Anticipatory Planning for Resilient Electric Vehicle Charging Services Under Coastal Hazards with Counterfactual Analytical Framework

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Motivation & Context

Vehicle electrification is a common climate mitigation strategy

- Promotion of Electric Vehicle (EV) requires better-planned EV charging stations (EVCSs) network for public use.
- Vehicle electrification challenges specific user groups (e.g., older adults, multi-family residents)

Climate-related Extremes increase adaptation demands of EVCS

- Sep. 28th, 2022, Hurricane Ian made landfall in southwestern Florida at category 4 intensity
- EVCSs and road network are vulnerable to the resulted hazards (e.g., winds and floods)

Resilience of EV Charging Network: Sustainable service flow between **EVCSs** and **User** under extremes.

Research Aim and Objectives

- Explore characteristics of BNEU that affect the resilience of public EV charging access to users under disturbances of Hurricane Ian hazards
- Anticipate how counterfactual worse-case scenarios of hurricane hazards would influence the BNEU resilience and mediate the effects

Method

A Framework of Tropical Cyclone Disturbances on Bipartite Network of EVCS and User

How Tropical cyclones could disturb the flow of EV charging service?

- Direct damage on EVCSs (with winds and floods).
- Impeding the station-user interactions along road networks.

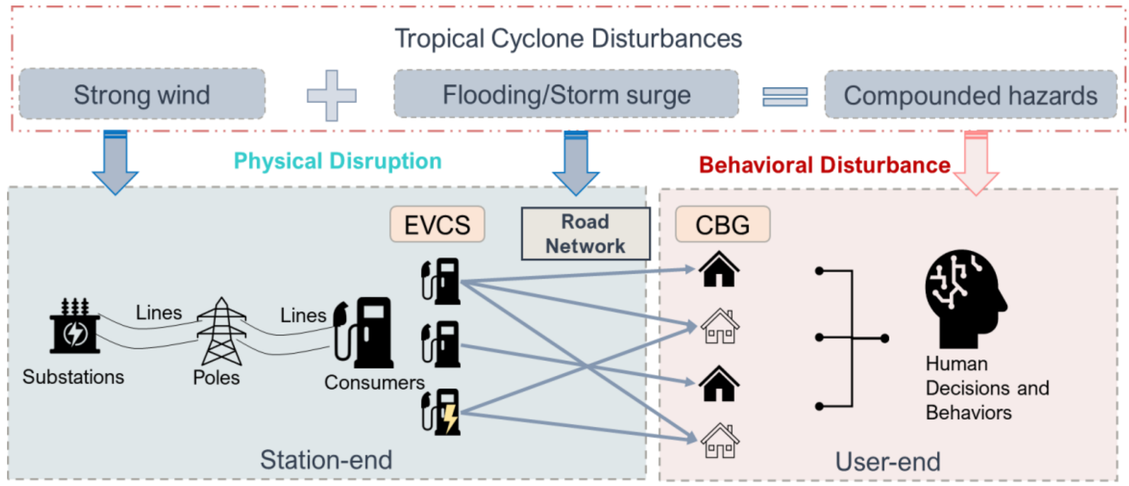


Fig.1. Bipartite Network of EV charging stations and Users (BNEU)

Counterfactual Analysis with MABM

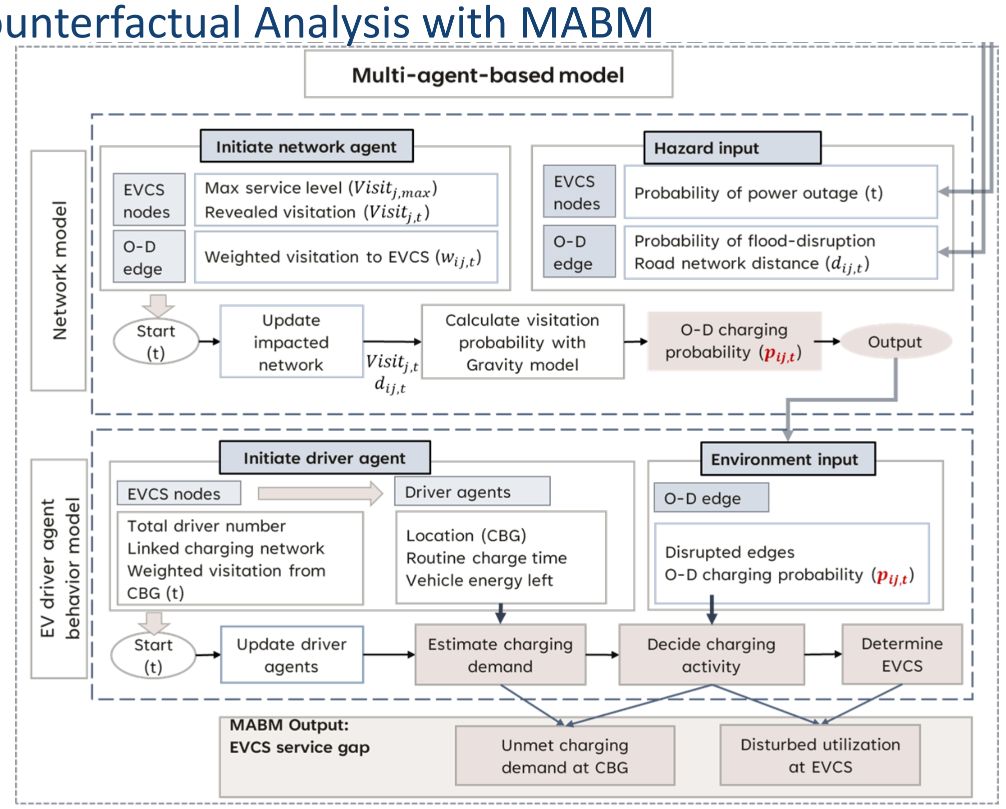


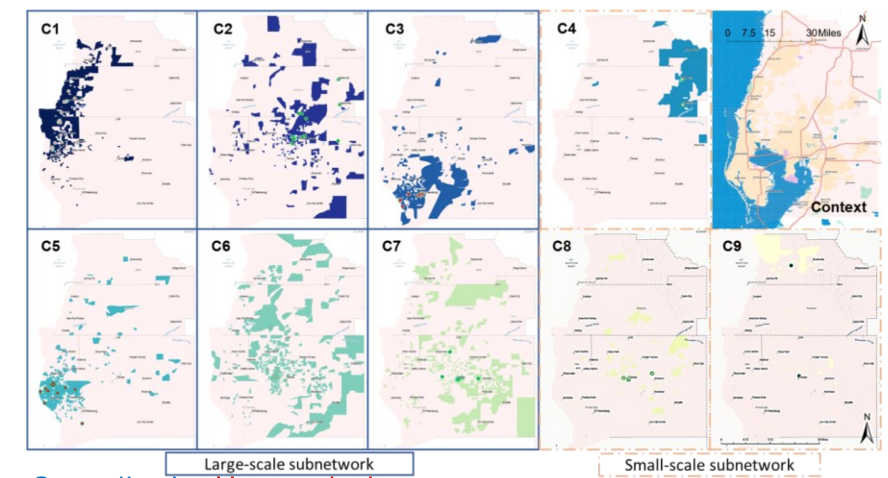
Fig.2. Flow of multi-agent-based simulation for refueling behaviors under hazards

Results

$$R_X = \frac{edge^{loss} - edge^{disrupt}}{edge^{loss}}$$

Sub-net	R_X
C1	2.784
C2	2.514
C3	2.153
C5	1.690
C6	1.598
C7	1.212
C4	1.834
C8	1.080
C9	1.034

Node number Centralization User-node degree



Centralization User-node degree Ratio

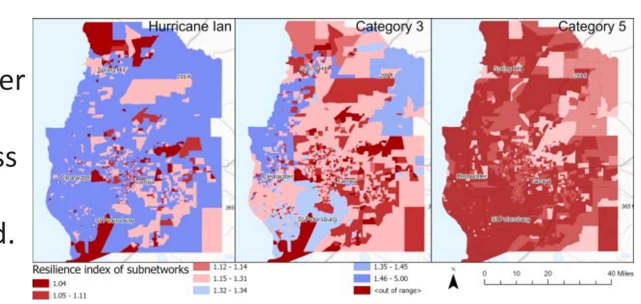
Tested features	Resilience measures of user-centric nodes			
	Correlation coef.		OLS regression coef.	
	Service gap	Recover speed	Service gap	Recover speed
Node degree	0.682***	0.423***	39.604***	0.270***
Average edge access	-0.369***	-0.371***	0.046	-0.001***
Average user adjacency	-0.366***	-0.208***	0.583	-0.005***
2 more vehicle	0.130***	0.012	-1231.76	0.009***
Median Income	0.077***	0.088***	62005.346	770.16***
Age > 65	-0.064**	-0.110***	-0.321	-0.005***

Tested features	Resilience measures of station-centric nodes			
	Correlation coef.		OLS regression coef.	
	Charging activity	Recover speed of usage	Charging activity	Recover speed of usage
Node degree	0.243 **	0. 200**	66.410	0.976
Average edge access	-0.245 **	-0.320**	-0.015	-0.161***
Average user adjacency	-0.172*	-0.168*	-0.032*	0.000
Bldg. height nearby	-0.192 *	-0.208*	-17.208	0.199
DCFC Port installed	0.180 *	0.189*	0.228	-0.005

Note. * p <.05. ** p<.01. *** p<.001

- Higher node degrees, dispersed network structures and longer distances occurred with higher resilience of BNEU, improving both station utility and user access.
- EVCSs with DCFC (Fast charging) ports and locating in less dense urban area are more resilience.
- Among all tested age groups, high proportion of older adults (i.e., aged over 65.) is related to less resilient access to BNEU

Node-level:
Intense hazards do not alter BNEU resilience features
Inequitable charging access for low-income and older adults would be magnified.



Subnetwork resilience:
The transaction of vulnerable subnetwork from inner-land suburban areas to coastal neighborhoods.
For moderate hurricane hazards (Category 3), a smaller decentralized network more resilient.

Implications

- BNEU framework generalizable to coastal communities with high risks of environmental hazards yet have limited historical experience to anticipate unseen vulnerabilities.
- Counterfactual analytical framework enables forward-looking proactive planning in response to climatic risks and electrifying vehicles

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