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Chih-Wei Hsu[1*]

KEYWORDS—*electric vehicle, public charging stations, geospatial, service area analysis*

INTRODUCTION—The transportation sector accounts for a third of the total greenhouse gas (GHG) emissions in the United States and 41% of GHG emissions in California (California Air Resources Board, 2018; US Environmental Protection Agency, 2018). The transportation sector GHG emission is greater in rural counties per capita, owing to higher vehicle ownership rates, less comprehensive public transportation systems, and longer trip distances (Federal Highway Administration, 2017; Tamayao, Blackhurst, & Matthews, 2014). In Humboldt County, a mostly rural county, approximately 54% of all GHG emissions came from transportation in 2006 (County of Humboldt, 2012). Addressing high emissions from the transportation sector will play a critical role in achieving California's climate goal of an 80% emissions reduction from 1990 levels by 2050.

Without dramatically changing the conventional auto-centric view of mobility in the United States, in northern California the most cost-effective near-term way to reduce the transportation sector GHG emissions is by electrifying the vehicle fleet (Fingerman, 2018). California has been a leader in promoting Zero Emissions Vehicles (ZEV) and the recent executive order B-48-18, Zero Emissions Vehicle Executive Order, committed California to adopt five million ZEVs by 2030. There are approximately 30.6 million vehicles registered in California; of that, 26.9 million vehicles are in non-rural counties (California Department of Motor Vehicles, 2018a). It is possible for California to achieve the five million ZEV goal in non-rural counties alone, however, the ZEV adoption should be equitable, with benefits spreading across demographic and geographic locations. Furthermore, under policies such as California's Low Carbon Fuel Standard, a lopsided ZEV adoption toward urban areas would result in rural areas subsidizing the urban low carbon fuel uptake (Fingerman, 2018). Beyond the GHG reduction benefits, electric vehicle (EV) adoption creates societal benefits. Direct benefits include reduced transportation expenses, such as fuel and maintenance costs. Other less understood benefits include local economic development and grid stabilization potential (Malmgren, 2016).

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To achieve an equitable EV adoption across demographic groups, price barrier and range barrier (more prevalent in used EVs), among others, would need to be overcome. Although financial incentive programs such as Clean Vehicle Rebate Project and Federal Tax Credit help lower the purchasing cost of electric vehicles, the post-incentive price of a new EV is still prohibitive to low-income households. This is evident through the Clean Vehicle Rebate Project survey. Of the survey respondents, 95% of EV owners have an annual household income higher than $50,000 and 76% of EV owners have an annual household income higher than $100,000 (Center of Sustainably Energy, 2017). Another study shows new EV owners have an average household income of $227,000 and used EV owners had an average household income of $173,400 (Turrentine et al., 2018). There are few programs such as the Electric Vehicle Assistance Program that are aimed at increasing EV adoption in low-income families, but no comprehensive plan has been developed both statewide and regionally in the North Coast. If policies were to be designed to increase EV adoption in rural low-income families, lower cost used EVs are likely to be the focus. However, the nascent used EV market does not offer many vehicle options currently. A first generation used EV has a lower price barrier but comes with limited range (e.g. used 2011–2016 Nissan Leaf with 50 to 70 miles of range [Plug-in America, n.d.]) thus creating a higher range barrier.

One way to lower the range barrier is to have a reliable and expansive public charging network. This study investigates the current public charging network comprehensiveness in Humboldt County by analyzing the public EV charging station service area coverage using the Network Analyst Tool in ArcMap. The result of the analysis will provide both visual and quantitative representations of the public EV charging network and identify the coverage gap for relatively high building density areas in Humboldt County.

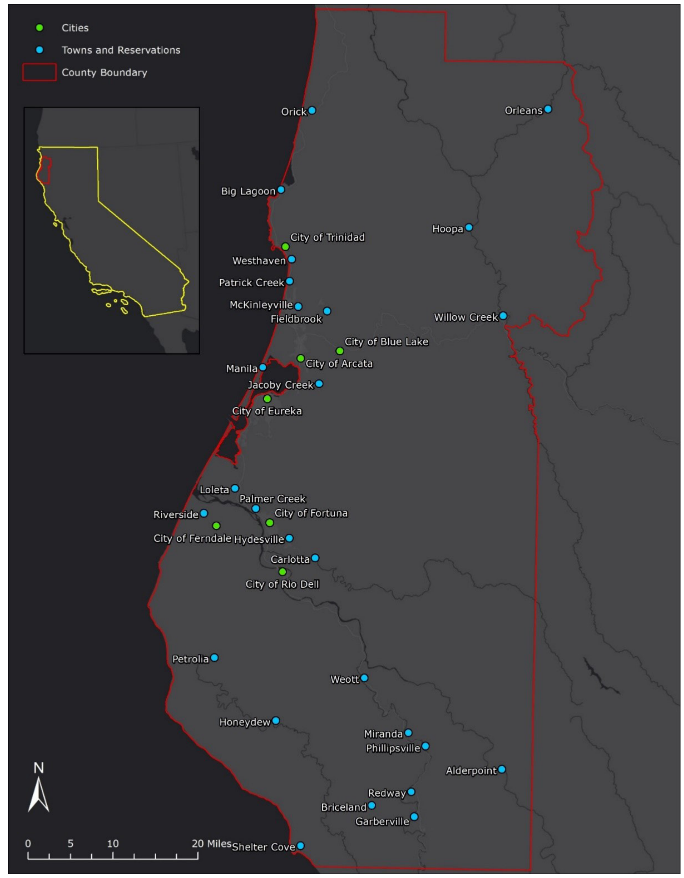

FIGURE 1. Humboldt County Map.

METHODS—*Data sources*. Geospatial data of Humboldt County used for the project includes Microsoft building footprint from GitHub (open source), the road way centerline, city, community service district, and county boundary shapefiles from Humboldt County Geospatial Information System Department website, digital elevation model raster files from US Geological Survey's The National Map website, public electric vehicle charging station locations obtained from Department of Energy's Alternative Fuels Data Center, and the 2017 Local Area Transportation Characteristics for Households survey data from Bureau of Transportation Statistics.

Service area analysis. Service area analysis on Humboldt County charging stations was done in ArcMap with the Network Analyst toolset extension. There were two types of service areas, one based on the traveling time and one based on traveling distance. The following steps were used to create the Humboldt County public EV charging station network file. First, Z (elevation) information was added to the road way centerline polyline shapefile with the mosaiced digital elevation model raster file using the Add Surface Information tool. Then, in the attribute table, the travel time for each road section was calculated by dividing the road section length by the speed limit. Finally, network file was created using the road way centerline file with the road length and travel time as cost attributes.

To perform the service area analysis, a new service area layer was created and the EV charging stations point shapefile was added as "facilities." For the travel time service area analysis, the default breaks in the analysis setting were set to 5, 15, 30, and 60 minutes. For the travel distance service area analysis, the default breaks in the analysis setting were set to 5, 15, 30, and 60 miles. For both analyses, travel direction was set as "towards facility." Finally, service area polygons buffered (called "Trim Polygons" in analysis setting) to 0.25 miles from the roads were generated for each analysis.

The portions of total buildings in the county covered by the current EV charging station service areas—both travel time and travel distance service areas—were calculated. This was done by dividing the number of buildings located within a given distance (i.e., 5, 15, 30, or 60 mi) or within a given traveling time (i.e., 5, 15, 30, or 60 min) from all EV charging stations by: a) the number of buildings in each city or town and b) the total number of buildings in the county.

Building density analysis. Microsoft building footprint GeoJSON file was read in as polygon shapefile first and then converted to point shapefile. To analyze the building density, the point shapefile was converted into a raster file using Point Density tool with building density per square-mile as the variable. The settings used for the tool were the following: "NONE" for the population field, 337.19 meters for the cell size setting, circle for the neighborhood setting, and 907.78 meters for the radius setting (to calculate the density per square mile).

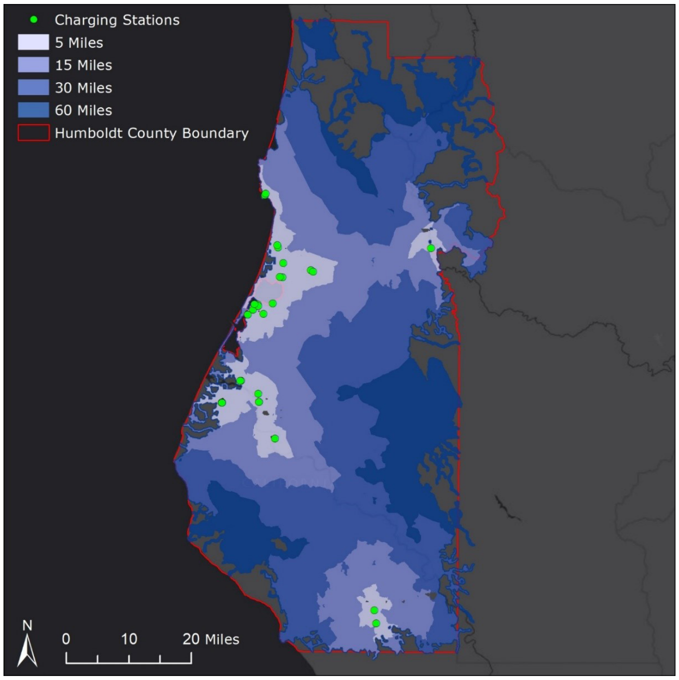

FIGURE 2. Public EV charging station service areas in Humboldt County based on traveling distance to each station. The grey areas within the county boundary indicate areas beyond the 60-mile service coverage.

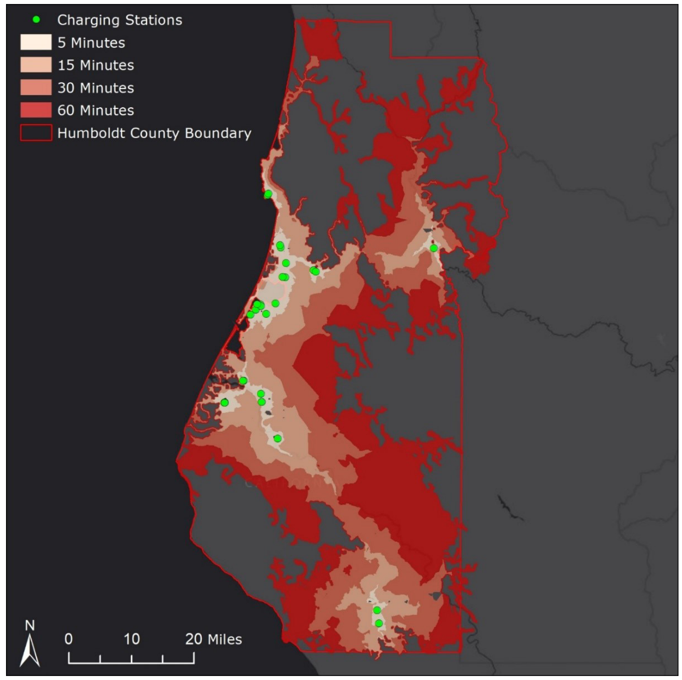

FIGURE 3. Public EV charging station service areas in Humboldt County based on travel time to each station. The grey area within the county indicates areas beyond the 60-minute service coverage

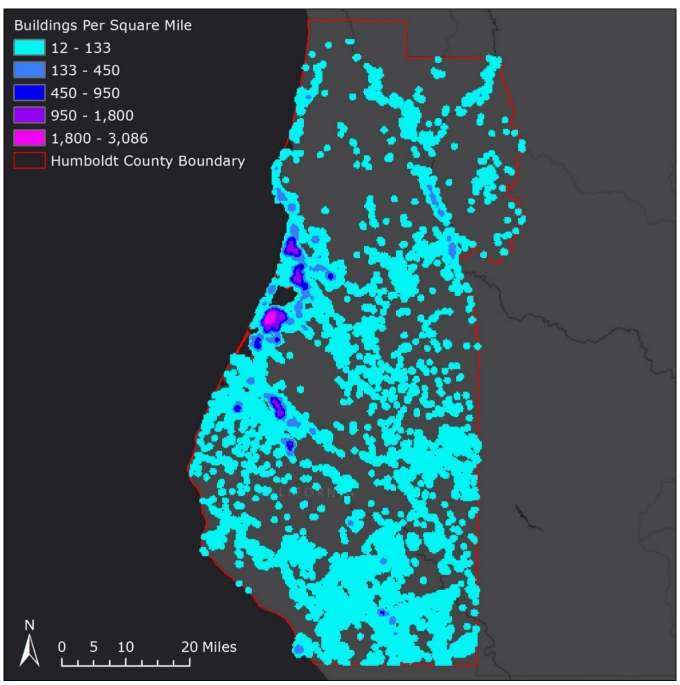

FIGURE 4. Building density map of Humboldt County. Grey shading indicates areas with less than 12 buildings per square mile.

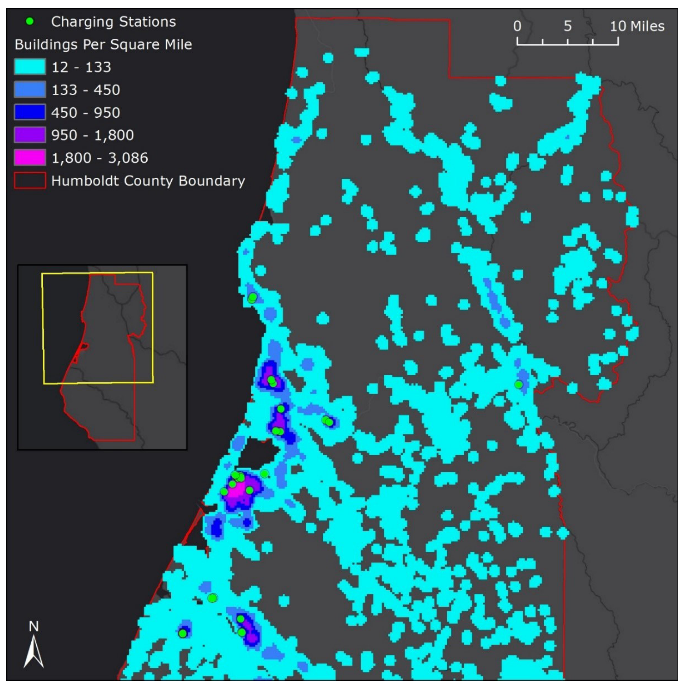

FIGURE 5. Public EV charging station locations overlaid with building density for northern Humboldt County. Areas with less than 12 buildings per square mile are in grey.

RESULTS—Humboldt County's 31 public EV charging station locations are located mainly in McKinleyville, the Humboldt Bay (Eureka-Arcata) area, and towns around Eel River (i.e., Loleta, Ferndale, and Fortuna) with the exception of Willow Creek, Blue Lake, Trinidad, Rio Dell, Garberville, and Benbow (FIG 1 & 2).

Service coverage by travel distance. At the five-mile service area level, service coverage (in terms of percent buildings covered) reaches 76%—approximately three in four buildings—county wide (TABLE 1). At the thirty-mile service area level, the EV charging station service network is connected across the county (FIG 2) and service coverage reaches 96% county wide (TABLE 1).

Service coverage by traveling time. The five-minute EV public charging service area level covered 62% of buildings in the county. At the thirty-minute EV public charging service area level, 91% of buildings in the county are covered and the service areas are connected across the county (FIG 3 & TABLE 1).

Service coverage and building density. Public EV charging stations in the county are located in areas with relatively high building density, however, not all areas with relatively high building density have public EV charging stations. Building density is highest in Humboldt Bay area (Eureka-Arcata), McKinleyville, and Fortuna (FIG 4). In addition to the aforementioned areas, public EV charging stations are also found in Trinidad, Blue Lake, Willow Creek, Ferndale, Rio Dell, Loleta, Garberville, and Benbow, just south of Garberville (FIG 5 & 6).

Service coverage gaps. For the purpose of the analysis, a high building density area is defined as areas with greater than 200 buildings per square mile. In the county, Hoopa, Miranda, and Shelter Cove are the only towns with high building density areas that are not covered by the five-minute and five-mile level public EV charging service area (FIG 7–10). Shelter Cove is the only town with high building density areas that are not covered by the fifteen-minute level public EV charging service area (FIG 8 & 10).

DISCUSSION—Based on the service area analysis result, more than three quarters, 76%, of the buildings in Humboldt County are within a five-mile distance of a public charging station and 62% within a five-minute travel time of public charging stations. This suggests that the public EV charging station coverage in Humboldt County is serving a majority of the buildings and population, however, not without some areas left behind. The

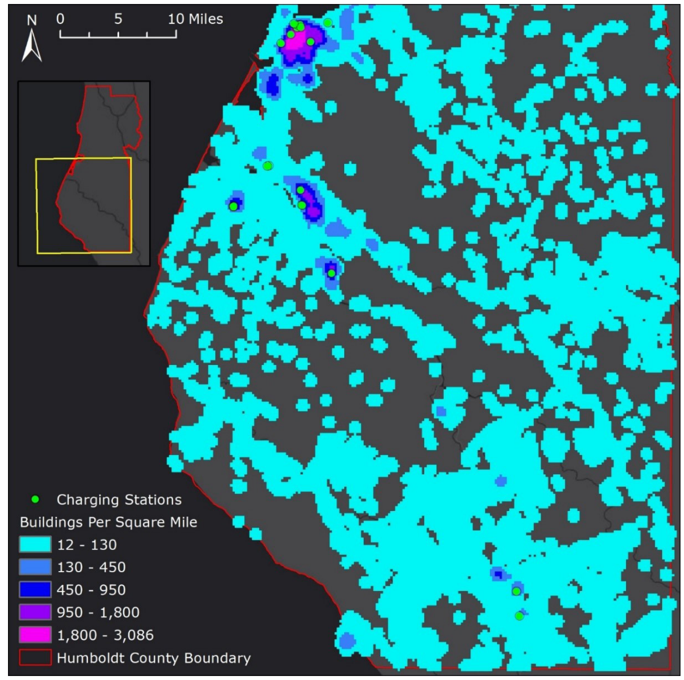

FIGURE 6. Public EV charging station locations overlaid with building density for southern Humboldt County. Grey shading indicates areas with less than 12 buildings per square mile.

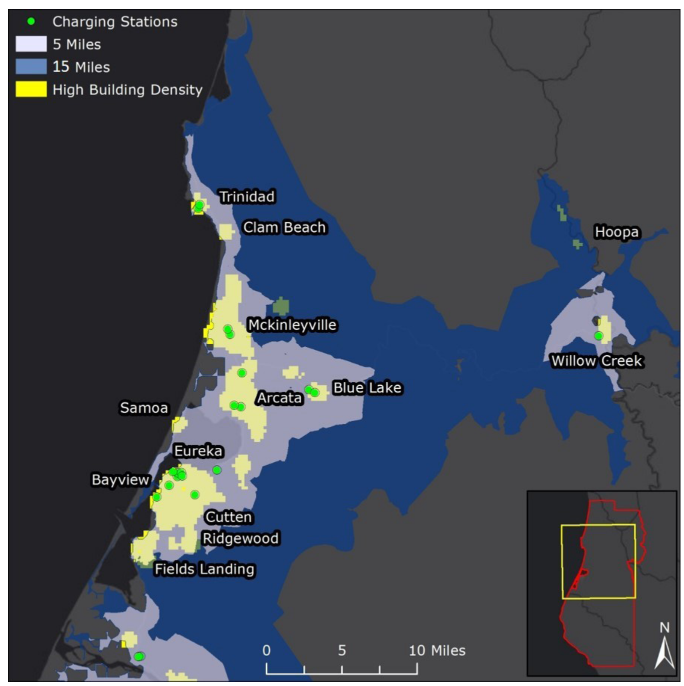

FIGURE 7. Northern Humboldt County high building density areas and public EV charging station coverage at five- and fifteen-mile level. Grey shading indicates areas beyond fifteen-mile service coverage.

Hoopa reservation, Miranda, and Shelter Cover are three high building density areas outside of the five-minute and five-mile EV public charging service coverages. Furthermore, there is currently no EVs registered in Hoopa (California Department of Motor Vehicle, 2018b). As EV market penetration increases, areas such as Hoopa will likely need public EV charging stations locally to support the local EV adoption.

A first generation used EV (FG-EV) has an approximate 60-mile range. Based on the 30- and 60-mile service area result, it is possible, however not necessarily practical, for the FG-EV to travel throughout the county. The 30-mile service area map (FIG 2) shows the round-trip limit for the FG-EV. To make longer travel by FG-EV

TABLE 1. Public EV charging station service area coverage, in terms of buildings covered, for cities and towns in Humboldt County based on distance and travel time. Note county-wide summary includes buildings located in other unincorporated areas (i.e. not in the following cities and towns). CSD stands for community service district.

Name	Total Buildings	Five Mi (%)	Five Mins (%)	Fifteen Mi (%)	Fifteen Mins (%)	Thirty Mi (%)	Thirty Mins (%)
Alderpoint	194	0	0	0	0	100	50
Arcata	27,030	100	23	100	49	100	74
Big Lagoon	334	0	0	97	32	100	66
Blue Lake	3,218	100	25	100	50	100	75
Briceland	123	0	0	100	33	100	67
Carlotta	1,395	0	0	100	26	100	63
Eureka	72,717	100	21	100	48	100	74
Ferndale	3,294	99	25	99	50	99	75
Fieldbrook	3,416	46	8	100	38	100	69
Fortuna	21,869	100	24	100	49	100	75
Garberville	1,994	100	21	100	48	100	74
Hoopa	2,912	0	0	87	19	100	59
Humboldt CSD	31,387	96	16	100	44	100	72
Hydesville	2,328	32	0	99	33	99	66
Jacoby Creek	1,973	90	7	100	38	100	69
Loleta	1,248	100	25	100	50	100	75
Manila	1,527	95	5	100	36	100	68
McKinleyville	27,034	99	23	100	49	100	74
Miranda	566	0	0	100	31	100	66
Orick	763	0	0	19	4	100	51
Orleans	264	0	0	0	0	0	0
Palmer Creek	668	100	25	100	50	100	75
Patrick Creek	54	100	0	100	33	100	67
Phillipsville	291	0	0	100	33	100	67
Redway	2,296	97	14	98	43	98	71
Rio Dell	6,045	100	25	100	50	100	75
Riverside	644	89	19	99	46	100	73
Trinidad	1,344	100	25	100	50	100	75
Weott	336	0	0	0	0	100	50
Westhaven	1,267	100	25	100	50	100	75
Willow Creek	3,912	98	19	100	46	100	73
County Wide	**68,405**	**76%**	**62%**	**88%**	**83%**	**96%**	**91%**

more practical, more public direct current fast chargers would need to be installed, however, not all FG-EV are compatible with fast chargers. The new model EVs provide more than 200 miles from a single full charge; thus range barrier does not post an issue for traveling within the county.

Although there is a temporal aspect—service areas based on traveling time—of this study, it does not investigate the charging time nor the delay in travel time based on charging station capacity (i.e. available plugs versus EV charging demand). To better understand the adequacy of the county's public charging infrastructure in this regard, EV travel modeling would need to be performed. An example of electric vehicle modeling has been done by the Schatz Energy Research Center (Schatz Energy Research Center, 2013).

The analytical method of this study can be applied in future studies to shed light on the relationship between EV adoption and charging network coverage to better understand the driving factors for EV adoptions.

CONCLUSION—EV adoption has multiple barriers;

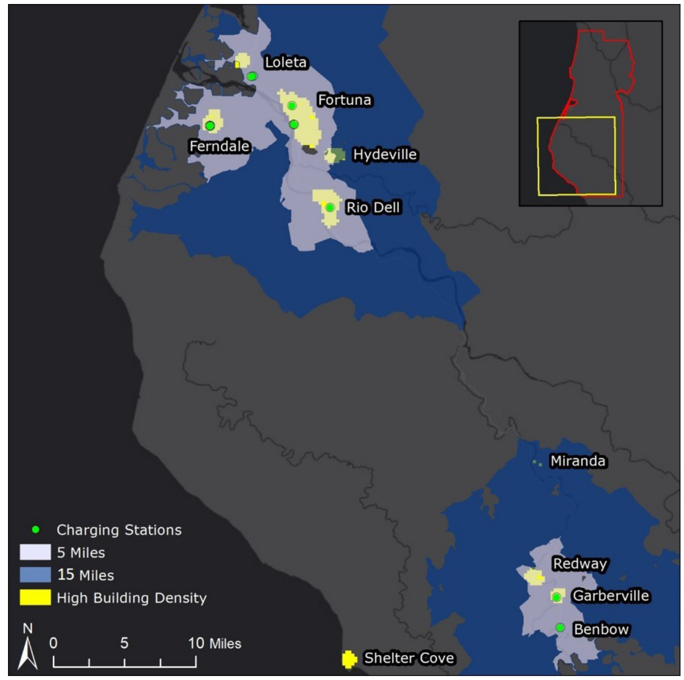

FIGURE 8. Southern Humboldt County high building density areas and public EV charging station coverage at five- and fifteen-mile level. Grey shading indicates areas beyond fifteen-mile service coverage.

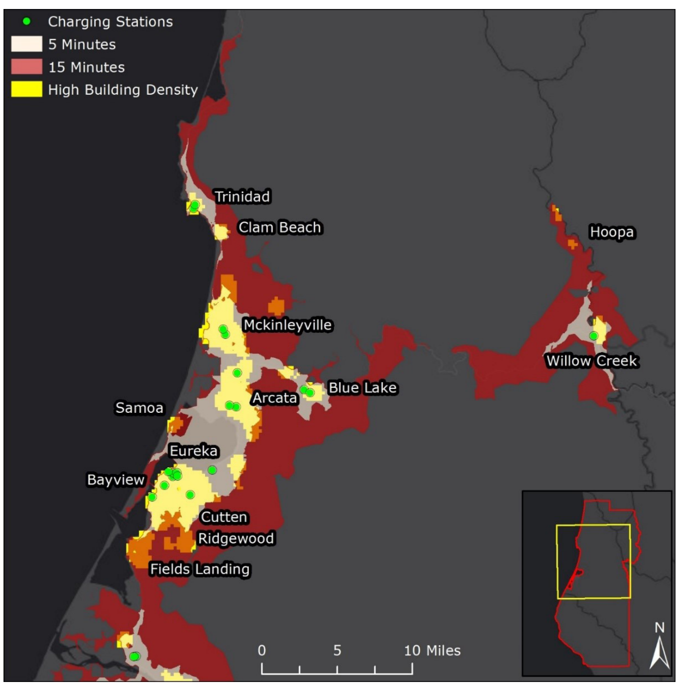

FIGURE 9. Northern Humboldt County high building density areas and public EV charging station coverage at five- and fifteen-minute level. Grey shading indicates areas beyond fifteen-minute service coverage.

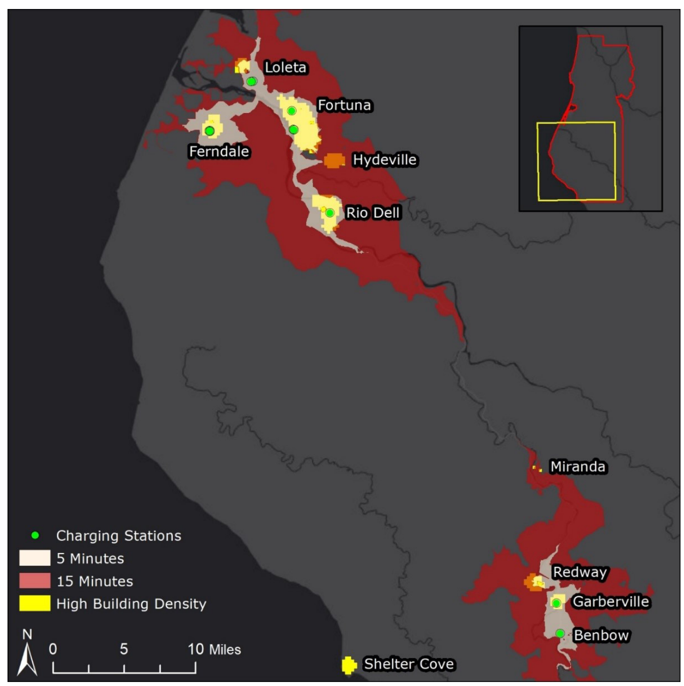

FIGURE 10. Southern Humboldt County high building density areas and public EV charging station coverage at five- and fifteen-minute level. Grey shading indicates areas beyond fifteen-minute service coverage.

this study focused on the range barrier by investigating the public EV charging station coverage in Humboldt County. The study found over 60% of buildings in the county are either within five minutes or five miles of travel from a public charging station. The study also found that Hoopa, Miranda, and Shelter Cove are the only areas with more than 200 buildings per square mile that are not currently within five minutes or five miles of travel from a public charging station. As EV market penetration inevitably increases, there may be a need to expand the public charging network to these areas.

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