The Cuban Electric Grid

Lessons and Recommendations for Cuba's Electric Sector

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Lessons and Recommendations for Cuba's Electric Sector

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Cover photo by Lisa Valdivia

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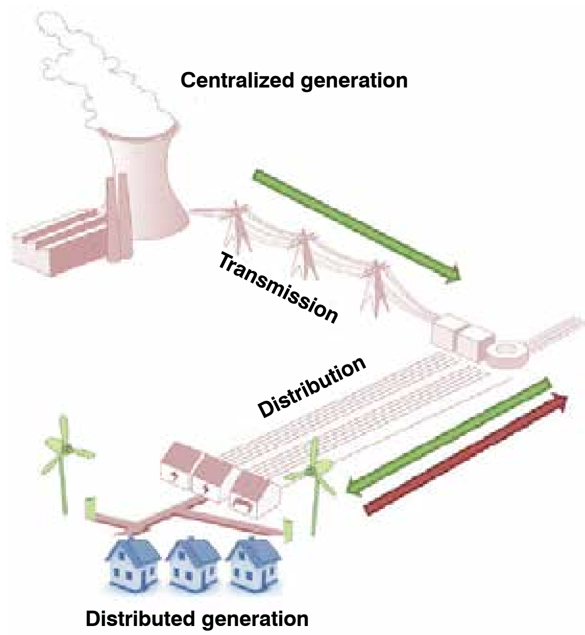
Definitions

Bagasse is the pulpy plant residue left over after juice has been extracted.[1] Sugarcane bagasse can be burned in power plants to generate electricity.

Capacity refers to the maximum output that a given generator of electricity is able to produce. Most of the capacity figures in this report are given in MW. One MW is roughly enough electricity to power 750 homes in the United States.[2]

Distributed Generation (DG) refers to power generation at the point of consumption, within distribution networks, or on the customer side of the network.[3] In contrast, centralized generation often involves larger plants that distribute power over longer distances through a transmission network.



Source: Institute for Energy Research

Distribution refers to the electricity delivery system that delivers power to homes and business from substations or distributed generators at a low voltage rate.[4]

Generation refers to the amount of electricity a generator produces over a given period of time, usually an hour. Most of the generation figures given in this report are in kWh. A 1 MW (1,000 kW) capacity plant operating continuously at capacity over one hour will thus produce 1,000 kWh.

Transmission refers to an electricity delivery system that delivers power from centralized generators to substations at a high voltage level, usually too high to be used by homes or businesses.[5]

Specific Fuel Consumption in power plants is the amount of fuel needed to produce a given amount of power. In this report, the unit used is the grams of fuel needed to produce a kWh of electricity.

Executive summary

From its 1959 revolution until the Soviet Union collapsed in 1991, Cuba imported oil from the Soviet Union through non-commercial barter agreements. It leveraged this cheap source of power to build infrastructure and expand electricity access to over 95% of its citizens.[6] The Soviet Union's collapse and consequent severing of oil import agreements severely and adversely impacted the Cuban electricity sector and economy. The electric sector was additionally devastated by blackouts and extreme weather events.

In response, the Cuban Government implemented the "Energy Revolution." This policy successfully replaced millions of inefficient household appliances with more efficient alternatives. The program was notable both for its impact on electricity demand and its speed. For example, lightbulbs throughout the country were replaced in roughly six months and reduced consumption 3–4% annually.[7]

In the mid-2000s, the Cuban government reached an agreement with a new exporter of heavily subsidized oil, Venezuela. This agreement between the countries sent Cuban doctors and professionals to Venezuela in exchange for inexpensive, imported oil. Venezuela provided roughly 100,000 barrels per day (slightly more than 60% of Cuba's supply) to Cuba under the agreement. A recent economic downturn in Venezuela, however, has resulted in lowered shipments of oil in the summer of 2016. In response, Cuban leaders have implemented energy saving measures in the state sector, avoiding cuts to residential demand (as of July 2016).[8]

Currently, electricity generation is dominated by oil. Fuel oil, whether in centralized or distributed systems, makes up over 80% of the generation supply.[9] Most of Cuba's oil comes from Venezuela, but between 30-40% of oil supply is produced domestically. The domestic oil is high-sulfur crude and burning this dirty oil leads to higher rates of failure in power plants and local pollution that causes serious respiratory ailments. Two combined-cycle natural gas generation plants meet about 14% of Cuban demand for electricity, with a third plant recently constructed. Roughly 50% of Cuba's electric power comes from imported fuel. Fuel costs account for 70–80% of generation costs and Cuba spends more money on energy, about 14% of GDP, than most nations.[10] A single state-owned utility, Unión Eléctrica, is responsible for managing and operating the electric grid.

Much of Cuba's electric grid utilizes oil high-sulfur crude oil, fuel oil, and diesel fuel. This resource is particularly polluting and creates significant harmful local air pollutants, including high levels of soot, sulfur dioxide, and nitrogen oxides.[11] Emissions from these pollutants are associated with a number of respiratory ailments including decreased lung function, aggravated asthma, and premature death.[12] These significant harms are amplified by the distributed nature of the grid, where generation is often located nearby large centers of the population.

Cuba's renewable energy resources currently represent a small but growing fraction of capacity. The country currently only generates about 4% of its electricity from renewables but is invested in expanding that profile. The Cuban government set a goal of 24% of generation from renewable sources by 2030.[13] The country recently signed agreements to build large, utility scale solar, wind, and bagasse plants. In each of these projects, the Cuban government has used foreign private parties to build the plants.

A key, unique aspect of Cuba's grid is its high levels of distributed generation, or power generated at or near the point of consumption. More than 40% of total generation capacity in the country is in distributed generation systems, a percentage second only to Denmark.[14] This distributed generation provides resiliency benefits against natural disasters like hurricanes and disruptions and centralized power plants, but may be less efficient than centralized generation. Burning high sulfur diesel and fuel oil in distributed systems also brings harmful local pollutants closer to population centers.

Most Cubans pay very little for electricity as an absolute figure. The residential electricity tariff is gradated based on consumption, with higher per kWh prices for larger consumers. The average household pays less than $0.02 per kWh consumed.[15] This rate, heavily subsidized by the government, is significantly lower than the average for neighboring Caribbean nations ($0.33/kWh). The average wage in Cuba, about $20/month, suggests however that the average household pays relatively significant amounts for electricity as a percentage of income. In contrast, industrial consumers are charged on a time-of-use tariff. Demand peaks in summer months.[16] Some evidence suggests system-wide demand peaks in the evening—or at least did in 2009.[17] Regardless, power consumption in Cuba is growing, including residential power usage increasing by 66.5% over the last decade and state sector consumption rising by 9.6% over the same period.[18]

As an island nation, with approximately 10% of its population living in low-lying areas on the coast, Cuba will feel the acute effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) projects that the country could lose 3% of its land by 2050.[19] Cuba has already seen an increase in the frequency and intensity of hurricanes. Long a participant in climate change action, Cuba has renewed its commitment by signing the Paris Agreement in 2016. Cuba submitted a contribution to that agreement, in which it pledged to massively increase renewable generation, increasing to over 650 MW each of solar, wind, and bagasse generating capacity.[20] This commitment is presented in broad strokes, however, and may be difficult to reach. Finding cost-effective and innovative solutions will be critical to meeting these goals.

Cuba's energy sector is approaching an inflection point. Significantly lowered Venezuelan oil imports could drive the need for a fundamentally redesigned energy sector. The easing of aspects of U.S. trade and travel sanctions in 2015 and 2016 has resulted in an influx of tourism and electricity demand.[21] The way Cuba responds to these near term challenges will help set the stage for its long term energy future.

This paper sets forth four sections. "Background on the energy sector" (page 8) provides historical context and background of the country's energy sector. "Current electricity sector" (page 11) describes the current energy sector, including details on the country's fuel sources, generation, transmission/distribution, and consumption of electricity. "Energy future" (page 19 describes key aspects of Cuba's energy future, including a focus on the future of the country's energy resources. Finally, "Recommendations" (page 27) provides a set of recommendations based on the analysis contained in prior sections.

These recommendations are focused upon cost-effective actions that may support the long-term sustainability and reliability of the Cuban energy sector. Particularly, this paper recommends:

- **Knowledge sharing.** Cuba should leverage already existing experiences from nations with similar energy profiles, particularly island jurisdictions and nations with highly distributed systems. Best practices and lessons learned, especially with respect to integrating renewable generation, can provide helpful experience and context.

- **Competitive procurement.** Cost comparison across resources is critical to making informed investment decisions. Rather than individual bilateral agreements, Cuba should consider an informed process able to competitively procure new electricity generation.

- **Renewable distributed generation.** Cuba should consider conducting a feasibility and cost/benefit study with respect to increasing renewable distributed generation. By leveraging the already existing highly distributed grid, a greater reliance on distributed renewable assets may provide discrete cost, reliability, environmental, and timeline advantages over potential alternatives.

- **Expand energy efficiency.** Cuba should consider expanding energy efficiency efforts to other areas and sectors, including supply-side, non-appliance, and industrial sectors. Previous energy efficiency programs have worked well, and an expansion upon an already successful model could reduce consumption in sectors that have not yet been targeted.

- **Examine tariff structure.** Current energy tariffs are structured to encourage energy conservation. Changes to the current structure could further support this aim, particularly with respect to industrial consumers' time of use rate.

- **Microgrids at high-demand locations.** Microgrids sited at high-consuming locations could ease transmission and distribution congestion and provide resiliency and reliability benefits for significant loads.

- **Invest in diverse mix of lower-carbon resources.** Investment in lower-carbon and alternative energy resources may allow for a cost-effective, clean energy future impossible with further buildout of dirty, fuel oil based generation. Evaluation of sources including solar, wind, natural gas, and energy efficiency resources should occur in the context of current emissions and cost profiles.

- **Consider mechanisms to stimulate and clarify foreign investment.** Implementing certain policies, laws, and actions may help to increase foreign investment in renewable energy projects by mitigating certain types of risk or increasing upfront capital.

Background on the energy sector

This section describes four distinct time periods in the history of the Cuban energy sector: (1) the period from revolution until 1991, when oil imports from the Soviet Union were a key driver of Cuban energy; (2) the ensuing period, when Cuba attempted to respond to economic crisis with energy efficiency, renewables, and domestic oil production; (3) Cuba's mid-2000s energy revolution, and its massive rollout of energy efficiency measures in response to hurricane-induced blackouts; and (4) Cuba's oil-importing relationship with Venezuela.

Pre-1991 relationship with USSR

From the early years of Cuba's revolutionary government until the early 1990s, Cuba's relationship with the Soviet Union was the dominant force in the state's energy sector. Cuba imported nearly 90% of its fuel needs from the Soviet Union over this time period.[22] Cuba accessed these fuel imports through a favorable barter agreement, under which Cuba provided sugar and other commodity exports in exchange for oil imports from the Soviet Union.[23]

Cuba utilized this heavily subsidized oil to expand electricity access to its citizens. In 1959, only about 50% of households in the island nation had access to electricity. By 1989, the electric grid provided service to 95% of households.[24] Total installed power generating capacity grew from 400 MW in 1958 to 4,000 MW in 1990.[25] This capacity paled in comparison to some countries; for example, Cuba's generating capacity was roughly 13% of the United States generation capacity per person in 1990. Cuba significantly outpaced other neighbors, however. By 1990 Cuba had roughly 1.8 times more generating capacity per person than the Dominican Republic and 1.3 times more than Jamaica.[26] At the same time, annual electricity consumption in Cuba grew from roughly 1,500 GWh to 9,700 GWh over the same period (1958 to 1990).[27] Because imported oil was central to this expansion, however, Cuba's energy sector was immediately and immensely stressed following the collapse of the Soviet Union in 1991 and the resulting termination of the countries' oil-for-sugar agreement.

Post-Soviet restructuring (1991–2005)

The Cuban economy contracted rapidly after the Soviet Union's collapse. Cuba's GDP fell 35% between 1989 and 1993 and oil, gas, and food shortages regularly affected the country.[28] The Cuban government responded with a 1993 National Assembly-approved national energy policy. This policy set forth three overarching goals—invest in energy efficiency and renewable energy, increase domestic oil production, and invest in the sugar industry to more efficiently utilize bagasse (sugarcane biomass) electricity generation.[29] Sugar has historically been a key export for Cuba and the country had previously traded sugar for oil from the Soviet Union.

Cuba focused its renewable energy efforts in rural areas. The country mobilized its scientific community to look at efficiency and renewable alternatives to centralized oil generation. It then outfitted key institutions that previously had been without electricity—rural schools, health clinics and social centers—with photovoltaic (PV) solar systems and micro-hydro plants.[30] The program successfully installed 2,364 schools and hundreds of doctors' offices and hospitals with PV systems by 2003.[31]

To increase domestic oil production, Cuba chose to allow third-party entities entry to the sector. Once a completely state-dominated sector, Cuba opened up a portion of its oil and gas exploration to foreign companies in 1993. Cupet, the state-owned oil company, adopted a production-sharing agreement (PSA) contractual structure with private oil companies. The PSA awards rights to third-party contractors to explore and produce oil within a specific geographical area at their own risk and recover costs, conditioned on shared profits with Cupet.[32] Most foreign involvement in Cuba's domestic production has been through a PSA between Cupet and a Canadian company, Sherritt.[33]

Investment in bagasse was less successful. Without support from the Soviet Union and with a shrinking economy, Cuba saw a huge collapse in sugarcane production. Production fell 57.4% from 1989 to 2000, and the downward trend has continued.[34] As a result, the proportion of electricity for primary consumption produced by bagasse has likewise fallen.[35]

These post-Soviet Union policy pivots in the 1990s proved insufficient in reducing stress upon the electric grid. The country's 11 thermoelectric plants only functioned roughly half the time due to aging infrastructure, complications from using high-sulfur heavy crude in power plants, and natural disasters. Hurricane-related blackouts in 2004 left one million without power for ten days.[36] The energy sector during this period thus faced internal reliability threats from under-performing power plants and external resiliency threats from extreme weather.

Energy revolution

The Cuban government responded to these energy resiliency and reliability issues with renewed efforts, through a policy known as the 'Energy Revolution.' The policy included several overarching goals,[37] and two--increased energy efficiency and greater use of sustainable resources—are emblematic of the variability of success experienced.[38]

Energy efficiency

Increasing energy efficiency quickly proved successful. In a matter of months, the policy replaced millions of appliances with more efficient, upgraded alternatives in Cuban homes. Cuba's energy efficiency program is notable both for its speed and its breadth. Over roughly six months the country quickly switched to compact fluorescent lightbulbs, reducing electricity consumption 3–4% annually. Cuban officials likewise replaced 2 million refrigerators and 1 million fans, installing more efficient, upgraded appliances. They distributed 3.3 million new electric stoves, 3.5 million rice cookers, and 3.2 million pressure cookers, replacing kerosene and liquid petroleum gas stoves.[39] Nearly all of the appliances were purchased from China, as part of a larger credit deal that also sent vehicles and distributed power generation systems to Cuba.[40]

Notably, the energy efficiency measures were focused on the residential sector, and within this sector, the measures specifically targeted appliance upgrades. This narrow focus allowed Cuban leaders to act quickly to affect a large portion of demand but left open the possibility of enacting further energy efficiency measures in other sectors with a much broader scope. Further energy efficiency measures that the government could enact are discussed in Recommendation 2, "Invest in solar energy distributed generation" (page 28).[41]

In addition to appliance upgrades, Cuban officials implemented a new electricity tariff to reduce demand. The tariff introduced progressive rates based on consumption levels, i.e., a tiered rate structure.[42] Consumer electricity cost remained extremely inexpensive, however, through heavy subsides – and remains so to this day. Even with the new tariff, the average consumer pays less than $0.02/kWh,[43] far lower than the average tariff across several Caribbean countries ($0.33).[44] Due to significantly lower average wages in Cuba, however, electricity prices as a percent of income are actually higher in Cuba than in neighboring island countries. Cuba's electricity tariff structure, particularly in the context of average household income, is discussed in more detail in "Demand consumption" (page 17).

Renewable resources

The Energy Revolution proved unable to increase the deployment of sustainable and renewable resources projected. Indeed, renewable electricity generation did not increase substantially until years later and remains an under-deployed and underdeveloped resource.[45] Instead, fuel oil remains the dominant source of electricity generation.

Relationship with Venezuela

Cuba's relationship with Venezuela is central to Cuba's current energy sector. The two countries entered into a barter agreement in 2000, which increased in the mid-2000s, and was similar to the previous barter agreement between Cuba and the Soviet Union. Under the agreement, Venezuela provides Cuba roughly 100,000 barrels per day of oil. In exchange, Cuba provides Venezuela services rendered by Cuban doctors and other professionals. Imports under this agreement currently account for about half of Cuban energy needs[46] and fulfill more than 60% of its crude oil supply needs. Between 2003 and 2009, Cuba imported $14 billion worth of oil. Eight billion was exchanged for services rendered by the doctor/professional deployment, and the other $6 billion was converted to low-interest 25-year debt.[47]

The agreement continues to provide Cuba with inexpensive oil, but recent economic strife in Venezuela may endanger the agreement's future. As of June 30, 2016, Venezuela was still sending about 90,000 b/d to Cuba. Cash payments to doctors deployed in Venezuela have been hindered however, suggesting potential uncertainty for the agreement's future. In response to Venezuelan economic troubles, Cuba ordered some state firms and joint ventures to reduce fuel consumption in June 2016.[48] More recently, Cuba has begun importing crude oil from Russia for the first time since the collapse of the Soviet Union.[49]

Cuban President Raul Castro first publicly acknowledged that Cuba's Venezuelan oil imports were diminishing in early July 2016. The government introduced targeted measures to respond to this decrease in oil imports, particularly focused on state sector energy consumption (notably giving preference to continued energy access in the residential, tourism, and nickel production sectors). State sector energy reductions include reduced bus services, less air conditioning, and reduced work days, with fuel allotments for government vehicles slashed in half.[50]

Should Venezuelan oil imports continue to diminish, Cuba must determine how best to respond. The recent imported crude oil is, according to expert Jorge Pinon, a clear sign that "Cuba is diversifying its long-term supply contracts in the event that its October 2000 subsidized oil agreement with Venezuela is terminated."[51] Blackouts remain a bad word in Cuban politics,[52] and leaders are wary of continuing a history of dependence on one import source for future energy needs.[53] However, a transition away from inexpensive imported oil requires smart policy planning and innovative thinking to facilitate efficient, reliable, sustainable, and cost-effective electricity.

Current electricity sector

This section describes the four key components to Cuba's electricity sector: (1) fuel sources, including fossil fuels and renewable energy resources; (2) existing centralized generation; (3) transmission, distribution, and distributed generation; and (4) electric consumption and demand.

Fuel sources

Overall

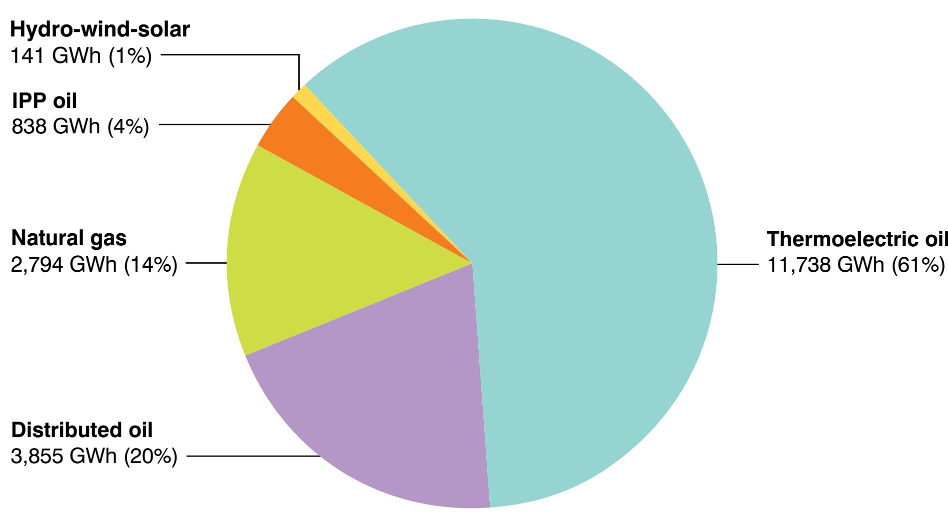
Cuba relies heavily upon liquid fuels for electricity generation. Indeed, it has the 5th highest percentage of total energy derived from liquid fuels in the world.[54] Fuel accounts for 70–80% of total generation costs.[55]

Oil remains the dominant fuel source for electricity. Of 19,366 GWh of gross electricity output in 2014, 61% was generated from fuel oil for centralized plants, 20% from fuel oil for distributed generators, 14% from natural gas, 4% from Independent Power Producer (IPP) oil including biodiesel from sugarcane biomass, and around 1% from other renewables.[56] These fuel sources are represented in Figure 1 below.

Imports make up a substantial portion of Cuba's fuel mix. In 2013, for example, Cuba imported 61.8% of its total crude oil consumption from Venezuela. The vast majority of this imported oil was used for electricity generation.[57]

FIGURE 1

Electric generation by fuel source in 2014[58]



Source: Jorge R. Piñón

Key players (government entities)

Ministry of Energy and Mines. Energy policy in Cuba is state driven, directed by the Ministry of Energy and Mines. Cuba had no ministry of energy until 2012. Before, the Ministry of Economy and Planning coordinated the Energy Commission, which in turn formulated the nation's energy strategy.[59] At that time, the Ministry of Basic Industries oversaw the electric sector. In 2012, Cuba separated out energy by creating the Ministry of Energy and Mines (and eliminating the Ministry of Basic Industries). This new agency assumed responsibility for all activities related to the energy sector, including oversight of the state-run utility Unión Eléctrica.[60]

CITMA. The ministry of Science, Technology, and Environment (CITMA) directs environmental policy. It was established in 1994 based on the desire to make sustainable development and environmental protection a policy priority and to provide a clearer and more integrated mandate for environmental governance.[61] The agency received additional authority with the passage of Law No. 81, the Environmental Law, in 1997. A key provision of the law for electricity generation, Article 125, states that Cuba should prefer the use of renewable energy resources wherever feasible.[62]

Cupet. Cupet is Cuba's vertically integrated state-run oil company. It is responsible for exploration, production, and refining domestic oil. It may enter into third party contracts with private parties.[63]

Cubasolar. Although technically not a governmental organization, Cubasolar is a quasi-independent organization which operates under the auspices of CITMA. It was created in 1994 to promote the use of renewable energy in Cuba.[64] Its tasks include organizing events, demonstration projects, and education on renewables. The organization also installed Cuba's first wind farm.[65]

Key entities (private party involvement)

Sherritt. As described above, the Canadian company Sherritt is a key player in both the Cuban extractives and power production industries. It partners with the Cuban government in oil and natural gas production and electricity generation from natural gas. The company produces just over 18,000 b/d of oil with Cupet[66] and about 21,000 b/d oil equivalent of natural gas through Energas.[67] In 2015, Sherritt received $117.5 million for oil and gas production services as part of its agreement with Cupet.[68]

Hive Energy. Hive Energy recently entered into the Cuban solar energy market. The British company was awarded a contract by Unión Eléctrica to build a 50 MW solar project in Mariel. This project, to be Cuba's largest solar farm by far, is expected to be completed in 2018.[69] Because this is the first agreement in a series of desired industrial-scale solar farms, the Mariel project will likely act as a pilot for future investment.

Goldwind. Goldwind is a Chinese wind turbine manufacturer that has provided wind turbines for multiple Cuban wind farms. They will provide the turbines for the planned wind farm Herradura 1, which will be a 51 MW capacity farm made up of thirty four 1.5 MW turbines.[70]

Fossil fuels

Cuba has increased domestic oil production in the last two decades. The country now produces around 50,000 b/d, or roughly 30-40% of its consumption needs. This represents a dramatic increase from around 9,000 b/d in 1991.[71] Most of this oil consists of low quality, high-sulfur oil that is extracted from shallow waters just off the coast.[72] As described in "Centralized generation" (page 16), burning this high-sulfur oil leads to failures in power stations and harmful local air pollution.

Cupet manages the majority of domestic oil production without foreign involvement, but roughly 18,000 b/d is produced through a production sharing agreement between Cupet and the Canadian company Sherritt. This agreement, the largest in of its kind currently in place in Cuba, provides oil at a unit operating cost of $7.43 per barrel in 2015, with realized prices of $29.91 per barrel.[73] This oil is consumed domestically in Cuba and Sherritt receives a portion of profits from the Cuban government. Overall, there has been roughly $2 billion in direct foreign investment in the oil and gas sector in Cuba since 1991.[74]

Natural gas production makes up a small but significant proportion of Cuba's fuel sources. Domestic production averages 43 billion cubic feet (21,000 b/d equivalent) per year and all current production is associated natural gas, recovered alongside oil. Cupet estimates the recovery rate of this natural gas to be 94%.[75] This natural gas production is conducted through a private/public corporation called Energas, made up of Sherritt, Cupet, and domestic utility Unión Eléctrica.[76]

Renewables

Cuba's renewable energy profile remains a small percentage of total generation; however, the country is laying the groundwork for increases in the near future. This future is described in more detail in "Future of Cuba's resources" (page 23). Cuba currently generates around 4% of its electricity from renewable sources, with bagasse being the major resource.[77] In addition, roughly 10,000 households and 34,900 people, or about 0.3% of the population, use electricity from renewable off-grid sources.[78]

Centralized generation

Overview

Cuba had 6,169 MW total installed generating capacity in 2014.[79] This represents a 19% growth from 2006, when the number stood at 5,176 MW. Cuba's generating capacity is significantly greater than other large Caribbean island nations, including the Dominican Republic (3,702 MW in 2013), Jamaica (918 MW in 2012), and Trinidad and Tobago (2,104 MW in 2012).[80] Cuba's population is greater than each of these nations, however. In this context, Cuba has a generating capacity of about 547 MW per million residents, while the Dominican Republic has roughly 356 MW/million residents and Trinidad and Tobago has 1,570 MW/million residents. Consumption differences are described in greater detail in "Demand/consumption" (page 17).

Key players

Unión Eléctrica (UNE). UNE is Cuba's vertically integrated utility that provides power to most of the country.[81] Established in 1960, UNE serves the over 95% of Cuban households and end-users with access to the electric grid.[82] UNE oversees the entire electric sector, including generation, transmission, and distribution. It oversees 35 companies including power-generating plants, provincial distribution companies, constructions firms, and consulting companies.[83] In 2010, UNE employed 33,949 people, including 7,810 technical personnel and 17,211 administrative and service personnel.[84] Detailed financial information about UNE is not available. Because Cuba relies so heavily on oil for electricity generation, the price of oil has an outsized impact on UNE's finances. UNE's financial situation depends both on the market price of oil and on the extent to which favorable trade agreements for oil exist.[85] Even with favorable oil prices and agreements, heavily subsidized retail electricity rates and low productivity at aging centralized power plants likely make it very difficult for UNE to avoid net losses each year.

Energas. Energas is a joint venture of the Canadian company Sherritt, Cupet, the state oil company, and UNE, the electric utility. Each party holds a 33% stake in the joint venture. The company is responsible for natural gas electricity generation at Varadero, Boca de Jaruco, and

Puerto Escondido. These plants, taken together, have a total generating capacity of 506 MW.[86] For its power generation services as part of Energas, Sherritt received $38 million from agencies of the Government of Cuba in 2015.[87]

Inter RAO. Inter RAO is a Russian electric power generating company. The company signed an agreement in 2016 to build four fuel oil generators (200 MW each) at two different existing Cuban fuel oil plants. The project will be financed by Russian export credits. Russia will present Cuba with a $1.3 billion loan at 4.5% interest, with repayments set to begin once the generators begin operating (planned completion is 2022–2024). The payments must begin by February 2025 and must be paid back within 10 years.[88]

Zerus. Zerus is a subsidiary of the Cuban Ministry of Sugar (AzCuba) dedicated to establishing joint ventures with foreign investors. Zerus partnered with Havana Energy to create the company Biopower to build bagasse power generation in Cuba. The company is structured as a 51% Zerus, 49% Havana Energy joint venture.[89]

Havana Energy. Havana Energy is a British company providing bagasse power generation services in Cuba. It is staffed with various British professionals and its principal shareholder is the Esencia Group, a larger British company working directly with Cuba on tourism and energy.[90] Havana Energy partnered with Zerus in 2012 in an agreement to build five 30 MW biomass power plants attached to sugar mills around the country.[91]

Siemens. Siemens is a German conglomerate company with a large energy division. Siemens signed a Memorandum of Understanding (MoU) with UNE in July 2016 to modernize the energy infrastructure of Cuba. The MoU envisions projects in power generation, transmission, distribution, and installation of Siemens' power generating technology.[92]

Fossil fuel generation

Cuba's generation is primarily concentrated in oil-fired power plants. In 2009, the country's primary centralized generation included nine oil-fired power plants and two gas-fired power plants (13.4%).[93]

Energas has since constructed a third natural gas plant in Boca de Jaruco. This combined-cycle plant became operational in 2014. The three major natural gas plants account for 506 MW of electric generating capacity, or about 8% of total generation capacity in 2014.[94]

A significant portion of Cuba's capacity is in distributed generation systems. Of 5,602 MW generating capacity in 2009, 2,436.7 MW capacity, or 43% of the total, was in distributed systems—fuel oil, diesel, and nickel industry generators.[95] Distributed generation in the country is discussed in more detail below in "Transmission, distribution and distributed generation" (page 15).

As described above, most of Cuba's domestic oil production produces high-sulfur crude oil. Use of this high-sulfur oil in electricity generation leads to frequent failures in power stations.[96] It also results in significant harmful local air pollutants, including high levels of soot, sulfur dioxide, and nitrogen oxides.[97] Emissions of these pollutants are associated with a series of respiratory ailments including decreased lung function, aggravated asthma, and premature death.[98] These significant harms are amplified by the distributed nature of the grid, where generation is often located nearby large centers of the population.

Renewable energy generation

Bagasse, the dry pulp residue left over after sugar extraction from sugar cane, is the most common renewable source of electricity in Cuba. Bagasse accounted for 3% of overall electricity production in the country in 2009, making up 80% of Cuba's renewable profile at that time.[99] As described above, however, use of bagasse to generate electricity has decreased since the 1990s, due to declines in the sugar industry. Since the Soviet Union was the chief

TABLE 1

Main fuel oil power plants (above 50 MW) in 2009[100]

Name (location)	Installed capacity (MW)	Operation (% of capacity)[101]	Number of workers	Year built	Technology origin	Fuel efficiency (grams of fuel oil/kWh)
Antonio Maceo (Rente)	450	65%	240	1966	Soviet	310
Antonio Guiteras (Matanzas)	330	65%	100	1978–79	Japanese/Czech	260
Lidio Ramon Perez (Felton)	500	65%	140	1996–2000	Czech	290
Maximo Gomez (Mariel)	450	57%	320	1965–69	Soviet	320
10 de Octubre (Nuevitas)	503	65%	250	1969	Czech	280
Carlos Manuel de Cespedes (Cienfuegos)	382	57%	300	1985	Japanese/French	260
Este de La Habana (Santa Cruz del Norte)	300	57%	150	1988-95	Soviet	250

importer of Cuban sugar cane, its collapse led to a decline in Cuba's sugar industry. Indeed, sugar production fell from 8.1 million tons in 1988 to 1.24 million tons in 2009.[102] The industry has recovered somewhat since then, to 1.8 million tons in 2015, but production is still far below pre-1990 levels.[103]

Cuba's solar industry is small but growing. In 2009, the country had only 1.8 MW of total installed solar PV capacity and 3.8 MW installed capacity in 8,000 solar water heaters.[104] Cuba has begun investing in utility-scale solar projects in recent years, however. Cuba's first solar farm began construction in Cantarana in 2013, built to an eventual capacity of 2.5 MW. The project was government financed.[105]

Wind generation is further developed than solar but still makes up only a small portion of total capacity. Currently, the country has 11.2 MW installed capacity in four wind parks.[106] The first of these wind parks was installed in 1996 by Cubasolar, a government-sponsored Cuban NGO. The turbines for that project came from Spain, and the funding came mostly from international NGOs.[107]

Cuba has about 65 MW in installed hydro power capacity. Most of hydropower comes from isolated systems in off-grid areas.[108]

The Russian company Inter RAO is building expanded generation capacity by adding generators at two of these plants. Inter RAO is building three new fuel oil generators, 200 MW each, in La Habana del Este and a third 200 MW generator at Maximo Gomez. In total, the project will add 800 MW, an additional 13% of generating capacity, and is expected to be completed by 2022–2024.[109]

Transmission, distribution and distributed generation

Transmission and distribution

Cuba's transmission and distribution network is extensive. Operated by Unión Eléctrica, it reaches over 95% of the country.[110] The transmission grid operates at 220/110 kV. In total, the country has 2,833 km of 220 kV lines and 4,188 km of 110 kV lines.[111]

Cuba has transmission and distribution losses that are roughly similar to those experienced in other countries in the Latin America and the Caribbean. One analysis suggested that transmission and distribution losses may be around 17%, citing bad technology used to mount conductors as a key contributor.[112] The Cuban government cites a slightly lower number, 2,951 GWh in losses in 2014, accounting for 15.3% of electricity generated.[113] This is higher than neighboring Dominican Republic (12% in 2013) but significantly lower than Jamaica (26% in 2013). The average for the Latin America and the Caribbean region was 15% in 2013.[114] It should be noted that unlike its neighboring countries in the Caribbean, Cuba experiences virtually no non-technical losses (i.e., theft).

Distributed generation

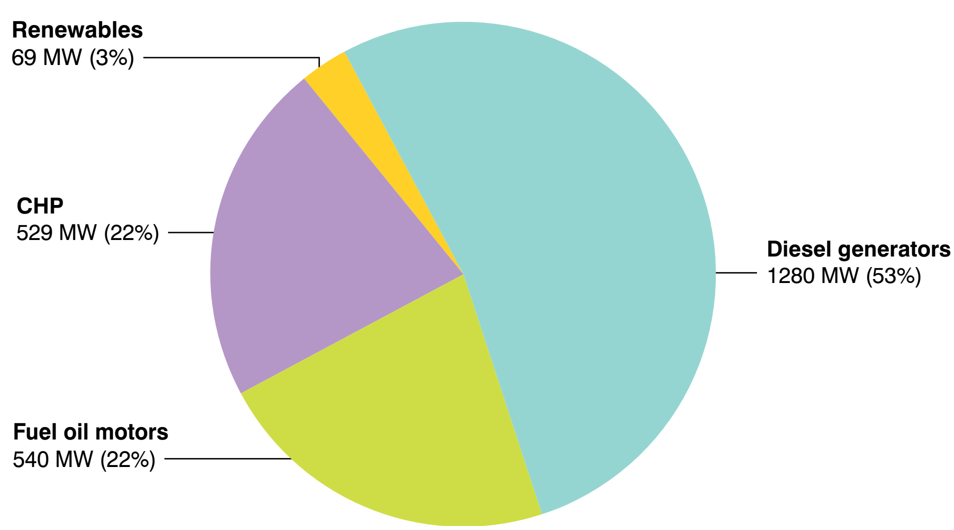
Cuban leaders invested heavily in distributed generation in response to widespread damage to transmission and distribution infrastructure from hurricanes in the mid-2000s.[115] By 2008 the country had invested $1.2 billion in DG.[116] As a result, Cuba has a highly distributed system. Indeed, Cuba has one of the highest percentage of total DG capacity in the world, second only to Denmark. In total, the country has built 2,497 MW of DG capacity, accounting for 42% of overall generation capacity.[117] The DG capacity is made up of diesel generators (1,280 MW), fuel oil motors (540 MW), combined heat and power (529 MW), and renewable energy sources (69 MW).[118] This breakdown is represented in Figure 2.

Cuba's investment in DG has provided resiliency benefits but is not without pitfalls. The system helps to mitigate extreme weather event related disruptions that can lead to catastrophic events. DG systems are more resilient in the face of natural disasters like hurricanes because each affected plant contributes a smaller capacity to the grid, they do not rely to the same extent on extended transmission networks, and they can be brought back online more quickly than centralized generation.[119] DG systems likely have higher specific consumption rates than the large oil-fired power plants they replaced, however.[120] Moreover, DG is typically sited closer to Cuban homes and communities. As such, the current DG in Cuba—which is typically quite polluting—causes local pollution in the form of, NOx, SO2, and particle emissions.[121]

DG systems are distributed widely throughout the country. Installations are in place in 116 out of 169 municipalities.[122] Some of the largest installations are in Moa (20 fuel oil generators, 174.6 MW), Mariel (11 fuel oil generators, 147.2 MW), and Havana (56 diesel generators, 85.6 MW).[123]

FIGURE 2

Distributed generation breakdown



Source: TK

Cuba's proportion of DG capacity is significantly higher than most countries. Only Denmark's DG capacity is higher, where 53% of overall capacity is found in distributed generation. The U.S. (8%) and Mexico (6%) electric grids contain significantly lower proportions.[124]

Demand/consumption

Overview

Per capita annual electricity consumption in Cuba was 1,425.5 kWh in 2013. This was higher than Jamaica (1,126 kWh) but lower than the Dominican Republic (1,516.5 kWh) and the average for developing countries in Latin America and the Caribbean (1,893 kWh).[125]

Cuba spends more money on energy, as a percent of GDP, than most nations. The total value of energy consumed is estimated at 14% of Cuba's GDP, whereas the world average is roughly 10%.[126]

Electricity consumption is growing rapidly in Cuba, including a 4.8% increase from 2014 to 2015 alone. Residential power use has increased 66.5% and state sector use increased 9.6% over the past decade.[127] A factor driving this large increase in residential consumption has been rising tourism and associated air conditioning and refrigerator use.[128] This increasing demand and decreasing supply (in the form of reduced oil imports from Venezuela), coupled with other weak economic indicators including low global prices for sugar and nickel, two main Cuban exports, has raised blackout concerns. This fear could be particularly pronounced in the summer months of July and August, when demand typically peaks.[129] In July 2016 the Finance Minister announced goals of reducing electricity consumption by 6% and fuel consumption by 28% in the second half of 2016.[130] Energy use by the state is to be rationed to allow for unfettered consumption in the residential and tourism sectors.

Tariff structure[131]

Residential consumers in Cuba are charged a tiered rate based on their monthly usage. The average household consumption is about 176 kWh/month.[132] Electricity in Cuba is heavily subsidized and, as an absolute figure, extremely cheap. Due to Cuba's significantly lower average wages, however, electricity prices per kWh for consumers, as a percent of income, are actually higher than in neighboring island countries.

TABLE 2

Residential electricity tariff update in 2010[133]

Monthly consumption (kWh)	Pre-2010 Tariff ($/kWh)	New tariff ($/kWh)
0 to 100	0.004	Same
101 to 150	0.012	Same
151 to 200	0.017	Same
201 to 250	0.025	Same
251 to 300	0.033	Same
301 to 350	0.054	0.063
351 to 500	0.054	0.075
501 to 1000	0.054	0.083
1001 to 5000	0.054	0.125
Over 5000	0.054	0.208

As part of its package of reforms in the mid-2000s Energy Revolution, Cuba introduced a tiered rate tariff, with rates increasing concurrent to consumption levels. This Updated Residential Electricity Tariff created two primary rate blocks: one applicable to consumption less than 100 kWh/month and one applicable to larger monthly consumptions. Those that consumed less continued to pay the previous, heavily subsidized rate of $0.0038/kWh.[134] For every increase of 50 kWh/month beyond 100 kWh, the tariff progressively increased. Cost was capped at $0.054/kWh for the highest consuming tier of over 300 kWh/month.[135]

The tariff was further updated in 2010. This update included further gradations for consumers of over 300 kWh/month, progressively increasing as consumption went up.[136] The updated rates are highlighted in Table 2.

Even with the tariff increases, electricity remains quite inexpensive, as an absolute figure, in Cuba due to heavy subsidies from the government. Electricity rates are much higher elsewhere in the Caribbean. The average electricity tariffs in the Dominican Republic ($0.20/kWh), Jamaica ($0.36), and across several Caribbean countries ($0.33) were significantly higher than Cuba's in 2012.[137] Thus the rate that the average Cuban household pays ($0.012/kWh) is only 6% of the Dominican Republic rate and less than 4% of the Jamaican rate.

Cuba's relatively low average salary is critical to understanding low residential electricity tariffs, however. The average Cuban salary was about $20/month in 2009,[138] much lower than in the Dominican Republic ($462/month) and Jamaica ($1,135/month) that year.[139] Assuming mean salary, Cubans consuming 100 kWh/month pay 2% of income in electric cost and those consuming 250kwh/month pay 31% of their income in electric costs. Cuba's mean monthly salary is only about 4% of the Dominican Republic's mean salary and less than 2% of Jamaica's mean salary. Thus, when considered as a percent of income, the average Cuban electricity price per kWh is about twice as high as Jamaica's and about 1/3 higher than in the Dominican Republic.

Cuban industry is charged under a different tariff structure than those in the residential sector. Industrial customers are charged based on a time-of-use rate with three time tranches. Peak load time is from 6-10 p.m., medium load time is from 6 a.m. to 6 p.m. and low load time is from 10 p.m. to 6 a.m.[140]

Energy future

This section describes three aspects of Cuba's energy future: (1) the connection between climate change and the energy sector; (2) changing political realities in Cuba with a reopening of ties with the United States and the potential for greater private sector investment; and (3) the potential future of Cuban energy resources.

Climate change and energy

Impacts and emissions

As an island nation, Cuba is facing potentially severe impacts if climate change continues unabated. Cuba has already seen an increase in dry periods and extreme weather events due to climate change. The International Panel on Climate Change projections predict sea level rise to reach 0.8m–1.5m by 2100. This scenario would see Cuba lose over 3% of its land by 2050 in addition to increases in dry periods and extreme weather events.[141] These potentially severe impacts present a good incentive for Cuba to be a leader in climate change mitigation.

Emissions in Cuba have risen sharply over the past decade. In 2004, the country emitted 36.5 Mt of CO_2 equivalent greenhouse gases.[142] In 2012, that number rose to 52.42 Mt. The country's emissions in 2012 were higher than the Dominican Republic (33.40 Mt) and Jamaica (15.47 Mt), but lower than Trinidad and Tobago (61.31 Mt).[143] Of their 52.42 Mt total GHG emissions, 35.92 Mt were CO_2 emissions.[144] Cuba's 2013 per capita CO_2 emissions were 3.5 metric

tons per capita. This number is also higher than in the Dominican Republic (2.1) and Jamaica (2.8) but significantly lower than in Trinidad and Tobago (34.5).[145]

Although Cuba's emissions represent a small fraction of worldwide emissions, they are expected to continue to increase. Cuba's emissions account for only about 0.1% of total global emissions, excluding land use change. Nevertheless, because the country relies so heavily on oil for electricity generation, CO_2 from electricity generation is expected to increase sharply by midcentury, as electricity demand increases.[146] Cuba's emissions and electricity futures are intertwined.

Climate change actions

Cuba has a long history of participating in climate change action. The country ratified the UN Framework Convention on Climate Change (UNFCCC) in 1994 and the Kyoto Protocol in 2002, and has implemented Clean Development Mechanism projects to build out renewable energy and combined-cycle gas electricity generation.[147]

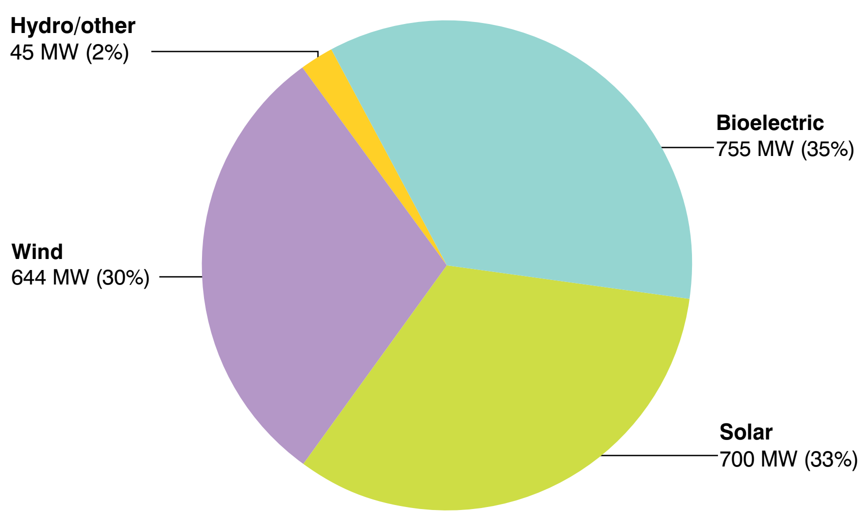
Cuba has also been actively engaged in negotiations to develop and implement the Paris Agreement, the 2015 agreement negotiated by 195 countries under the UNFCCC to implement greenhouse gas mitigation, adaptation, and finance starting in 2020. Cuba signed the agreement, along with over 100 other nations, on April 22, 2016.[148] Prior to the drafting of the Paris Agreement, Cuba submitted an Intended Nationally Determined Contribution (INDC) to the UNFCCC.

Cuba's INDC lists both past actions to mitigate contributions and future commitments. The INDC discusses energy efficiency measures taken as part of the Energy Revolution and notes that forest cover in Cuba has increased from 13.9% to 29.4% in 2014. Further, the country proposes a commitment to install 2,144 MW of renewable energy electricity generation by 2030. This is to be made up of 19 sugar and forest-fired bioelectric plants (755 MW), 13 wind farms (633 MW), 700 MW in solar photovoltaics, and 74 small hydroelectric plants. Finally, the INDC outlines two energy efficiency measures in the residential sector—a plan to distribute 13 million LED lamps and replace 2 million electric stoves with induction cookers.[149]

If the Paris Agreement does indeed foster a change towards lower carbon economies, it presents a unique opportunity for Cuba. As two observers noted, Cuba can take a different approach from other developed nations by moving directly to a low-carbon economy.[150] This point in time likewise represents a proverbial "fork in the road" for Cuba's energy sector. Given current import, system,

FIGURE 3

Proposed makeup of renewable energy profile in 2030



Source: TK

ISTOCKPHOTO

and resource pressures, as described above, the choices made by the country now as to how the sector is structured will have long-term impacts upon its resource mix and carbon intensity.

Near-term future

Reopening with the United States

Cuba's resumption of diplomatic relations with the United States represents a historic milestone for the island nation. The U.S. reopened its embassy in Havana and Cuba raised a flag outside its own embassy in in Washington in July, 2015.[151] The direction of future relations between the countries, however, largely remains to be determined. In June 2017, President Trump announced his decision to reverse some of President Obama's policies, particularly those relating to self-guided educational travel and investment with entities owned or controlled by Cuba's military. But diplomatic relations are still intact, along with most other Obama era regulations on Cuba and Trump's NSC memorandum highlighted the importance of continued bi-lateral engagement on science, the environment and other issues deemed to be in the interest of the United States and the Cuban people.[152] Nonetheless, the U.S. trade embargo on Cuba remains in place and lifting it would require Congressional approval.[153]

Increased investment in tourism in Cuba is a likely outcome of the diplomatic reopening. Tourism increased 16% from 2015 to 2016, to 3.5 million visitors.[154] In March 2016, The Obama administration eased restrictions on travel for American citizens—making travel to Cuba easier for educational activities and 11 other categories of activities. At the same time, the administration made it easier for U.S. dollars to be used in transactions with U.S. banks, making it easier for Cuban businesses to benefit from American travel.[155]

Increased tourism would likely create new energy demands on Cuba's already stressed electric grid. Cuban leaders will need to balance addressing this new short-term demand with longer term energy goals.

Much remains to be seen on whether progress will continue between the countries through U.S. presidential executive action, eventual action by congress, or full engagement of U.S. energy companies in Cuba. After the election of Donald Trump in November 2016, steady progress in relations is no longer guaranteed. President-elect Trump has made conflicting statements on the detente and has at least threatened the possibility of scuttling ties.[156] Overturning executive actions by the Obama administration would be easy, should the Trump administration choose to do so.[157] But already existing business ties between U.S. companies and Cuba, the popularity of lifted travel restrictions, and lobbying from industry groups in agriculture, technology, and tourism may make undoing of recent progress in the relationship difficult.[158]

Investment

Private sector investment in Cuba's energy sector could play a crucial role in helping the country confront near-term energy challenges. The Cuban government does not have a long history of bfostering private investment, but recent developments may change the picture. The country first opened to foreign investment in 1995.[159] In 2014, a new foreign investment law passed. The 2014 law slashes taxes on investment profits from 30% to 15% and gives investors eight years of exemption from paying taxes.[160] In the two years since the law was passed, only $1.3 billion of projects were approved, far below the government's $2 billion annual goal.[161]

The new investment law has had practical effect on investor finances, as evidenced by its impact on Sherritt. Sherritt's oil and gas tax rates were reduced from 30% to 22.5%, and its power tax rate was reduced from 30% to 15%. As a result, Sherritt received a tax recovery of $31.7 million in oil and gas payments for the Government of Cuba in 2015.[162]

In addition, Cuba recently opened the Mariel Special Development Zone in an area west of Havana. Mariel offers tax advantages in addition to the 2014 foreign investment law, including a 10-year holiday on profit taxes and greater flexibility in compensating employees. At the end of 2015, Mariel had approved eight projects worth about $200 million.[163] Investment there may prove attractive for renewable energy projects, as Hive Energy will build its 50 MW solar plant, described above, in the Mariel Zone.

To meet its 2030 renewable energy goals, Cuba estimates it will need $3.5 billion. The government recently announced that it will allow some of these renewable energy projects to be 100% foreign owned, rather than joint ventures with state-owned companies. The move was hailed as "unprecedented" for Cuba by a Havana Energy executive.[164] Cuban leaders appear willing to develop new strategies to attract more international investment to meet their ambitious renewable energy goals.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Investment challenges

Those new to working in Cuba will need to be cognizant of certain aspects and issues relating to foreign investment in the country. Three commonly reported challenges for foreign investment include 1) an opaque and slow approval process for energy projects; 2) access to financing, given Cuba's isolation from the world financial system and limited foreign currency resources; and 3) the credit quality of UNE, the single buyer, particularly given the mandate to heavily subsidize electricity, which puts significant strains on UNE's finances.

According to several sources, there is a general difficulty of doing business in Cuba, and this could represent a significant obstacle in the future. Regulatory power is concentrated and, according to some, agency staff lack incentives to take action particularly when dealing with foreign companies. Foreign companies often are required to use local labor and may lack control over their own workforce. Further, a lack of basic resources in the country, from the internet and raw materials to basics like paper, presents a distinct challenge.

There are many other challenges specific to energy—an outdated grid, a single off-taker, lack of available data, the government's limited access to foreign currency and limited ability to access international banks, lack of precedent for long-term PPAs being negotiated and honored, and a lack of access to guarantees from international development banks.[165]

Ultimately, growth in Cuba's energy sector will be unique to the Cuban context. As scholars Julia Sagebien and Eric Leenson describe, a key overarching question in business investment in Cuban energy is "[h]ow can Cuba achieve an optimum outcome in terms of business competitiveness, economic well-being, and the preservation of long-held social values, while also building Cuban sustainability?"[166]

Future of Cuba's resources

Renewable energy

Cuban leaders have given clear signals of their confidence in the ability of renewable energy to power the country's future. In 2014, the government announced that it plans to generate

24% of electricity in Cuba from renewable sources by 2030. As part of the announcement, Cuba unveiled an initial set of projects requiring $600 million in investments and plans to allocate more than $3.5 billion to developing renewables by 2030.[167] There are questions surrounding the ability of the government to meet such an ambitious goal as it was made under the assumption of significant overall capacity increases.[168] Downward-revised GDP growth projections in 2016[169] may suggest that such high overall capacity growth will be infeasible. Nevertheless, as a signal of intent, the goal represents a commendable and clear commitment to invest in renewable energy.

Solar energy

Cuba is a country with excellent solar resources. The daily average solar energy that reaches Cuban land throughout the year is 5 kWh/m^2.[170] Cuba has higher solar potential than countries that thus far have better utilized their solar resources. For example, about 2.9 kWh/m^2 reaches Germany daily, yet Germany has invested in 40 GW of solar energy capacity that accounted for 7.5% of net electricity consumption in the country in 2015.[171] A key barrier to investment in further solar energy is the initial capital costs to build PV systems.[172] Cuba is attempting to overcome this barrier, at least in part, with private partnerships. Recently, government officials reached an agreement with the British company Hive Energy to build a 50 MW solar project in Mariel. This project is expected to be completed in 2018 and generate up to 93 GWh of electricity each year.[173] To reach its goal of 700 MW of solar capacity by 2030,[174] the government is looking for further private investment, including investment in a 100 MW plant in Cuba's western provinces.[175]

Case study: Hawaii

Hawaii provides an example of an island jurisdiction undergoing an energy transition towards greater renewable electricity generation. Hawaii had a previous fuel source makeup similar to Cuba's—high use of oil for electricity generation. Hawaii still relies on oil for 70% of the state's electricity generation.[176] However, the state is attempting to transition away from oil generation and associated high import costs by investing significantly in solar and other renewables.

To this end, Hawaii already generates a large percentage of its electricity from renewables. It reached 21.1% of electricity generated from renewable resources in 2014.[177] Roughly one-third of this 21.1% renewable electricity generation came from solar in 2014—about 600 GWh.[178] The majority of solar generation on the island is in distributed systems. Over 600,000 DG solar systems have been installed on Hawaiian homes.[179] These customers were mostly paid through a net metering program where the utility paid DG customers for any excess generation beyond their own consumption.

Hawaii plans to continue renewable energy deployment at a rapid pace. It has a Renewable Portfolio Standard that calls for 30% of electricity from renewables by 2020, 40% by 2030, and 100% by 2045.[180] State Hawaiian officials are thus invested and confident in the ability of solar and other renewables to provide cheap energy for the islands in the near future.

Research shows that renewable energy may not only be environmentally beneficial for Hawaii, but also the most cost-effective option. A Department of Energy study found that "there are many opportunities for renewable energy to provide net value to Hawaii. These are primarily driven by the high cost of petroleum fuels used in electric generation. In a future liquefied natural gas (LNG) scenario, renewables still appear to be a lower-cost option in many cases."[181]

TABLE 3

Large-scale proposed and signed renewable projects

Type	Location	Capacity size	Status	Private partner
Solar	Mariel	50 MW	Planning/building expected completion: 2018	Hive Energy (Britain)
Solar	Western Provinces	100 MW	Looking for investors	
Wind	La Tunas	51 MW	Planning/puilding expected completion: 2018	Goldwind (China)
Wind	Maisi	174 MW	Looking for investors	
Wind	Banes	102 MW	Looking for investors	
Bagasse	5 sugar mills throughout country	150 MW	Planning/building	Havana Energy (Britain)

Wind energy

Cuba also has extensive wind resources. The country has an estimated potential of 2,550 MW that could be derived from Class 4 and 5[182] wind areas.[183] To reach its goal of 633 MW of wind generation capacity by 2030,[184] Cuba plans to build 13 wind farms along the northern coast of the country. Foreign capital has been earmarked to build seven out of 13 of these wind farms. One such project is already underway, called Herradura 1. The Chinese company Goldwind is providing the wind turbines for this planned 52 MW plant, made up of thirty-four 1.5 MW turbines.[185] Cuba is seeking further investment in two large wind farm projects. It is seeking $100 million for a 102 MW Banes Wind Farm and $285 million for a 174 MW Maisi Wind Farm. Both projects are planned to be 100% foreign capital enterprises with UNE as the Cuban partner.[186]

Biomass

Cuba plans to substantially increase its electricity generation from biomass. The country's INDC sets a goal of building out 755 MW of capacity[187] from 19 sugar and forest-fired bioelectric plants by 2030.[188] In 2012, the first recent major expansion of biomass was agreed to between Zerus and Havana Energy. Havana Energy agreed to build five 30 MW biomass power plants attached to sugar mills throughout the country.[189]

Hydro power

While Cuba has the potential to generate more electricity from hydro, a wide-scale expansion seems unlikely. The country has an estimated 650 MW of hydro capacity, which would be about 10 times larger than current capacity. However, a large proportion of unutilized potential is in protected or naturally sensitive areas.[190] Cuban leaders do not appear to be planning an expansion of hydro power on the same scale as other renewables. The INDC calls for building 74 small hydroelectric plants but includes no capacity goal.[191]

Ocean energy

In 2008, the University of Matanzas partnered with CITMA and EDF to hold a workshop on ocean energy in Cuba. The workshop explored offshore wind, tides, and waves, with a special emphasis on ocean thermal energy conversion (OTEC) and recommended more research into the potential of these resources. As of the summer of 2016, however, no utility-scale projects have been built or planned in Cuba.

Fossil fuels

Oil production

Cuba has the potential to increase domestic oil production. The U.S. Geological Survey estimates that there are 4.6 billion barrels of oil in Cuba's Exclusive Economic Zone (EEZ).[192] With the addition of U.S. oil services and equipment, it is estimated that oil production could grow to more than 75,000 b/d, up from the current 50,000.[193] As noted above, the Russian company Inter RAO is building 800 MW expanded generation capacity at two existing fuel oil plants in a project expected to be completed in the mid-2020s.[194]

As discussed in greater detail in the previous EDF whitepaper, *Bridging the Gulf*, domestic oil production creates a number of potential environmental impacts and risks including oil spills in Cuban waters, degradation of marine and coastal habitats, increased CO_2 emissions, and impaired air quality.[195] As *Bridging the Gulf* describes, because of the "intertwined relationship between coastal economies and the local environment," these may likewise lead to substantial economic impacts and risks.[196]

Natural gas

Natural gas could potentially form a significant part of Cuba's energy future. The U.S. Geological Survey estimates 9.8 trillion cubic feet of liquid natural gas, or about 1.7 billion barrels of oil equivalent in Cuba's EEZ.[197] The U.S. EIA estimates that 2.5 trillion cubic feet of this, or about 430 million barrels of oil equivalent, can be accessed using current production methods.[198] The role of natural gas in Cuba is explored in more detail in *Bridging the Gulf*.[199]

Recommendations

1. Knowledge sharing for institution and capacity building

Cuban leaders can learn from experiences in other countries that have undergone or are in the midst of similar energy transitions. Such countries can serve as examples of the ways in which renewable and clean energy institutions can be built and expanded. Two aspects of electricity generation in other countries appear particularly applicable to Cuba—(1) renewable distributed generation and (2) solar generation in island nations.

Denmark serves as an example of a country that was able to successfully integrate high levels of renewables into a highly distributed generation system. Denmark is the only country in the world with a higher percentage of total generation capacity in distributed systems than Cuba. Over 50% of generation capacity comes from distributed sources,[200] and in 2015 wind turbines generated 42% of Danish electricity consumption.[201] Danish leaders moved towards a policy of promoting DG at least in part as a response to the 1970s oil crisis.[202] While a precise discussion of exactly how Denmark was able to build its distributed, renewable system is beyond the scope of this paper, scholars point to a few factors that would be relevant to the Cuban context. First, Denmark successfully combined targeted government funding of renewable projects with bottom-up innovation activities. This strategy saw successful implementation of small-scale wind farms as leaders learned what worked with the Danish grid.[203] Second, small municipality and rural cooperative utilities became system owners, giving them a stake in generation. This, combined with utility acceptance of DG, allowed a build out of DG at the local level.[204] Finally,

Cuban and international participants gather at an ocean energy conference in Varadero, Cuba, sponsored by EDF in 2008.

Denmark regularly consulted the U.S. and other European countries to develop its most innovative DG projects.[205] Denmark's DG system has a number of differences with Cuba that make an exact replica of its system impossible—most notably very good wind resources and an interconnected grid with neighboring countries. Nevertheless, technical knowledge sharing between Cuba and Denmark could be beneficial to Cuba much in the same way as cross-national knowledge sharing helped Denmark build its DG grid.

Cuba can also learn from other island nations and island jurisdictions looking to build more renewable energy generation. As noted in the example above, Hawaii could serve as a model for an island jurisdiction transitioning from fuel oil generation to renewable generation. Further, Cuba could look to NGOs that help coordinate island energy action. For example, the Carbon War Room, a nonprofit focused on fighting climate change, secured a commitment from several Caribbean island nations to begin replacing diesel generators with renewables.[206] The Carbon War Room has further partnered with the Rocky Mountain Institute and the Clinton Climate Initiative to create the Islands Energy Partnership. This new partnership's goal is to guide energy transition strategies, scale up renewables projects, and aid in governmental and technical capacity.[207] These developments could help Cuba develop its renewable profile in two ways. First, it can learn from the successes and failures of renewable projects on smaller islands. Second, it can draw directly on the funding and knowledge of the Islands Energy Partnership in developing institutional capacity to build renewable projects.

2. Invest in solar energy distributed generation

Cuba should consider conducting a feasibility and cost/benefit study with respect to solar energy distributed generation. Investing in solar DG means building solar capacity at sites where electricity demand comes from. This could either be at locations where current distributed generation sites exist around Cuba, or directly on or around buildings throughout the island. A feasibility and cost/benefit study could determine the ability and cost-effectiveness of investing in such renewable DG. The plan could focus first on critical infrastructure to provide added resiliency benefit. Cuba already has experience installing solar DG on critical facilities—2,364 schools, 350 doctors' offices, and hundreds of hospitals were already equipped with PV systems by 2003.[208] Cuba should consider widely expanding this program to make solar DG an essential part of its growing renewable energy portfolio.

Solar DG can both mitigate near-term energy shortages and help Cuba meet longer-term energy goals. With an economic crisis in Venezuela resulting in decreased oil exports to Cuba,[209] Cuban leaders need energy solutions that allow them to act quickly and effectively if they want to avoid widespread load shedding and blackouts reminiscent of previous decades. Similarly, ambitious long-term renewable energy goals will only be successful if Cuban leaders find renewables that work with the Cuban context and are not overly costly. Solar DG has the potential to meet both of these overarching challenges.

In the short term, solar DG presents many advantages over comparable alternatives. First, solar DG can be installed rapidly. In the U.S., the median solar DG project completion time is 53 days,[210] whereas natural gas plants take at least 1.5 to 2 years to build and coal-fired plants take even longer (3 to 6 years).[211] Cuba has been stockpiling oil resources to guard against shortages; one analyst estimates that they have a 60-day stockpile.[212] This safeguard will not last long enough to build large fossil fuel plants but could potentially bridge a resource gap to solar DG systems. Second, solar DG provides power during times of the day when the public sector is likely most active. Although available data (from 2009) suggests that overall electricity demand may peak in the evening, Cuba plans to first shed load in the public sector, where energy use will naturally peak during working hours.[213] This may suggest either that demand has shifted to peaking during the day or that something characteristic to the Cuban grid, such as its high levels of distributed generation, makes reducing demand at daytime hours effective at avoiding blackouts. Or the move may have been for other reasons, and not in response to grid needs. Cuba likewise experiences peak demand in summer months. Solar power is most abundant during these same daylight, summer hours. Third, solar DG has the potential to be integrated into an already existing system. More than 40 percent of generating capacity in Cuba is already DG,[214] so solar DG could likely leverage the existing grid. If a feasibility study concludes that solar DG can be built into this already existing system, Cuba could potentially continue its distributed system, built largely in response to resiliency concerns from previous energy shortages and hurricanes battering transmission networks.[215] Solar DG could thus further strengthen and amplify resiliency benefits already inherent in the existing system.

Solar DG also provides comparative advantages over alternatives in meeting Cuba's longer-term policy goals. First, solar energy is often a cost competitive solution. In other island nations, solar energy can be one of the cheapest energy resources once constructed; it does not require fuel imports to continue operation.[216] PV systems that are smaller than 1 MW have an expected lifetime of 33 years and operating and maintenance costs of between $19–21 per kW per year.[217] As explained above, solar is likely one of the lowest cost options for future energy generation capacity increases in Hawaii.[218] Cuban officials thus may not need to sacrifice cost effectiveness to invest in solar. Second, solar DG can reduce local air pollution. Unlike diesel and fuel oil distributed generation, solar DG does not bring harmful health effects of fossil fuel burning closer to population centers. Replacing some of this diesel DG with solar DG would lower noise, NOx, SO2, and particle emissions, as well as the consequent and serious respiratory ailments associated with these pollutants. Even if solar DG was additive—rather than used as a replacement for existing diesel DG—investment could avoid the need to build more locally polluting DG or other, more costly generating assets. Third, solar energy does not require fuel imports from other countries, giving Cuban leaders greater control over resource planning. Finally, investing in solar DG would help support Cuba's stated goal of generating 24% of its electricity from renewables by 2030.

3. Implement a competitive generation procurement process

Cost comparisons across resources will be critical to making investment decisions with respect to not only solar DG, but all other new electricity generation resources. One method Cuba could consider implementing is a competitive and transparent process for procuring new electricity generation. The government could set a desired increased MW goal (and additional desired energy characteristics) and then consider bidding proposals from different entities and resources to compare costs. Cost should not be the only consideration in choosing between projects, but a structured and competitive procurement process could help Cuban leaders make more informed decisions about relative costs of different resources and can help demonstrate the cost-effectiveness of building new solar DG.

4. Expand energy efficiency programs to supply-side management and demand-side beyond appliances

Cuba's energy efficiency initiatives enacted as part of the Energy Revolution in the mid-2000s were impressive for their size and speed. The country was able to replace millions of inefficient household appliances with more efficient alternatives in a matter of months. Replacement of lightbulbs alone saved an estimated 3 to 4% of Cuban electricity consumption.[219] Although the program affected a large swath of electricity demand, it was narrowly focused on residential appliances. Planned energy efficiency measures up to 2030 appear similarly focused. The country plans to distribute 13 million LED lamps and replace 2 million electric stoves with induction cookers.[220] Cuban leaders likely want to expand on previous successes in energy efficiency measures by continuing to replace household appliances with more efficient alternatives.

Cuba could expand its energy efficiency efforts. For example, energy efficiency in supply-side management of electricity generation and transmission appears to be an unexplored area. Supply-side management (SSM) "refers to actions taken to ensure the generation, transmission and distribution of energy are conducted efficiently."[221] Cuba could consider a number of SSM measures through a series of interventions. For instance, it could enact a program for widespread operational improvement at existing plants, including housekeeping, maintenance, and performance monitoring. Another intervention could focus on upgrading generation units through installation of new burners and heat recovery measures. Finally, leaders could focus on transmission and distribution line improvements by overcoming voltage constraints, building substation improvements, and increasing the cross sectional area of lines.[222] Cuban leaders have already worked to enact some of these measures. For example, in the mid-2000s, modernization efforts focused on improving efficiency at several fuel oil generation plants.[223] Further, UNE recently signed a MoU with Siemens in July 2016 with the goal of modernizing power generation, transmission, and distribution infrastructure. So far, Siemens has provided training activities for UNE personnel.[224] Ideally, the agreement will help Cuba move toward nationwide large-scale interventions in energy efficiency in generation, transmission, and distribution that mirrored efficiency interventions into residential demand.

Energy efficiency efforts could likewise be expanded to end-use projects targeting building improvements beyond appliances. Home weatherization, for example, appears to be an unexplored area where investment could provide a cost-effective pathway to reducing energy demand.

Cuban leaders have already seen the benefits that energy efficiency actions can provide. Efficiency interventions in generation, transmission, and distribution could provide similar benefits that prior residential efficiency measures enacted as part of the Energy Revolution allowed. First, more efficient generation and distribution provide more reliability for the grid. Second, if demand stays constant, less fuel is needed to produce the same supply, so energy efficiency provides cost savings. Finally, less fuel oil is needed to produce the same supply, and thus less local pollution and fewer CO_2 emissions are released per kWh produced.

5. Change electricity tariff to flatten the demand curve

Currently, residential customers are charged through an inclining block-rate tariff, and industrial customers are charged through a time-of-use tariff. Changes to both tariffs to better match supply with demand could help to address potential reliability concerns. Electricity is inexpensive in Cuba, and thus changes in price might not be expected to change behavior. Residential electric costs as a percentage of income is higher, however, than in neighboring countries. Thus, changes in electricity rates may be able to foster response by consumers and lead to an electricity system less vulnerable to blackouts. If rates can help shift demand from peak times to lower-demand times, then demand is less likely to outstrip supply at any given time.

UNE could alter its electricity tariffs in two ways to help flatten load. First, it could augment the current time of use rate for industrial consumers. For instance, by increasing prices at peak times and decreasing prices at low-demand times, UNE could further shift industrial demand towards times of the day when overall demand is low. This would put less strain on the grid at peak hours. Second, UNE could consider expanding its time-of-use rate to residential consumers. Expanding a time-of-use rate to the residential sector could help flatten the demand curve but would need to be implemented with great care. That said, there appears to be some understanding within the country that electricity supply and price varies with usage, as the already implemented inclining block rate necessarily varies more than a flat rate. It would be important to design the rate so that it does not become prohibitively expensive to use necessary electricity at peak hours, and further implementation considerations—outside the scope of this paper—must be evaluated before such a change is recommended. A theoretical time-of-use rate, however, could shift non-essential electricity use to non-peak hours without increasing overall monthly prices for consumers. This could help foster a more reliable grid less prone to blackouts at peak hours.


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6. Build microgrids at high-consuming destinations

Cuba could consider siting power in close proximity to the highest-consuming areas of the Country. That is, microgrids and/or DG at high-consuming locations could help to avoid transmission and distribution related losses as tourism, demand from private businesses, and strain on the grid grows. The Rocky Mountain Institute's study of microgrids on small islands and remote locations offers a number of lessons learned. For instance, the study found that utilizing renewables in microgrids can lower costs, diverse resource mixes can help increase system resiliency, and energy storage can be beneficial to a successful microgrid.[225] Cuba could partner with private entities to build renewable microgrids at, for example, hotel clusters. These microgrids could provide further resiliency benefits through a diverse mix of resources in a small area.

Building these microgrids may additionally help secure private financing to increase the resiliency of the Cuban grid. In essence, particular consumers may be willing to pay more for ensured reliability. Building such grids might increase the cost of tourism or other business at that locale, but this extra cost would bring the added benefit of reliable power. This, in turn, could reduce the strain on the electric grid at large from increasing electricity demand. It would be important to ensure that investing in such projects does not create two Cubas, one for those with the ability to pay for reliable electricity and one for those who cannot. Nevertheless, the country could look to these microgrids as small experiments in building renewable energy on the island and in developing resource mixes that work best for the country as a whole. The projects could thus work as a benefit for both high-energy consumers and the larger Cuban electricity sector.

7. Invest in alternatives to fuel oil generation

Lowering the amount of electricity generated from fuel oil should be a long-term goal for Cuban policymakers. Fuel oil likely makes up too great of a portion of the electricity mix to be phased out over a short horizon. Nevertheless, burning of fuel oil, especially domestically produced Cuban fuel oil, is environmentally and economically harmful. Moving away from fuel oil generation could lead to less local air pollution, fewer GHG emissions, and lowered cost.

Further, since burning high sulfur domestic oil leads to failures in power stations, lessening its use can also help avoid costly repairs.

Due to the high-emitting and polluting nature of fuel oil, both renewable energy and natural gas resources would lead to environmental and human health benefits. Recent actions by Cuban leaders represent encouraging signs that the country is interested in alternatives to fuel oil. One alternative is utility-scale solar energy. Cuba's agreement with Hive Energy to build a 50 MW plant is a promising signal that building utility-scale solar infrastructure is achievable in the country. Another alternative is wind energy. Like the Hive Energy plant, Cuba's expected Herradura 1, a 52 MW plant, is an encouraging sign that the government views wind energy as a sound investment in its energy future. Third, bagasse could serve as an increasingly important part of the resource mix. Cuba's post-revolution history demonstrates that bagasse could make up a much higher portion of electricity generation in the country than it does today, and investments in 150 MW of bagasse generating capacity with Havana Energy is an encouraging start to encouraging its widespread use. Fourth, natural gas provides a potential lower-emissions bridge fuel, and Cuba has recently added a third natural gas combined-cycle plant which could signal increased interest in the resource. Although there remain signs that the country may continue to depend on imported fuel oil, each of these instances represent points of departure towards a future, less oil-dependent resource mix of Cuban energy.

8. Consider mechanisms to stimulate and clarify foreign investment

Cuba has recently taken actions to stimulate foreign investment in renewable energy. Allowing some renewable energy projects to be 100% foreign owned, for example, is both encouraging and underscores the seriousness of the government's interest in increasing clean energy resources. More is needed, however, to reach the estimated $3.5 billion needed to meet the country's 2030 goals.[226]

Cuba should consider whether mechanisms, policies, and laws can be clarified to stimulate increased foreign investment in renewable energy. This recommendation could take a variety of forms, including understanding and resolving foreign investment restrictions, working with international development agencies, crafting guarantees to help mitigate credit risk, public-private partnerships, and joining international entities that can provide access to otherwise unavailable forms of financing.

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