Global Development and Environment Institute
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Puerto Rico, Climatic Extremes, and the Economics of Resilience

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The devastation from climate disasters from the recent powerful Hurricanes Harvey, Irma, and María brings new attention to the economics of climate change. Neither rich nor poor are exempt from — nor prepared for — their potential for extreme disruption. For those in the path of such mega-storms, their *scale*, *intensity*, *pace* and *frequency* are definitive for any level of adaptive resilience.

For the Caribbean, preparing for and managing climate risks and vulnerabilities is an essential planning and development challenge, given the scientific outlook for the region's climate for this century. The 2017 hurricane season has made this clear, with its severe impacts on many Caribbean islands. The enormity of the economic and human costs and losses in Puerto Rico[1] — its moderately complex economy (2016 GDP: $103 billion)[2] shattered, the prolonged collapse of its entire electricity system, the vast social and economic upheaval, and uncertain future prospects — provide a lens into what's at stake.

Facing the extreme consequences of these mega-storms and their unacceptably costly disruptions, *marginal* economics seems inadequate. What are proper economic analyses of their abrupt and massive impacts and their lasting consequences? Facing the prospect of continued intense hurricanes, what is the value of an acceptable level of resilience and how much is it worth investing in achieving it?

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Sustainability and climate resilience

Climate scientists say these powerful storms will be a larger share of the annual mix in the region, with current trends showing increased frequency and intensity. Warmer atmosphere and ocean waters in the tropics provide the conditions for these mega-storms to form, and when they do they can form quickly and intensify rapidly. The same "cauldron" just as easily can give rise to several major storms in a row, as occurred during the 2017 season. What would more similarly extreme hurricanes mean to the Houston area, to southern Florida, but especially to the Virgin Islands, Puerto Rico and the other impacted Caribbean islands?

Powerful storms are not the only growing climate challenge that Puerto Rico and the Caribbean face.[3] The same warming of waters that feeds more powerful hurricanes also raises ocean levels, a concern for the islands they surround; not only coastal erosion and shoreline losses (a problem for much coastal development), but also the further inland reach of storm surges, all the more so with the added energy of mega-storms. Current hot weather year-round will include more days and nights with higher temperatures, a trend observed for over half a century. There are plenty of temperature-related health concerns, and longer heat waves have greater impact especially on more vulnerable sectors of the population (children, older people, those without cooling, or with certain medical conditions, for example). Increased solar exposure means decreased productivity in outdoor work and reduced recreational value outdoors. Extremes in precipitation and in drought are both increasing in frequency.

In Puerto Rico, the context for all this is an island deep in debt after many years of economic troubles, with high poverty rates, saddled with the costly, aging infrastructure of a bankrupt energy system with decades of inadequate and poor management and maintenance; its centralized nature made it highly vulnerable to island-wide disruption. Irma and then María were the perversely "perfect storms" that exposed the enormous cost of low climate resilience.

There is a path toward greater adaptation capacity and climate resilience that calls for a level of social, environmental, and economic balance, in which these elements are in some form of harmony, or at least not at cross purposes. The scope and nature of the emergency in Puerto Rico highlights the role of two important issues: the design and condition of the *energy system infrastructure* and *the degree of socioeconomic poverty and inequality*.

A transition out of fossil fuels toward a more robust decentralized energy system, designed and built to meet the challenge of extreme storms from a changing climate, is the ticket to a healthier economy with lower energy costs in the long run. Seeking and leveraging the highest degree of co-benefits along economic, environmental and social dimensions is essential.

Socioeconomic and climate justice

Climate justice is a particularly acute matter in the Caribbean. There is an extra dimension to the scope and level of damages and costs, in the short term and especially in the long run, resulting from the prevailing levels of socioeconomic inequality. Nature doesn't care nor discriminate — the injustice comes from what the storms come across their way over those islands: the distribution and condition of the people who live there and their socioeconomic context.

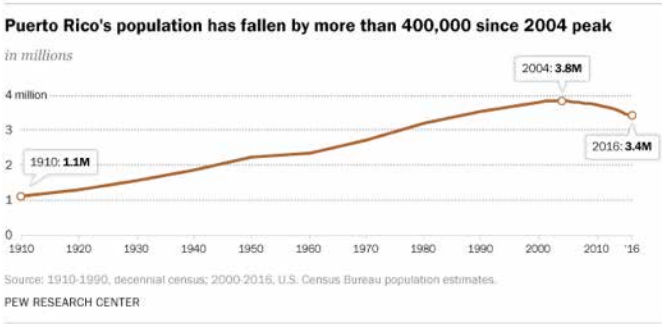
Much of the Caribbean has been building and accumulating climate disaster risks for a long time. The rapid pace of development in Puerto Rico during the second half of the past century produced many inadequate structures (in type and/or location), most along the coasts but also in towns in the mountainous interior. Puerto Rican scientists have been warning about unfettered coastal construction for a long time.

But the overall destruction of homes, neighborhoods, and impacts on the livelihood and health of their residents is much greater *because* of and *in proportion* to the levels of poverty and inequality. Serious upheaval can be temporary for some with the resources to deal with the situation, temporarily relocate if necessary, go without income for a time…yet completely devastate the lives of others who lose the little they have, plus income or jobs they simply cannot do without, etc.

It is not hard to imagine how much less damage, how quicker the recovery, how much less tragedy and fewer resources needed to repair and recover, if most families and homes approached the safety and preparedness of middle class households. Besides basic fairness and justice, investing in reducing inequalities is more productive, and brings even higher long-term returns to society, in places facing recurring climate challenges of great scale and intensity.

Puerto Rico before the storms

Puerto Rico had been in a prolonged economic crisis for more than a decade, since well before the global "Great Recession." Large-scale job losses fed a growing exodus[4] to the mainland (now surging after María), while debts grew to insolvency. The economic model under which Puerto Rico industrialized and developed during the second half of the 20th century ran its course, then went off the rails when Congress phased out the enabling favorable corporate tax treatments. The island's debt is about $74 billion, plus $53 billion in unfunded pension liabilities. Congress established the Financial Oversight and Management Board in 2016, with



the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), "a process for restructuring debt, and expedited procedures for approving critical infrastructure projects."[5] Debate on the island's colonial status is sure to intensify.

Reliable power is the lifeblood of the highly electrified Puerto Rican economy, with the public Puerto Rico Electric Power Authority (PREPA) at the heart of it.[6] PREPA's evolution is woven into the island's economic development and industrialization since the early 20th century. It is the island's main employer, with over 6,000 employees (despite a 30% decline in recent years). PREPA declared bankruptcy in July 2017, with its share of the public debt at ~$9 US billion plus over $2 billion in underfunded pension obligations. How it came to bankruptcy is a long story, but it was not a surprise; the collapse of electricity system with September's hurricanes was no surprise either. PREPA's electricity system had become brittle from old age and inadequate maintenance, planning and management, as documented for the Puerto Rico Energy Commission (PREC) in November 2016.[7] Control of PREPA and its planning for the future is part of the evolving (sometimes conflictive) relationship between the Oversight Board, the governor, and legislature of the island.

The 2017 storms: María, after Irma

Puerto Rico was spared direct impacts from the most powerful hurricanes for nearly a century, the main exceptions being Hugo in 1989 and Georges in 1998 (both Category 3). On September 6, 2017, the eye of Category 5 Irma just missed the main island (not as lucky were the smaller Vieques and Culebra islands). Damage estimates were in the billion-dollar range; electric power was knocked out across the island for over one million people. But less than two weeks later, with Puerto Rico barely back on its feet, María cut a destructive path diagonally through the center of the island.

Before/after María. Near Ciales, in Puerto Rico's center-north.
https://twitter.com/Alastor/status/920301231037468678

María started as a tropical storm on Saturday, September 16, and hit Dominica as Category 5 on Monday, only 15 hours after being Category 1 in strength. By Wednesday, September 20, it struck Puerto Rico's southeast, winds just below the threshold into Category 4. There were sustained wind speeds of 155 mph over part of its path through the island, and of 120-130 mph over much of it. Precipitation was over 20 inches over much of the island and more in many places, up to 3 feet or so. Landslides destroyed many bridges and roads, and took or displaced many hillside homes. It is said to be tenth in intensity among recorded Atlantic hurricanes (the second was Irma).

Energy: core of the economy

Electricity *generation* two months after María was barely at the 50% level. With promises of reaching 95% by mid-December, it was 64.7% on December 15. The *end-use availability* of that energy, however, was lower and highly uneven since the transmission (especially over the mountains) and distribution system sustained the worst damages. News reports have detailed the severity and urgency of disrupted critical services, from potable water availability to hospital and other medical services, police and fire protection, food distribution and refrigeration, air conditioning, and all other educational and economic activity.

What do we lose when we lose power?

Source: (Klinger C, Landeg O, Murray V. Power Outages, 2014)[8]

With the urgent priority to restore electricity to as many and as soon as possible, repairs to existing electric system facilities and equipment focused especially on the fallen or destroyed power lines of the transmission and distribution system. Merely rebuilding "as was," however, means reproducing the very vulnerability to extreme weather events seen in the now crippled island.

Aside from increasingly vulnerable and unreliable power,[9] Puerto Rico's steep electricity costs — two to three times the average in the mainland states of the U.S. (only higher in Hawaii) — represent an even greater "*effective energy burden*" to the population and the island's economy; this has been a serious drag on the island's household, business and government activity for decades. Simply: paying double the prices of the U.S. mainland average with roughly half the average purchasing power of Mississippi effectively means Puerto Ricans carry *quadruple* the power burden vs. the average counterpart in that state.

A key electricity price component is the "pass through" of the costs of expensive imported fossil fuels[10] at prices that can change greatly in any year – PREPA's fuel import costs were $1.2 billion in the 2015-16 fiscal year (ending June 2016), down from a high of $2.9 billion for FY2011-12. Such volatility makes reliable long-term planning harder for all and syphons a lot of money out of the local economy. Conversely, every dollar saved from the billions annually paid to foreigners would circulate locally instead, a stimulus. Households could afford more of the greater supply of goods and services that business with a lower energy bill can provide – not to mention the "global good" imperative to reduce fossil fuel emissions quickly (to reduce the likelihood of extreme weather phenomena, like María).

Fossil fuels are also the lifeblood of the transportation sector so important to everyone in Puerto Rico (with more vehicles per capita and per square mile than most places in the world). Transportation emissions join those from power plants in their global

warming duties. Unlike power plants, whose emissions mainly affect the health of the families who live near them, breathing transportation emissions is common, more so in the many areas of dense traffic (though there are cities in the world with greater traffic and traffic jams, San Juan competes well). Respiratory diseases triggered or worsened by power plant and vehicle emissions come with higher medical costs and other losses for those who are afflicted the most. Gradually expanded and improved public transportation and planning for a future with electric vehicles when they become more affordable would have real long-term value here.

Fallen trees, power poles and lines, broken or collapsed roads and bridges mean that electricity can't be delivered where it is needed. The massive disruption in transportation also complicates deliveries of essential goods from the ports, including the very fuel that keeps backup generators running at key facilities like hospitals and for those lucky enough financially to afford them. Hence, recovery is slow, tentative, and extremely incremental, and must focus first on essential services like hospitals, water and sewers, security, etc.

Carolyn Cole/Los Angeles Times via Getty Images

Toa Alta | Ricardo Arduengo/AFP/Getty Images

"Build back better" has to mean more than merely replacing downed power lines and poles and restarting the power generation plants. The current fuel and energy supply chains are overly centralized and not redundant or robust enough to avoid paralysis when a strong shock disables them. The cost of an economy paralyzed for weeks and months is prohibitive. Unchecked, the accelerated exodus from the island will continue to deplete the talent base in the island. One report from November 17 lists over 168,000 people left for Florida, with another 100,000 already booked for Orlando alone by year's end;[11] other estimates could double that by 2020.

A resilient electricity system?

Emerging from this crisis, some lessons are coming into focus, centered on building resilience in the power system:

- a distributed, networked system of electric micro-grids needs to grow and evolve around the existing legacy conventional capacity, to limit and minimize the degree of disruptions from severe shocks (components detaching selective-

ly when impacted, without risking the entire system)

- full-participation by households, businesses, and other institutions in energy conservation and efficiency programs (the cheapest form of energy savings comes from avoided use)[12]
- a growing share of renewable energy sources with appropriate energy storage solutions
- new smart grid functionality to optimize and coordinate demand and supply-side management options as the grid evolves
- true resilience means that all components of the electricity system have to be designed, built, or upgraded to withstand the highest storm intensities possible
- moving away from fossil fuel imports as a strong stimulus to the economy, freeing up significant resources for other priorities.

Because of the higher electricity costs in Puerto Rico and the Caribbean, solutions that reduce costly fuel imports are economical, much earlier, than in other more competitive places. The potential for large fuel savings and reduced volatility of prices from greater use of renewable sources can stabilize and lower electricity prices, a long-term stimulus to the economy and to improved investment prospects. A gradual carbon-tax, properly designed to offset its burden on those least economically able, can speed along the transition.

A growing share of renewable energy sources (today solar and wind, others in the future when they become economically viable, e.g., marine energy sources) integrated with expanding energy storage capacity — both built and installed to "high-category" storm strength standards — provides "resilience services," reducing the scope of the power outage gaps (in scale, locations, and duration of impacts and disruptions):

- Ample storage capacity can allow essential services to be strategically extended for a critical time when power generation is lost, enough to mobilize resources better where needed and to prepare for unavoidable consequences.
- Surviving hardened capacity in solar and wind resources that can snap back into service quicker in the wake of damaging storms can restore activity to local communities, or at least the same essential services while the rest of the system is worked on.

"Smart" energy grid functionality, rooted in a digital information and analytic web, can support flexible demand management and system responses based on changing conditions and short-term supply and demand forecasts. But the regulatory and energy market policy design has to incentivize and synchronize producers and consumers via dynamic price signals, responsive to locational and temporal changes in both supply and demand.

Conclusion

The post-María challenge in Puerto Rico is daunting because of its multiple dimensions: financial, economic, infrastructural, social, climate/environmental. There are equally great opportunities to emerge from this crisis with a more resilient grounding for a sustainable economy. Like many other Caribbean islands, Puerto Rico has no choice but to invest in much greater readiness and resilience facing extreme climactic events of great destructive power.

The electricity system at the core of the island's economy has to transform itself into a modern, flexible decentralized smart network of coupled micro-grids, with an expanding share of renewable energy sources and energy storage growing around the legacy infrastructure. It has to minimize the extent of island-wide losses in essential services during extreme shocks. A shift away from costly and volatile fossil fuel imports over time will bring greater energy security, free up significant financial resources to circulate within the local economy, help reduce and stabilize electricity rates, and stimulate all sectors. Fewer greenhouse gas emissions will contribute to improved air quality and health, and to avoided medical costs while providing the island's share of the global effort to contain the very global warming that affects islands like Puerto Rico so disproportionately.[13]

It is not only a technological and economic challenge, however, but also a political one. The quality of governance in Puerto Rican institutions, both political and administrative, created the conditions for the post-María calamity the island is in. This has been especially true of PREPA for a very long time.[14] There has been much talk of privatization as an answer, but there are other applicable models probably better suited for Puerto Rico. A perennial "captive market" for imports from the U.S. ($25 billion in 2016 goods alone),[15] Puerto Rico's economy does not need more funds flowing out of the island to outside owners buying assets at depressed bargain prices. At a minimum, mixed local equity or participation is needed. There are other models to learn and blend from that deliver reliable and affordable electricity: cooperative, municipal, substantial community-based assets, etc. More importantly: effective *transparency and accountability* that earns the sustained trust and buy-in from the population.

These storms' rapid intensification to high-category force is noteworthy also because the conditions for sustained, deep warmer waters that enabled it are the expected trend in the region. This brings its own dimension and implications for readiness and preparedness, beyond efficient and timely tracking of storm trajectories and intensity: improved rapid response capacity and mobilization of resources, and ample and sustained communication with a population that is well-informed and knowledgeable about their availability and how to access them. This is critical for people of lesser mobility or physical agility. Inadequacy in this temporal regard can be extremely costly

in lives and in the provision and continuity of essential services.

Finally, the achievable resilience is limited by a high level of poverty and socioeconomic inequality. Investing in reducing both is not only good from a social justice perspective, but "good business" with high societal returns in the context of extreme regional climate phenomena – much less damage and disruption when disasters strike, quicker recovery from them, and ultimately fewer resources needed. Jointly tackling energy system resilience and high energy costs, greenhouse gas emissions, and inequality feed a *virtuous cycle* much better than only one or another (or none).[16]

Endnotes

[1] While the focus here is on Puerto Rico, other Caribbean islands suffered enormous impacts from Irma or María, especially Dominica and Barbuda, but also the U.S. Virgin Islands, British Virgin Islands, St. Martin, Turks and Caicos, Anguilla and others, as well as much larger ones like Cuba.

[2] Poorer in per capita terms than all 50 states U.S., Puerto Rico has the highest per capita income in Latin America (both in nominal or "purchasing power parity" terms).

[3] Sea level rise, rising temperatures and extremes in precipitation and droughts are also a concern in Puerto Rico. See: "Sea Level Rise," Dr. Aurelio Mercado, UPR-Mayagüez. http://pr-ccc.org/download/SLR-AurelioMercado.pdf; "Increase in the Number of Hot Days for Decades in Puerto Rico 1950-2014," Rafael Mendez-Tejeda, ***Environmental and Natural Resources Research*** Vol 7, No 3 (2017). DOI: https://doi.org/10.5539/enrr.v7n3p16 (http://www.ccsenet.org/journal/index.php/enrr/article/view/69243); "Be Thankful, California. At Least You're Not Puerto Rico", Eric Holthaus, ***Slate***, June 22, 2015. http://www.slate.com/blogs/the_slatest/2015/06/22/drought_in_puerto_rico_it_s_much_worse_than_california.html

[4] "Key findings about Puerto Rico," Jens Manuel Krogstad, Kelsey Jo Starr and Aleksandra Sandstrom. March 29, 2017. ***Pew Research Center***. http://www.pewresearch.org/fact-tank/2017/03/29/key-findings-about-puerto-rico/; "The Causes and Consequences of Puerto Rico's Declining Population". Jaison R. Abel and Richard Deitz. ***Current Issues in Economics and Finance***. Volume 20, Number 4, 2014. Federal Research Bank of New York. https://www.newyorkfed.org/medialibrary/media/research/current_issues/ci20-4.pdf.

[5] Financial Oversight and Management Board: https://juntasupervision.pr.gov/. Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA): https://www.congress.gov/bill/114th-congress/senate-bill/2328/.

[6] For more on PREPA see: https://www.aeepr.com/INVESTORS/History.aspx; the U.S. Energy Information Administration (EIA): https://www.eia.gov/state/analysis.php?sid=RQ.

[7] The Puerto Rico Energy Commission (PREC) was created in 2014 "to regulate, monitor and enforce the energy public policy of the Commonwealth of Puerto Rico": http://energia.pr.gov/en/. See PREPA's fiscal plan before the 2017 storms: http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf. For an earlier thorough diagnosis of the utility's state of affairs, see the November 2016 expert report to the PREC by Fisher and Horowitz, ***Synapse Energy Economics***: http://energia.pr.gov/wp-content/uploads/2016/11/Expert-Report-Revenue-Requirements-Fisher-and-Horowitz-Revised-20161123.pdf.

[8] Klinger C, Landeg O, Murray V. Power Outages, Extreme Events and Health: a Systematic Review of the Literature from 2011-2012. PLOS Currents Disasters. 2014 Jan 2 . Edition 1. doi: 10.1371/currents.dis.04eb1dc5e73dd1377e05a10e9edde673.

[9] A year before María, power went down for three days in most of the island after a power plant fire (https://www.theguardian.com/world/2016/sep/23/puerto-rico-electricity-returns-outage). The island experiences a power outage rate several times that of any mainline utility.

[10] All fuel and most food is imported, at higher prices due to restrictions by law requiring shipping in vessels built, owned and operated by U.S. citizens (Jones Act). See Fuel Cost (in millions) to the right, from "PUERTO RICO ELECTRIC POWER AUTHORITY Power Revenue Bonds, Series 2013A", p. 49 https://www.aeepr.com/INVESTORS/DOCS/Financial Information/Official Statement/PREPA Revenue Bonds Series 2013A.pdf;
See also Fuel Cost from the June Monthly Reports for 2014, 2015, 2016, under Financial Information, in https://www.aeepr.com/INVESTORS/:

Fuel Costs

	Fiscal Year Ended June 30				
	2009	2010	2011	2012	2013[1]
Average fuel cost per equivalent barrel (net of handling costs)	$ 76.23	$ 76.55	$ 95.91	$ 118.39	$ 111.17
Number of equivalent barrels used (in millions)	25.18	26.22	23.89	24.51	23.42
Fuel cost (in millions)	$1,919.8	$2,006.9	$2,291.4	$ 2,901.8	$2,603.6
Net kWh generated (excluding purchased power) (in millions)	15,099.4	15,652.1	14,543.5	14,569.7	13,781.6
Average net kWh per equivalent barrel	599.7	597.0	608.8	594.4	588.4
Average fuel cost per net kWh generated (in cents)	12.71	12.82	15.76	19.91	18.89

[1] Unaudited.

$2,345	million	FY 2013-14,
$1,894.857	million	FY 2014-15,
$1,210.5	million	FY 2015-16,

[11] A Great Migration From Puerto Rico Is Set to Transform Orlando, Lizette Alvarez, ***New York Times***, November 17, 2017. (https://nyti.ms/2hIugSO). See also a recent survey that provides additional context on the current and expected migration trends to the U. S.: Will Puerto Ricans return home after Hurricane María? Alexis R. Santos-Lozada, ***The Conversation***, November 17, 2017. (https://theconversation.com/will-puerto-ricans-return-home-after-hurricane-maria-87160).

[12] Puerto Rico scores "7.5 points out of a possible 50" on ACEEE's 2017 State Energy Efficiency Scorecard. Clearly a lot of potential exists, but adequate incentives are needed for their promotion to be rewarded with proper incentives, and even be profitable via avoided costs (http://aceee.org/sites/default/files/pdf/state-sheet/2017/puerto-rico.pdf).

[13] While it is true that Puerto Rico, and the Caribbean, contribute a small share of the global greenhouse gas emissions in absolute terms, Puerto Rico's per capita emissions level is that of other middle-income countries; all emissions reductions are equally consequential.

[14] Fisher, J. and A. I. Horowitz. 2016. Expert Report: State of PREPA's System, Load Forecast, Capital Budget, Fuel Budget, Purchased Power Budget, Operations Expense Budget. Prepared for the Puerto Rico Energy Commission regarding Matter No. CEPR-AP-2015-0001, November 23, 2016.

[15] 2016 U.S. TRADE WITH PUERTO RICO AND U.S. POSSESSIONS. FT895/16. https://www.census.gov/content/dam/Census/library/publications/2017/econ/ft895-16.pdf. See Table 1: Shipments from the United States to Puerto Rico by Schedule B Commodity and Method of Transportation. Calendar Year 2016
U.S. to Puerto Rico Total, All Methods of Transportation: $25,151,071 (Value in Thousands).
On a per capita basis, this is about the same as U.S. exports to the much wealthier Canada and 4 times Mexico's (top 2 recipients), which took in $266.8 and $231 billion, respectively. In absolute value, Puerto Rico's imports from the U.S. compare to U.S. exports ($ billion) to: France $30.9, Brazil $30.3, Singapore $26.9, Taiwan $26.0 and Switzerland $22.7, the 11th to 15th top recipients.

[16] A recent study of a 'green growth' path to a decarbonized energy system in Puerto Rico by 2050, with a customized economic analysis using input-output tables of the island economy (IMPLAN 2015), including a carbon tax and fairly conservative technical and financial assumptions: "Austerity Versus Green Growth for Puerto Rico," Amanda Page-Hoongrajok, Shouvik Chakraborty, Robert Pollin. Working Paper, Political Economy Research Institute, August 22, 2017. https://www.peri.umass.edu/publication/item/1016-austerity-versus-green-growth-for-puerto-rico.

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