UNIVERSITY of WASHINGTON

Powering the last mile: Distributed & Equitable Charging for Electric Three Wheelers in Kolkata, India

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BACKGROUND & MOTIVATION

83 cities exceed air quality by 10x
including Delhi, Kolkata, and Mumbai, according to the World Health Organization's guidelines

Transportation accounts for 14% of energy-related emissions
in India according to a report published by NITI Aayog

India's Fossil Fuel Dominated Electricity Supply

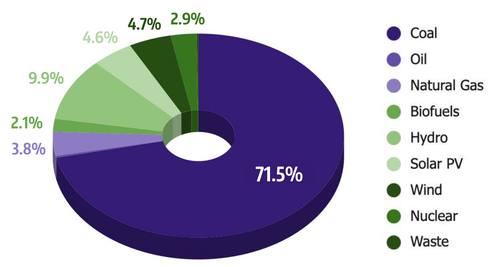


Figure 1: As electric vehicle penetration increases, charging infrastructure that is grid-tied would mean vehicles are **charging from a 'dirty' grid**.

Electric Vehicle Type Distribution in West Bengal

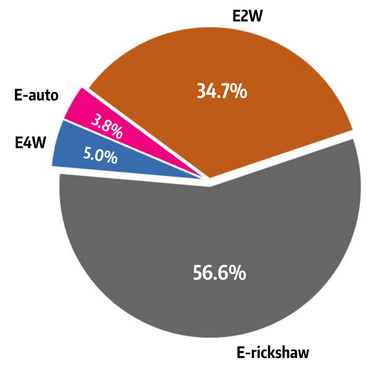


Figure 2: Electric three wheelers make up more than **half the share of all registered electric vehicles** in West Bengal, India.

Why Three Wheelers?

Figure 3: Three wheelers currently exist in three different forms in Kolkata. The most common is the diesel-operated autorickshaw (left). The two electric counterparts are the toto (center) and the e-rickshaw (right).

Demand Responsive; fixed & flexible Routes; first & last mile connectivity
Lower power requirements for charging; less grid strain / congestion
Job opportunities for the low-income; improved livelihoods

RESEARCH OBJECTIVES

Determine the techno-economic feasibility of distributed, off-grid charging infrastructure for electric three wheelers in Kolkata, India.

Objective 1
Determine how three-wheeler charging stations can be spatially and equitably distributed to expand their last-mile services from/to major public transit

Objective 2
Determine the economic advantages and disadvantages of distributed charging infrastructure for three wheelers in comparison to centralized charging.

STUDY REGION

ROI in West Bengal

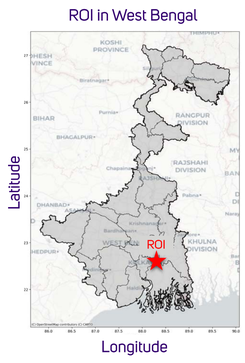


Figure 4: The region of interest (ROI) for this study is Kolkata and its adjacent villages as indicated on the map on the state of West Bengal. The administrative boundaries follow the following order: state, district, sub-district, block, village. All **data is analyzed and disaggregated at the village level granularity**. The **Kolkata urban core** region is further **disaggregated into wards**.

METHODOLOGY

Spatial Analysis
Disaggregate socioeconomic variables and features into village-level granularity for area of interest (AOI)

- Population Size
- Relative Wealth Index
- Distance to Transit
- Mode of Travel

Site Scoring
Develop scenarios to weight variables to determine equitable spatial distribution of charging infrastructure

- Contiguous, undeveloped land
- Population + Wealth
- Distance to Transit
- Latent 3W Demand

System Sizing
Determine the number of batteries that can be charged based on PV system size subject to land availability

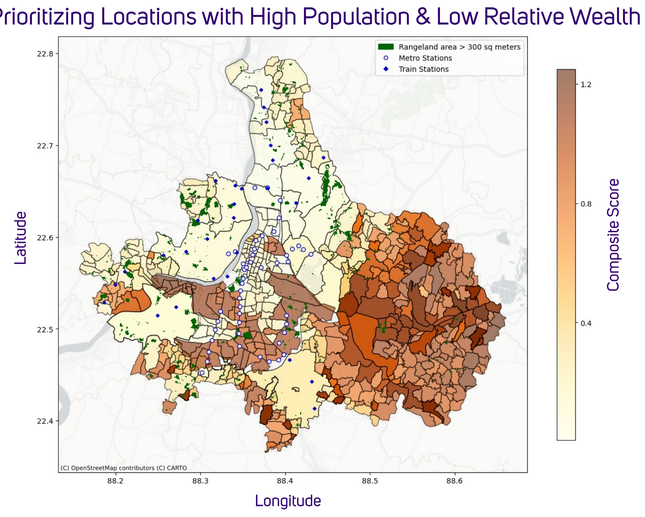
- PV System Size
- Battery Type
- Battery Specifications

INFRASTRUCTURE SITING

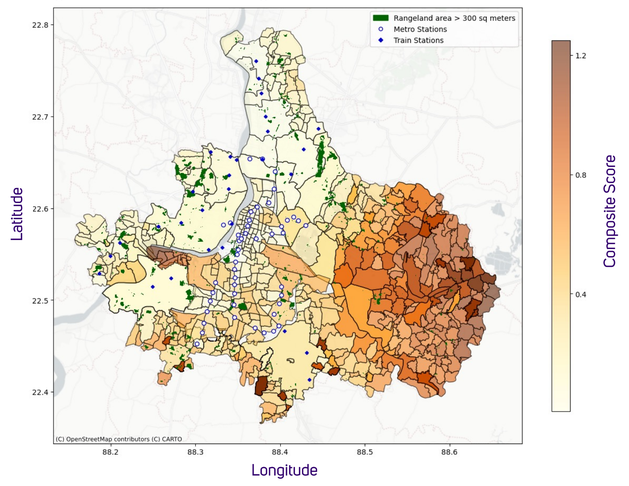
Table 1: Three key variables and features were prioritized to ensure siting of charging infrastructure was distributed equitably in spatial coverage. Each village and ward was assigned a composite score based on different weights assigned to each feature. Three different scenarios were tested with higher weights assigned to one specific feature. A **higher weight assignment implies prioritizing a specific feature to promote spatial equity**.

	Population & Relative Wealth Index	Distance to Transport	Latent 3W Demand
Scenario 1	**0.75**	0.25	0.25
Scenario 2	0.25	**0.75**	0.25
Scenario 3	0.25	0.25	**0.75**

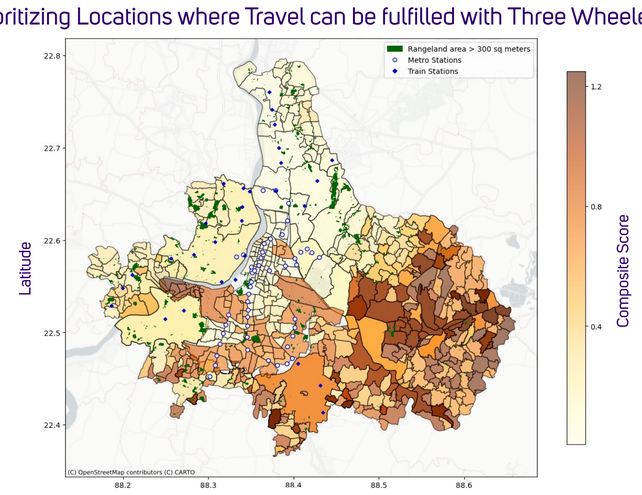
Prioritizing Locations with High Population & Low Relative Wealth



Prioritizing Locations with Longer Distances to Train & Metro Stations



Prioritizing Locations where Travel can be fulfilled with Three Wheelers



CHARGING SYSTEM

Figure 5: E-rickshaws will typically have dedicated overnight parking facilities as illustrated in the photo. These makeshift garages present an **opportunity to implement solar-based charging** where batteries charged during the day can be swapped overnight with discharged batteries reducing the need for grid-tied electricity.

PV-Based Battery Charging Algorithm

Annual Hourly PV Output + Battery Specifications + Random Normal SoC

For each hour of each day determine the PV output
↓
If PV output > 0, random choice initial SoC assigned to battery
↓
If SoC < 1 and enough PV energy available to charge, deliver hourly charging energy to battery
↓
Update battery SoC
Calculate remaining PV energy
↓
If battery SoC > 0.8, stop charging battery and count towards total batteries charged

Table 2: A solar-based charging system was modeled for different system sizes. Literature has typically shown solar charging garage capacities ranging between 30 kW and 50 kW. However, due to the urban travel patterns of three wheelers, land availability is a large concern for siting solar-based charging. Contiguous, undeveloped land is necessary for siting PV modules and thus system sizes were appropriately selected to account for this siting constraint.

PV System Size	Approximate Land Area Required	Average Batteries Charged Daily	Maximum Batteries Charged Daily	Total Batteries Charged Annually
15 kW	100 m^2	8	27	3,134
30 kW	200 m^2	16	39	6,191
50 kW	300 m^2	27	61	10,209

NEXT STEPS

Distributed, off-grid charging

Economic analysis and comparison for implementing distributed, off-grid charging vs. grid-tied charging in charging garages, fueling stations or residential charging
(NPV, ROI, Charging Price, Operator Costs)

Grid-tied charging