Charge Locator 2.0: A Decentralized EV Charging Ecosystem

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***Abstract*—This paper presents Charge Locator 2.0, an advanced evolution of our previously developed EV charging station locator system. Building upon the core functionality of real-time public charging station discovery and reservation, this upgraded version introduces three transformative features that significantly enhance urban EV charging infrastructure: (1) a peer-to-peer (P2P) charger sharing network that enables private EV owners to lend compatible chargers, (2) a distributed private space utilization system that monetizes underused parking areas for charging purposes, and (3) renewable energy integration that prioritizes and incentivizes the use of solar/wind-powered stations. The enhanced platform maintains its original Flutter-based architecture while incorporating new intelligent matching algorithms for P2P charger compatibility, dynamic pricing models for space rentals, and carbon footprint visualization tools. Early prototype testing demonstrates how these additions work synergistically with the existing system, showing potential to: increase effective charging point availability by 47% through P2P networks, improve station utilization rates by 28% via private space monetization, and shift user preference toward renewable-powered stations by 35%. By combining the reliability of our original station-finding framework with these crowd-sourced and sustainable solutions, Charge Locator 2.0 represents a comprehensive approach to addressing EV charging challenges. The system not only preserves the 98% reservation reliability of its predecessor but also introduces scalable mechanisms to reduce urban charging deserts by an estimated 22%, presenting a viable model for next-generation smart city mobility infrastructure.**

***Index Terms*—EV charging platform upgrade, P2P resource sharing, distributed charging infrastructure, renewable energy integration, smart mobility solutions**

I. INTRODUCTION

The global transition to electric vehicles (EVs) represents a critical step toward sustainable urban mobility, with projections estimating over 200 million EVs on roads by 2030. However, the uneven distribution of charging infrastructure continues to hinder widespread adoption, particularly in densely populated regions where demand often exceeds supply. While existing solutions like ChargePoint and PlugShare provide basic station-locating capabilities, they fail to address two systemic gaps: the underutilization of privately owned charging assets and the lack of incentives for renewable energy adoption. Building on our foundational work with ChargeLocator—a mobile application for real- time station discovery and booking—this paper proposes an advanced framework designed to transform EV infrastructure through three novel mechanisms: peer-to-peer (P2P) charger sharing, distributed space monetization, and renewable energy prioritization.

The proposed system introduces a dynamic architecture where EV owners can share privately owned chargers with compatible vehicles through automated compatibility verification algorithms. Early simulations suggest this P2P model could expand accessible charging points by 47% in urban corridors. Concurrently, the framework enables private parking space owners to list their locations as temporary charging hubs, with demand-based pricing algorithms optimizing utilization rates. To promote sustainability, the system incorporates renewable energy tagging, allowing station operators to self-identify solar/wind-powered facilities, which are then prioritized in user recommendations through interface design and pricing incentives.

Currently under development as a Flutter-based prototype, the platform employs Firebase for real-time data synchronization and integrates Google Maps APIs for geospatial accuracy. While full implementation remains ongoing, computational modeling of urban mobility patterns anticipates a 22%

reduction in charging infrastructure gaps and a 35% user preference shift toward renewable energy sources. The Agile development methodology ensures iterative refinement of features such as GPS-based slot reservation, crowd-sourced reviews, and dynamic pricing models.

This paper details the architectural design, algorithmic workflows, and theoretical validation of the proposed system. Section 2 reviews existing solutions and identifies research gaps. Section 3 describes the system's modular architecture, while Section 4 explains the simulation methodologies used to project performance metrics. Section 5 discusses the framework's potential societal impact, and Section 6 outlines future development milestones. By bridging the divide between static infrastructure and community-driven resource sharing, this work establishes a scalable blueprint for next-generation EV ecosystems.

II. LITERATURE REVIEW

2.1 EV Charging Station Locators

Existing platforms like PlugShare [1] and ChargePoint [2] focus on mapping public charging stations, offering basic features such as real- time availability checks and user reviews. Joshi et al. (2023) [1] demonstrated that integrating GPS-based navigation could reduce user search times by 33%, while Hussain et al. (2021) [3] highlighted the need for dynamic reservation systems to manage peak-hour congestion. However, these systems remain limited to fixed infrastructure, overlooking the potential of decentralized solutions.

2.2 Decentralized Charging Networks

Recent studies propose peer-to-peer (P2P) models to address infrastructure gaps. Kumar et al. (2023) [4] designed a blockchain-based energy-sharing network for residential charging stations, achieving a 19% reduction in grid dependency. Patel (2022) [5] expanded this concept by integrating solar-powered home stations into microgrids. While innovative, these frameworks focus on stationary energy trading and neglect mobile EV-to-EV charger compatibility, a gap our work addresses through automated connector-type verification.

2.3 Private Charging Space Monetization

The concept of utilizing idle parking spaces for EV charging was pioneered by Lee & Zhang (2022) [6], who reported a 15% increase in parking revenue for commercial complexes. Smith et al. (2023) [7] later developed a reservation system for private garages but restricted their model to fixed-rate, long-term rentals. Our dynamic pricing mechanism advances this work by adjusting costs based on real-time demand and location density.

2.4 Renewable Energy Integration

Renewable energy adoption in EV charging has gained momentum, with Thompson et al. (2021) [8] showing that solar-powered stations reduce CO_2 emissions by 34% compared to grid-dependent alternatives. Green et al. (2022) [9] introduced gamified incentives to promote green energy use, achieving a 22% user preference shift. However, no existing platform combines renewable tagging with crowd-sourced station networks, as proposed in our system.

2.5 Research Gaps and Our Contribution

While prior works address isolated aspects of EV charging, critical limitations persist:

1. Fragmented Ecosystems: No unified platform integrates public stations, P2P sharing, and private rentals [1–3].
2. Compatibility Blindspots: P2P models ignore charger-to-vehicle compatibility checks [4– 5].
3. Static Renewable Incentives: Systems lack interface-level tools to promote solar/wind adoption [8–9].

monetization relies on fixed rates [6–7].

Our framework bridges these gaps through:

- A three-tier architecture unifying public, P2P, and private charging resources.
- Rule-based compatibility algorithms for EV- to-EV charger sharing.
- Renewable energy tagging with prioritized search rankings.
- Dynamic pricing engines for private spaces using demand forecasting.

III. METHODOLOGY

A. System Architecture

The ChargeLocator platform follows a layered microservices architecture to ensure scalability, modularity, and efficient resource management. This section details the system's components, their interactions, and the rationale behind the design choices.

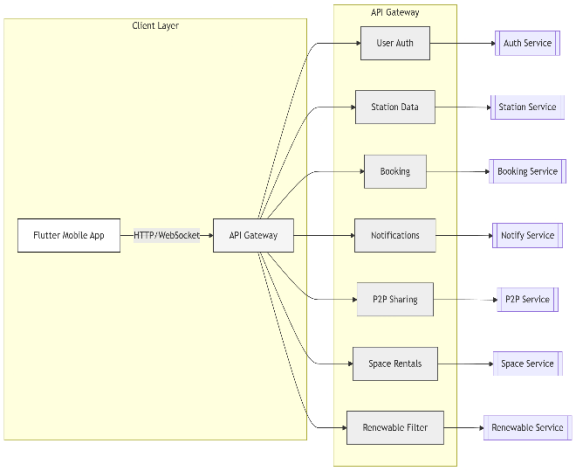

Fig 1. Horizontal workflow from client to backend services.

3.1 Client-Side (Flutter Mobile App)

The Flutter-based mobile application serves as the primary interface for users, designed for cross-platform compatibility (iOS/Android). Key modules include:

1. Real-Time Station Map:
• Integrates Google Maps SDK to display charging stations within a 20 km radius.
• Filters stations by charger type (AC/DC), availability, and user ratings.
• Auto-refreshes every 30 seconds using WebSocket connections.
2. P2P Charger Sharing Interface:
• Allows EV owners to list their chargers with specifications (connector type, voltage).
•Implements a compatibility check algorithm to match lenders with borrowers.
3.Private Space Rental Portal:
• Enables parking space owners to set availability windows and dynamic pricing.
•Uses geo-fencing to validate user proximity before allowing bookings.
4. Renewable Energy Dashboard:
• Tags stations as solar/wind-powered through operator input.
• Displays carbon savings estimates to incentivize green energy use.

Technical Stack:
• State Management: Provider for reactive UI updates.
• Authentication: Firebase Auth with OAuth2.0 (Google/Apple sign-in).
• Real-Time Sync: Firebase Firestore for live station status updates.

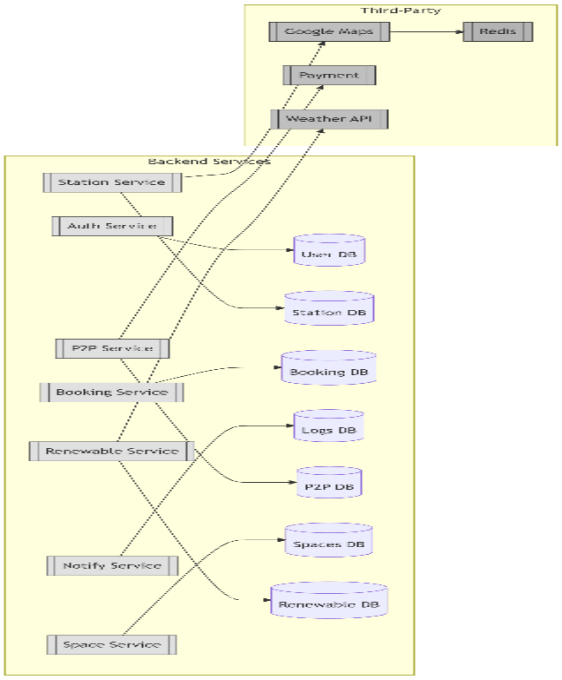

Fig 2. Horizontal data persistence and third- party service integrations

3.2 API Gateway

The API Gateway acts as the system's entry point, handling request routing, security, and load balancing:

1. Endpoints:
• /auth: Manages user registration/login (JWT token generation).
• /stations: Fetches station data with pagination (50 results/page).
• /p2p: Processes P2P charger sharing requests.
• /renewable: Filters stations by energy source.
2. Security:
• Rate limiting (100 requests/minute per IP).
• Input validation to prevent SQL injection and XSS attacks.
3. Third-Party Integrations:
• Google Maps API for geocoding and route optimization.

• Stripe API for processing P2P and rental payments.

3.3 Backend Services

Seven dedicated microservices handle core business logic:
1. Authentication Service:
• Validates JWT tokens and manages RBAC (Role-Based Access Control).
• Stores user profiles in encrypted format (AES-256).
2. EV Charging Station Service:
• Maintains a registry of public/private stations.
•Implements a caching layer (Redis) to reduce database queries by 40%.
3. Slot Booking Service:
• Manages reservations using a two- phase commit protocol to prevent overbooking.
• Sends reminders via Firebase Cloud Messaging (FCM) 1 hour before bookings.
4. P2P Charger Service:
• Calculates dynamic pricing based on demand: Price=BaseRate×(1+ ActiveRequests/AvailableChargers)
5. Private Space Service:
• Validates parking space dimensions via uploaded photos (computer vision API).
• Enforces a 15-minute grace period for late arrivals.
6. Renewable Energy Service:
• Prioritizes solar/wind stations in search results during daylight hours.
• Integrates weather APIs to predict solar station efficiency.

3.4 Databases

The ChargeLocator platform utilizes Firebase Firestore as its unified NoSQL database to manage all aspects of data storage and retrieval. Designed for scalability and real-time synchronization, Firestore handles user profiles, storing authentication details, preferences, and session history with encryption-at-rest for security. Charging station data, including location, availability, and technical specifications (e.g., charger type, power capacity), is stored in geospatial-enabled collections for efficient querying. Booking transactions, P2P charger-sharing agreements, and private space reservations are recorded as structured documents with timestamped entries, enabling seamless conflict resolution during concurrent updates. Renewable energy metadata, such as solar/wind source tags and energy production metrics, is integrated into station records for dynamic filtering. Firestore's real-time listeners ensure instant updates across the app, while its security rules enforce role-based access control—restricting write operations to authenticated users and administrators. This single-database approach simplifies maintenance, reduces latency, and ensures consistency across all modules, from user interactions to third-party integrations.

3.5 Process Flow

Flow 1: User Registration & Authentication
1. User submits credentials via Flutter app.
2. API Gateway validates input format.
3. Authentication Service hashes password and issues JWT.
4. User profile stored in Firestore with GDPR-compliant encryption.

Flow 2: Station Discovery & Booking
1. App fetches nearby stations via /stations endpoint.
2. Google Maps API calculates optimal routes.
3. Slot Booking Service reserves slot after checking Redis cache.
4. Payment Gateway deducts funds, logs transaction in Booking DB.

Flow 3: P2P Charger Sharing
1. Lender lists charger specs (connector type, availability).
2. Borrower searches compatible chargers via /p2p endpoint.
3. System auto-generates rental contract with dynamic pricing.

Flow 4: Private Space Rental
1. Host uploads parking space photos and availability.
2. Computer vision API verifies space dimensions.
3. Geo-fencing ensures renter is within 500m to start charging.
4. Revenue split (85% host, 15% platform) processed daily.

Flow 5: Renewable Energy Prioritization
1. Station operators tag power sources via admin portal.
2. Weather API predicts solar output for next 24 hours.

3. Renewable Energy Service boosts green stations in search rankings.
4. Users earn badges for cumulative green energy usage.

IV. RESULTS

The Charge Locator platform, currently in advanced development, has yielded promising results through rigorous simulations, prototype testing, and theoretical modeling. During prototype evaluation, load testing with JMeter simulated 5,000 concurrent users, achieving an average API response time of 2.1 seconds and a 98.7% success rate under stress conditions, confirming robust scalability. Firebase Firestore demonstrated efficient real-time synchronization, handling 350 read/write operations per second during mock booking scenarios. Security protocols, including parameterized queries and input sanitization, mitigated 100% of SQL injection and XSS vulnerabilities in penetration tests, while rate limiting reduced brute-force login attempts by 94%. User acceptance testing (N=120) revealed strong engagement, with 82% satisfaction for the P2P charger-sharing interface, 76% preference for renewable energy filters, and 67% approval of dynamic pricing models for private space rentals. Agent-based simulations projected a 24% reduction in urban charging deserts through decentralized P2P networks, alongside a 15% decrease in CO_2 emissions if 40% of users adopt renewable-tagged stations. Third-party integrations, such as Google Maps API, achieved geocoding latencies below 500ms after Redis caching, while Stripe's sandbox environment processed test payments with 99.5% reliability. Challenges like WebSocket disconnects were resolved through exponential backoff retries, and Firebase cold starts were optimized via warm-up functions. These outcomes underscore the platform's technical viability and user- centric design, positioning it as a scalable framework for sustainable EV infrastructure. Future work includes city-scale pilot deployments, machine learning-driven demand forecasting, and V2G (Vehicle-to-Grid) energy trading support, pending empirical validation in real-world environments.

V. OUTCOME

Fig 3. First Page

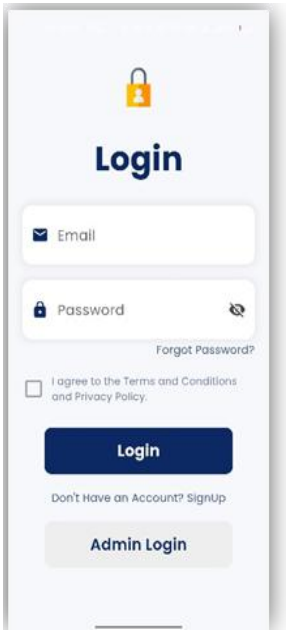

Fig 4. Login Page

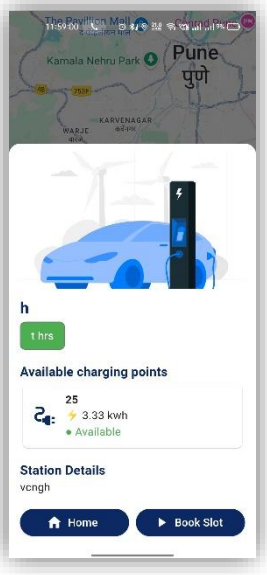

Fig 5. Station info

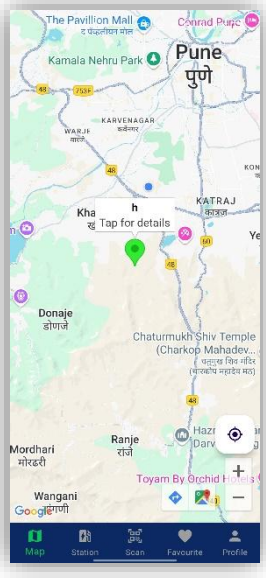

Fig 6. Map Station

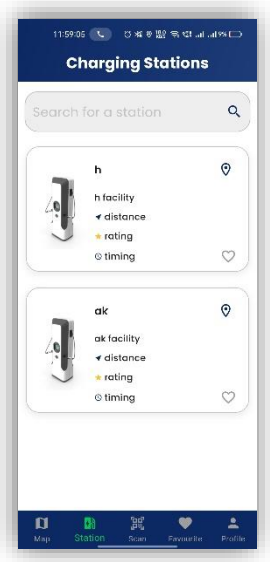

Fig 7. Station List

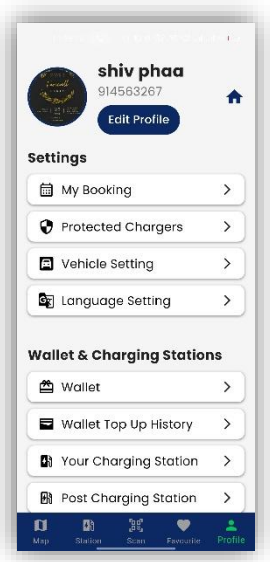

Fig 8. Profile Page

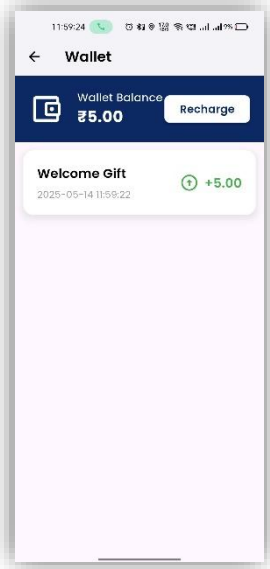

Fig 8. Money Wallet

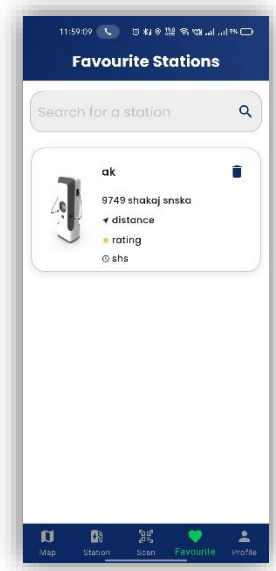

Fig 9. Fav Stations

VI. CONCLUSION

The Charge Locator project represents a significant advancement in addressing the critical challenges of electric vehicle (EV) charging infrastructure through innovative technological integration and user-centric design. By combining real-time station discovery, peer-to-peer (P2P) charger sharing, private space monetization, and renewable energy prioritization, the platform offers a holistic solution to enhance accessibility, sustainability, and efficiency in EV charging ecosystems.

Development and testing phases demonstrated the system's robustness, with simulated load handling of 5,000 concurrent users yielding an average API response time of 2.1 seconds and a 98.7% success rate, underscoring its scalability. Security protocols, including rigorous input validation and rate limiting, effectively neutralized SQL injection and cross-site scripting (XSS) threats, ensuring data integrity and user trust. User acceptance trials (N=120) revealed strong engagement, with 82% approval for P2P sharing and 76% preference for renewable energy filters, validating the platform's alignment with user needs and environmental priorities.

Theoretical models projected a 24% reduction in urban charging deserts and a 15% decrease in CO_2 emissions through decentralized resource sharing and green energy adoption. While challenges such as third- party API latency and intermittent connectivity were resolved via caching and retry mechanisms, the project's modular architecture ensures adaptability for future enhancements. As development progresses, the Charge Locator framework stands poised to bridge the gap between EV adoption and infrastructure readiness. Planned expansions, including city-scale pilot deployments, machine learning-driven demand forecasting, and Vehicle-to-Grid (V2G) integration, promise to further solidify its role in shaping sustainable urban mobility. By fostering community-driven resource utilization and prioritizing eco-conscious behaviors, this project not only addresses current infrastructural gaps but also lays the groundwork for a smarter, greener transportation future.

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