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CP 6521

May 6th, 2021

Analysis of Socioeconomic Factors and

Links to Systemic Risk of Energy Supply Shortfalls:

Example from Texas, U.S.A., February 2021

OVERVIEW

This research project started as an attempt to map the region of Texas's power grid and set of energy consumers most strongly affected by the winter storm and subsequent power outages in mid-February 2021. However, having examined the relationship between socioeconomic status variables—such as percentage of population below state poverty lines per census tract—and the probability of an area having few (if any) redundant power supply paths to counteract possible cascading outages cause by disruptions at critical power stations or substations, I became more broadly interested in studying the relationship between socioeconomic status and the probability of areal redundancies in the power grid.

To assess the relationship between network measures within the U.S. power grid and socioeconomic "vulnerability," which I define independent of the canonical social vulnerability index or "SVI" from related literatures in Geographic Information Systems and Developmental Economics alike. For the former, I use power transmission network information including substations, generation facilities, transmission lines, and consumer/supplier coverage regions. All power data is provided courtesy of the United States Department of Homeland Security and includes data through the end of 2018 as of the writing of this report. Population density per square kilometer from the Oakridge National Laboratory's global gridded population density information matched to the same time period as all other socioeconomic datasets (*i.e.,* 2018).

MOTIVATION

From February 14th through February 19th, a series of winter storm events causes cascading power failures across much of Texas, Arkansas, Louisianna, and other south-eastern regions. Despite having been caused by antiquated infrastructure, largely linked to “iced” natural gas pipes that were not able to meet demand significantly increased demand during near-polar conditions, Texas’ unique decentralized energy grid contributed to a meta natural disaster in which residents queued for hours in freezing temperatures to access basic items such as fuel or propane to cook food and remain warm at home.

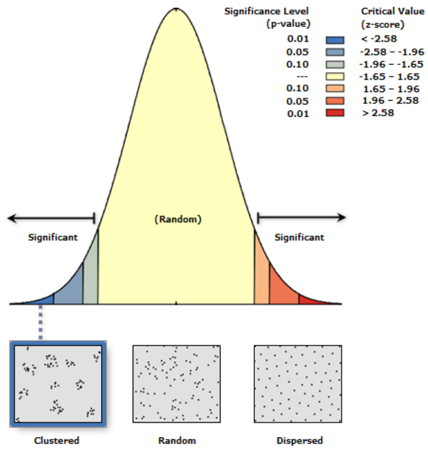
For my research, I examine the structure of the power grid using transmission line and substation network data to construct a geospatial network dataset, linking it to both the underlying population layers.

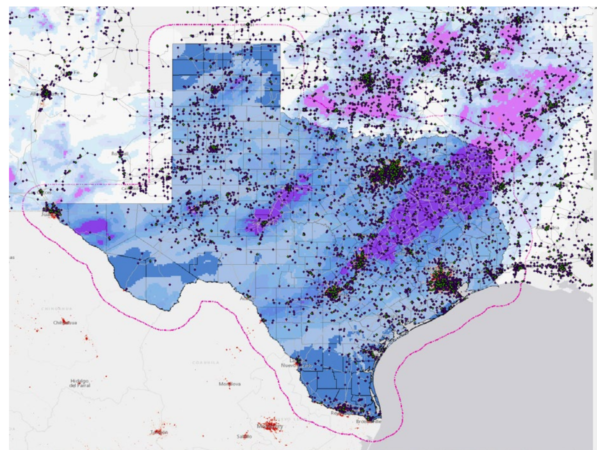
INITIAL DISTRIBUTION OF POWER SUBSTATIONS

First, to test a preliminary hypothesis that the distribution of power substations across the state of Texas is uniform. An Average Nearest Neighbor procedure run on the spatial positioning of power sub-stations strongly rejects the hypothesis of uniformly distributed stations, finding instead that power stations are highly clustered. This is, of course, not an unexpected result as the state’s population and therefore its internal energy demand is highly concentrated within several key urban sprawls in the central and eastern portions of the state, with few high-demand areas in the wester n and southern portions of the state. \

WINTER PRECIPITATION ACCUMULATIONS

The data for winter snow and ice accumulation was difficult to track down for Texas. Most sources only provided daily *new* accumulation amounts. However, citing a slow state-wide winter storm response and sub-zero temperatures prohibiting natural melting of frozen precipitation, I assumed for this project that total accumulations were likely to be a moving sum of precipitation to-date from the start of the winter storm event on February 14th. Therefore, I have mapped total accumulations across the time period, which ranges from 0" to over 68.1" in total snow and/or ice.





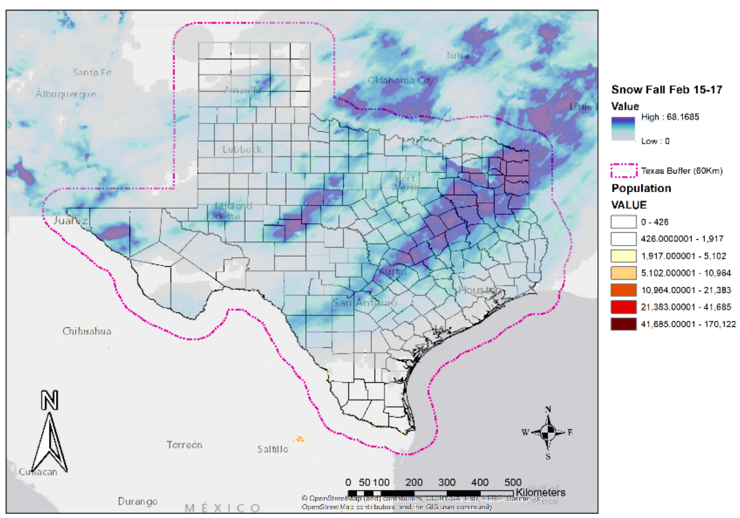


Figure 1 –(Left) Average Nearest Neighbor Statistic for Power Distribution Substations in Texas. The results here indicate that the distribution is highly concentrated. (Right) The state of Texas colored to reflect population by dot-density (black), social vulnerability scores per county are given in shades of blue with darker shades corresponding to more socioeconomically vulnerable regions. Finally, the pink and purple swatches reflect the path of highest average precipitation during the February 2021 winter storm events, as well as highlighting the areas in which power transmission systems received the most damage from the natural disaster itself rather than subsequent human error. (Center) Snowfall records from the winter storm event in February, 2021

z-score: -457.342079
p-value: 0.000000
Nearest Neighbor Ratio: 0.102051

Given the z-score of -457.342078984, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Observed Mean Distance:	2193.2343 Meters
Expected Mean Distance:	21491.4718 Meters
Nearest Neighbor Ratio:	0.102051
z-score:	-457.342079
p-value:	0.000000

POWER NETWORK

To better visualize the risks inherent to Texas' power grid, I constructed a network dataset in ArcCatalog using data from the U.S. Department of Homeland Security regarding all power generation stations, substations, and transmission lines for the United States. There is some mismatch in data here as the transmission network information contains records from 2019, but not necessarily current up-to-the-minute records. Given also that the datasets contain entries with different source types (*e.g.,* "IN SERVICE," "PLANNED," "NOT IN SERVICE," *et cetera*) it stands to reason that some stations included in my analysis may not have been in service during the winter storm event but could now register as producing on the grid, or vice versa. However, given that the number of "IN SERVICE" substations and transmission lines vastly exceed the number of any detractor elements in the network, I have chosen to assume the network is, currently, as it was at the time of the winter storm event.

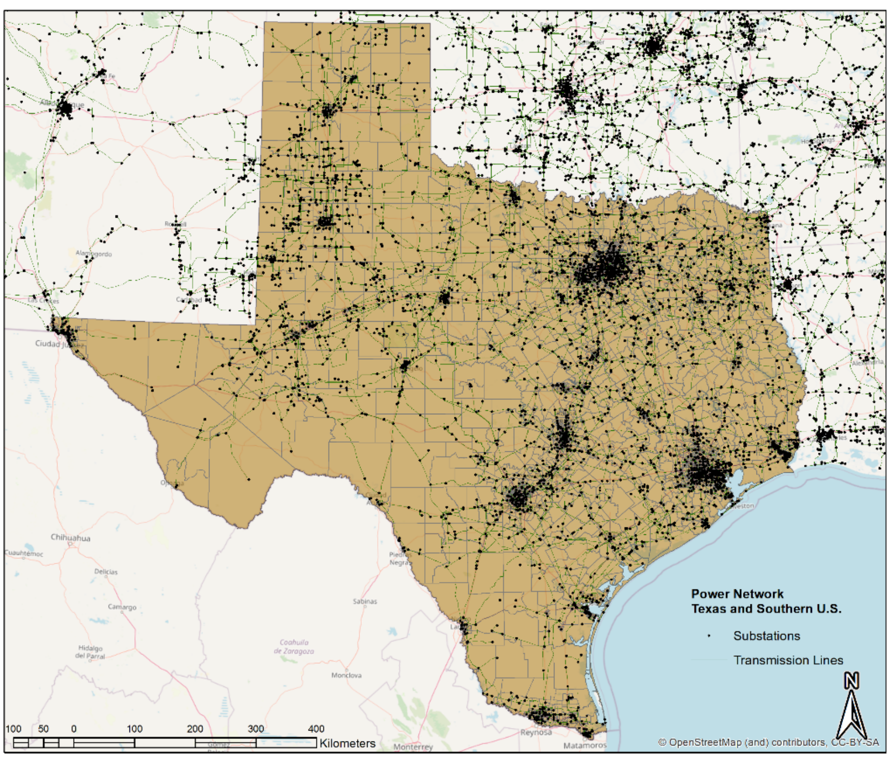


Figure 2 - The power grid within the state of Texas contains significant transmission redundances in the eastern portions of the state, while scare few such "safeguards" exist in the western and southern regions of the state.

Figure 2 above shows that the distribution of power substations and transmission lines matches largely that of the population distribution: highly concentrated around cities in the eastern part of the state.

ASSESSMENT

Given the time and data constraints for this project, many self-imposed, I use the information presented to offer a hypothesis as to why the snow storms in the east contributed a catastrophic failure of the energy grid. Namely, I believe it is likely that transmission lines and natural gas pipelines alike were maintained less frequently than those in the western and southern regions, due to the presence of many network redundancies to carry excess load should energy demand spike. However, in areas that did not have such redundancies, maintaining and weatherproofing the limited existing energy infrastructure would be a higher-priority item for local populations who may rely on them for support during a largescale weather event.

REMAINING AGENDA

This project is left wholly incomplete. However, there is significant room to grow. Using the American Community Survey data, supplemented with social data provided by NASA through the LULC family of datasets, I can map social vulnerability indices and socioeconomic factors more directly to the map in order to search for relationships between economic vulnerability and social characteristics such as race, gender, sex, level of education, immigration status, as well as geographic features.