

Public Safety Risk: Effects of Complete Power Grid Destruction by Hurricane

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Abstract— *This paper discusses of all the consequences and effects after the loss of electrical systems caused by hurricane Maria on the island of Puerto Rico. Puerto Rico is in the Caribbean and is very susceptible to catastrophes due to natural events which cause different social effects in the population. In this article, the major affected areas will be mentioned, from the water and communications systems to health and the economy in Puerto Rico after Hurricane Maria. We will mention the fragility of the country's infrastructure and possible measures to re-establish these services in the most expeditious manner. The disasters caused by the hurricane on the island can be likened to the damage generated by a terrorist attack, which can give us an indication of how to act after a catastrophe.*

Keywords— *Maria, hurricane, catastrophe, security, terrorist attack, Puerto Rico, electrical security, PREPA*

I. INTRODUCTION

The use of electricity is so commonplace for people in modern countries that it has become an essential part of daily life. Everything from, health, security, communications and economic transactions depends on electricity in some way. This is the case in Puerto Rico. Puerto Rico's electricity consumption per capita is around 5GWh with a total population of 3.5 million [3]. PR has the biggest electricity consumption comparing to other major islands in the Caribbean (e.g. Cuba: 1,434kWh, Jamaica: 1,055kWh, Dominican Republic: 1,578 kWh).

The power generation, transmission and distribution system in Puerto Rico is controlled by a single public entity known as the Puerto Rico Electric Power Authority (PREPA) [1]. PREPA is the biggest public power utility in the United States. There are seven different types of power sources, they can be seen in Fig. 1[2]. The majority consumption of energy is at the north of Puerto Rico and the production at the south, because of this the transmission lines must cross the island's mountainous terrain. This creates difficult access for maintenance and recovery of the transmission lines. In Fig. 2 shows where the biggest power consumption is concentrated [3]. Also, when these lines or the generation is affected the north and northeast is greatly affected creating long periods of blackouts. The transmission lines that cross the island can be seen in Fig 3.

As was mentioned before the majority consumption is in the north and northeast. This unbalanced power generation and consumption has affected the electrical services of the citizens of Puerto Rico in this past days. One of the biggest blackout due to human errors occurred September 21, 2016. The origin of this blackout was the insufficient maintenance of equipment that failed and caused a fire to break out in the Aguirre power station [4]. This created some uncertainty and distrust in the citizens towards PREPA [5]. Not even a year after the 2016 blackout, Puerto Rico was hit by hurricane Maria on September 20, 2017, creating the biggest blackout in history, not only for Puerto Rico, but also for the USA and still going [6]. The atmospheric event has exposed how the island was not prepared for the devastation caused by the total power and communication loss; not unlike what could happen after a coordinated terrorist attack [7].

Maria is not alone as the only hurricane that has caused costly damages to the economy and the infrastructure in Puerto Rico. Hurricane George on September 21, 1998, also wreaked havoc and caused around \$6 billion in combined infrastructure and cost to the economy. At the time of writing this paper, Maria has cost an estimated \$50 billion in damages to infrastructure and lost economic activity. [8].

Percentage of Generation by Type

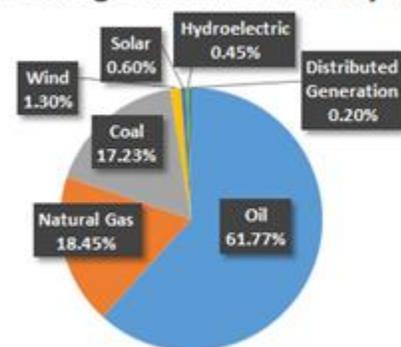


Fig. 1. Percentage of the Generation of Energy by Type [2]

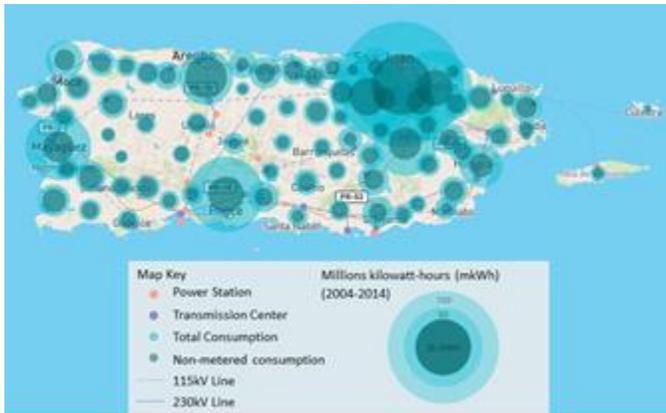


Fig. 2. Municipal Energy Consumption of Puerto Rico [3]



Fig. 3. Transmission and generation of Puerto Rico [3]
 II. ELECTRICAL SYSTEM SECURITY

In most of countries, the different systems or products depend of electricity to function or to be produced. A human error, natural phenomena and terrorist attack could cause an electric failure. Electric system failure creates discomfort on the different users. Prolonged blackouts cause a domino effect that affects society daily life and essential services. In Fig. 4 it can be seen the before and after the path of Maria.

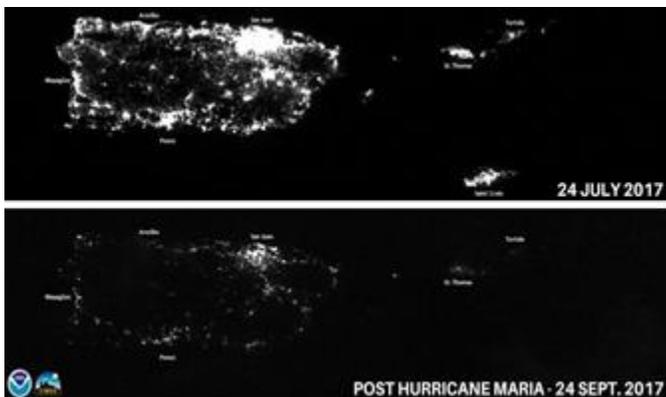


Fig. 4. Before and after blackout [9]

A. Water and Sanitary System

The water treatment facilities and pumping stations should not suffer much damage in an incident, man-made or natural, that was centered on the electrical system. Still a complete blackout would render the water authority out of commission. This was the case during the aftermath of the hurricane. The pumping stations lost power and only those who had cisterns had running water [10]. Water quality is also an issue during the emergency. Lack of power affected water quality monitoring as many of the treatment facilities and laboratories were put out of service. [11].



Fig. 5. People struggling to get water in spring [12]

B. Communications

One of the greatest difficulties of an electric system failure after the hurricane Maria in Puerto Rico is communication. After nine days of the event, only 96 of the 1600 communication towers that extend throughout the island were functioning. This is only equivalent to a total of 30% accessibility of communication [13]. Currently, we all obtain and depend on portable systems that allow us to communicate from telephone lines and Internet [14].

Without access to communication, we are limited to acting in our behalf when an emergency occurs since we cannot call the police or call for an ambulance. Many people with necessities were trapped in their homes when a simple call could save a life. The lack of communication and information can have us make terrible decisions which can generate more problems.



Fig. 6. People looking for cellphone signal to reach families and friends [11]

C. Health

The blackout was so massive, 3 days from the event there were only 12 out of 69 working hospitals[15] Six days from the event the hospitals that did have generators, required police escorts for the fuel deliveries[16]. A month from the event only 45 hospitals had grid power, 6 had been closed and the remaining 18 were working using generators [17]. An order was issued regarding the relocation of medications that were not classified as controlled substances from pharmacies that had no power to pharmacies that did have some sort of power to facilitate the distribution to those in need[18]. Lack of power in funeral homes caused a backlog in morgue hospitals, to remedy this the government issued 911 cremations without requiring autopsy. Among those cremated were people who died due to unavailable dialysis machines or oxygen supply [19][20].

The psychological effect of the prolonged blackout should not be ignored. One study done on the people of New York after hurricane Sandy found that: “The impact on mental health was substantial, she concluded; there was a significant increase in emergency room visits for substance abuse problems, psychosis, mood disorders and suicides throughout the city.” This could very well be compared to what a terrorist attack would achieve [21].



Fig. 7. USNS Comfort was sent to help the Island [22]

D. Economy

After the passage of Hurricane Maria, the population of Puerto Rico had shortages of food, water, electricity, gasoline, medical services, and among others, which generated a strain on the economy of the country. Since there was a common need, people lacked these services to the point of scarcity. Without having means of distributing these services, people did not have access to acquire anything, which means that there is no money flow in the country. Another problem after the event was the structural losses in the island, this includes all the infrastructure of the country, hundreds of light poles being found on the ground after the hurricane, hundreds of families lost their homes and belongings, and several rivers overflowed causing floods. These physical losses are all economic losses for citizens and for the country. Economists have an initial estimate \$50 billion in damages to infrastructure, and the productive capacity. [23]

The island received a very strong blow even in the shops. Many large and small companies did not have the normal demand that they commonly have. This caused several companies to present large economic losses and in other cases led to similar closures.

One of the consequences most felt in the population was the way to acquire what little there was as there were no communication systems and the only way to buy a product was with cash. This caused everyone to withdraw large amounts of money from their bank accounts, which caused shortages and losses in banks, extremely long lines in front of the banks. The banks established a moratorium on mortgages and car loans to allow what little money remained in people’s hands to be used during the emergency [24]. These were the results of this problem.



Fig. 8. Long lines at the banks after almost three weeks without service [12]

E. Security

Due to the failure of the electrical system, a domino effect begins where the security fails somewhat quickly. It starts with the insecurity of the streets, when the electrical system fails due to the signal lights not functioning, which creates kilometeric traffic. Without the electrical systems functioning, car accidents are more probable at night due to poor vision from the lack of having nocturnal electricity. This failure in the transit also provokes that the first solution should be that the political body directs the transit [25]. This induces that less service from the police that spend their labor in making order in the streets and enforcing the law as robberies and security begin to increase [26][27]. Before hurricane Maria, the political body was found working in the streets during the day to control the transit that generates a physical waste that makes less availability of the service of the police when it is needed [28]. One of the solutions behind the passing of the hurricane Maria in Puerto Rico were to find a curfew which prevents that the people do not go outside at night, even though this was a bit counterproductive now that it impedes that the people can go out for some important reason or necessity [29].



Fig. 9. Man get a shoot in robbery of his gasoline cans. [30]

III. RECONSTRUCTION OF PUERTO RICO ELECTRICAL SYSTEM

Quick response from the government agencies that oversee crisis management is essential after a hurricane, terrorist attack or other. This did not happen in Puerto Rico. The complete electrical and communications system failure in with the added obstacle of all the storm debris made this impossible.

“Many of the steps to be taken would be similar to those taken in response to a major natural disaster, such as a hurricane: that is, identify the damage, clean it up, repair equipment, and restore power.” [7]. These are the steps a utility would take to repair the grid. In Puerto Rico, PREPA, would be assigned these tasks. It is a public corporation and because of this in essence the government is in charge of the reconstruction efforts. The local authorities do not have the man power to be able to do this in a reasonable time. Outside help in the form of aid from the Federal Emergency Management Agency (FEMA) and the United States Army Corps of Engineers (USACE). Additional help in the form of private contractors. [31]

This hiring of private contractors is the first of the lessons learned and certainly will not be the last. While getting the right personnel to do the rebuilding of the grid is urgent business, such decisions should not be rushed. This rushed decision led to the hiring of the Montana based company called Whitefish Energy Holdings. There were some irregularities regarding the compensation and the how the contract came into fruition. The total amount was to be \$300 million on a no bid contract; highly unusual for a no bid contract. This was more alarming since the company had only two full time employees and the time of the signing. This unleashed a controversy which only hindered the reconstruction efforts. The contract was soon annulled [32]. While the government struggled to rebuild the badly injured grid, the citizens turned to emergency generators. Larger generators were also installed by the USACE in lieu of grid power [33] [34].

IV. EXPERIENCE LEARNED AND PREPARATION FOR FUTER EVENTUALITY

As it was stated before in this paper the response from the government was slow and sometimes none. Meaning that the preparation for natural phenomena like hurricane Maria depends in most of the time in its citizens. One of the best solution for the electricity problems is photovoltaic systems in residence based in studies suggested in [36]. The U.S. Bureau quicks facts of PR states that persons in poverty in Puerto Rico is 43.5% and the median household income (in 2016 dollars) is \$19,606 [35]. Knowing the fact that all the Puerto Ricans may not be able to buy PV systems to satisfies their power consumption is suggested a small and economic PV system supplemented by another fuel generator. By doing these long lines in gas station and other fuel demands will be less.

In Fig. 10 it can be see another low-cost alternative option for this kind of eventuality. After Hurricane Maria, Dr. Efrain O'neill, Dr. Marcel Castro, Dr. Erick Aponte with several professors and students joined forces to design and construct four portable PV systems to provide light and electricity to small electric loads in rural towns in PR. The first Oasis de Luz was installed at Jayuya, PR. A second project has been installed in Caguas, PR. The remaining two projects will be installed at Orocovis and Aibonito, PR. This project has been sponsored by the IEEE Foundation, INESI, CIESESE, and UPRM. Also, after Hurricane Maria, was created a Whatsapp Group named OxygenPR with the intention to bring oxygen tanks, and other supplies to elderly people in PR. Members of OxygenPR are Dr. Eduardo Ortiz, Eng. José Maeso (CIESESE Co-PI), Dr. Anastasia Kytsul (Russian Honorary Consul at PR), Mr. Ismael Pagan (UPRM's Civil Engineering Dept.), students and faculty members, etc.



Figure 10: One of the oasis installed by UPRM faculty, personal and students.

V. CONCLUSION

There are many lessons that can be learned from the passing of Maria over Puerto Rico; these should not be soon forgotten. Lessons such as supply chain and logistics for personnel deployment, how to rebuild the grid over hazardous terrain where after a terrorist attack bridges may be destroyed, and roads blocked by debris, coordination of services without an existing communication system, etc. These can be applied in areas regarding the preparation and response to inclement weather or man-made disruptions to the electrical system.

REFERENCES

- [1] "Sistema Electrico", Aeepr.com, 2017. [Online]. Available: https://www.aeepr.com/Aees/sistema_electrico.asp. [Accessed: 30- Oct-2017].
- [2] "Distribución Porcentual de la Generación de Energía por Tipo – Comisión de Energía de Puerto Rico", Energía.pr.gov, 2017. [Online]. Available: <http://energia.pr.gov/datos/distribucion-porcentual-de-la-generacion-de-energia-por-tipo/>. [Accessed: 30- Oct- 2017].
- [3] "Consumo Energético Municipal (2004-2014) – Comisión de Energía de Puerto Rico", Energía.pr.gov, 2017. [Online]. Available:

- <http://energia.pr.gov/datos/consumo-municipal/>. [Accessed: 30- Oct-2017].
- [4] "Apagón arropa a toda la Isla", El Nuevo Dia, 2017. [Online]. Available: <https://www.elnuevodia.com/noticias/seguridad/nota/apagonarropaatodalaisla-2243641/>. [Accessed: 30- Oct- 2017].
- [5] <http://webcache.googleusercontent.com/search?q=cache:IUCL5v5XHOKJ:www.oslpr.org/2013-2016/%257BD32E79DA-BE9F-48B1-8AEF-C5A8FCC2FB6A%257D.doc+&cd=10&hl=en&ct=clnk&gl=pr>
- [6] R. Avila, "Apagón de Puerto Rico es el más largo en la historia de la nación americana", Metro, 2017. [Online]. Available: <https://www.metro.pr/pr/noticias/2017/10/26/apagon-puerto-rico-mas-largo-la-historia-la-nacion-americana.html>. [Accessed: 30- Oct- 2017].
- [7] National Research Council (U.S.), Terrorism and the Electric Power Delivery System. National Academies Press, 2012.
- [8] C. Otero, "Impacto multibillonario de María", El Vocero de Puerto Rico, 2017. [Online]. Available: http://www.elvocero.com/economia/impacto-multibillonario-de-mar-a/article_5f364bf0-a176-11e7-892a-ff1a85c871da.html. [Accessed: 31- Oct- 2017].
- [9] "NOAA Satellites (@NOAASatellites) on Twitter", Twitter.com, 2017. [Online]. Available: <https://twitter.com/NOAASatellites>. [Accessed: 02- Nov- 2017].
- [10] Español, C. (2017). Huracán María provoca que AAA pierda sistema de visualización de sus plantas. [online] CB en Español. Available at: <http://cb.pr/huracan-maria-provoca-que-aaa-pierde-sistema-de-visualizacion-de-sus-plantas/> [Accessed 29 Oct. 2017].
- [11] Ortega, M. (2017). Alerta por la calidad del agua tras el paso del huracán María. [online] El Nuevo Dia. Available at: <https://www.elnuevodia.com/noticias/locales/nota/alertaporlacalidaddelaguatraselpasodelhuracanmaria-2364980/> [Accessed 29 Oct. 2017].
- [12] Taylor, A. (2017). Disconnected by Disaster—Photos From a Battered Puerto Rico. [online] The Atlantic. Available at: <https://www.theatlantic.com/photo/2017/09/disconnected-by-disasterphotos-from-a-battered-puerto-rico/540975/> [Accessed 29 Oct. 2017].
- [13] El Nuevo Dia. (2017). Telecomunicaciones: 30.5% del servicio se ha restablecido. [online] Available at: <https://www.elnuevodia.com/negocios/empresas/nota/telecomunicaciones-3050delservicioseharestablecido-2361611/> [Accessed 31 Oct. 2017].
- [14] El Nuevo Dia. (2017). Falta de electricidad pone en peligro servicios de telefonía e internet. [online] Available at: <https://www.elnuevodia.com/negocios/empresas/nota/faltadeelectricidadponeenpeligroserviciosdetelefoniaeinternet-2367092/> [Accessed 31 Oct. 2017].
- [15] Metro. (2017). Metro Pavia y hospitales afiliados listos para brindar ayuda. [online] Available at: <https://www.metro.pr/pr/estilovida/2017/09/22/metro-pavia-hospitales-afiliados-listos-brindar-ayuda.html> [Accessed 31 Oct. 2017].
- [16] Telemundo. (2017). Crítica situación en los hospitales de Puerto Rico tras paso del huracán María. [online] Available at: <http://www.telemundo.com/noticias/2017/09/25/critica-situacion-en-los-hospitales-de-puerto-rico-tras-paso-del-huracan-maria> [Accessed 31 Oct. 2017].
- [17] El Nuevo Dia. (2017). Sigue en aumento el restablecimiento de energía eléctrica y agua potable. [online] Available at: <https://www.elnuevodia.com/noticias/locales/nota/sigueenaumentoelrestablecimientodeenergiaelectricayaguapotable-2367357/> [Accessed 31 Oct. 2017].
- [18] Calero, M. (2017). Muy pocos hospitales y farmacias funcionan en Puerto Rico. [online] CB en Español. Available at: <http://cb.pr/muy-pocos-hospitales-y-farmacias-funcionan-en-puerto-rico/> [Accessed 31 Oct. 2017].
- [19] NOTICEL. (2017). Gobierno de Puerto Rico autorizó 911 cremaciones luego del paso de María. [online] Available at: <http://www.noticel.com/el-tiempo/huracanes/gobierno-de-puerto-rico-autoriz-911-cremaciones-luego-del-paso-de-maria/646853243> [Accessed 31 Oct. 2017].

- [20] USA TODAY. (2017). Real death toll in Puerto Rico is probably 450 — much higher than official count. [online] Available at: <https://www.usatoday.com/story/news/world/2017/10/18/real-death-toll-puerto-rico-probably-450-much-higher-than-official-count/774918001/> [Accessed 31 Oct. 2017].
- [21] Time. (2017). How Power Outages Can Affect Mental Health. [online] Available at: <http://time.com/4968766/puerto-rico-hurricane-maria-power-outage/> [Accessed 31 Oct. 2017].
- [22] "Barco hospital USNS Comfort se quedará en San Juan y pacientes podrán solicitar servicios médicos sin referido", Univision.com, 2017. [Online]. Available: <http://www.univision.com/puerto-rico/wlii/noticias/huracan-maria/barco-hospital-usns-comfort-se-quedara-en-san-juan-y-pacientes-podran-solicitar-servicios-medicos-sin-referido>. [Accessed: 02- Nov- 2017].
- [23] Carlos Antonio Otero, E. (2017). Impacto multibillonario de María. [online] El Vocero de Puerto Rico. Available at: http://www.elvocero.com/economia/impacto-multibillonario-de-maria/article_5f364bf0-a176-11e7-892a-ff1a85c871da.html [Accessed 31 Oct. 2017].
- [24] Carlos Antonio Otero, E. (2017). Popular aclara dudas sobre moratoria en préstamos. [online] El Vocero de Puerto Rico. Available at: http://www.elvocero.com/economia/popular-aclara-dudas-sobre-moratoria-en-pr-stamos/article_b344cd74-a7b2-11e7-9271-53c42380b719.html [Accessed 31 Oct. 2017].
- [25] [Carlos Antonio Otero, E. (2017). Popular aclara dudas sobre moratoria en préstamos. [online] El Vocero de Puerto Rico. Available at: http://www.elvocero.com/economia/popular-aclara-dudas-sobre-moratoria-en-pr-stamos/article_b344cd74-a7b2-11e7-9271-53c42380b719.html [Accessed 31 Oct. 2017].
- [26] Primera Hora. (2017). Policía evalúa constantemente el manejo del tránsito. [online] Available at: <http://www.primerahora.com/noticias/policia-tribunales/nota/policiaevaluaconstantementeelmanejodeltransito-1251504/> [Accessed 31 Oct. 2017].
- [27] Anon, (2017). [online] Available at: <https://www.elnuevodia.com/noticias/locales/nota/urgenmayorseguridade nluquiloporalzaenfechorias-2360294> [Accessed 31 Oct. 2017].
- [28] Metro. (2017). Labor encomiable en medio de la crisis. [online] Available at: <https://www.metro.pr/pr/noticias/2017/09/28/labor-encomiable-medio-la-crisis.html> [Accessed 31 Oct. 2017].
- [29] Metro. (2017). Gobernador decretó toque de queda en Puerto Rico. [online] Available at: <https://www.metro.pr/pr/noticias/2017/09/20/gobernador-decreto-toque-queda-puerto-rico.html> [Accessed 31 Oct. 2017].
- [30] Acentúa 'María' problemas de salud en Puerto Rico - El Independiente en Línea", El Independiente en Línea, 2017. [Online]. Available: <http://www.elindependienteenlinea.com/site/2017/10/01/acentua-maria-problemas-de-salud-en-puerto-rico/>. [Accessed: 02- Nov- 2017].
- [31] "La AEE necesitará apoyo del gobierno federal y compañías privadas", El Nuevo Día, 2017. [Online]. Available: <https://www.elnuevodia.com/noticias/locales/nota/laeenecesitaraapoyode lgobiernofederalycompaniasprivadas-2362162/>. [Accessed: 02- Nov- 2017].
- [32] "Montana Whitefish Energy had two employees before Hurricane Maria hit.", USA TODAY, 2017. [Online]. Available: <https://www.usatoday.com/story/news/world/2017/10/26/puerto-ricos-gov-rossello-orders-audit-whitefish-contract-fix-power-grid/803095001/>. [Accessed: 02- Nov- 2017].
- [33] "El Cuerpo Ingenieros ha instalado 366 generadores en Puerto Rico", El Nuevo Día, 2017. [Online]. Available: <https://www.elnuevodia.com/noticias/locales/nota/elcuerpoingenieroshain stalado366generadoresenpuertorico-2370931/>. [Accessed: 02- Nov- 2017].
- [34] Anon, 2017. [Online]. Available: <https://www.nytimes.com/2017/10/07/us/puerto-rico-power-generators.html> [Accessed: 02- Nov- 2017].
- [35] "U.S. Census Bureau QuickFacts: Puerto Rico", Census Bureau QuickFacts, 2018. [Online]. Available: <https://www.census.gov/quickfacts/fact/table/PR/PST045216>. [Accessed: 15- Jun- 2018].
- [36] A. Irizarry, J. Colucci and E. O'neil, "Achievable Renewable Energy Targets For Puerto Rico's Renewable Energy Portfolio Standard", Uprn.edu, 2008. [Online]. Available: http://www.uprm.edu/aret/docs/ARET_for_PR_RPS.pdf. [Accessed: 15- Jun- 2018]