A Machine Learning Approach for Transmission Line Hardening

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Context

- **Hurricane Maria** made landfall in Puerto Rico on September 20th, 2017.

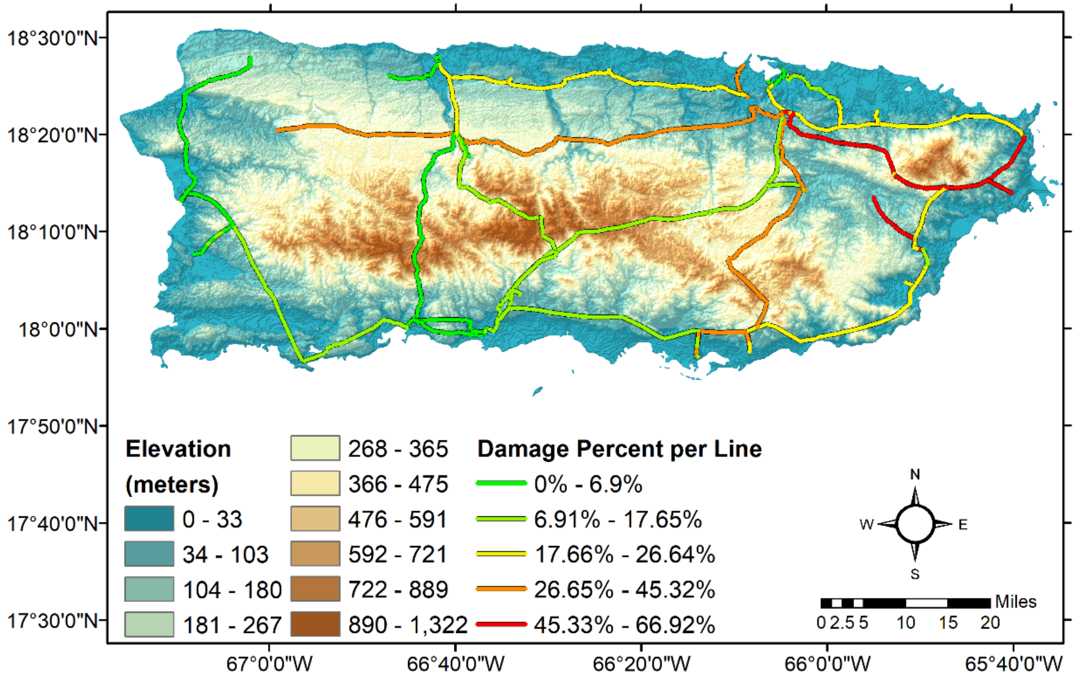
- It reached peak intensity over the eastern Caribbean with maximum sustained winds of 175 MPH, making it the **tenth-most intense Atlantic hurricane** on record.

1. https://www.abc12.com/content/news/The-Latest-Maria-continues-strengthening-hits-175-mph-445920463.html

Context

- Almost all the 2,400 miles of transmission lines, 30,000 miles of distribution lines and 342 substations were knocked out by the storm.

- Total losses from the hurricane were estimated at between $52 and $95 billion, with $17B for the power infrastructure alone.

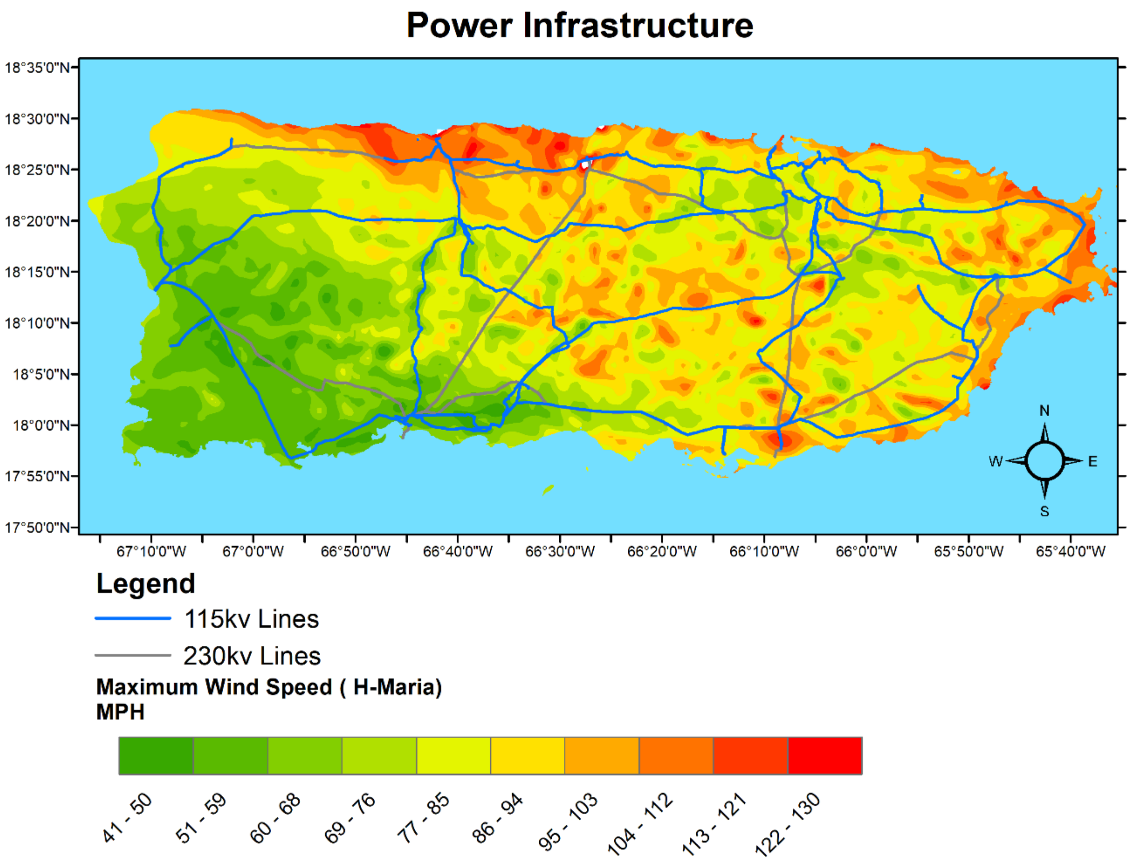


1. https://www.nytimes.com/2017/12/29/us/puerto-rico-power-outage.html
2. https://weather.com/storms/hurricane/news/2017-10-20-puerto-rico-hurricane-maria-by-the-numbers

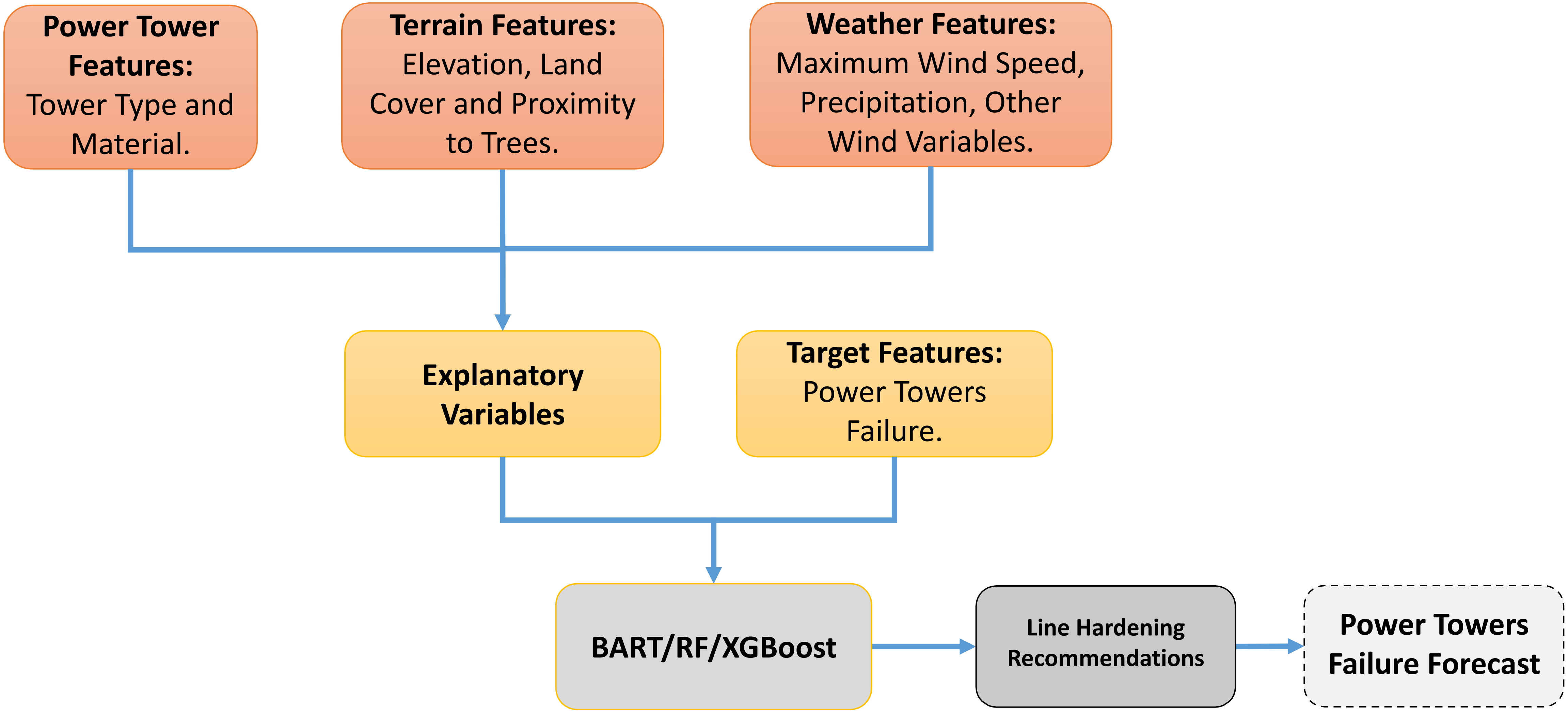
Objective

- Anticipate damage in the power infrastructure of tropical coastal environments when exposed to extreme weather events (Extreme precipitation, extreme wind and landslides)

- Explore methods to increase the resiliency in the power infrastructure when exposed to extreme weather events



General Framework for resiliency of the transmission system.



Explanatory Variables

Power Tower Features:

Explanatory Variable	Source	Units
Type of tower	Utility Data	categorical
Material of the tower	Utility Data	categorical

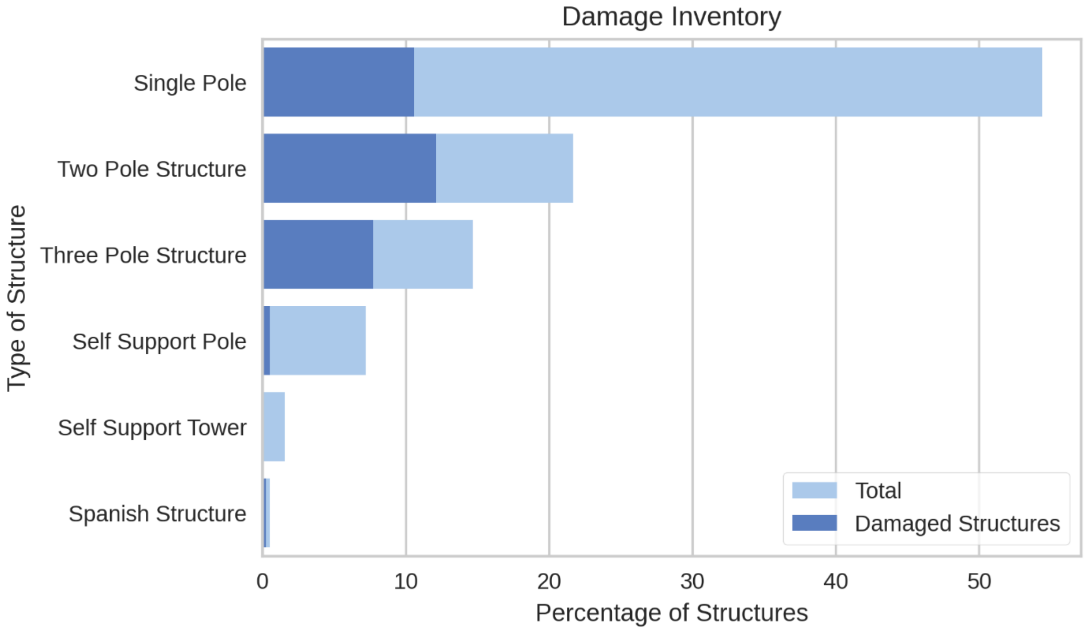
Terrain and Weather Features:

Explanatory Variable	Source	Resolution	Units
Maximum Wind Speed.	WRF	1km x 1km	MPH
Duration of Wind Speed greater than 20 MPH.	WRF	1km x 1km	hours
Duration of Wind Speed greater than 30 MPH.	WRF	1km x 1km	hours
Duration of Wind Speed greater than 40 MPH.	WRF	1km x 1km	hours
Cumulative Rainfall.	WRF	1km x 1km	inches
Elevation.	USGS	100m x 100m	feet
Land Cover.	USGS NLCD	30m x 30m	categorical

115kv Transmission Lines Hardening

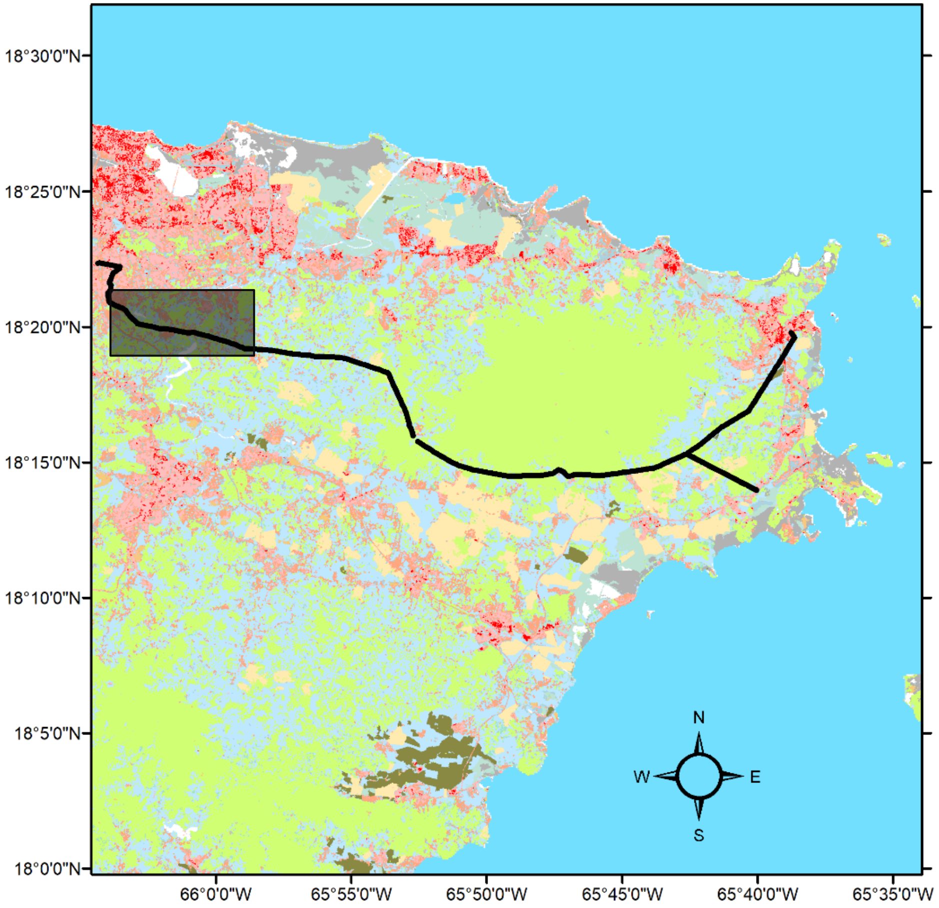
The hardening study consist of replacing the weak structures with higher damage rate by stronger more resilient ones. In the three considered hardening scenarios, the types of towers below were replaced by **Steel self-support poles**:

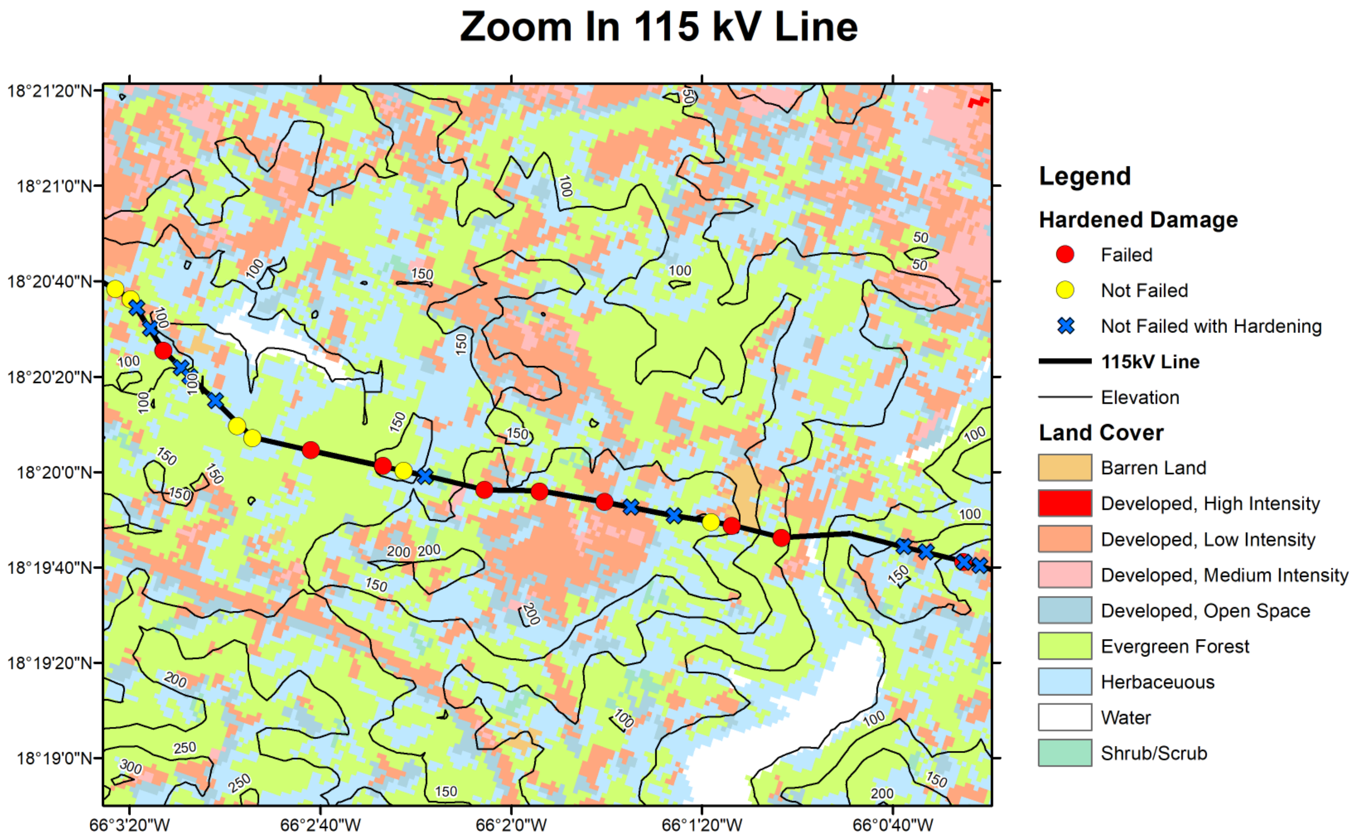
- **Hardening #1**
  - Wood Two Pole Structure
- **Hardening #2**
  - Wood Two Pole Structure
  - Wood Three Pole Structure
- **Hardening #3**
  - Wood Two Pole Structure
  - Wood Three Pole Structure
  - Wood Single Pole



Damage inventory for one of the 115kv transmission lines

Results



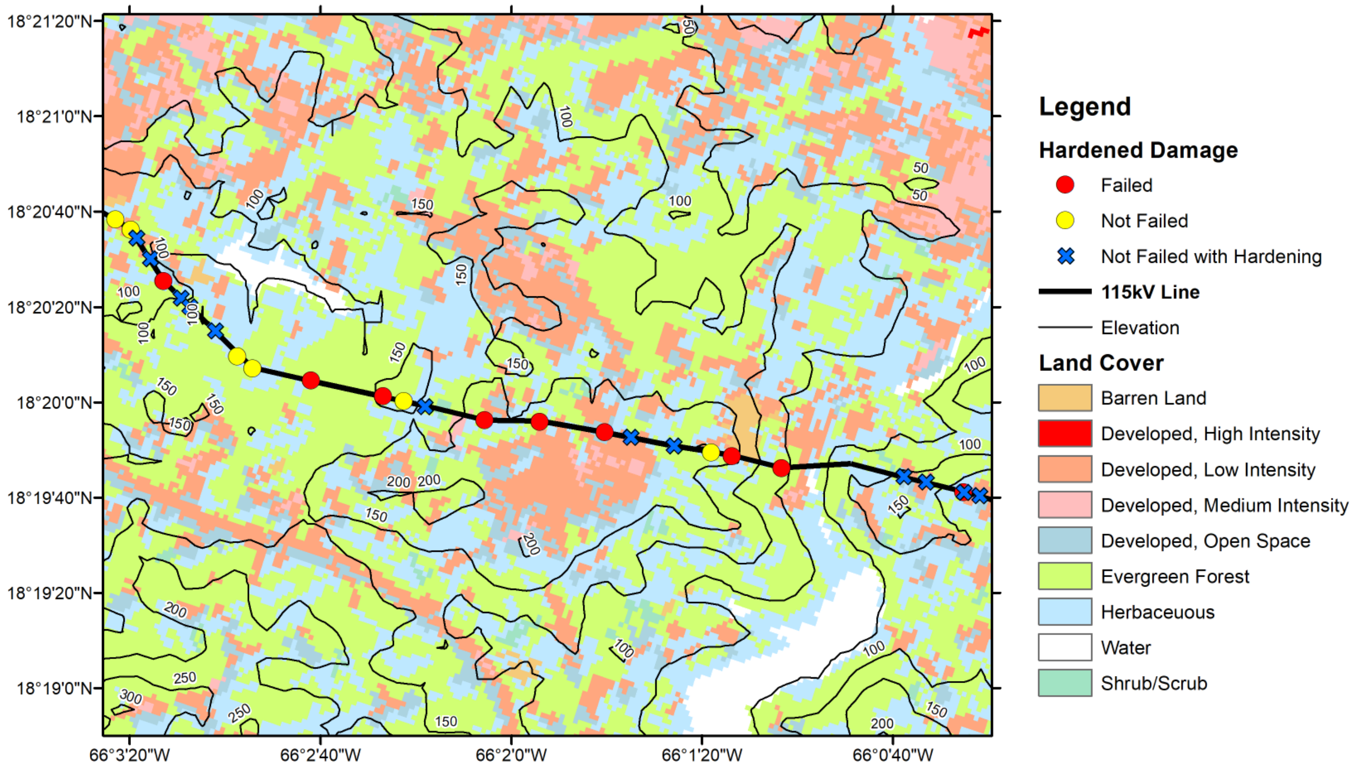


Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, 2004. Development of a 2001 National Landcover Database for the United States, Photogrammetric Engineering and Remote Sensing, Vol. 70, No. 7, 829-840.

Results

- 74% of structures failed **without hardening**.
- 34% of structures failed **with hardening**.

Zoom In 115 kV Line



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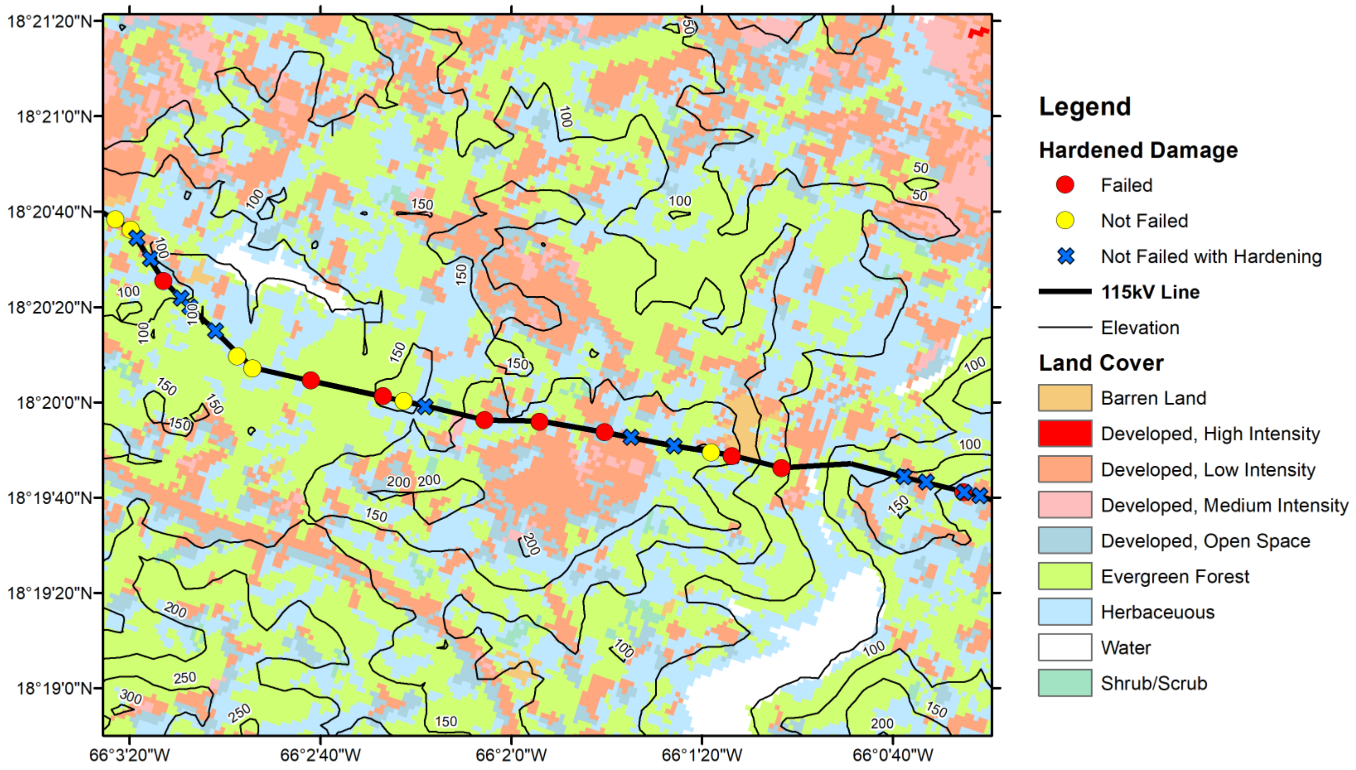
Results

Type of Hardening	Undamaged Structures
Steel Self Support Pole	66%
Steel Single Pole	61%
Tubular	43%
Without Hardening	26%
Wood Self Support Pole	21%

Zoom In 115 kV Line



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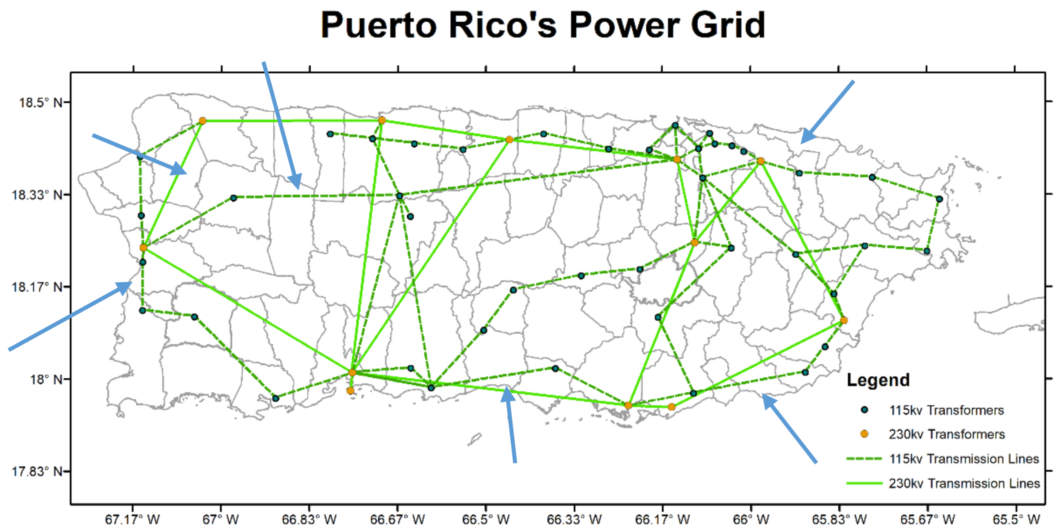
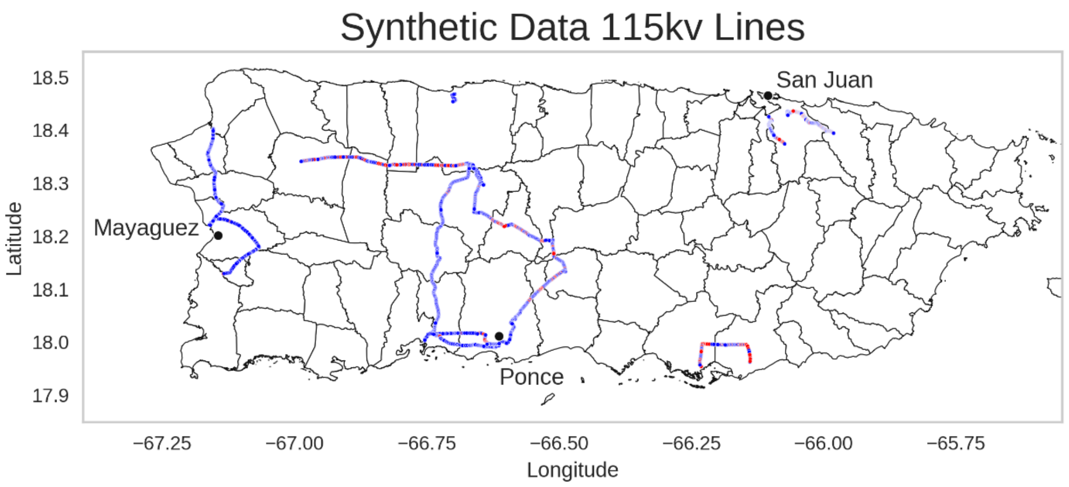
Whole Island Analysis: Synthetic Data

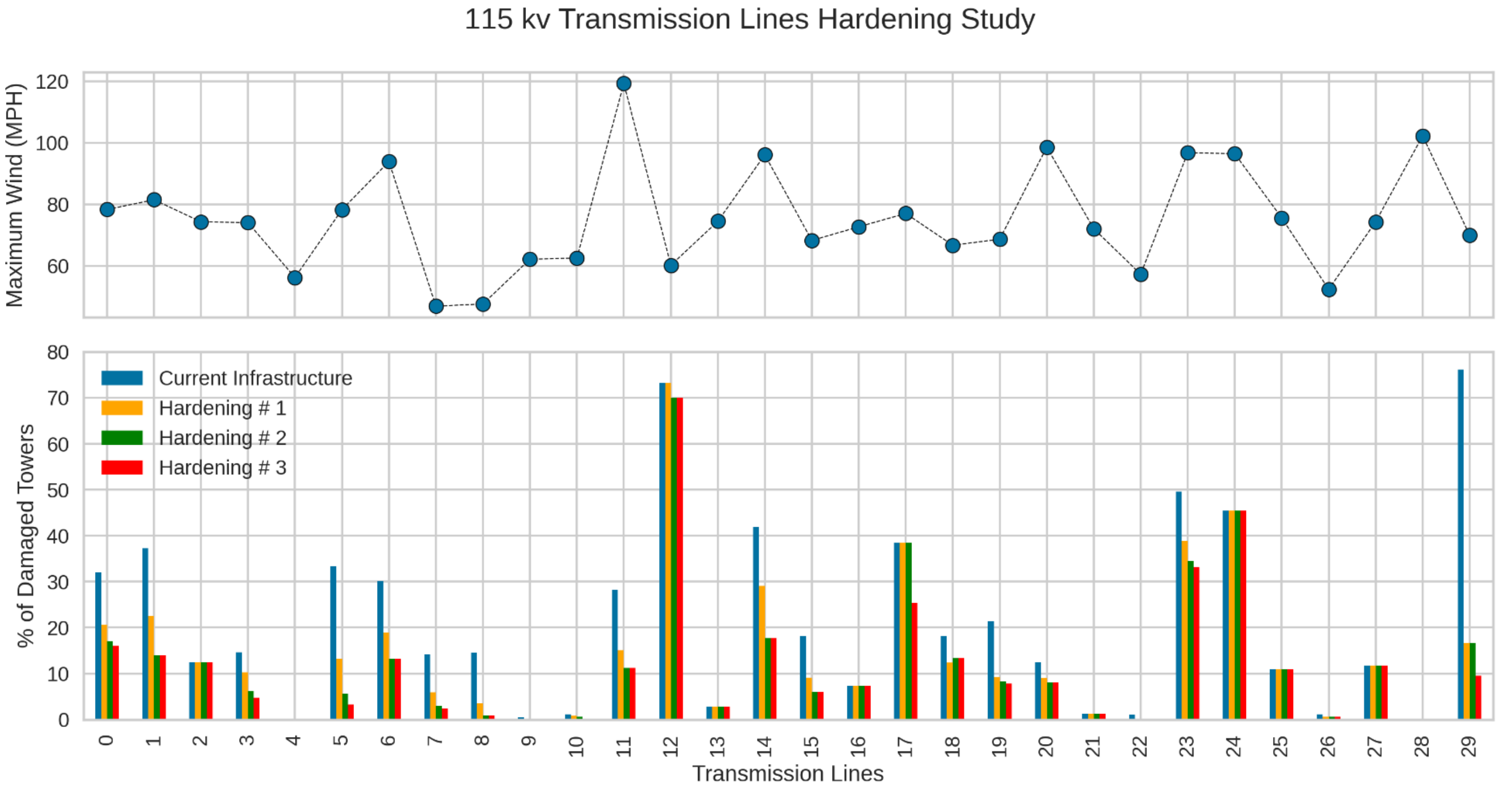
- 6 of the 115kv lines are missing from the dataset
- Shapefile with the path of the lines is available





Whole Island Analysis: Results

- Hardening #1 had a **mean improvement** of 7%
- Hardening #3 had a **mean improvement** of 10%
- **Maximum Improvement** of 66% on line 29
- Power Towers experienced wind speeds ranging from **50 to 120 MPH**



Conclusions

- The type of structure that **failed the most** was the **wooden two-pole**, followed by the **wooden three pole**
- Replacing these structures by **Steel Self-Support Poles** resulted in an **average reduction of 10% of damaged towers** in the lines
- The **maximum** improvement was of **66%** on Hardening #3 (replacing all wooden structures)
- Landslides were not explicitly considered in this study
- A future study will include the analysis results in a **coupled power-water network model**. Giving insights on how the hardening will directly influence the availability of these resources after an extreme event

References

1. Pokhrel, Rabindra, et al. "Observation and modeling of Hurricane Maria for damage assessment." Weather and Climate Extremes 33 (2021): 100331.
2. Bagheri, Ali, et al. "Resilient transmission hardening planning in a high renewable penetration era." IEEE Transactions on Power Systems 34.2 (2018): 873-882.
3. Hou, Hui, et al. "Risk assessment and its visualization of power tower under typhoon disaster based on machine learning algorithms." Energies 12.2 (2019): 205.
4. Yuan, Hao, et al. "Resilience assessment of overhead power distribution systems under strong winds for hardening prioritization." ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering 4.4 (2018): 04018037.

Thank you!

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