy Research Working Paper* 7974, *World Bank, Washington, DC. Also forthcoming in* International Journal of Forecasting.

Expanding Cross-Border Electricity Trade to Promote Hydropower in South Asia

South Asia's hydropower potential remains mostly unexploited because of constraints on regional electricity trade. Relaxing these constraints would offer huge benefits

South Asia has impressive potential for hydropower generation, and more than 80 percent of it has yet to be exploited. Utilizing this hydropower potential would bring enormous economic and environmental benefits to the region—including growth opportunities through exports of surplus hydropower, greater flexibility and lower supply costs in power systems, and reductions in greenhouse gas emissions and local air pollution.

Why does such a large share of the region's hydropower potential remain unexploited? Among the main reasons are the limited provisions for trading electricity across borders. Regional electricity trade is limited to small volumes of bilateral trade between India and its eastern and northern neighbors (Bangladesh, Bhutan, and Nepal). The capacity of cross-border transmission interconnections is only a tenth of the potential hydropower that could be traded.

In a recent study Timilsina examines the importance of enhancing regional electricity trade to promote hydropower in South Asia and estimates the potential of hydropower development and trade under different scenarios. The author also identifies several factors that are critical to promoting hydropower in the region—and shows that developing this resource through the expansion of cross-border electricity trade would benefit all countries participating in regional electricity trade and cooperation.

The author's analysis shows that Afghanistan, Bhutan, and Nepal would have surplus hydropower potential even under highly optimistic scenarios on the growth of their domestic electricity demand. Utilizing this surplus capacity would require enhancing access to markets (in Bangladesh, India, and Pakistan) by expanding cross-border transmission capacity and developing regional electricity trade agreements.

In India, where domestic hydropower is growing more slowly than total generation capacity, hydropower from neighboring countries, especially Bhutan and Nepal, is needed to provide flexibility in the large power system. And the rapid increase in generation capacity based on intermittent resources (wind and solar) means an even greater need for hydropower to balance the power system.

Differences across the region's countries in monthly or seasonal load profiles provide an opportunity to maximize the utilization of hydropower plants, sharing reserve margins and thereby lowering electricity supply costs. In addition, regional electricity trade would help countries with "peaky" loads (such as Nepal, where peak lighting and evening cooking coincide) either to avoid the expansion of peak load capacities or to improve the capacity utilization of peak load plants that have already been built in the absence of cross-border trade.

Finally, because hydropower is among the economic options for reducing greenhouse gas emissions, its development would help Bangladesh, India, and Pakistan meet their greenhouse gas mitigation targets under the Paris climate agreement.

What would a scenario of unconstrained cross-border electricity trade mean for the development of hydropower and its economic and environmental benefits in the region? The author estimates that under this scenario hydropower capacity would almost quadruple—from 64 gigawatts today to 241 in 2040. The region would save almost $100 billion in electricity supply costs over the next two decades through the substitution of hydropower for fossil fuels.

The monetary value of hydropower trade would be huge relative to GDP, especially for Nepal and Bhutan. For Nepal the unrestricted export of surplus hydropower to the regional market would generate $289 billion over the 20-year period, assuming an average price of $0.08 per kilowatt-hour (the 2018 price). This amount is 10 times Nepal's GDP in 2017. Similar benefits would accrue to Bhutan and Afghanistan, though their electricity export revenues would be smaller. And thanks to imports of cheaper hydropower from their neighbors, Bangladesh, India, and Pakistan would benefit from lower power supply costs.

As noted, hydropower development would contribute to the ability of Bangladesh, India, and Pakistan to meet targets under the Paris climate agreement. Under the scenario of unconstrained regional electricity trade, carbon dioxide (CO_2) emissions in the power sector would be lower relative to the corresponding baseline in all three countries in 2030: 43 percent lower in Bangladesh, 9 percent lower in India, and 3 percent lower in Pakistan. The corresponding reduction for the region as a whole would be 11 percent.

The findings of the study should be interpreted with care. The estimates of hydropower development and the corresponding economic and environmental benefits over the next two decades indicate only the potential. And this potential will not be realized in the absence of strong political will and commitment and without urgent action on concrete plans and strategies.

Govinda R. Timilsina. 2018. "How Would Cross-Border Electricity Trade Stimulate Hydropower Development in South Asia?" Policy Research Working Paper 8513, World Bank, Washington, DC.

The Nexus of Energy Supply and Human Health

Energy supply can lead to costly human health problems that need to be considered in designing energy policies and strategies

Energy is essential to economic growth and human welfare. But through its production and use, energy also has adverse effects on human health. This happens through three channels: accidents, occupational exposure to harmful substances (such as coal dust in mines and power plants), and air pollution.

Energy mining and production activities, such as coal mining and oil and gas drilling, are a source of accidents as well as long-term occupational exposure of miners to harmful substances or pollutants. Energy transformation activities, such as power generation and charcoal production, involve health risks through all three channels—accidents, occupational exposure, and air pollution. And energy consumption activities, such as the use of biomass fuels and coal for cooking, cause health risks through air pollution, especially for women and children and mostly in developing countries.

The types of health impacts vary across different stages of the energy supply chain. Hazardous substances released from energy mining operations (lead, arsenic, cadmium, mercury, chromium) damage the nervous, respiratory, and immune systems and cause cancers and cardiovascular disease. Oxides of sulfur and nitrogen released from the burning of coal in power plants cause asthma, cardiac disease, ischemic stroke, and chronic obstructive pulmonary disease. Harmful air pollutants such as suspended particulate matter, carbon monoxide, polyaromatic hydrocarbons, and volatile organic compounds produced by the burning of fossil fuels in power generation and transportation, and of biomass fuels and coal in household cooking, all cause lung cancer and cardiovascular and respiratory disease.

Despite these wide-ranging sources of risk, however, studies investigating the links between the energy supply chain and human health are limited. Drawing on the existing knowledge base, a paper by Timilsina discusses these links at different stages of the energy supply chain and draws some policy implications.

Air pollution gives rise to the most prominent adverse effects of energy on human health. Two forms pose the greatest risks: outdoor or ambient air pollution and indoor or household air pollution. While fossil fuel combustion in power plants and road transportation is the main source of ambient air pollution, use of biomass fuels and coal for cooking is the primary source of household air pollution. Ambient and household air pollution is estimated to cause more than 6 million premature deaths each year. The most vulnerable population is in the developing world, where more than 90 percent of premature deaths related to air pollution occur, primarily among poor people.

Women, children, and the elderly suffer the most from air pollution—and specifically from household air pollution. More than 60 percent of all premature deaths attributed to household air pollution occur among women and children, who face greater exposure to indoor smoke from cooking and home heating. The risks from household air pollution are again greatest for people in developing countries—because of their reliance on traditional biomass fuels for cooking and home heating, the main source of air pollution in households. In India alone, more than a million premature deaths occur annually as a result of indoor air pollution. The impact falls mostly on low-income households, which lack access to clean fuels for cooking and must therefore rely on traditional biomass fuels.

The large scale of these impacts suggests that controlling air pollution, specifically particulate matter, should be the main policy focus in addressing the human health effects of energy supply. This would call for fiscal and regulatory policy instruments that provide incentives to use energy efficiently and to switch to cleaner fuels. Despite being a major health concern in developing countries, however, local air pollution issues are overshadowed by climate change agendas. Yet fossil fuels and wood fuels that cause deforestation and forest degradation are key contributors to both global climate change and local air pollution. Policies that encourage substitution of cleaner fuels can therefore help in addressing both problems.

For accidents and occupational exposure, the other two channels for the human health impacts of energy, coal is the primary source in the energy sector. Most accidents in the coal sector occur in mining, mainly underground explosions and flooding. Explosions of oil and gas wells, pipelines, and tankers are another major source of accidents in the energy supply chain. Nuclear power, though perceived as the energy source posing the biggest threat to people, has caused the fewest fatalities among the energy carriers.

Overall in the energy sector, more than 95 percent of accidents occur in developing countries. Poor households are particularly vulnerable to accidents as well as occupational exposure in the energy industry because they provide much of the workforce engaged in mining coal, driving oil tankers, drilling for oil and gas, and hauling coal in power plants. Reducing the human health impact from accidents and occupational exposure in the energy supply chain will require strengthening and rigorously enforcing safety standards.

Govinda R. Timilsina. 2017. "The Nexus of Energy Supply and Human Health." Policy Research Working Paper 8129, World Bank, Washington, DC.

Can Improved Biomass Stoves Be Cost-Effective in Mitigating Climate Change?

The results of a choice experiment survey in Ethiopia suggest that improved biomass stoves can be cost-effectively incorporated into a carbon payment program

Nearly 40 percent of people around the world, and 68–90 percent in Sub-Saharan African countries, rely on solid fuels for cooking—particularly biomass such as wood and agricultural residues. Traditional cooking methods are harmful both to the environment and to human health, with inefficient stoves leading to greater deforestation and greenhouse gas emissions (both contributors to climate change) as well as to respiratory health issues.

Without a major change in policy, the number of people relying on traditional biomass fuels is expected to remain about the same in 2030 as today. Thus alongside efforts to move to alternative fuel sources, improving environmental and health outcomes will also require replacing traditional stoves with improved ones that have greater fuel efficiency and lower emissions.

To effectively promote the adoption of improved stoves, policy makers need to know what characteristics of improved stoves are most important to users, how much people are willing to pay for them, and what factors constrain the adoption of such stoves—all issues on which there is limited information. To fill this gap in knowledge, a team of authors conducted a choice experiment study in rural Ethiopia. There, about 96 percent of the population relies on wood, charcoal, branches, dung, and agricultural residues for household energy, all of which produce smoke and harmful emissions when burned.

The study consisted of a choice experiment in which respondents chose between possible hypothetical stoves based on their identified characteristics. The characteristics of improved stoves for the study were identified through multiple focus groups. The data were collected through a survey of 504 randomly selected households in 36 randomly selected villages in the regional states of Amhara, Oromiya, and SNNP (Southern Nations, Nationalities, and Peoples).

The findings show that respondents prefer improved stoves that have high levels of durability, reduce cooking time, use less fuel, and produce less smoke. Households with fewer than three children value each of these characteristics more than do households with more than three children. And households that are less than 50 percent female care more about cooking time, fuel reduction, and smoke reduction than do those that are majority female.

The findings also show that the biggest barrier to the adoption of improved stoves in Ethiopia is their availability. In addition, those who have seen an improved stove before place a higher value on them. This suggests the potential importance of improving the availability of improved stoves in rural Ethiopia as well as increasing awareness of the stoves and their benefits.

Finally, the study analyzed the cost-effectiveness of improved stoves for greenhouse gas mitigation under a carbon payment program—a program providing results-based payments to developing countries for actions to reduce carbon emissions (such as an REDD+ program). The analysis is based on the Mirt stove, which is used to cook the traditional Ethiopian flatbread. This stove leads to fuelwood savings in the field of 25 percent, or 634 kilograms per household per year, which translates into a reduction in annual carbon dioxide (CO_2) emissions of 0.94 tons per stove.

On this basis the Ethiopian government's ongoing initiative to distribute 11.45 million stoves would lead to a reduction in annual CO_2 emissions of about 10.77 million tons. Based on the 2015 price of $13.93 a ton from carbon allowance auctions in California, these annual carbon savings would be worth about $150 million, or about $13 per household. At the lower price of voluntary carbon emission reductions of around $6.00 a ton, these annual savings would be worth about $65 million, or about $5.70 per household.

Survey respondents indicated a willingness to pay about $8 more on average for a stove reducing fuelwood use by 25 percent. The price of the Mirt stove is about $12. Thus a carbon payment equal to just the carbon savings from a single year could more than close the gap between the marginal willingness to pay and the price of this stove.

But the carbon savings would be realized only if the stoves continue to be consistently used, and the monitoring and verification required in coupling carbon payments to the use of an improved stove would be challenging. One feasible option could be a program that gives part of an annual carbon payment directly to households (say, $4 a year) and uses another part (say, $2 a year) to educate households about the benefits of the stoves and to verify their use (perhaps by hiring and training community members). At the end of three years, after the full value of the stoves has been covered, the full carbon payment could be provided to households as an added incentive to continue using the stoves.

Sahan T. M. Dissanayake, Abebe Damte Beyene, Randall Bluffstone, Zenebe Gebreegziabher, Gilbert Kiggundu, Shannon H. Kooser, Peter Martinsson, Alemu Mekonnen, and Michael Toman. 2018. "Improved Biomass Cook Stoves for Climate Change Mitigation? Evidence of Preferences, Willingness to Pay, and Carbon Savings." Policy Research Working Paper 8499, World Bank, Washington, DC.

Can Peer Pressure Encourage People to Adopt Energy-Saving Technologies?

Laboratory experiments show that people may adopt innovations more quickly after seeing peers do so, even if the choice of technology differs

The diffusion and adoption of new technologies, whether physical or virtual, is central to development and growth. This prompts some questions for policy makers: What drives people to accept or reject novel approaches or products? What information do they pay attention to (or ignore) when making these decisions? How much do they care about what others are doing? Is there a trade-off between taking the fully optimal action and simply taking some action? What, if anything, can be done to encourage socially beneficial behavior?

These issues come into play in many areas, from agriculture to education to business management. But one area where they are particularly relevant, and where climate change suggests that much is at stake, involves energy and the environment. In a paradox that scientists and natural resource economists refer to as the *energy efficiency gap*, growing evidence has shown that both consumers and firms routinely fail to adopt new energy-conserving processes and products—even when those technologies yield discounted cost savings relative to the status quo. A recent paper by Jamison, Owens, and Woroch uses laboratory experiments to further explore and disentangle these issues.

In the experiments each participant plays the role of an agent (for example, a citizen or a manager) and is placed in a group of six. All are initially assigned the status quo technology (A), which pays out a small reward in every round. In every round they either choose to stay with A or decide to irreversibly upgrade to technology B or C; that is, the decision, once made, is final. B is a safe new technology that pays out a larger reward. C is a novel but risky technology that will be either a failure (paying out nothing) or a success (paying out the maximum reward possible).

Subjects receive imperfect signals about the quality of C in every round. Thus they face a trade-off between waiting—and in choosing to wait, obtaining only a small reward while doing so but thereby receiving more information for making a choice—and reaping immediate expected benefits of upgrading but possibly making the wrong choice. The environment therefore mimics a case in which the energy efficiency gap is due not to a lack of information or desire but to behavioral factors such as "regret aversion" and hesitancy about being wrong.

The paper considers three treatments for the group dimension. In the first, subjects observe nothing about their peers, so the choice becomes an individual decision problem. In the second, subjects observe their peers' decisions after each round (though not the private signals), but the value of C is entirely independent (uncorrelated) from one to the other, so conceptually this treatment should be no different from the first. In the third, they again observe the others' decisions, but now everyone has the same underlying value for C so there is potential to learn useful information from observation. Thus at each stage in this third treatment (until making the irrevocable investment decision) participants receive both public and private information and must decide how to proceed. This endogenous choice of timing is unusual in the literature on herding behavior and signaling.

The experiments lead to two main results. The first is that in all treatments subjects on average wait longer than is theoretically optimal to make a choice between B and C. This delayed adoption is consistent with the previously observed energy efficiency gap and may be due to regret aversion, risk attitudes, status quo bias, or another behavioral factor. Interestingly, this delay is reduced in both the treatments with peer observation, even though in one of them subjects are fully aware that their peers' information (and therefore actions) is irrelevant for their own payouts.

In looking at which technology is chosen, the paper finds evidence of a modest intrinsic preference for B (the safe one). Beyond that, subjects rationally use their private and (in the treatment where relevant) public information, placing relatively greater weight on the private signals. So the second main result is that while theoretically the uncorrelated treatment should look identical to the solo treatment, in practice it looks almost identical to the perfectly correlated treatment. This turns out to be a good thing: even though subjects do not imitate their peers' actions, they do imitate the simple fact that their peers have made a decision, partially overcoming the temptation to delay.

The laboratory conditions, though stylized, capture several important real-world dimensions of the diffusion of energy technologies: uncertainty about benefits, observation of public and private information, and freedom to choose the timing. To the extent that behavioral obstacles seem to be causing welfare-reducing delays, the results suggest that "nudges" may be able to improve outcomes more effectively—and probably less expensively—than regulation or subsidies. Spreading the word about early or lead adopters, while being somewhat agnostic about the specific decisions, may encourage others to at least break free of their inertia and improve on the status quo.

Julian C. Jamison, David Owens, and Glenn Woroch. 2017. "Social Learning about Environmental Innovations: Experimental Analysis of Adoption Timing." Policy Research Working Paper 7955, World Bank, Washington, DC.

Solar Lanterns and Youth Academic Performance in Bangladesh

Providing solar lanterns to children in unelectrified households boosted their study time in the short term—but not their academic performance

Most low-income countries are on track to achieve universal access to primary education. But gains in access have not necessarily led to gains in learning outcomes. This has prompted researchers to explore alternative interventions to improve student learning. Recent studies involving randomized control trials have provided valuable evidence about the effectiveness of such interventions as remedial tutors, computer-assisted learning, incentives for teachers, and reductions in class size.

Empirical research has paid less attention to the after-school home-study environment. One potentially critical factor in this environment is adequate nighttime lighting, because many students in developing countries are expected to work during the day to help their family. Yet achieving universal access to electricity has been a challenge for many low-income countries.

Where access to electricity is limited, can solar lanterns help improve children's academic performance? In a recent study Kudo, Shonchoy, and Takahashi used a randomized control trial to evaluate this question on the river islands of northern Bangladesh. The study provided solar lanterns under a free-leasing agreement to a randomly selected subset of the target population—students enrolled in grades four through eight—for 16 months (September 2013–December 2014).

The authors selected 882 sample children, all from unelectrified households, at 17 local schools and implemented within-grade randomization at each school. To differentiate the treatment intensity, they divided the students into three groups: some of the students received both a main high-capacity solar device and two smaller lanterns; others received only a main high-capacity solar device; and the rest served as a control group and received no devices.

Compared with the control households, those that received three solar lanterns reduced their kerosene expenditure by about 75 percent over the 12 months of 2013/14, which in turn reduced total household expenditure by 6 percent (about $63), while those that received one reduced their kerosene spending by about 50 percent and their total household spending by 2 percent (about $21).

The provision of solar lanterns had a significant effect on home-study time. Between September 2013 and April 2014 students receiving lanterns reduced daytime study by about 5–8 minutes each day and increased nighttime study by 20–25 minutes, a net effect equivalent to an increase of 45–75 hours of home-study time over the eight months. The treated students also almost completely substituted solar lanterns for kerosene lamps for their nighttime study. The increase in net study time was more evident in November 2013, just before the annual examination season of December, during which home-study time increased by about 20 hours. These findings hold true whether students received three solar lanterns or only one.

Moreover, the school attendance rate initially increased as a result of the provision of solar lanterns, though this effect did not last long. If only the cost of the solar lanterns is considered, and with the life of a solar lantern assumed to be five years, this intervention raised student participation by about 0.6 years per $100 spent.

But the increase in study time and initial improvement in school attendance did not translate into improvement in the academic performance of treated children as measured by schools' final examination scores in December 2013 and 2014. While non-treated students could have learned from their treated peers, minimizing the difference in academic performance between the treatment and control groups, this potential learning spillover did not explain the finding of no academic improvement.

The results of this experiment might suggest that introducing simple solar products in other modestly disadvantaged settings cannot be expected to have substantial effects on learning outcomes. The experiment was conducted in a setting where the provision of solar lanterns was expected to have the greatest positive impacts: Access to electricity was limited in the study area. And the study distributed solar lanterns directly to students, which might have given them priority over other household members in the use of the lanterns. Moreover, the replacement of kerosene lamps with solar lanterns, by reducing indoor air pollution, could potentially improve students' health and thus their academic performance.

Yet the study area had many other constraints on academic performance, such as in the availability of good teachers and in households' ability to afford complementary education (like private tutoring, which can be crucial for home learning support, especially for students with illiterate parents). Thus it is possible that providing solar lanterns for students could boost learning outcomes where the students have better educational environments than those in the study area. This may depend both on the overall quality of educational inputs—such as teaching, school facilities, the home learning environment, and access to light—and on the complementarity across those inputs.

Yuya Kudo, Abu S. Shonchoy, and Kazushi Takahashi. 2017. "*Can Solar Lanterns Improve Youth Academic Performance? Experimental Evidence from Bangladesh.*" World Bank Economic Review, *https://doi.org/*10.1093/*wber/lhw*073.

The Complexities of Integrating Renewable Energy into a Power System

Integrating wind and solar into a power system requires a planning approach that fully considers the variability of these resources

Many developing countries have become interested in integrating wind and solar into their national power grids. These renewable energy technologies can reduce reliance on imported fuels while avoiding emissions of carbon dioxide and local air pollutants, and their investment costs have dropped sharply. But the variability of wind and solar introduces complex technical and economic issues into power system planning.

Much work on renewables has been done over the past 20 years—especially since 2012, when large-scale, grid-connected wind and solar generation began to quickly ramp up in many countries around the world. To ensure optimal integration of large-scale wind and solar, however, the methodology needs to be standardized and rigorous case studies need to be carried out, especially for developing countries.

A look at the methodology of studies on integrating renewables suggests that many of those from the past two decades fall in one of three categories.

First, simple "back of the envelope" analyses that rely on comparison of the levelized cost of electricity—a measure averaged over the lifetime of a power generation asset that fails to capture the variability of renewable resources across different time frames (from subhourly to seasonal and interannual). Many such studies have been undertaken to assess policies or investment decisions. While they focus on the economics of renewables, they ignore nearly all the technical aspects that are important in power system planning.

Second, detailed production costing or transmission power flow models that look at operational aspects of generation or transmission systems. These more technically focused studies are devoid of economics. They are essentially "feasibility checks" of particular power system plans, including those with a high share of renewable resources. They provide no insight into how much of the mix should be renewables, however.

Third, planning models of different vintages—from those of the 1970s to modern planning tools—that consider economic and technical issues jointly. Least-cost planning studies, for example, consider renewables as part of the portfolio of generation resources. Key challenges in using these models are to determine what level of detail can realistically be modeled and how to coordinate among a hierarchy of long- and short-term models. A modern planning model that can fully capture the variability of renewables across all time frames can help determine the optimal mix of renewables and nonrenewables—one that allows renewables to fill a critical niche in the system without jeopardizing system security.

In a recent study Bankuti, Chattopadhyay, and Song undertook such an exercise for Bangladesh, which had been contemplating a 500-megawatt (MW) solar project since 2011. The authors developed the first comprehensive renewable integration study for the country, combining a suite of planning models that deal with long-term capacity expansion, a detailed dispatch model, and a transmission power flow analysis. The proposed solar project, estimated to cost $2.76 billion, is an expensive proposition for a country struggling to find good baseload generation options. Moreover, the authors' analysis of past operational practices shows that lack of economic considerations in power generation scheduling during most peak hours poses a great challenge in accommodating large-scale, grid-connected solar generation.

Yet solar might play an important part in the country's power system. Bangladesh is undergoing a major change in its fuel mix as it runs out of cheap domestic gas and relies increasingly on imports for both primary fuels and electricity. Solar could help alleviate the impending domestic energy crisis, especially because its cost is dropping at a time that Bangladesh's supply costs are on the rise. The authors find that the economic potential of solar could be somewhere between 1,000 and 4,200 MW (between 6 percent and 26 percent of peak demand) by 2025, depending on the cost of solar, the price of gas, and the cost of financing. If renewable generation costs drop below 6.5 cents per kilowatt-hour, renewables could account for up to 4,200 MW of generation capacity, though this would require massive improvements in operational practices to maintain system security. A more realistic target is in the range of 2,400–2,900 MW (about 15–18 percent of peak demand). In extreme cases, in which the poor operational practices continue or gas prices remain low for the next few years, the potential might be limited to 1,000 MW.

The study demonstrated the importance, in developing a clear pathway for renewables, of bringing together the economic and technical issues through a systems approach and undertaking rigorous analysis. It also had practical outcomes for Bangladesh. The study developed a sound basis for a plan to integrate renewables and provided inputs for the preparation of the country's first major solar project. It also transferred its model to the System Planning Division of the Bangladesh Power Development Board, which has since used the model to update the country's power system master plan.

Miklos Bankuti, Debabrata Chattopadhyay, and Chong-Suk Song. 2018. "*Integrating Variable Renewable Energy in the Bangladesh Power System: A Planning Analysis.*" *Policy Research Working Paper* 8517, *World Bank, Washington, DC.*

Interactions of Renewable Energy Standards with Carbon Emission Trading for Climate Change Mitigation

Different policy measures to reduce greenhouse gas emissions can overlap in ways that may dilute the efficacy of each policy

Countries around the world are introducing policies for greenhouse gas mitigation. These include renewable energy technology (RET) mandates (such as renewable energy requirements for electricity supply); energy efficiency standards (such as for buildings and automobiles); fiscal policy incentives (such as subsidies and tax exemptions); and carbon pricing instruments (such as carbon taxes, emission offset mechanisms, and emission cap and trade systems).

The member states of the European Union have introduced policies of all these types. With the aim of meeting pledges under the Paris climate agreement, so have some developing countries. China, for example, has been implementing fiscal and regulatory policies aimed at greenhouse gas mitigation for more than a decade. In 2017 the country also introduced a national emission trading system (ETS). Today the ETS covers only electricity generation, but in the future it is expected to also cover other sources of greenhouse gas emissions, such as manufacturing industries.

Economic theory suggests that the most efficient policy mechanism for achieving greenhouse gas mitigation targets is an appropriate pricing instrument. Simply getting the pricing right encourages economic agents to change technologies and behaviors in the desired ways, avoiding the need for separate policies to promote adoption of efficient and clean technologies. Indeed, in many instances, introducing policies with overlapping objectives could dilute the efficacy of each policy and thus increase the overall cost of achieving a greenhouse gas mitigation target. A recent study by Fan, Wu, Timilsina, and Xia on China demonstrates this insight empirically.

The study uses a computable general equilibrium (CGE) model representing the behavior of all economic agents—households, governments, industries, and international trade—for all 30 administrative regions in China. Because the model captures the links between production sectors as well as between economic agents, it can measure impacts on all sectors and agents of a policy shock anywhere in the economy.

The model assumes a national ETS that allows the administrative regions in China to trade their carbon dioxide (CO_2) emission allowances, creating incentives for regions where reducing CO_2 emissions is less costly to produce fewer emissions than their allowances and then to sell the surplus emission reduction to regions where reducing CO_2 emissions is more costly. The ETS would thus reduce the overall cost of meeting specified emission reduction targets. But a separate policy introduced earlier in China, an RET mandate requiring electricity supply companies to rely on renewable energy sources for a certain fraction of their electricity sales, would reduce the effectiveness of the ETS in two ways: It would reduce the size of the emission trading market. And it would reduce the price of tradable emission permits (or reduce the emissions traded in the market).

The study shows that to achieve a 10 percent reduction of CO_2 emissions in China from the base case (the situation in the absence of the ETS), a national ETS would cause slight losses in GDP and welfare. If as part of the strategy to achieve that target a separate RET mandate was introduced on top of the ETS, this would exacerbate the GDP and welfare losses. The reason is that while an ETS creates incentives for the market to implement the cheapest CO_2 mitigation options, the RET mandate forces the power generation industry to divert resources to implementing renewable energy technologies, no matter how costly they are. This diversion of resources to costlier options would increase the cost of achieving the greenhouse gas mitigation targets and ultimately lead to higher costs for the economy and the society.

Moreover, the additional RET mandate would reduce the demand for emission permits in the production sectors trading the permits, causing the carbon market to shrink. It would reduce the volume of emission permits traded by 1.5 percent and their price by 3.5 percent. This would result in a decrease in the transfer of funds associated with emission trading between regions as well as between sectors. Indeed, the study shows that the transfer of funds from the central to the western region under the ETS would drop by 29 percent because of the effect of the RET mandate on the size of the ETS market.

Combining an RET policy with an ETS would, however, lead to a greater reduction in fossil fuel consumption than the ETS policy alone—and thus to a greater reduction in local air pollution. Given the importance of this in China, a model accounting for the benefits of the lower pollution might show that a combined ETS and RET policy would be more economic than the ETS policy alone. But quantifying these benefits in each of China's 30 administrative regions is an enormous task and beyond the scope of the study. Additional policy instruments can also be justified where an emission trading scheme does not capture all potential sources of emissions (such as the household sector), which is often the case.

Ying Fan, Jie Wu, Govinda R. Timilsina, and Yan Xia. 2017. "*Understanding the Interactions between Emissions Trading Systems and Renewable Energy Standards Using a Multi-Regional CGE Model of China.*" *Policy Research Working Paper* 8159, *World Bank, Washington, DC.*

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