



## **Energy Access and Economic Growth: How can Science and Technology Help?**

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COP21 just ended with a much-celebrated acknowledgement and recognition climate change represents an “urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation.” The Paris Agreement also welcomed the UN resolution on the Sustainable Developments Goals as well as the adoption of the Addis Ababa Action Agenda of the Third International Conference on Financing for Development. An important part of the Paris Agreement was the acknowledgment of the *“the need to promote universal access to sustainable energy in developing countries, in particular in Africa, through the enhanced deployment of renewable energy.”* While the Paris Agreement has been rightly hailed as a success, we must expand energy access to the poor as an urgent priority as we pursue our climate goals. Science and technology can help meet this challenge.

For the countries where the nearly 1.2 billion live without access to electricity and nearly twice that without access to clean cooking, the promise of universal energy access to a sustainable energy goal is center-stage. While access to electricity reached much of the world over the course of the twentieth century, the last billion do not want to wait that long. They want access to a range of energy products and services that have enabled modern homes, business, communication, agriculture, and industry, such as cell phones. It is also recognized that many of the other aspirations of the poorer countries (such as eliminating poverty and moving towards fuller employment, universal access to quality health and education) will never be achieved without reliable electrical power.

While the last billion still struggle for their first clean electric light, the first billion that got electricity are so far ahead in their consumption that the greenhouse gas (GHG) emissions from their power generation will have global-scale adverse impacts if the emissions continue unabated. The environment does not care whose emissions these will be. Hence in spite of the large geographic variations in natural and human resource endowments, and the ability to carry out large capital investments in decarbonization, world leaders at COP21 recognized the importance of sharply slowing down GHG emissions through the increased use of renewable energy and energy efficient technologies. Ironically those who are least responsible for this state of affairs, i.e. the poorest or those living in particularly vulnerable geographies of small island states will disproportionately feel the impact from such emissions. So how can science and engineering communities respond so that the poorest countries can help themselves achieve universal access within their political imperatives and their own geographic and economic context.

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The science community can be proud of the fact that a combination of basic research, applied engineering and scaled manufacturing of solar photovoltaic (PV) cells has already enabled first access to lighting and cell-phone charging for millions of people. Yet, this is a drop in the bucket compared to the larger need. The developing world is also taking a pathway to energy access that could lead the way towards what the developed world might need in the future. Scaled mass production of PV cells was fueled by demand incentivized through feed-in-tariffs. In the developed world, this led primarily to grid-tied installations, either large solar PV farms or grid-connected rooftop systems. However their biggest impact in the poorest countries has been through rapid growth in stand-alone solar-battery systems (all the way from flashlight level lighting from a small PV-battery-LED light to PV-battery systems that are a thousand times larger and can power a 100 square meter home with several appliances).

The particular services that the poor tend to pay for first are lighting and information communication technology (ICT) broadly, including cell-phones/smart phones use, television and DVD players. The most successful have been stand-alone systems in which solar PV provide the generation source and a battery provides storage (where the batteries are primarily lead-acid or lithium-ion), with financing and distribution models that are either outright purchase or some form or rent to own or pay as you go models. The systems that have scaled rapidly in the energy access arena are those which have first costs ranging from \$50 to \$300. Entrepreneurs providing such systems commercially do not charge per kWh tariffs, but instead try to recover capital through some form of a recurrent payment plan or a pay as you go plan. If one computes the prices per kWh of electricity for these systems, they are at least an order of magnitude higher than conventional grid-power. This high cost is primarily due to three reasons: 1) inherently high cost of battery storage and associated electronics; 2) inability to fully utilize electricity that can be potentially produced each day, (a stand-alone system cannot benefit from the aggregation of diverse demands unlike a grid); and, 3) high transaction cost of financing and servicing such stand-alone systems.

The fact that the poor are willing to pay what amounts to several US dollars per kWh is simply a manifestation of the even more expensive, inconvenient and sometimes unsafe alternatives (disposable batteries, candles, kerosene) that they otherwise have to rely on. When they do have access to a small PV/battery system, in order to stay within their household budgets the poor limit their consumption to around one kWh per month and use that first kWh for lighting, cell-phone charging and small electronics. The systems are generally sized to provide this level of service. While for brevity and illustrative clarity, it comes across as if all poor have one common demand level, which is not at all the case. There are a range of systems in the marketplace from those that provide a fraction of a kWh per month to those that provide a few kWh per month.

The poor would of course like to use electricity for other uses too because of the tremendous convenience and ecosystem of appliances that electricity provides. These uses at home would include cooking, refrigeration, thermal comfort, lifting water as well as a multitude of communication, computing, learning and entertainment services that electronics provide today. Residential consumption is just one vector of demand. Studies show that to lift a home, a village, or a region out of poverty one needs to create opportunities for income generation and accelerate those that exist. Such broader economic benefits of energy services derive from powering agriculture, irrigation, agro-processing, storage or drying; powering small businesses and industry; powering even the most basic shopkeeper and the artisan. Costs of stand-alone PV-battery systems are such today



that it would be prohibitively expensive to meet these demands. Yet it is these activities that are likely to lead to income and economic growth. While the poor may be willing to pay \$3/kWh for the first kWh or two, but for the level of consumption that they aspire to, they cannot afford \$3/kWh. If grid power is provided to the same poor, say at a price of say 10 cents to 20 cents/kWh, their consumption increases to nearly 30 to 50 kWh/month.

It is worthwhile contrasting this situation to that in the developed world. If indeed one had a rooftop system with a grid connection—with the ability to buy power and sell power during times of surplus as well as access to low interest finance instruments—one could offset grid consumption and potentially come out ahead if grid power costs exceeded 20 cents/kWh. The scaling up of rooftop deployments in the developed world through net metering and through feed-in-tariffs is happening because of the grid-connected nature of these systems. So *grid parity* in the developed world implies per kWh solar PV prices for each marginal kWh that are comparable to each marginal kWh of grid power. For the poor who are not connected to the grid, a PV+battery system is not at grid-parity. In fact it is costing them 10-fold per kWh more than those consumers in their country lucky enough to be connected to the grid.

A grid connection to the poor may cost \$1200 per household when one accounts for all the capital costs associated with generation, transmission and distribution. Lacking other options, electricity providers are furiously trying to finance such infrastructure for the number of households their governments can afford to connect each year, but leaving a significant number unconnected for now. Put bluntly, those lucky enough to have a grid connection pay \$0.20 per kWh. Those who do not have a grid connection in effect pay more than \$3/kWh. If indeed the longer-term public policy goal is to provide for the ability to server higher demand levels of 30 to 50 kWh/month, the least-cost approach for the government would inevitably imply access through a grid-connected system for all but the most remote populations. One also needs to recognize that the actual loads in a community the size of a small town of several thousand households can be nearly twice purely residential loads.

The poor themselves recognize the advantages of lower cost power and the additional advantage that a grid-based system provides, which is the ability to flexibly increase (or decrease for that matter) consumption as ability to pay or generate income grow. This latter feature of the grid as opposed to a PV-battery system is underappreciated since in developed countries the first use of electricity was through the grid. In fact large grid systems leverage to their technical and commercial advantage the spatial diversity of loads (e.g. difference amongst customers) and temporal diversity (growth in consumption over years and varying consumption during different times of the day) across a very large number of consumers. Hence the poor who lack electricity access are pushing their government representatives hard to provide grid connectivity even when governments are offering subsidies and discounts on off-grid systems.

It was through a quest that emerged out of these constraints that our own work in Africa led us to deploy 16 pilot systems in Mali and Uganda five years ago. We tested a micro-grid concept that we hoped would adapt to many of the constraints of the poor and yet provide electricity both a lower price point per kWh than a stand-alone system, and at a lower capital cost than a grid connection. Moreover the system would try to emulate the features of the grid that the poor valued most, i.e. the flexibility of use. The capital costs per customer would be limited to \$400 so that a poorer country



could deploy three times as many such connections as a \$1200 connection. If one would leverage the higher kWh willingness to pay of the poor for the first few kWh then some of the capital could be recovered through a tariff. The most important findings over time was that consumption increased in spite of high tariffs and that income generation activities led to load diversity.

We wish we had access to a petrol or diesel or biofuel powered “dream machine” that would be capable of providing up to a maximum of one kW of power at any point in time, whose fuel consumption would linearly reduce with lower loads, a machine that could operate 24-7 without maintenance issues endemic of small engines, and provide a fuel to electrical conversion efficiency of 25%. The capital cost of such a one kW machine would ideally be \$1000, the same per kW cost or similar much larger systems. This innovation would have been truly “contextual” and remains a challenge for the world. This machine could have provided reliable, scalable, flexible grid-like electrical power at 50 cents per kWh. Indeed such a dream machine does not exist today.

So we relied on the same basic technology, i.e. solar PV plus battery but through innovative battery management, demand and supply management, increasing utilization lowering electronics, installation, maintenance and financing costs through shared capacity and automation, allowing pay as you go metering and largely unattended operation over multiple years, we are now able to drive the cost of pay-as-you-go service to \$1/kWh (with no additional fixed monthly costs to the consumer). If governments were willing to finance the initial capital costs of say \$400/customer (about one-third of the capital cost of a grid connection) then the poor could obtain grid-like service for the first 5 to 10 years before the grid arrives. Such options would provide an additional degree of freedom beyond grid connectivity to rapidly and cost-effectively reach the universal electricity access targets.

In the process they could become pioneers in the kind of innovations today that the developed world might need tomorrow. They could provide the initial market demand for the next generation of power systems that will inevitably need smart meters, wireless communication, lower-cost storage, electrical and electronic controllers/drives, super efficient appliances, DC distribution and improved micro-grid operating systems that manage diverse loads, supply and storage as a system. Numerous different innovators, start-ups have adopted the same approach and the space of micro-grids is now moving from a curiosity to a state of many young entrepreneurs with governments and multi-lateral banks taking notice.

It is however equally if not more important to recognize that we do not today have off-grid or micro-grid technologies that can power both the homes as well as social and commercial demands of the poorer countries at price points that allow them to power agriculture and industry. The one exception to this is small-scale hydropower where a year round reliable stream-flow is available.

For now, power levels commensurate with needs for economic growth still rely on interconnected grids fed by mostly dispatchable electricity generation (usually fossil, large hydro or nuclear). The challenge for humanity and especially for scientists and engineers is that variable sources such as wind and solar alone (without affordable means to make them dispatchable) cannot meet the aspirations of all those that gathered at COP21. To fully decarbonize our economies and do so affordably, we will need to develop one or more of the following technologies: safe modular nuclear power, ultra efficient (on land and water) biofuels, electrical, thermal and grid-scale storage such as



compressed air or pumped hydro systems, and simultaneously drive towards extreme efficiency in material processing/use, transportation, buildings, electrical equipment and appliances. Some of these technologies combined with smart operation and management of demand, supply and storage will also allow us to drive increased penetration of variable sources such as wind and solar power. Hence science and technology will have a vital role to play in the future that we all want and need.