Efficiency and Micropower for Reliable and Resilient Electricity Service: An Intriguing Case-Study from Cuba

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In 2004, Cuba's 11 million people suffered 188 days of blackouts lasting more than an hour and exceeding 100 megawatts (MW) of lost load. In 2005, the blackouts rose to 224 days. But in 2006, they fell to just three days, and in 2007, to zero. What happened?

News from Cuba can be sparse, controlled, and unreliable. But recently published reports, vouched for by two reliable observers who recently visited Cuba, reveal a story with important implications for reconstructing reliable electric service in places like Iraq and Afghanistan.

Before Fidel Castro took power in 1959, Cuba was 59% electrified, rising by 1989 to 95%. But the electricity system, built around centralized (mainly Soviet-built) oil-fired power stations, was hit hard by higher oil prices, the economically devastating loss of Soviet patronage in 1991, 1990s U.S. sanctions, and the recent fall in the price of nickel, which earns half the island's export revenues. A national efficiency-and-renewables effort launched in 1993 brought solar power to all nonelectrified rural schools (2,364 of them), clinics, and social centers, so educational TV and computers could reach every schoolchild. Yet the energy crisis intensified. In 2004, two hurricanes left a million eastern Cubans blacked out for ten days and seriously damaged the grid, especially the east-west links. By 2005, Cuba's power supplies hung by a thread. Its 11 big thermal power plants, a quarter-century old, broke down about two-fifths of the time. Moreover, grid losses averaged 17% (*vs.* the U.S. 7%), most household appliances were inefficient, electricity tariffs encouraged waste, and three-fourths of Cubans cooked with kerosene. The collapsing power system finally forced fundamental change.

In 2006, the government launched *La Revolución Energética*. Two years later, Cuba had cut its kerosene use by 66%, LPG (bottled gas) 60%, and gasoline 20%—and blackouts had been banished by a combination of efficient end-use and micropower in a more granular grid.

The cornerstone was a greatly intensified emphasis on efficient end-use deployed *en masse*. Nearly all incandescent lamps in the country (over nine million) were switched to free compact fluorescents in six months. Almost two million refrigerators, over a million fans, 260,000 pumps, and 182,000 air conditioners were switched to models with efficiencies comparable to U.S. Energy Star. All these devices were shipped from China under export credits, and bank financing supported the larger customer purchases. Public-sector pumping, lighting, refrigerator, and air-conditioner efficiencies were raised too.

Electric tariffs were steeply inverted, with an unchanged and very cheap (0.4¢/kWh) "lifeline" rate but a quadrupled price (still only 5.4¢/kWh) for large users. Extensive and ambitious public energy education was added across school curricula, in print and broadcast media, and in community organizing, with 13,000 social workers bringing energy education to the grassroots and linking it to other social objectives. Meanwhile, to speed a shift from kerosene to efficient electric cooking (potentially switching and even saving fuel), nearly 3.5 efficient million rice cookers and over three million pressure cookers were sold to households.

Most strikingly, Cuba decentralized the architecture of its decrepit, fragile electrical system. In 2006, the government installed 1,854 diesel and fuel-oil-fired microgenerators totaling 1,820 MW, clustered in 110 municipalities. The $362-million system upgrade also included extensive grid refurbishment that reduced losses and outages. Blackouts plummeted. Another 6,000-odd emergency backup generators totaling 690 MW in about 4,000 critical sites (hospitals, food plants, schools, etc.) added resilience. By the end of 2007, over half of Cuba's 5,861 MW of generating capacity was distributed: 22% diesel, 9% fuel-oil, 12% backup, 9% cogeneration, 1% hydro, 0.1% wind and solar, and the rest conventional, comprising 39% central oil-fired, 6% gas-fired (using gas produced with domestic oil and previously flared), and 1% diesel peakers. Of the 11 big, inefficient, and unreliable oil-fired plants, reportedly five were shut down, displaced by far more reliable distributed sources and by efficient use.

The new grid architecture's resilience was soon tested. In 2008, two hurricanes in two weeks extensively damaged the grid, felling 167 transmission towers, but the distributed generators and their netted mini-grids maintained critical services, and portable diesels ran islanded (isolated) microgrids in some hard-hit areas. As Nicholas Newman commented, "Such a [decentralized] system has several advantages, including having a more robust system able to cope better with mechanical breakdowns and natural disasters. It also has the added advantage over large power plants in being relatively cheap and quick to install. Cuba is becoming less dependent on costly large power plants and more able to adjust its fuel mix to meet changes in energy supplies and natural conditions."

The distributed engine-generators use about 18% less oil per kWh than the central plants, though they can cause local noise and air pollution. In time, some will be replaced by wind and solar capacity. Cuba reported a 2005–07 reduction in CO_2 emissions equivalent to 18% of its 2002 emissions, and its refrigerator and air-conditioner replacements have rapidly phased out CFCs from the household sector.

The temporary generation fix relied on oil both because the global shortage of wind turbines caused long delivery times and because President Chávez swaps Venezuelan oil for the services of one-fifth of Cuba's plentiful doctors. But Cuba's strategic goal remains to shift to renewables, in which its major potential includes 5 kWh/m^2-d average insolation and ~5–14,000 MW of economic wind potential at 50-m hub height. Cuba indeed pioneered the world's first ocean-thermal-energy-conversion plant in 1930; in that era, microhydro, wind, solar water heating, and solar crop drying were widely used, and now they're making a comeback.

Wind and solar farms are starting to sprout, distributed solar power systems exceed 8,000 (with a plan to reach the remaining unelectrified 100,000 houses), and 31 of the 180 microhydro systems are grid-linked. Another important distributed generator is 478 MW of bagasse cogeneration at sugar mills, with another 826 MW of cogeneration potential identified. (Pilot projects are also exploring fuel production from inedible biofeedstocks like jatropha.) Two pilot regions aim at all-renewable power, one from hydroelectricity, the other from hydro, photovoltaics, and bagasse cogeneration.

The resulting training has helped Cuban technicians install over 1 MW of photovoltaics in Venezuela, Bolivia, Honduras, South Africa, Mali, and Lesotho. Cubans also reportedly helped Venezuela to save some 2,000 MW of electricity, including 72 million compact fluorescent lamps, and installed over two million lamps in 93,000 Haitian households. Cuba has exported elements of its energy revolution to a dozen countries in the region, creating both social and diplomatic benefits. In contrast, the U.S., whose domestic energy policy also emphasizes efficiency and renewables (at least rhetorically), has not yet aligned its foreign policy nor much of its development aid with what it seeks to practice at home, and still supports World Bank and similar development aid overwhelmingly biased toward central-station solutions.

Cuba's aggressive and coherent domestic energy policy was probably facilitated by its unusual political system and social conditions, but the impressively rapid and effective technical results hold widely transferable lessons that merit dispassionate reflection and emulation.

For the U.S. military, which has lately used restoration of reliable electricity and other basic services in places like Baghdad's Sadr City as a highly effective counterinsurgency tool, the Cuban success is especially instructive. Since the 2003 invasion of Iraq, U.S. experts who knew the value of efficiency and micropower have tried three times to shift the reconstruction of Iraq's decaying power system in this more resilient direction, but the previous Administration vetoed it each time. By the time the 2009 troop surge turned the tide, targeted attacks had brought the overcentralized grid to one attack away from collapse, while Iraqi entrepreneurs had improvised thousands of distributed back-alley engine-generators (albeit at high cost for the informal fuel logistics). Perhaps policymakers will get it right the fourth time in Iraq.

Encouragingly, this lesson is being learned more quickly in Afghanistan, where more remote, distributed, austere settlements often make efficiency and renewables the only practical strategy. How ironic it would be if Cuba's shift from the Soviet-style centralized model to a resilient energy system—inadvertently sped by U.S. sanctions that complicated repairs of the big old power plants—now helped inspire the U.S. to bring Cuban-style benefits to some of the most troubled areas of the world.

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