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GreenRide: A Real Time Ride Hailing and Smart Campus Mobility System for Solar Powered Electric Tricycles at a Nigerian University, with Fleet Simulation on Real Campus Map and Solar Data

Nnaemeka Ugwumba

nnaemeka_ugwumba@uniport.edu.ng

University of Port Harcourt https://orcid.org/0009-0000-2493-9846

Clement Barisua Ndeekor

clement.ndeekor@uniport.edu.ng

University of Port Harcourt, Port Harcourt, Nigeria

Ilodigwe Nzube Emmanuel

University of Port Harcourt, Port Harcourt, Nigeria

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Clement Barisua Ndeekor
clement.ndeekor@uniport.edu.ng
Department of Computer Science, Faculty of Computing
University of Port Harcourt, Port Harcourt, Nigeria

Nnaemeka Kingsley Ugwumba
nnaemeka_ugwumba@uniport.edu.ng
Department of Computer Science, Faculty of Computing
University of Port Harcourt, Port Harcourt, Nigeria

Ilodigwe Nzube Emmanuel
Department of Computer Science, Faculty of Computing
University of Port Harcourt, Port Harcourt, Nigeria

Abstract

Many African universities are large enough that moving between hostels, faculties, clinics and gates takes a vehicle, yet intra campus transport is often informal. At the University of Port Harcourt, Nigeria, solar powered electric tricycles now carry students inside the campus, but riders find them by waiting at a single charging spot, flagging one down or calling a driver whose number they happen to know. This paper presents GreenRide, a web based ride hailing system for campus solar tricycles, and evaluates how well such a system can serve the campus. GreenRide gives passengers, drivers and administrators separate browser interfaces, matches requests through Socket.io broadcast, shares the driver's live position on an OpenStreetMap map, and stores users and rides in MongoDB behind JSON Web Token authentication with email verification. Because no live fleet was available, we built a simulation of a working day from 07:00 to 19:00 on the real campus, using 193 named campus places and the road network from OpenStreetMap and hourly 2020 solar output for the campus from PVGIS. We compared the informal system with three dispatch rules (GreenRide as built, nearest tricycle, and nearest tricycle with battery checks) across 5 to 30 tricycles, 300 to 1,200 requests per day, and 10 dry season and 10 rainy season days. The informal system never served more than 69 percent of requests, however many tricycles were added. With enough tricycles, GreenRide with nearest tricycle dispatch served every request: at 300 requests per day and 20 tricycles, mean waiting time fell from 9.8 minutes to 4.4 minutes. The broadcast rule now used by GreenRide sent tricycles on long empty trips, about half of all kilometres, and more than doubled waiting time compared with nearest dispatch. When demand exceeded what the fleet could carry, battery energy, not matching, limited the service to about 21 to 24 trips per tricycle per day, and rainy season sunshine, 32 percent lower than dry season sunshine, cut the share served by up to 15 points. We give a fleet sizing rule, a dispatch change and an energy aware charging policy for campus solar tricycle services.

Keywords: smart campus mobility, ride hailing system, solar powered tricycle, electric three wheeler, campus transportation, University of Port Harcourt, Nigeria, real time dispatch, Socket.io, web application, fleet simulation, OpenStreetMap, PVGIS solar data, sustainable transport, sub Saharan Africa

1 Introduction

Travel within a university campus rarely receives the attention given to travel to the campus, yet on large campuses it decides how much of a student's day is spent walking between places [6, 15]. The University of Port Harcourt (UNIPORT) is one of the largest federal universities in Nigeria. Its grounds spread across the Choba, Aluu and Alakahia communities of Obio/Akpor Local Government Area in Rivers State, with hostels, faculties, the health centre, the stadium, banks and three gates scattered over several kilometres. In the road network we extracted for this study, the average road distance between two parts of the campus is 2.3 kilometres and the longest is 5.3 kilometres.

UNIPORT transport works in two layers. Shuttle buses run between parks inside the campus and points outside it, such as the main gate, Choba junction and Alakahia junction. They are not designed to move a student from a hostel to a lecture hall or from one faculty to another. The second layer is newer: solar powered electric tricycles that operate only inside the campus. They are clean and quiet and suit the distances involved, but they run without any coordination. There is one charging spot where tricycles gather, and many students do not know where it is. A student who needs a ride can walk to the charging spot, hope that a tricycle passes and flag it down, or call a driver whose phone number they collected earlier. A student who cannot do any of these walks.

Ride hailing platforms changed urban travel by giving passengers and drivers a shared, real time view of supply and demand [28]. The same idea can be applied inside a campus at much lower cost, because the area is small, the vehicles are few and the users already carry smartphones. This paper presents GreenRide, a web based ride hailing system built for the solar tricycles at UNIPORT. Passengers request a ride from a browser, every available driver receives the request in real time, the first driver to accept is assigned, and the passenger follows the tricycle

on a map until pickup. An administrator dashboard gives the university its first structured record of intra campus trips.

Building such a system raises a question that functional testing cannot answer: how much does it actually improve service for a given number of tricycles, and what limits it? A ride hailing app does not create vehicles. It changes who finds which vehicle and how far vehicles drive empty. Solar tricycles also add an energy limit that petrol vehicles do not have, and that limit changes with the season. Since no live fleet was available for a controlled trial, we built a simulation of the campus from open data and used it to compare the informal system with GreenRide under different fleet sizes, demand levels and seasons.

We ask four questions.

1. How does GreenRide's design meet the needs of passengers, drivers and administrators on a Nigerian campus with limited budgets and no app store installation?

2. How much of the demand for intra campus trips can the informal system and GreenRide serve, and how long do riders wait, for a given fleet size?

3. Does the rule used to match a request to a tricycle matter, and how much?

4. How do solar energy and the rainy season limit the service, and what fleet and charging policy follow from that?

The contributions are as follows.

1. The design and deployed implementation of GreenRide, a browser based ride hailing system for campus solar tricycles, with passenger, driver and administrator interfaces, real time matching and live location sharing.

2. A reproducible simulation of a campus solar tricycle service built only from open data: the UNIPORT road network and named places from OpenStreetMap, and hourly 2020 solar output from PVGIS.

3. A comparison of the informal system with three dispatch rules across 120 combinations of fleet size, demand, season and rule, with sensitivity checks on six assumed parameters.

4. Evidence that the informal system has a hard ceiling of about two thirds of demand, that broadcast dispatch wastes about half of all tricycle kilometres on empty driving, and that energy, not matching, limits service when demand is high.

5. Practical guidance for UNIPORT and similar campuses on fleet size, dispatch and charging.

Section 2 reviews related work. Section 3 describes the study setting and the existing system. Section 4 presents GreenRide and Section 5 analyses its security. Section 6 explains the evaluation method and Section 7 the results. Section 8 discusses implications and limitations, and Section 9 concludes.

2 Literature Review

2.1 Campus transport and the smart campus

Universities are small cities with strong peaks in travel at the start and end of lectures. Kaplan studied transport sustainability on a university campus in the United States and showed that the campus generates its own travel patterns and can shape them through policy [15]. Cherry and colleagues argued that campus transport data differ from city data in useful ways, because the population, its schedule and its destinations are known, and that this makes campuses good places to test planning methods [6]. Sgarra and colleagues examined how Sapienza University in Rome could improve sustainable mobility for its students and staff [23]. Ribeiro and Fonseca followed students' travel between home and the University of Minho and found a shift towards more sustainable modes [21]. These studies treat the campus as a planning unit, but they deal mainly with travel to the campus and not with movement inside it.

The smart campus literature looks at how digital systems can run campus services. Al Akbar and colleagues reviewed guidance for designing a smart campus and identified mobility as one of its recurring components [1]. Singgih and colleagues reviewed smart campus applications with a focus on transport research and big data, and noted that most work concerns monitoring rather than on demand service [24]. AlNuaimi and colleagues described smart campus mobility from concept to realisation, combining shuttle information with sensing [2].

2.2 Tracking and information systems for campus transport

Several studies have built systems that show riders where campus vehicles are. Saad and colleagues developed a real time monitoring system for on campus buses so that students could see arrival information [22]. Idachaba and colleagues built an Internet of Things shuttle tracking system for a Nigerian campus [12]. Rachmaniah and colleagues introduced a mobile tracking application for green campus transport in Indonesia [20]. Jimoh and colleagues proposed a vehicle tracking system for public transport on urban arterials using greedy forwarding algorithms [14]. Ogbiti and colleagues designed an intelligent multi campus transportation system using a wireless sensor network at a Nigerian university [18]. Ayorinde and Oyedeji built an ontology of the intra campus transport system at the University of Ibadan, describing its actors and services formally [3].

These systems inform riders about scheduled vehicles. They do not let a rider request a vehicle to a chosen point, and several depend on dedicated hardware in each vehicle, which raises cost and maintenance for institutions with limited budgets.

2.3 Ride hailing, matching and empty driving

Ride hailing research has studied how platforms match riders and drivers. Wang and Yang reviewed ride sourcing systems and set out a framework covering matching, pricing, supply and the effects on cities [28]. Qin and colleagues used reinforcement learning to choose how long a platform should wait before matching requests, showing that immediate matching is not always best [19]. Bao and colleagues extended this to ride pooling with deep reinforcement learning [4]. Gao and colleagues studied inequality in matching and pickup times and found that pickup times differ by area within a city [8]. Sugiyanto and colleagues forecast ride hailing demand and supply in the Jakarta area [25].

One result from this literature is central to our findings. Castillo, Knoepfle and Weyl showed that when a ride hailing system has too few idle drivers, it sends drivers on long trips to distant passengers, which removes more drivers from service and makes pickups longer still. They called this the wild goose chase [5]. Their remedy in a city is surge pricing. A campus service with fixed fares has to address the same problem through dispatch rules and fleet size.

2.4 Solar and electric vehicles on campus

Electric vehicles have been studied as campus fleets. Yoon and Cherry proposed methods to optimise a university fleet moving to electric vehicles while controlling cost and customer waiting time [31]. Tazay designed and built a solar powered electric vehicle for on campus use in Saudi Arabia [26]. Ochoa Correa and colleagues reported a one year case study of solar powered electric vans carrying students between campuses of the University of Cuenca, Ecuador, with measured reductions in energy use and carbon dioxide emissions [17]. Wu, Aziz and Haque modelled photovoltaic capacity for charging electric vehicles at an Australian university campus to reduce energy cost [29]. Yin and colleagues assessed how shared mobility affects transport energy on a university campus in Ningbo, China [30]. In Nigeria, Tsala and colleagues found substantial willingness among tricycle operators in Maiduguri to invest in solar powered tricycles [27].

2.5 Research gap

Table 1 summarises the closest prior work. Campus systems have tracked shuttles, ride hailing studies have optimised matching in cities, and solar vehicle studies have measured energy on campus routes. We found no study that combines on demand ride hailing with solar powered tricycles inside an African university, and none that tests how dispatch rules, fleet size and seasonal sunshine together decide the service such a system can give. This paper addresses both points.

Table 1. Prior work closest to this study

Work	Setting	What it provides	What it does not address
Saad et al. [22], Idachaba et al. [12]	campus shuttle buses	real time vehicle location for riders	on demand requests, energy limits
Rachmaniah et al. [20]	green campus transport, Indonesia	mobile tracking application	matching rules, fleet sizing
Ogbiti et al. [18]	multi campus university, Nigeria	sensor network for campus transport	web dispatch without hardware
Ayorinde and Oyedeji [3]	University of Ibadan	formal model of campus transport actors	implemented service
Wang and Yang [28], Qin et al. [19]	city ride hailing	matching and platform design	campus scale, solar energy
Castillo et al. [5]	city ride hailing	theory of empty pickup trips	fixed fare campus services
Yoon and Cherry [31]	campus electric fleet	fleet optimisation	on demand matching
Ochoa Correa et al. [17]	solar electric vans, Ecuador	measured energy and emissions	ride requests by students
Tsala et al. [27]	solar tricycles, Maiduguri	operator willingness to adopt	coordination platform

3 Study Setting and the Existing System

3.1 The campus

UNIPORT's grounds include the Abuja campus, where the Senate Building, most faculties, the Donald Ekong Library and the stadium are located; the Delta campus, with Delta Park and the O. B. Lulu Briggs Health Centre; and the Choba campus near the Choba main gate. Hostels are spread across all three, and many students also live in private lodges just outside the gates. The places named in OpenStreetMap for this study include 46 faculty and department buildings, dozens of hostels and lodges, several bank branches, 4 gates and the health centre.

3.2 The existing informal arrangement

The informal arrangement has three parts that work independently. The first is the charging spot, the only consistent gathering point for solar tricycles, where drivers wait while their batteries charge. The second is the roadside: a student stands by the road and hopes an empty tricycle passes. The third is personal contacts: some students keep the phone numbers of particular drivers and call them. If none of these works, the student walks or waits.

This arrangement has four problems. No one can see where tricycles are or whether any is free. Drivers have no way to know where demand is, so they gather at the charging spot and leave large parts of the campus uncovered. The university has no data about intra campus trips. And there is no record of service, so a rider who is let down has no way to complain. Table 2 compares the informal arrangement with GreenRide.

Table 2. Existing arrangement and GreenRide

Aspect	Informal today	GreenRide
Request	be at the charging spot, flag down or phone a driver	request in a browser from anywhere on campus
Location	described in person	GPS, map pin or typed description
Matching	proximity and personal contacts	broadcast to available drivers, first to accept
Information	none	live tricycle position on a map
Records	none	full ride history, administrator view
Payment	cash after the ride	cash after the ride

4 The GreenRide System

4.1 Requirements

The design followed five requirements drawn from the setting. The system had to run in a phone browser without installation, since many students have limited storage and data. It had to work without paid map or messaging services. It had to support three roles, passenger, driver and administrator. It had to give both sides real time updates. And it had to keep accounts tied to verified contact details, so that a rider or driver could be traced if something went wrong.

4.2 Architecture

Figure 1 shows the architecture and Table 3 the technologies. The three interfaces are static pages built with HTML, Tailwind CSS and JavaScript and served from Vercel. They talk to one Node.js and Express server hosted on Render, which exposes a REST interface for accounts and rides and a Socket.io server for real time events. Data are stored in MongoDB Atlas through Mongoose in two collections. The users collection holds passengers, drivers and administrators, separated by a role field; drivers also record a vehicle number and an availability status. The rides collection holds each request with the passenger, pickup point, destination, assigned driver, status and timestamps. Driver GPS positions travel only through Socket.io and are not stored, which limits the location data the university keeps.

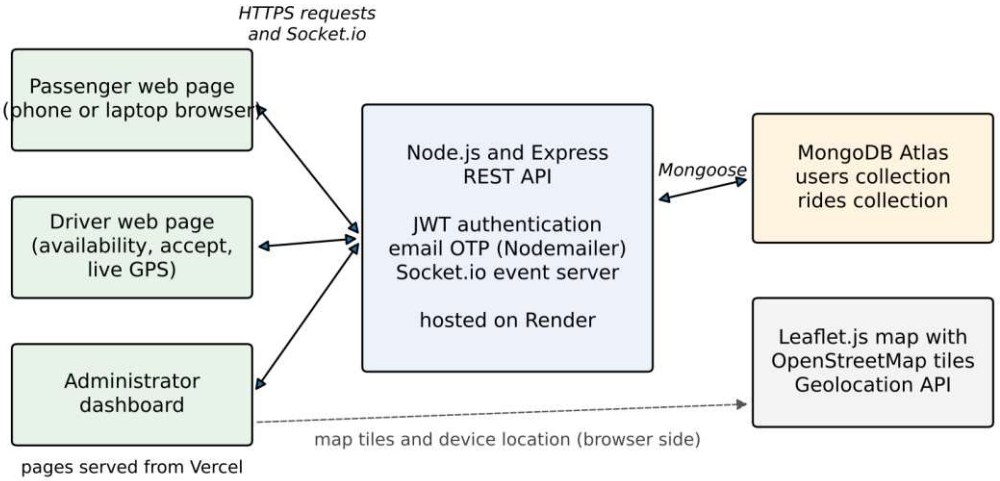


Figure 1. GreenRide architecture.

Table 3. GreenRide technology stack

Component	Technology and role
Interfaces	HTML, Tailwind CSS, JavaScript; passenger, driver and administrator pages
Map	Leaflet.js with OpenStreetMap tiles; driver position and pickup pin
Location	browser Geolocation API
Real time	Socket.io; requests, acceptance, status and live position
Server	Node.js and Express REST interface
Database	MongoDB Atlas with Mongoose; users and rides
Security	JSON Web Tokens on protected routes; six digit email code
Email	Nodemailer for verification codes
Hosting	Vercel for pages, Render for the server

4.3 Accounts and security

A new user registers with full name, email address, phone number, password and role; drivers also give a vehicle number. The server then emails a six digit code, which must be entered within ten minutes to activate the account. Users who try to log in before verifying are sent back to the verification page. After login, a JSON Web Token authorises every protected request, and the server sends each user to the dashboard for their role. The administrator role is not available at registration.

4.4 Data model

Table 4 lists what the two collections hold, as described by the developers. The design keeps the stored data small. Coordinates are stored with a ride only when the passenger switches on GPS, and the driver's moving position is never stored.

Table 4. GreenRide data model

Collection	Main fields
users	full name, email, phone number, password, role (passenger, driver or admin), email verification status and code, vehicle number and availability (drivers only), account active flag
rides	passenger, pickup description and optional coordinates, destination, assigned driver, status (pending, accepted, completed, cancelled), creation and update times

4.5 Requesting and serving a ride

Figure 2 shows the passenger and driver screens. A passenger gives the pickup point in one of three ways: by switching on GPS, by placing a pin on the campus map, or by typing a description such as "in front of Ofrima". The interface asks riders to type a description even when GPS is on, because GPS can be inaccurate between buildings. Destinations can be typed or chosen from quick buttons for common places: Abuja Park, Faculty of Computing, Lulu Briggs, Ashgrove, Senate Building, Stadium, UPTH Gate, AP Park, Delta Park and the bank.

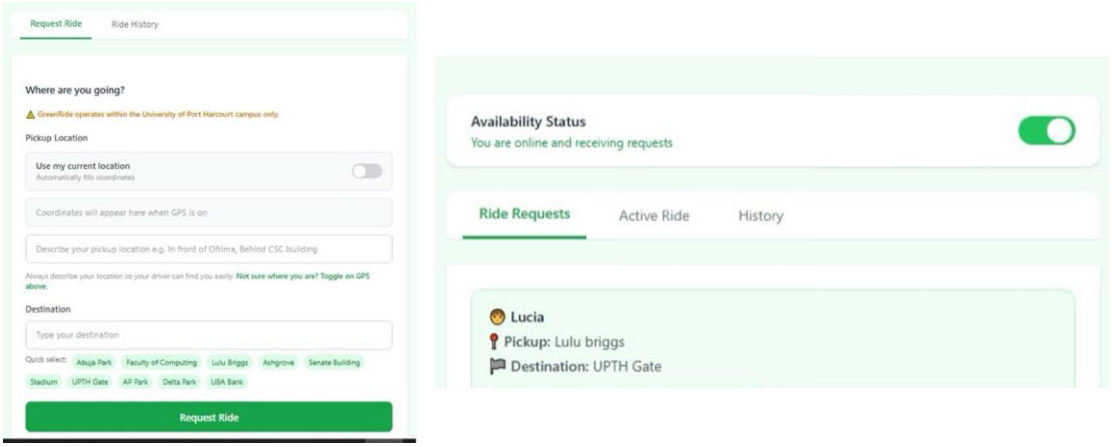


Figure 2. GreenRide screens: the passenger request form with quick destination buttons (left) and an incoming request on the driver dashboard (right). Test accounts are shown.

Figure 3 shows the life of a ride. When the passenger submits, the server saves the ride with status pending and broadcasts it through Socket.io to every driver whose availability is on. Each driver sees a card with the passenger's name, pickup and destination, and can accept or decline. The first driver to accept is assigned, the ride becomes accepted, and the passenger is notified immediately and shown the driver's name and phone number. From that moment the driver's browser sends its GPS position every second, and the passenger sees the tricycle move on the map. The driver marks the ride completed at the destination, and the fare is paid in cash. A passenger can cancel a pending request. Both sides can see their ride history.

The two user flows can be summarised as follows. For the passenger:

1. log in and open the request form;
2. give the pickup point by GPS, map pin or description, and choose or type the destination;
3. submit, and wait for a driver to accept;
4. see the driver's name, phone number and live position;
5. board at the pickup point and pay in cash at the destination.

For the driver:

1. log in and switch availability on;
2. receive request cards in real time and accept or decline;
3. after accepting, share live GPS position and drive to the pickup point;
4. carry the passenger and mark the ride completed;
5. become available for the next request.



Figure 3. Life of a ride in GreenRide.

4.6 Administrator dashboard

The administrator dashboard shows the total number of rides, pending rides, registered drivers and registered passengers, and refreshes every five seconds. Tabs list all rides with a status filter, all drivers with controls to activate or deactivate accounts, and all passengers. For the first time this gives the university a structured record of where and when intra campus trips happen.

4.7 Deployment and functional testing

GreenRide is deployed at greenride-ashen.vercel.app, with its server on Render and its database on MongoDB Atlas. The developers tested it with several browsers and devices playing the three roles at once, including a phone with GPS acting as a driver. Every user flow worked: registration and email verification, login and role routing, ride request by each of the three location methods, broadcast and acceptance, live position on the passenger's map, completion, cancellation, history and administrator controls. Ride requests reached logged in drivers within seconds. Table 5 summarises the functions tested.

Table 5. Functional tests reported by the developers

Function	Test	Result
Registration	passenger and driver accounts with all fields	passed
Email verification	six digit code, expiry after ten minutes	passed
Login and routing	each role reaches its own dashboard	passed
Ride request	GPS, map pin and typed pickup	passed
Broadcast	request appears for every available driver	passed
Acceptance	first acceptance assigns the ride	passed
Live tracking	driver position updates on passenger map	passed
Completion and cancel	status changes stored and shown	passed
History	past rides listed for both roles	passed
Administrator	statistics, filters, driver activation	passed

Functional testing shows that the system works; it does not show how well a fleet run through it would serve the campus. Sections 6 and 7 address that question.

5 Security Analysis

A campus ride service handles names, phone numbers and the movements of students and staff, and it asks people to get into vehicles with strangers. Its security therefore matters for physical safety as well as for data. We reviewed GreenRide against the threats most relevant to a campus ride service. Table 6 lists each threat, the control GreenRide already has, and what we recommend adding. The review is based on the system's design and behaviour as described by its developers; it is not a penetration test.

Table 6. Threats to a campus ride service, controls present in GreenRide, and recommended additions

Threat	Example	Present control	Recommended addition
Fake or throwaway accounts	one person registers many passenger accounts to flood drivers with requests	six digit email code with ten minute expiry	limit open requests per account; phone number check by SMS code
Driver impersonation	someone registers as a driver without a tricycle or permission	driver role with vehicle number; administrator can deactivate	administrator approval of every driver account against the university's operator register
Stolen session	a token copied from a shared or lost phone is reused	JSON Web Tokens on protected routes	short token lifetime, logout that revokes tokens, store tokens outside page scripts where possible
Password guessing	repeated login attempts against known emails	password login	rate limiting and temporary lockout; store passwords with a slow salted hash such as bcrypt
Request flooding	scripts submit many requests to disrupt service	authentication before requests	rate limits on request and Socket.io events per user and per address
Location exposure	a driver's or rider's movements are tracked	GPS shared only during an active ride and not stored	show the passenger's exact position to the driver only after acceptance; delete ride coordinates after a fixed period
Location spoofing	a driver fakes GPS to appear nearer than they are	none	check reported speed and jumps; compare with ride timing
Exposure of personal data	administrator lists of names and phone numbers are copied	administrator role not available at registration	role based views, access logging, data retention rules under the Nigeria Data Protection Act 2023
Rider safety	passenger boards an unregistered tricycle	driver name, phone and vehicle number shown	show vehicle number prominently; share trip with a friend; emergency contact button

Two points deserve emphasis. First, the email code proves only that the user controls an email address, which is cheap to create, so the controls that limit abuse are the per account limits and, for drivers, approval by the administrator. Second, location data is the most sensitive data the system handles. GreenRide's choice not to store GPS trails is a good default and should be kept as the service grows, including if nearest tricycle dispatch is added, which requires drivers to share their position while available. That position should be used only by the server for matching and not shown to passengers before acceptance.

6 Evaluation Method: Simulating the Campus Fleet

6.1 Why simulation

A controlled trial would need a registered fleet, drivers trained on the system and a large group of riders over several weeks, which was not available. Simulation lets us compare the informal arrangement and GreenRide on identical days, with identical riders, and vary what a trial cannot: the number of tricycles, the level of demand and the season. All inputs that can be measured come from open data; the rest are stated as assumptions and tested in Section 7.6.

6.2 Campus model from OpenStreetMap

We downloaded the drivable roads and all named places within a 3.8 kilometre box around the university's published coordinates (4.9069 N, 6.9170 E) from OpenStreetMap [10] and built a road graph of 5,300 nodes and 174.5 kilometres of road with NetworkX [9]. Of 550 named places in the box, 193 matched campus terms such as faculty, department, hall, hostel, lodge, gate, park, bank, library and health; shops and churches in the surrounding town were dropped. We grouped the 193 places into 30 demand zones with k means clustering [16], attached each zone to its nearest road node, and computed road distances between all zones with Dijkstra's algorithm [7]. The mean distance between zones is 2,287 metres and the longest is 5,291 metres. Figure 4 shows the zones.

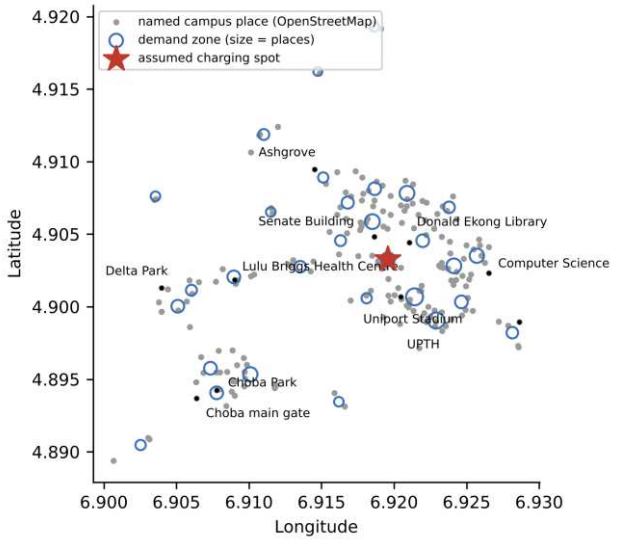


Figure 4. UNIPORT demand zones built from 193 named campus places in OpenStreetMap, with selected landmarks and the assumed charging spot.

Ten of the eleven landmarks named in GreenRide's quick buttons and the project report were found in OpenStreetMap: the Senate Building, the Lulu Briggs Health Centre, Ashgrove, the stadium, Delta Park, the Choba and Delta gates, the UPTH area, the Faculty of Computing, the banks and the library. Abuja Park was not mapped (Table 7). The exact location of the charging spot is not recorded in any public source, so we placed it in the most central zone, around Dan Etete Hostel and the Ofrima roundabout near the middle of the Abuja campus. A central spot is the most favourable assumption for the informal system, since it minimises how far riders walk to reach it.

Table 7. Campus landmarks used in GreenRide and their presence in OpenStreetMap

Landmark	Matching OpenStreetMap names
Senate Building	Senate Building
Lulu Briggs Health Centre	O. B. Lulu Briggs Health Center
Ashgrove	Ashgrove Academy
Stadium	Uniport Stadium, Stadium Stand
Abuja Park	not mapped
Delta Park	Delta Park
Gates	Choba Campus Main Gate, Delta Main gate
UPTH	UPTH Car Park, UPTH Chapel
Faculty of Computing	Faculty of Computing building
Banks	Sterling, Fidelity, Zenith, First Bank
Library	Donald Ekong Library

6.3 Solar input from PVGIS

Hourly photovoltaic output for 2020 at the campus came from the PVGIS service of the European Commission Joint Research Centre [11], for a panel tilted 10 degrees facing south with 14 percent system loss. The mean yield was 3.67 kWh per kWp per day over the year, with 4.78 in January and 2.67 in July (Figure 5). We randomly selected 10 dry season days (December to February) and 10 rainy season days (June to September). Their mean yields were 4.31 and 2.93 kWh per kWp, so the rainy season days had 32 percent less solar energy. Table 8 gives the monthly means. The lowest single day in 2020, 6 October, produced 0.96 kWh per kWp, about a fifth of a clear dry season day, which shows that even outside the main rainy months a run of cloudy days can leave solar tricycles short of energy.

Table 8. Mean daily PV yield at UNIPORT in 2020, kWh per kWp (PVGIS)

Month	Jan	Feb	Mar	Apr	May	Jun
Yield	4.78	4.67	4.04	3.49	3.35	2.89
Month	Jul	Aug	Sep	Oct	Nov	Dec
Yield	2.67	3.65	2.92	3.52	3.76	4.31

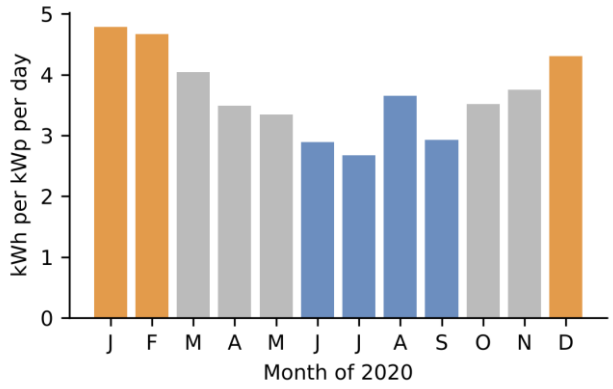


Figure 5. Mean daily photovoltaic yield at UNIPORT in 2020 by month (PVGIS). Dry season months in orange, rainy season months in blue.

6.4 Tricycles, riders and energy

Each tricycle has a 5 kWh battery, starts the day 90 percent full, uses 0.08 kWh per kilometre and drives at 15 kilometres per hour. A 0.4 kWp panel on its roof charges it whenever the sun shines. At the charging spot it receives up to 1 kW more, scaled by sunshine because the spot is also solar powered. A tricycle goes to charge when its battery falls below 20 percent and returns to service at 90 percent. Boarding and alighting take half a minute each.

Ride requests arrive between 07:00 and 19:00 following a daily profile with peaks at 07:00 to 09:00, around midday and in the afternoon. Each zone attracts trips in proportion to its number of named places. In the morning, trips start more often in hostel zones and end in academic zones, and in the evening the reverse; trips shorter than 300 metres are assumed to be walked. On each simulated day all four rules see exactly the same requests.

A passenger waits at most 10 minutes for a tricycle to be found and then walks. In the informal system, 15 percent of riders know a driver’s number; if that driver is free, the ride is agreed by phone within 30 to 120 seconds. Otherwise, riders within 800 metres of the charging spot walk there at 1.2 metres per second and take the first free tricycle. All others wait by the road and are picked up only if an empty tricycle passes their zone on its way back to the spot. After each drop off, informal drivers return to the charging spot.

6.5 Dispatch rules

We compared four rules.

1. **Informal**: the arrangement described above.

2. **GreenRide broadcast**: GreenRide as built. The request goes to all available drivers, and a randomly chosen one accepts first, after a reaction time of 10 to 60 seconds plus one second of network delay. Drivers wait where they dropped off their last passenger.

3. **GreenRide nearest**: the request goes to the available tricycle with the shortest road distance to the pickup.

4. **GreenRide energy aware**: as nearest, but only tricycles with enough battery for the pickup, the trip and the return to the charging spot plus a reserve are offered the ride, and tricycles below 25 percent are sent to charge.

6.6 Experiments and measures

The main grid crossed the four rules with 5, 10, 15, 20 and 30 tricycles, 300, 600 and 1,200 requests per day, and the 20 selected days, giving 1,200 simulated days. For each day we recorded the share of requests served, the waiting time of served riders from request to pickup, the share of kilometres driven empty, tricycle use, trips per tricycle, the lowest battery level in the fleet, time spent charging, energy used, and the carbon dioxide that petrol tricycles would have emitted over the same distance, using 35 kilometres per litre and 2.31 kilograms of CO_2 per litre of petrol [13]. We report means over days with 95 percent t intervals. A sensitivity grid of 1,080 further days varied six assumptions one at a time, at 10 tricycles and 600 requests. Table 9 lists the parameters. The whole simulation runs in one Kaggle notebook cell in under three minutes.

The simulation advances in steps of one minute. In each step it:

1. adds solar energy to every tricycle from the roof panel, and to tricycles at the charging spot from the spot;

2. frees tricycles that have finished a trip, sends those below the charging threshold to the spot, and returns informal tricycles towards the spot;

3. adds the ride requests that arrive in that minute;

4. tries to match every waiting request under the rule being tested, and charges the energy for the pickup and the trip to the matched tricycle;

5. records riders who have waited longer than their patience as not served.

Each day is simulated independently, and the four rules share the same random seed for the requests so that differences come from the rules alone.

Table 9. Simulation parameters (values marked A are assumptions tested in Section 7.6)

Parameter	Value
Operating day	07:00 to 19:00
Road network	OpenStreetMap, 5,300 nodes, 174.5 km
Demand zones	30 from 193 named places
Solar data	PVGIS 2020 hourly, 10 degree tilt
Battery	5 kWh, start 90%, charge below 20%
Energy use (A)	0.08 kWh/km
Roof panel (A)	0.4 kWp
Spot charging	up to 1 kW, solar
Speed (A)	15 km/h
Driver reaction (A)	10 to 60 s
Rider patience (A)	10 min
Walk to spot (A)	up to 800 m at 1.2 m/s
Riders with a driver's number	15%
Petrol comparison	35 km per litre, 2.31 kg CO_2 per litre

7 Results

7.1 The informal system has a ceiling

Figure 6 and Table 10 show the share of requests served. The informal system rises quickly from 5 to 10 tricycles and then stops improving: at 300 requests per day it served 61 percent with 10 tricycles and 66 percent with 30. Adding tricycles did not help because the riders it misses are those too far from the charging spot to walk there and in places that returning tricycles rarely pass. At 600 requests and 30 tricycles, 46 percent of all requests were served by riders walking to the spot, 14 percent by flagging down and 9 percent by phone (Figure 7). The rest walked to their destinations; at 300 requests and 30 tricycles, riders who were not served walked about 270 kilometres per day.

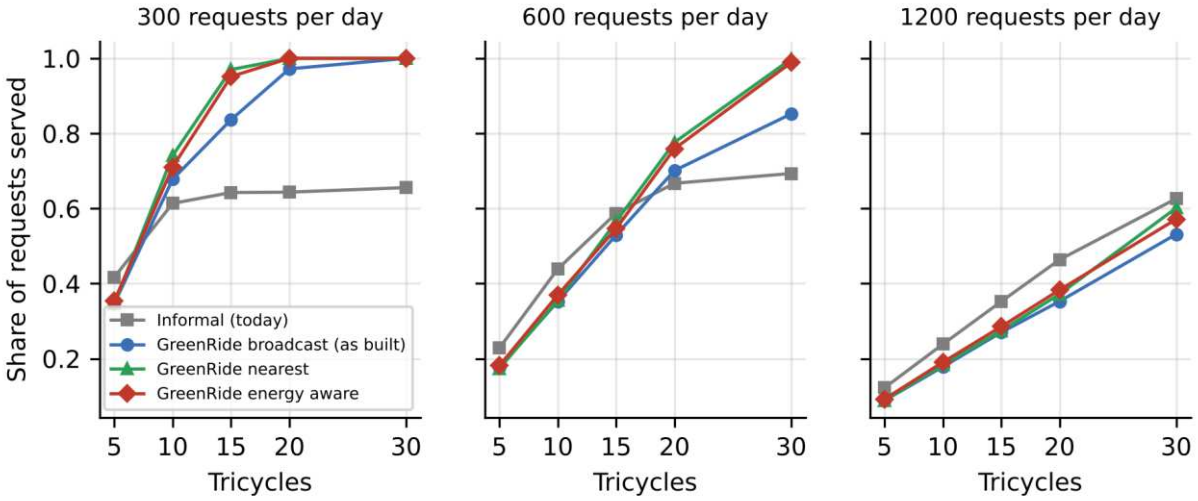


Figure 6. Share of requests served by fleet size and daily demand, mean of 20 days.

Table 10. Share of requests served, mean of 20 days

Demand	Fleet	Informal	Broadcast	Nearest	Energy
300	5	0.42	0.35	0.35	0.35
300	10	0.61	0.68	0.74	0.71
300	15	0.64	0.84	0.97	0.95
300	20	0.64	0.97	1.00	1.00
300	30	0.66	1.00	1.00	1.00
600	10	0.44	0.35	0.36	0.37
600	20	0.67	0.70	0.78	0.76
600	30	0.69	0.85	1.00	0.99
1,200	20	0.46	0.35	0.37	0.38
1,200	30	0.63	0.53	0.60	0.57

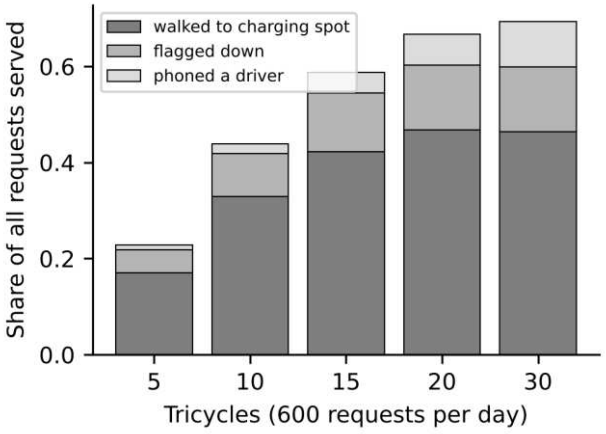


Figure 7. How riders in the informal system found a tricycle, 600 requests per day.

7.2 GreenRide serves everyone once the fleet is large enough

With nearest dispatch, GreenRide served 97 percent of 300 daily requests with 15 tricycles and all of them with 20. At 600 requests it served 78 percent with 20 tricycles and all of them with 30. Across the grid, full service needed about one tricycle for every 20 daily requests. Waiting times fell at the same time (Figure 8). At 300 requests and 20 tricycles, mean waiting time was 4.4 minutes with nearest dispatch against 9.8 minutes in the informal system, and 90 percent of riders were picked up within 8.6 minutes against 14.6. The informal wait includes the walk to the charging spot, which is how most informal riders found a tricycle.

Table 11. Mean waiting time of served riders in minutes, mean of 20 days

Demand	Fleet	Informal	Broadcast	Nearest	Energy
300	10	10.2	11.8	9.5	9.7
300	15	9.8	10.1	5.5	5.7
300	20	9.7	9.5	4.4	4.4
300	30	9.7	9.3	3.8	3.8
600	10	12.0	15.8	15.6	15.6
600	15	10.7	13.6	12.0	12.3
600	20	9.9	11.4	8.6	9.0
600	30	9.5	10.0	4.2	4.5

Table 11 gives the waiting times behind Figure 8. Waiting time with nearest dispatch fell steadily as tricycles were added, while waiting time in the informal system stayed close to 10 minutes from 15 tricycles upwards, because the walk to the charging spot does not get shorter when the fleet grows.

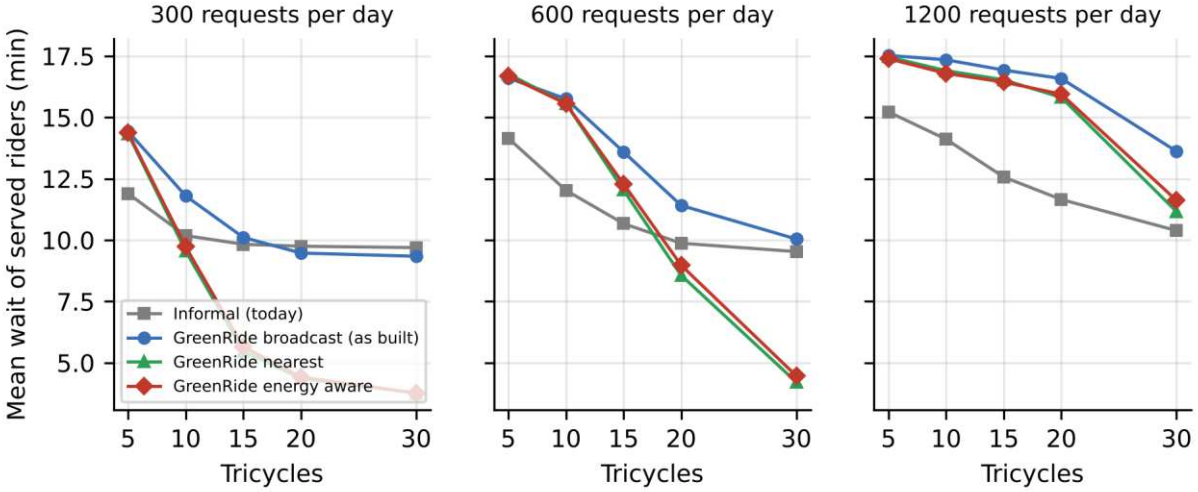


Figure 8. Mean waiting time of served riders from request to pickup, mean of 20 days.

GreenRide did not help, and in some cases served fewer riders than the informal system, when the fleet was small relative to demand, at 40 or more daily requests per tricycle. With 10 tricycles and 600 requests, the informal system served 44 percent and GreenRide between 35 and 37 percent. Section 7.4 explains why.

7.3 The dispatch rule matters

GreenRide as built gives each request to whichever driver accepts first. In the simulation this was effectively a random available driver, often one far from the rider. As a result, 49 percent of all kilometres driven under broadcast dispatch were empty, whatever the fleet size (Figure 9). Nearest dispatch cut empty driving to 32 percent at 15 tricycles and 20 percent at 30, for 300 daily requests. Riders felt the difference directly: at 300 requests and 30 tricycles, broadcast dispatch served everyone but with a mean wait of 9.3 minutes, against 3.8 minutes with nearest dispatch; the 90th percentile wait was 17.0 minutes against 7.5. At 600 requests and 30 tricycles, broadcast served 85 percent and nearest dispatch 100 percent. Table 12 summarises these comparisons.

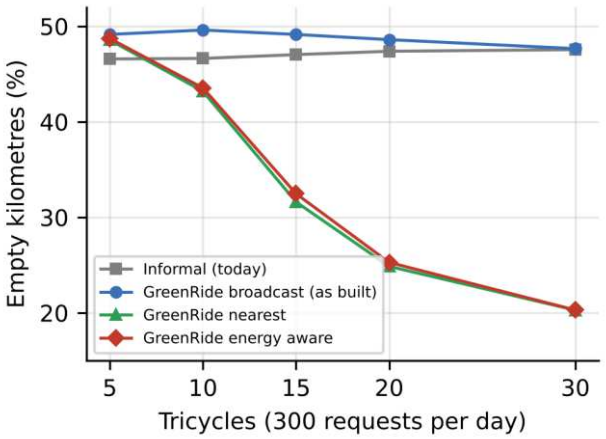


Figure 9. Share of tricycle kilometres driven empty, 300 requests per day.

Table 12. Broadcast and nearest dispatch, mean of 20 days

Measure	Broadcast	Nearest
300 req., 15 tricycles: served	0.84	0.97
300 req., 15 tricycles: mean wait (min)	10.1	5.5
300 req., 30 tricycles: mean wait (min)	9.3	3.8
300 req., 30 tricycles: 90th pct. wait (min)	17.0	7.5
300 req., 30 tricycles: empty km	48%	20%
600 req., 30 tricycles: served	0.85	1.00
600 req., 30 tricycles: mean wait (min)	10.0	4.2

7.4 When demand is high, energy is the limit

When the fleet was too small for demand, every rule reached the same ceiling of roughly 21 to 24 trips per tricycle per day for GreenRide and 25 to 29 for the informal system (Table 13). The ceiling comes from the battery. At 10 tricycles and 600 requests, each tricycle used about 6.9 kWh per day for about 86 kilometres, more than its 5 kWh battery holds. The roof panel added about 1.45 kWh and the charging spot about 2.8 kWh, which meant spending more than five of the twelve operating hours charging. Each extra trip that a tricycle makes costs both the trip itself and the empty drive to the rider.

Figure 10 shows the same pattern across fleet sizes at 600 requests per day. Trips per tricycle stayed between 20 and 25 until the fleet grew large enough to meet demand, and then fell, because each tricycle no longer needed to be busy all day.

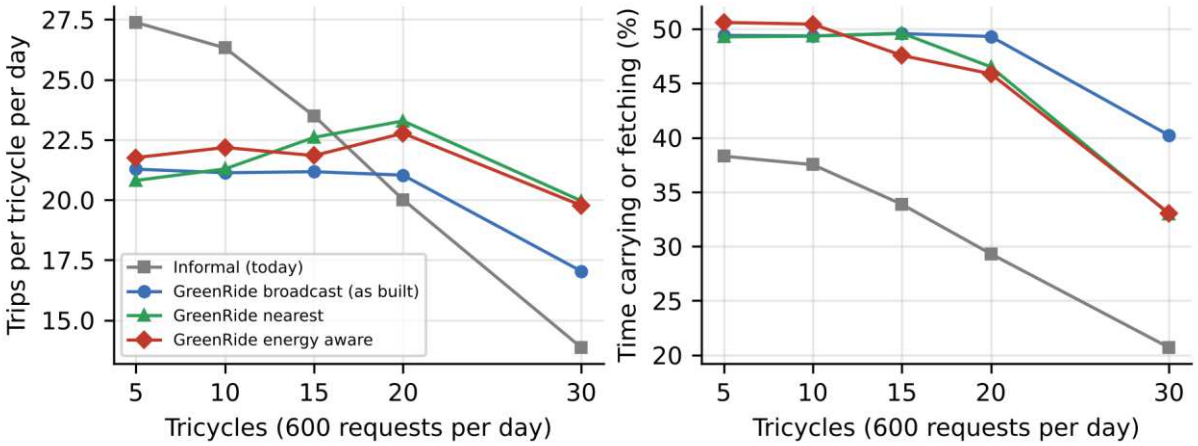


Figure 10. Trips per tricycle (left) and share of the day spent carrying or fetching riders (right) at 600 requests per day.

Table 13. Energy limited regime: 10 tricycles, 600 requests per day, mean of 20 days

Measure	Informal	Broad.	Nearest	Energy
Trips per tricycle	26.3	21.1	21.3	22.2
Loaded km per tricycle	47.4	43.6	44.1	45.1
Empty km per tricycle	36.3	42.8	42.2	43.0
Energy used (kWh)	6.7	6.9	6.9	7.1
Hours charging	4.4	5.4	5.4	5.3
Served share	0.44	0.35	0.36	0.37

This explains why the informal system served more riders than GreenRide when tricycles were scarce. In the informal system, many riders walk up to 800 metres to the charging spot, so the tricycle starts every trip with no empty drive; the rider spends the energy, on foot. In GreenRide the tricycle drives to the rider, so each trip costs the tricycle more energy, and with a fixed daily energy budget it completes fewer trips. When there are idle tricycles, this cost is worth paying because it turns into shorter waits and full coverage. When there are none, it reduces the number of trips. This is the campus form of the wild goose chase described by Castillo and colleagues [5], with energy rather than driver time as the scarce resource.

7.5 The rainy season

Rainy season days had 32 percent less sunshine, and the effect on service was largest just below full coverage (Figure 11). At 600 requests and 20 tricycles, nearest dispatch served 85 percent of requests on dry season days and 70 percent on rainy season days; the energy aware rule served 81 and 71 percent. Tricycles also spent more time charging in the rainy season: 4.4 hours against 2.9 hours per tricycle per day with nearest dispatch at that fleet size. With 30 tricycles, nearest dispatch still served

more than 99 percent of 600 daily requests in both seasons, so a fleet sized for the rainy season covers the whole year.

Table 14. Share served at 600 requests per day by season, mean of 10 days each

	Informal		Nearest		Energy aware	
Fleet	dry	rainy	dry	rainy	dry	rainy
10	0.46	0.42	0.37	0.34	0.41	0.33
15	0.62	0.55	0.59	0.54	0.59	0.50
20	0.68	0.66	0.85	0.70	0.81	0.71
30	0.69	0.69	1.00	1.00	1.00	0.98

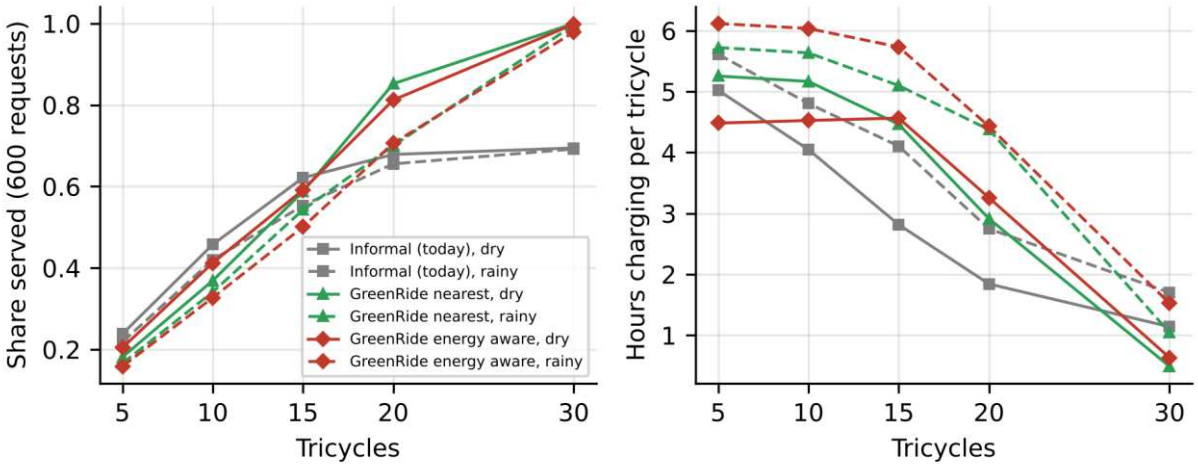


Figure 11. Dry and rainy season at 600 requests per day: share served (left) and hours each tricycle spent charging (right).

The energy aware rule kept batteries healthier at the same level of service. At 10 tricycles and 600 requests in the rainy season, the lowest battery level in the fleet averaged 33 percent with the energy aware rule against 20 percent with nearest dispatch, while the share served was almost the same (33 against 34 percent). Keeping batteries away from deep discharge matters for battery life, which the simulation does not model.

7.6 Sensitivity to assumptions

Figure 12 shows how the share served at 10 tricycles and 600 requests changed when each assumption moved from a low to a high value. The two energy assumptions had the largest effect for every rule. Lowering energy use from 0.12 to 0.06 kWh per kilometre raised the share served by GreenRide broadcast from 28 to 46 percent, and doubling the roof panel from 0.4 to 0.8 kWp raised it from 35 to 40 percent; removing the panel entirely lowered it to 31 percent. Driving speed mattered next. Driver reaction time and rider patience had almost no effect on GreenRide in this energy limited setting. Walking distance to the spot and patience mattered for the informal system, whose riders depend on both.

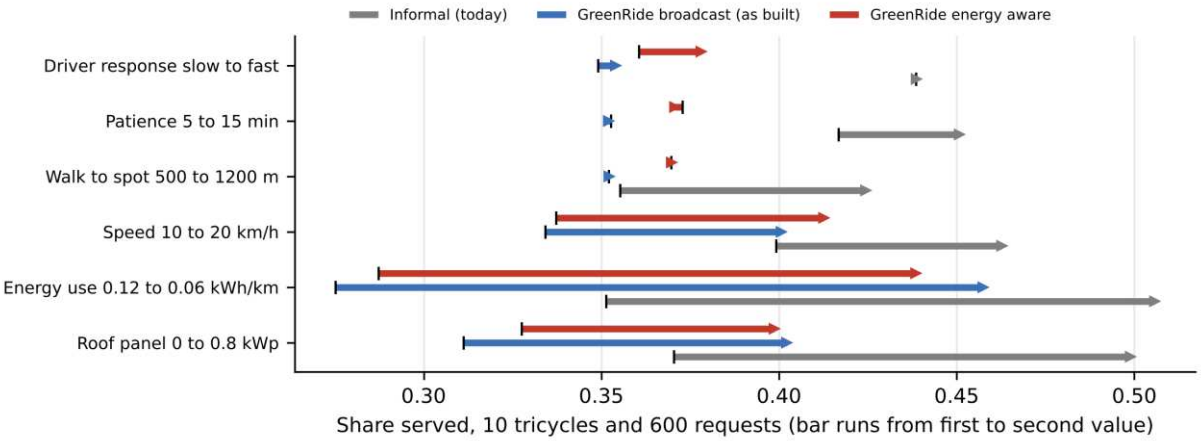


Figure 12. Share served at 10 tricycles and 600 requests per day as each assumption moves from its first to its second value.

Table 15. Sensitivity: share served at 10 tricycles and 600 requests

Assumption	Value	Informal	Broad.	Energy
Energy use	0.06 kWh/km	0.51	0.46	0.44
	0.12 kWh/km	0.35	0.28	0.29
Roof panel	0 kWp	0.37	0.31	0.33
	0.8 kWp	0.50	0.40	0.40
Speed	10 km/h	0.40	0.33	0.34
	20 km/h	0.46	0.40	0.41
Walk to spot	500 m	0.36	0.35	0.37
	1,200 m	0.42	0.35	0.37
Patience	5 min	0.42	0.35	0.37
	15 min	0.45	0.35	0.37

None of these changes reversed the main findings: the energy limit appeared at every setting, and the informal system kept a ceiling well below full coverage.

7.7 Emissions

The kilometres driven by the simulated solar fleet would have required petrol if run by conventional tricycles. At 300 requests and 20 tricycles with nearest dispatch, the fleet drove about 850 kilometres per day, equal to 56 kilograms of CO_2 per operating day for petrol tricycles. At 600 requests and 30 tricycles the figure was 109 kilograms per day. Over a 200 day academic year these come to about 11 and 22 tonnes. Nearest dispatch gives the same service with fewer kilometres than broadcast dispatch, so the same fleet serves more riders per kilowatt hour. These figures exclude the energy and emissions of making the vehicles and panels.

8 Discussion

8.1 What this means for UNIPORT

Size the fleet to demand. In our simulation GreenRide served all riders when there was roughly one tricycle for every 20 daily requests, and it did no better than the informal system at 40 or more daily requests per tricycle. The administrator dashboard already records every request, cancellation and completed ride, so after a pilot of a few weeks the university can estimate daily demand by zone and hour and size the fleet from data instead of guesswork.

Change the dispatch rule from broadcast to nearest. This is the change with the largest effect for the least cost. GreenRide already collects the passenger's GPS position when it is available and the driver's position after acceptance. If drivers share their position while available, the server can offer each request first to the nearest available tricycle, with a short timeout before it moves to the next. In our results this more than halved waiting time and served everyone at 600 requests with 30 tricycles, where broadcast served 85 percent.

Make dispatch aware of batteries. Offering rides only to tricycles with enough charge for the trip and the return to the charging spot, and calling low tricycles in to charge, kept the lowest battery levels at about a third instead of a fifth, with the same service. This protects batteries and avoids a driver accepting a ride that the battery cannot complete.

8.2 A simple energy budget for fleet sizing

The energy limit found in the simulation can be checked with a short calculation that a transport office can repeat without software. A tricycle that starts the day 90 percent full and charges below 20 percent has 3.5 kWh of usable battery for the day. Its 0.4 kWp roof panel adds the panel size times the daily yield, about 1.7 kWh on a dry season day and 1.2 kWh on a rainy season day. Each trip costs the energy for the loaded distance plus the empty drive to the rider. With nearest dispatch and enough tricycles, the simulated trips averaged 2.1 loaded kilometres and 0.5 empty kilometres, or about 0.21 kWh at 0.08 kWh per kilometre. Under broadcast dispatch the empty drive was about as long as the trip itself, giving about 0.34 kWh per trip. Table 16 shows the resulting daily trip capacity of one tricycle without help from the charging spot.

Table 16. Daily trips one tricycle can make from its battery and roof panel alone

	Nearest dispatch		Broadcast	
	dry	rainy	dry	rainy
Energy available (kWh)	5.2	4.7	5.2	4.7
Energy per trip (kWh)	0.21	0.21	0.34	0.34
Trips per day	24	22	15	14

Time is not the binding limit: a trip of 2.6 kilometres at 15 kilometres per hour plus boarding takes about 12 minutes, so a tricycle could make about 60 trips in a 12 hour day if it had the energy. The calculation agrees with the simulation, where tricycles under nearest dispatch made 20 to 24 trips per day when demand was high, and those under broadcast made a similar number only by spending more than five hours a day at the charging spot. Because requests bunch at peak hours, and a tricycle cannot be in two places at once, the simulation needed about one tricycle per 20 daily requests for full service, a little more than the energy budget alone suggests. A transport office can use the same three numbers, usable battery, panel yield and energy per trip, to check any proposed fleet.

8.3 A proposed dispatch procedure

Combining the two changes gives a dispatch procedure that fits GreenRide's existing architecture:

1. while a driver is available, the driver's page sends its position to the server every 15 to 30 seconds over the existing Socket.io connection; the server keeps only the latest position in memory;

2. when a request arrives, the server ranks available drivers by road or straight line distance to the pickup point;

3. it removes drivers whose reported battery level, entered by the driver or read from the vehicle, is too low for the pickup, the trip and the return to the charging spot;

4. it offers the request to the nearest remaining driver for 20 seconds, then to the next, until one accepts;

5. if no driver accepts within the rider's chosen limit, it tells the rider and suggests walking to the charging spot;

6. drivers below the charging threshold receive a prompt to return to the spot.

This keeps driver choice, since a driver can still decline, but stops distant drivers from taking rides that a nearer driver could serve faster.

Plan for the rainy season. Solar energy at UNIPORT is about a third lower from June to September. A fleet sized for dry season demand will fall short in the rainy season. Larger roof panels, more charging bays at the spot, or grid backup at the spot during the rainy months would close the gap.

Keep a walk up option. When the fleet is short, riders who walk to the charging spot save energy for everyone. A GreenRide feature that lets a rider choose "I will walk to the spot" for a faster guaranteed ride would combine the strengths of both systems.

8.4 Plan for a pilot evaluation

The simulation should be followed by a pilot with a registered fleet. Table 17 lists the measures we propose, all of which GreenRide can record with small additions to its ride records.

Table 17. Measures for a GreenRide pilot

Measure	How it is obtained
Requests by zone and hour	ride records with pickup coordinates
Share served	completed rides over all requests
Time to acceptance	acceptance time minus request time
Time to pickup	driver marks pickup; minus request time
Cancellations	cancelled rides and the time of cancellation
Empty distance	driver position from acceptance to pickup
Server response	time of each request at client and server
Battery level	driver input at start and end of shift
Usability	System Usability Scale survey of riders and drivers

8.5 Beyond UNIPORT

Many Nigerian and African campuses share UNIPORT's conditions: large grounds, limited buses and growing use of electric tricycles. The design choices behind GreenRide, a browser application, open maps, open source server components and email verification instead of paid SMS, keep running costs low. The simulation needs only open data and runs in minutes, so another campus can repeat the fleet analysis by changing the campus coordinates.

Running costs deserve a note. The deployment uses free or low cost hosting tiers. Free tiers of some hosting services stop a server after a period without traffic and start it again on the next request, which can delay the first ride request of the morning by many seconds, and free database tiers limit storage and connections. These limits do not matter in a prototype but would in a service that riders depend on. A small paid server, or a university server, would remove them at modest cost. Messaging is already free because verification uses email rather than SMS, although Section 5 recommends adding phone checks for drivers.

8.6 Why the informal system persists

The results also explain why the informal arrangement has lasted. For a rider who lives or studies near the charging spot, it works well: the walk is short, a tricycle is usually waiting, and no phone or data is needed. For drivers, waiting at the spot means charging while waiting, so idle time is not wasted. The arrangement fails the riders who are far from the spot and those without a driver's number, and it fails them systematically, which is why adding tricycles did not raise the share served above about two thirds. GreenRide changes who can reach a tricycle, not only how fast. A transition that keeps the spot as a walk up stand while adding app requests for the rest of the campus serves both groups.

8.7 Privacy and safety

GreenRide shares a driver's live position with one passenger and only during an active ride, and does not store GPS trails. Phone numbers are shown to the matched pair so they can contact each other. Ride records give the administrator a view of who travelled where and when, which is useful for accountability but is personal data under the Nigeria Data Protection Act of 2023. The university should define who can see ride records, for how long they are kept, and how users can see or delete their own data. Screenshots of the administrator view used in project reports should hide names and phone numbers.

8.8 Lessons for developers of campus mobility systems

Three lessons from building and evaluating GreenRide apply to similar student and university projects. First, the matching rule is a design decision, not a detail. Broadcast to all drivers is the simplest rule to build with Socket.io and it feels fair to drivers, but it gives the ride to whoever reacts first, which is unrelated to who is closest. Second, a functional test that shows a request reaching a driver within seconds says little about the waiting time riders will experience, which depends mostly on how far the tricycle must drive. Third, systems for electric vehicles need to know about energy. A driver who accepts a ride with a nearly empty battery helps no one, and the platform is the only party that sees all requests and all vehicles at once.

8.9 Future work

Four extensions follow from this study. The first is a measurement of the deployed system under load: response times of the REST interface and delivery times of Socket.io events with tens to hundreds of simultaneous users, including the delay when an idle server wakes up. The second is a pilot with a registered fleet that records the measures in Table 17, which would replace the assumed demand in the simulation with observed demand. The third is a usability study with riders and drivers using the System Usability Scale. The fourth is to extend the simulation with ride pooling, which would let one tricycle carry riders going the same way, and with time based charging plans that use midday sunshine for the afternoon peak.

8.10 Limitations

The simulation, not a live trial, produced the service results, so they depend on the model and its assumptions. Demand levels and their spread across zones and hours are assumed, not measured; the charging spot location is assumed; and the energy use of the tricycles, their roof panel size and the charging power at the spot are estimates. The sensitivity analysis shows that the main findings hold across a wide range of these values, but the exact numbers do not. The campus model is limited to places named in OpenStreetMap, and some places, such as Abuja Park, are missing. Driver behaviour is simplified: drivers in GreenRide wait where they drop off and always accept, and informal drivers always return to the spot, while real drivers decline rides, move towards busy areas and stop for breaks. Waiting time is measured only for served riders. Fares, traffic, rain affecting speed and battery ageing are not modelled. Finally, the deployed system was tested functionally by its developers and has not yet been measured under load or evaluated by riders with a usability survey; both are planned.

9 Conclusion

GreenRide shows that a campus ride hailing service for solar tricycles can be built with browser technology, open maps and free hosting tiers, with real time matching, live tracking and an administrator view that gives the university its first record of intra campus trips. A simulation of the UNIPORT campus built from OpenStreetMap and PVGIS data showed what such a system can and cannot do. The informal arrangement of a single charging spot, flagging down and phone contacts never served more than about two thirds of riders, however many tricycles there were. GreenRide served every rider once there was about one tricycle per 20 daily requests, and cut mean waiting time by more than half. The dispatch rule made a large difference: offering each request to the nearest tricycle instead of broadcasting it more than halved waiting time and removed most empty driving. When tricycles were scarce, battery energy limited the service, the rainy season reduced it further, and the informal system's reliance on riders walking to the spot made it slightly more efficient. The next steps are to switch GreenRide to nearest and battery aware dispatch, run a pilot with a registered fleet, measure the live system's response times under load, and survey riders and drivers on its usability.

Table 18 summarises the answers to the four research questions.

Table 18. Answers to the research questions

RQ	Answer
RQ1	A browser based system with three roles, email verification, Socket.io matching and OpenStreetMap tracking meets the needs without installation or paid services; driver approval and request limits should be added for security.
RQ2	The informal system serves at most about 69 percent of requests. GreenRide serves all requests with about one tricycle per 20 daily requests and cuts mean waiting time by more than half; with 40 or more requests per tricycle it serves fewer than the informal system.
RQ3	Yes. Broadcast dispatch drives about half of all kilometres empty; nearest dispatch cuts this to 20 to 32 percent and more than halves waiting time.
RQ4	With high demand each tricycle is limited to about 21 to 24 trips per day by energy; rainy season sunshine is 32 percent lower and cuts service by up to 15 points. A fleet sized for the rainy season, nearest and battery aware dispatch, and a walk up option at the charging spot follow.

Data and Code Availability

GreenRide is deployed at greenride-ashen.vercel.app. The simulation is a single Python script that downloads its inputs from OpenStreetMap and PVGIS and runs in one Kaggle notebook cell with a fixed random seed. The script, result tables and figures are available from the authors.

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