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(An autonomous Institute affiliated to Savitribai Phule Pune University)
Department of Computer Engineering

Artificial Intelligence and Machine Learning LAB

TY Comp: Batch A2

Smart EV Charging System
Using Predicitive Analysis &
Reward Based DynamicPricing

Group Number: 7

Group Members

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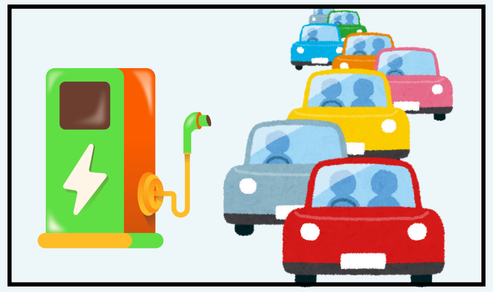
INTRODUCTION

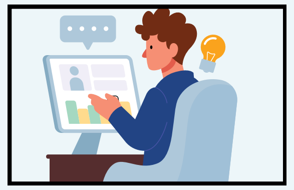
The rapid adoption of Electric Vehicles (EVs) is transforming the transportation landscape worldwide. With more EVs on the road, charging stations are under pressure to manage peak demand, optimize energy use, and ensure customer satisfaction.

Traditional charging infrastructure faces three major challenges:

Inefficient cost prediction: Stations cannot anticipate session costs accurately



Unbalanced grid load: peak-hour congestion and wasted renewable energy



Lack of personalization: no incentives for eco-friendly behavior

This project develops an intelligent EV Charging Analytics system using Machine Learning (ML), Time-Series Forecasting, and Dynamic Pricing. It predicts charging costs, forecasts demand, segments users, and adapts pricing in real-time, while encouraging green behavior through gamified rewards.

PROBLEM STATEMENT

- Limited forecasting for station-wise demand
- No real-time pricing adjustment
- No dynamic clustering of users
- Inability to compare EV impact vs. conventional vehicles
- Inefficient user engagement
- Lack of carbon-awareness

OBJECTIVES

- Predict total session cost.
- Segment users into behavioral clusters using KMeans.
- Forecast hourly and daily demand using ARIMA.
- Real-time, user-friendly GUI for interaction & simulation.
- Introduce green points & gamification to encourage sustainable behavior.
- Implement dynamic pricing based on demand
- Renewable energy share, and grid CO_2 intensity, Trees saved and Comparison with PConventional vehicles

DATASET

[Link to Dataset](#)

Number of Records: 2000+ charging sessions

Data Dimensions: 40+ columns capturing temporal, energy, vehicle, user, environmental, grid, anomaly, and payment details.

Session & Time Info

- session_start_time, session_end_time
- session_duration_min, hour_of_day, day_of_week, is_weekend
- session_date, event_day, holiday_flag, holiday_or_weekend

Station & Location Info

- station_id,
- location_city

Vehicle Info

- vehicle_type, battery_capacity_kWh, max_charger_power_kW
- start_soc_%, end_soc_%, expected_energy_from_soc_kWh

Energy & Cost Info

- charging_power_kW, energy_consumed_kWh, total_cost_INR
- price_per_kWh_INR, implied_cost_per_kWh

Environmental & Grid Info

- ambient_temperature_C, humidity_%
- renewable_share_%, grid_load_MW, carbon_intensity_gCO2_per_kWh

Traffic & Operational Metrics

- traffic_index, duration_diff_min, expected_total_cost_INR, cost_diff
- energy_vs_expected_kWh, energy_vs_max_pct, max_possible_energy_kWh

Anomalies & Gamification

- anomaly_flag, anomaly_reasons, cost_anomaly_flag, anomaly_score
- points_earned, points_redeemed

User & Payment Info

- user_id, payment_method, charging_session_status

FLOWCHART

Link to Code

01 — Data Acquisition

Load EV charging dataset from CSV.

02 — Preprocessing

Handle missing values, encode categorical variables, extract features, parse timestamps.

03 — Supervised Learning

- Random Forest Regression & Linear Regression
- Predict total charging cost (total_cost_INR)

04 — Time-Series Forecasting

ARIMA(2,0,2) for hourly demand prediction

05 — Clustering

StandardScaler + KMeans(n=3) Identify user/session behavior patterns

06 — Dynamic Pricing Engine

Load ML predictions, carbon intensity & reward pointsrging dataset from CSV.

07 — GUI

Tkinter-based interface for login, dashboard, charging simulation & dynamic price display

- The system starts by collecting raw EV charging data and preparing it for analysis: This ensures all inputs are clean, structured, and ready for machine learning.
- Machine learning models then learn from past sessions to predict future cost and demand: This helps the system make smarter decisions instead of using fixed rules.
- The dynamic pricing module adjusts charging prices based on demand, renewable energy and CO_2 levels: This makes the system fair, efficient, and environmentally responsible.
- User behavior is analyzed through clustering to understand different charging patterns: This helps in providing more personalized insights and rewards.
- The GUI ties everything together, allowing users to interact with the system in real time Users can view predicted prices, track rewards, and monitor their environmental impact easily.
- Overall, the workflow ensures accurate predictions, smart pricing, and a smooth end-to-end charging experience.

PREPROCESSING STEPS

MISSING VALUE HANDLING

- Numeric columns: replaced with column mean to avoid bias.
- Categorical columns: replaced with 0 or default to ensure no missing labels break encoding.
- Ensures smooth model training without NaN errors.

DATE - TIME PARSING

- Extracted hour-of-day, weekday, and weekend/holiday flags to capture temporal patterns.
- Computed session_duration_min from start and end times for use as a feature or analysis.
- Enables time-aware demand prediction for ARIMA and ML models.

LABEL ENCODING

- Converted categorical fields (station_id, location_city, vehicle_type, user_id) into integer IDs.
- Helps ML models handle non-numeric data efficiently.
- Maintains consistency for repeated categories.

FEATURE SELECTION

- Used all numerical columns except the target (total_cost_INR) for regression tasks.
- Excluded cluster labels to prevent data leakage.
- Ensures models learn from relevant information and generalize well.

PREPROCESSING GOAL

Clean, structured, ML-ready dataset for cost prediction, demand forecasting, clustering & dynamic pricing

SUPERVISED LEARNING – COST PREDICTION

Models Used

- Random Forest Regressor: handles nonlinear relationships and interactions between features.
- Linear Regression: checks if a simple linear relationship exists.

Data Splitting

- Train/Test Split: 75% training, 25% testing to evaluate model generalization.
- Ensures we don't overfit and can measure real-world performance.

Metrics Computed

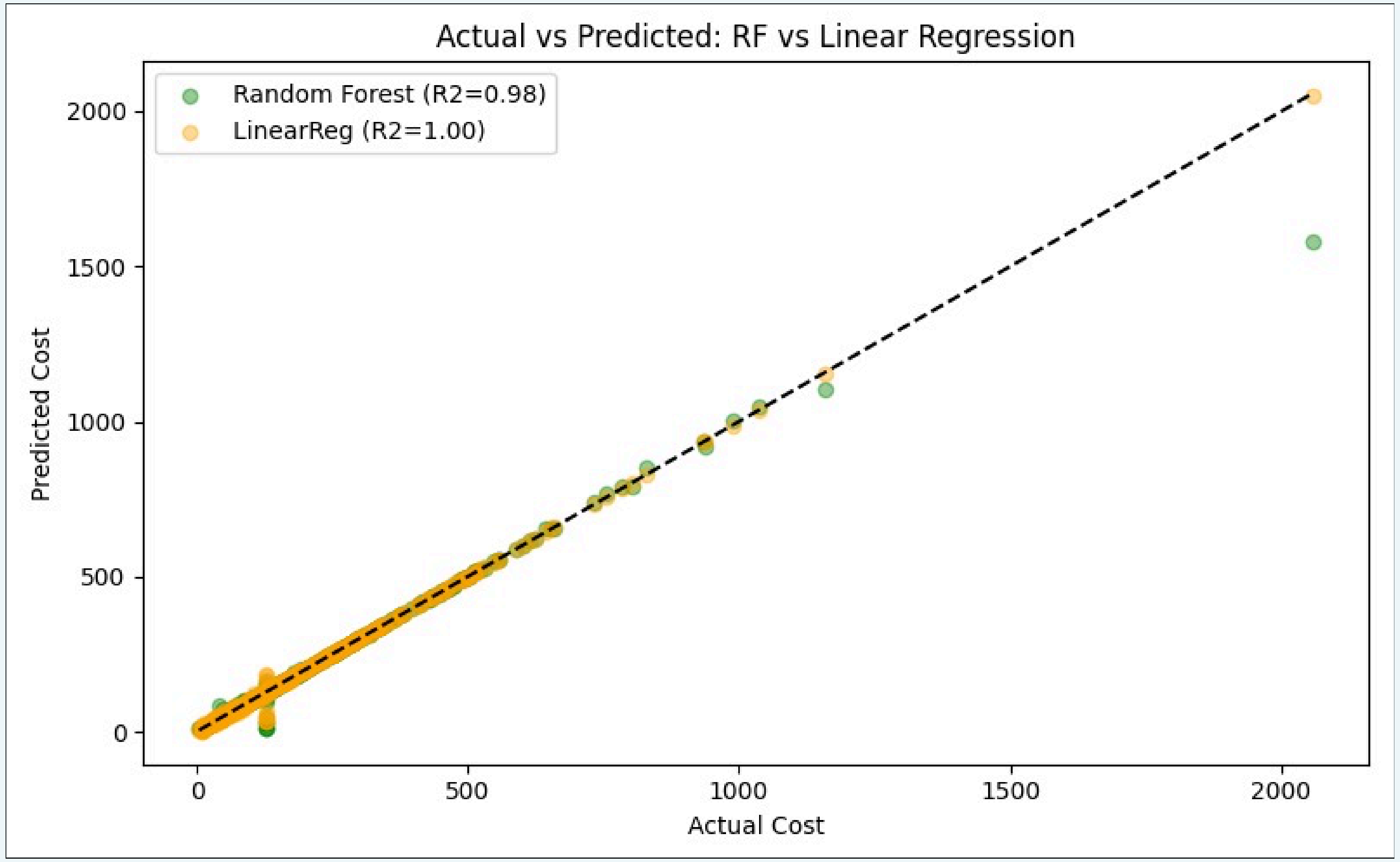
- **R^2 (Coefficient of Determination):** indicates how well predictions match actual values.
- **MAE (Mean Absolute Error):** average absolute difference between predicted and actual costs.
- **RMSE (Root Mean Squared Error):** emphasizes larger errors, useful for sensitive predictions.

Comparison & Insights

- Random Forest often performs better for complex, nonlinear data.
- Linear Regression gives a baseline; good if features are linearly related.

Visualization

- Scatter plot of Actual vs Predicted for both models highlights accuracy and deviations.
- Allows quick understanding of model performance across the dataset.



ARIMA TIME SERIES ANALYSIS

Forecast EV charging demand for upcoming hours to optimize station usage and pricing.
Helps in planning for peak hours, energy supply, and staff allocation.

Data Preparation

- Extract hourly sessions from session_start_time.
- Focus on most active city for meaningful forecasts.
- Missing hours filled with 0 sessions for continuous time series.

ARIMA Model

- ARIMA(p,d,q):
  - p = autoregressive term
  - d = differencing order to make series stationary
  - q = moving average term
- Captures trends and patterns in historical session counts.

Forecasting

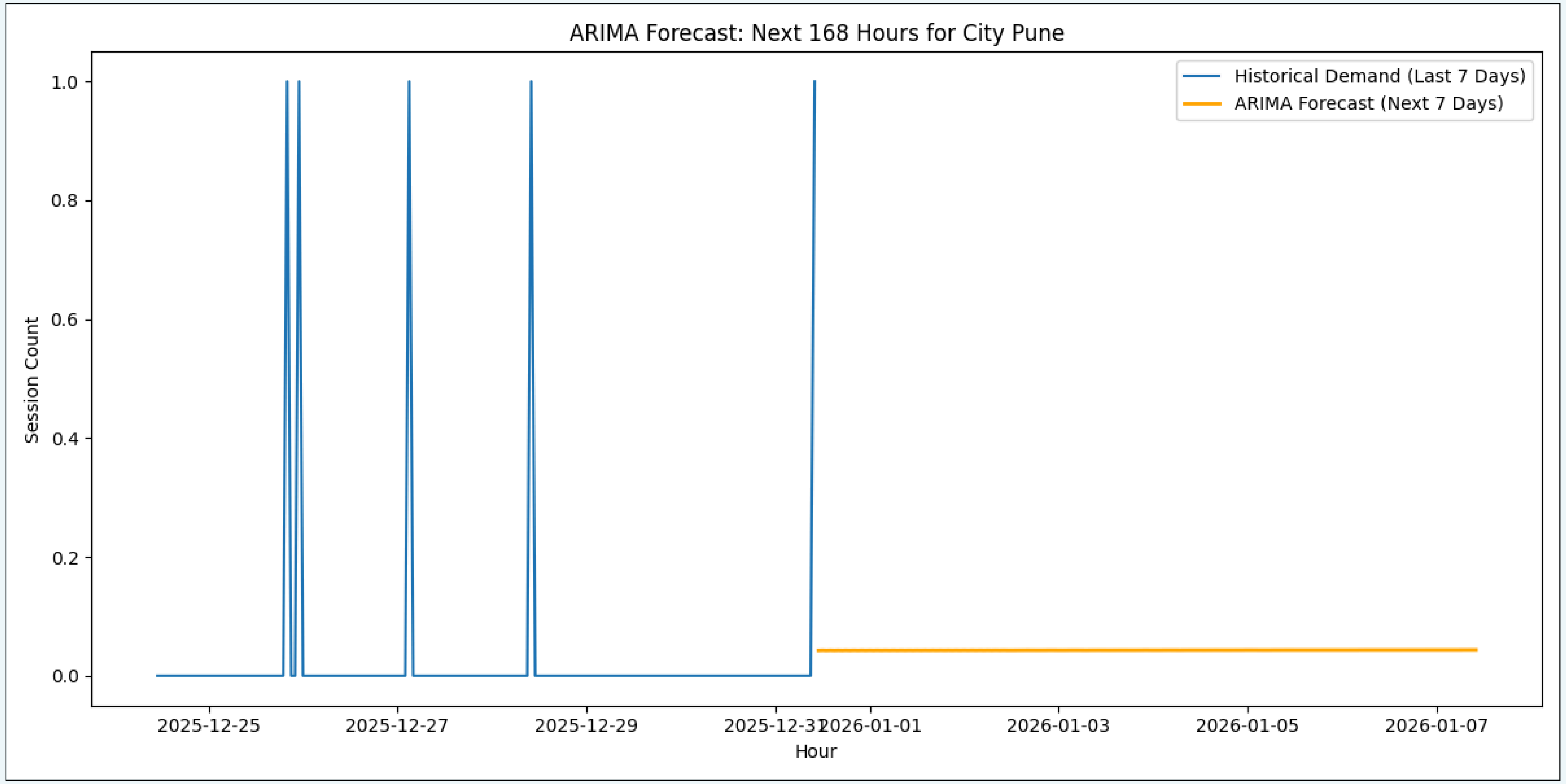
- Predicts weekly sessions of EV charging demand.
- Visualized as a line plot showing historical vs predicted values.

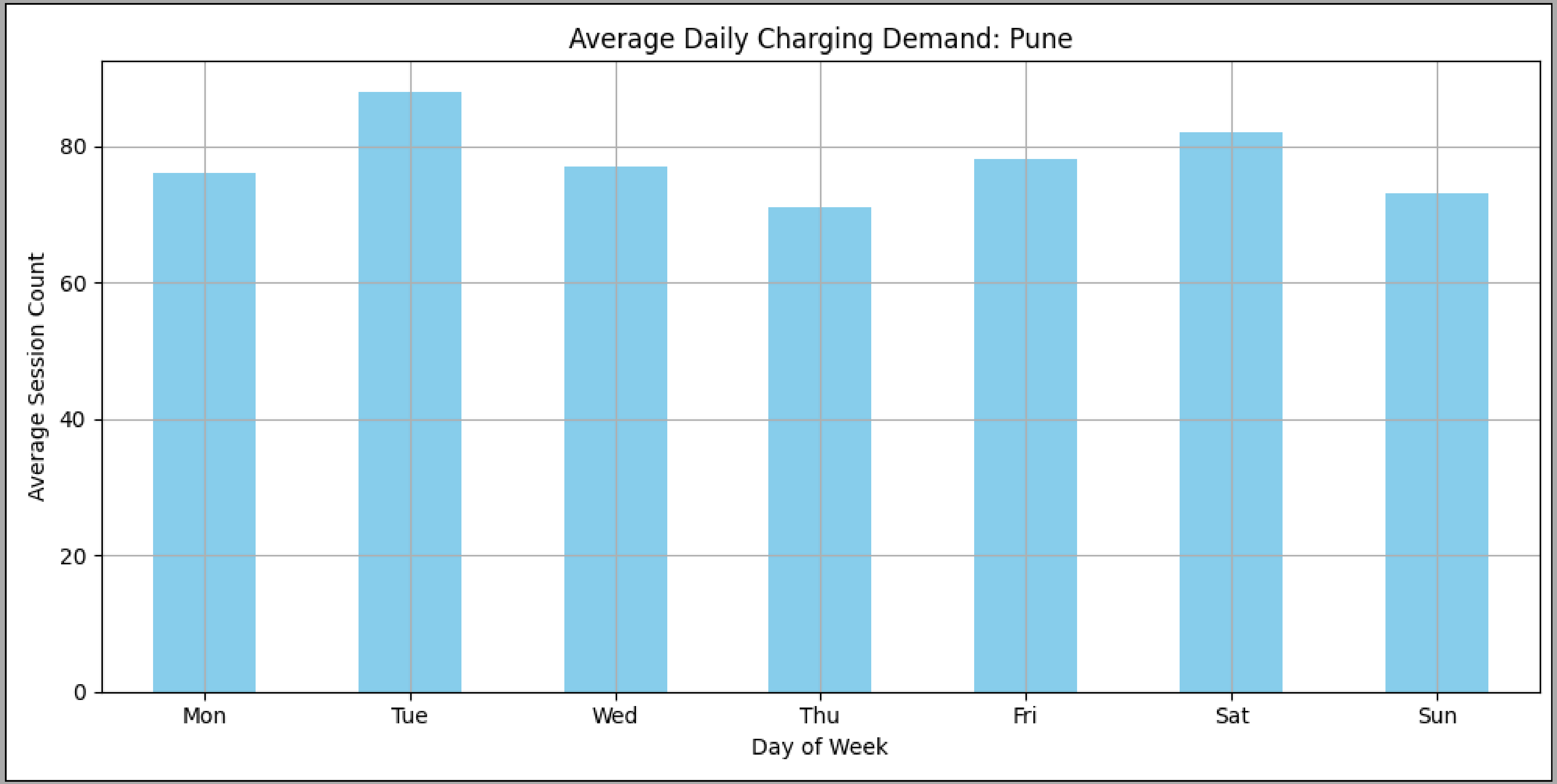
Insights

- Identify peak charging hours.
- Plan dynamic pricing and resource allocation based on predicted demand.
- Early identification of low-demand hours helps offer discounts or promotions.

Visualization

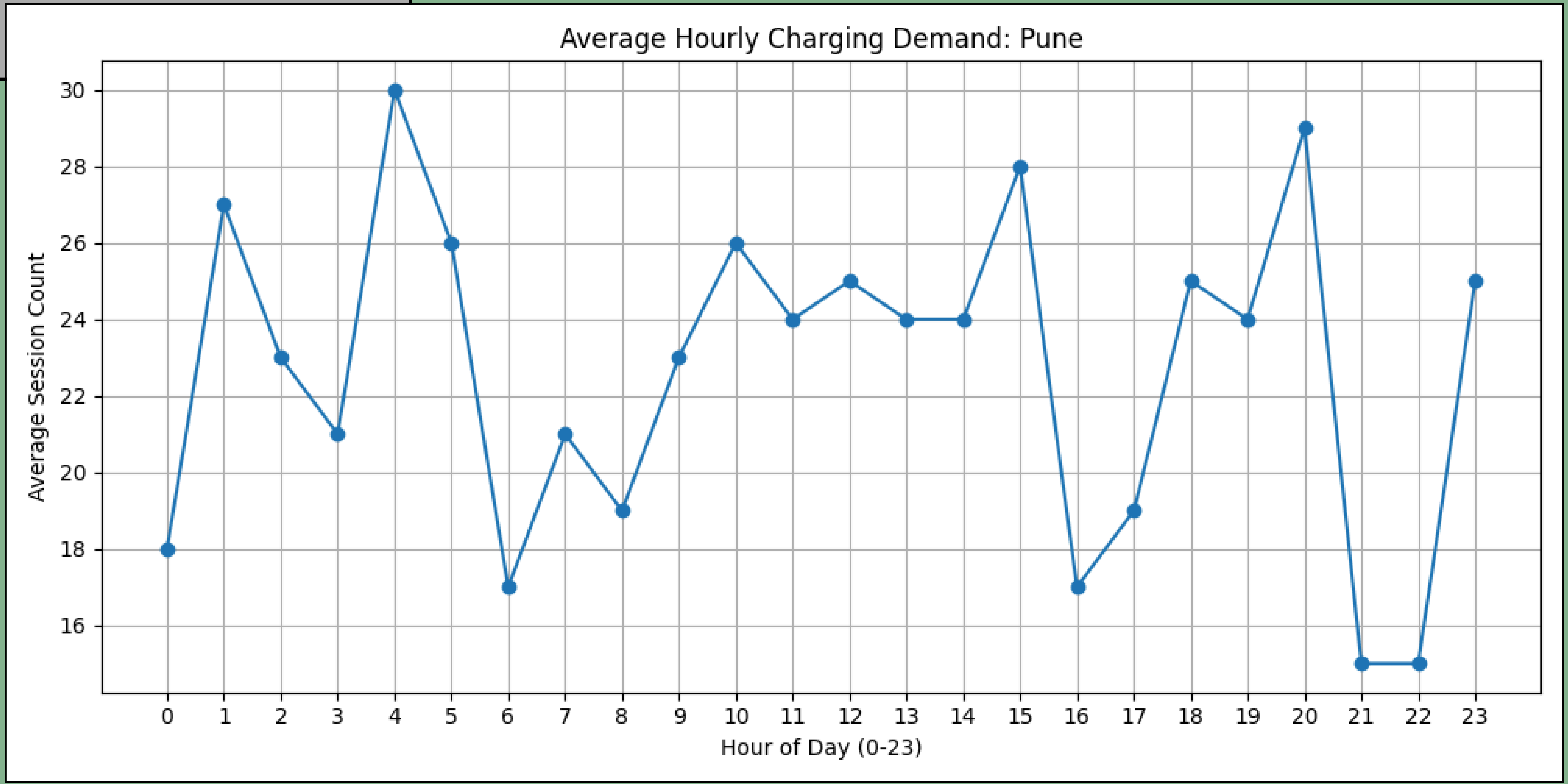
- Plot of historical sessions (blue) vs ARIMA forecast (orange) for easy comparison.
- Forecast allows data-driven decision making for station management.





DAILY DEMAND

HOURLY DEMAND



UNSUPERVISED LEARNING - KMEANS CLUSTERING

Data Preparation

- Selected numerical features excluding target variables (total_cost_INR, duration_hours, etc.).
- Standardized features using StandardScaler for uniform clustering.

KMeans Algorithm

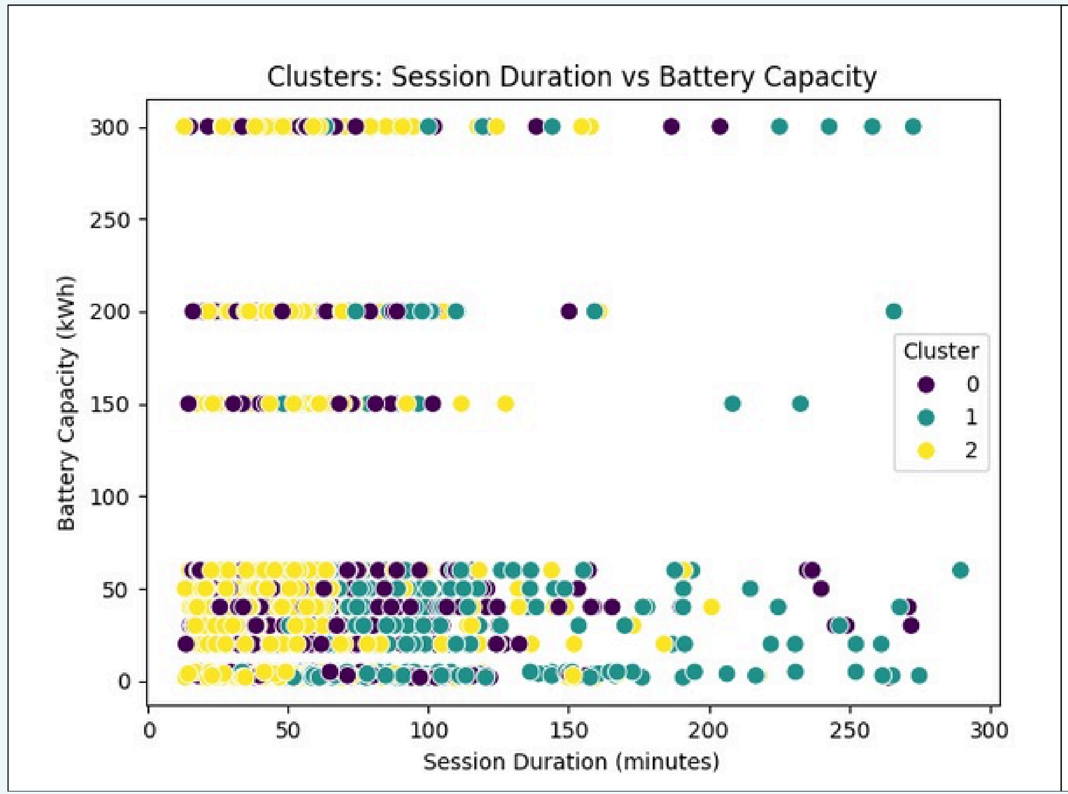
- Iteratively assigns sessions to clusters to minimize within-cluster variance (WCSS).
- Used the Elbow Method to choose optimal number of clusters **(k=3)**.
- Calculated Silhouette Score to measure cluster quality.

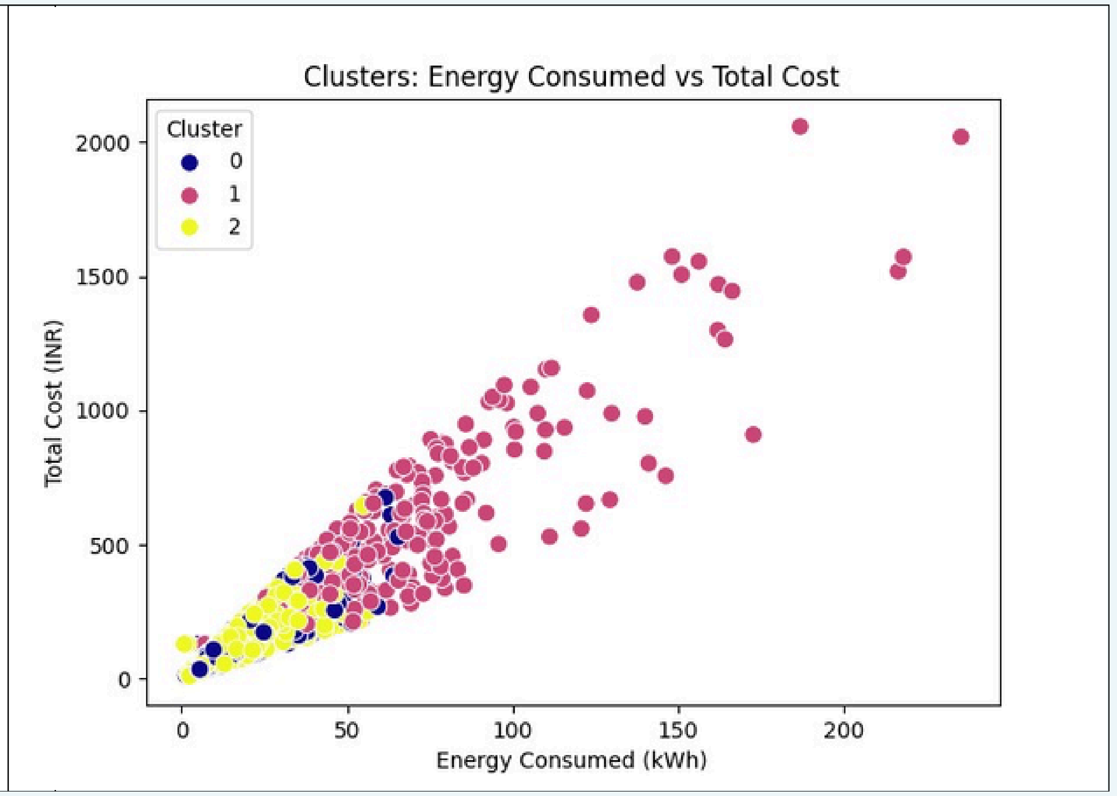
Cluster Insights

- **Cluster 0:** Represents balanced or average charging behavior, appearing across short, medium, and long sessions due to multi-feature clustering.
- **Cluster 1:** Shows higher variability in energy usage and cost, indicating diverse charging patterns rather than a specific session length or battery size.
- **Cluster 2:** More frequently observed in lower-duration and lower-energy sessions, but still overlaps with other ranges because clusters form from combined features.
- These clusters reflect multi-dimensional user behavior patterns and can be used to design targeted incentives, personalized pricing, and improved station scheduling.

Visualization

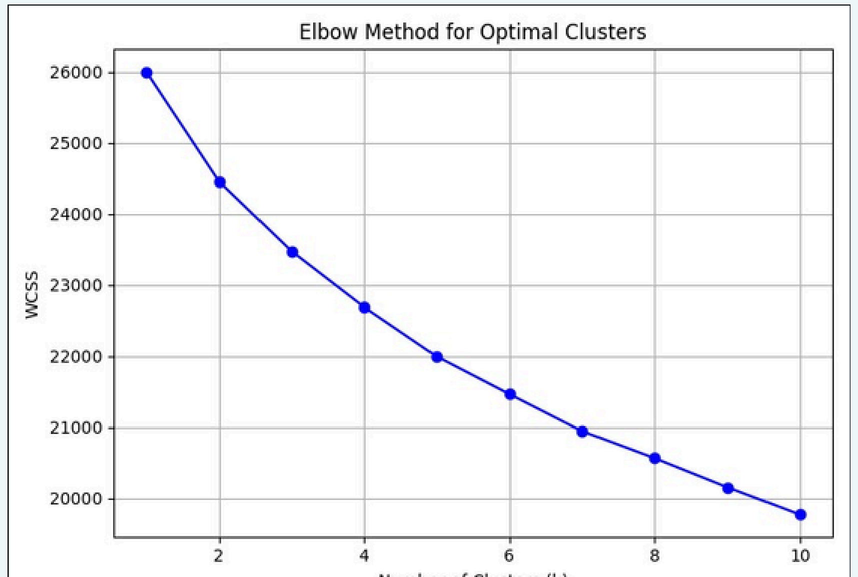
- Session Duration vs Battery Capacity colored by cluster.
- Energy Consumed vs Total Cost colored by cluster.
- These visualizations reveal behavioral patterns for each cluster.





Business Implications

- Plan charging slots for different user types.
- Predict demand spikes for high-energy sessions.
- Personalize dynamic pricing based on cluster behavior.



FEATURES

01

CO_2 & Environmental Impact Calculator

- Compares EV vs Petrol for every charge session.
- Computes:

1. Total EV CO_2
2. Equivalent petrol CO_2
3. CO_2 saved in grams
4. Trees-equivalent impact (1 tree ≈ absorbs 21,000 gCO_2).

- Gives user a clear environmental motivation.

02

Reward System (Green Points)

- User earns 1–2 points per eco-friendly session.
- Points can be redeemed for discounts in future sessions.
- System tracks:

1. Total sessions
2. Average CO_2 footprint
3. Total “trees saved”

- Unlocks a “Super Green Badge” for consistently low emissions.

03

Dynamic Pricing Algorithm

- Demand prediction based on hour, day, city, and grid conditions.
- Adjusts price using a multiplier:

1. High demand: higher price
2. Low demand: discounted price
3. Low carbon intensity: eco-discount

- Ensures fairness: Minimum price = ₹5 regardless of inputs.
- GIVES notifications on Peak Hours/Off Peak Price Drops
- Allows to choose cheapest stations in the city

04

Automated Session Logging

Every charging session is logged into session_logs.csv:

- User ID
- Timestamp
- Price before/after discount
- Points used/earned
- Avg CO_2
- Trees contributed
- Badge status
- This helps with:
  - ✓ Monitoring long-term user behavior
  - ✓ Auditing price decisions
  - ✓ Future analytics or dashboards

These features work together to make EV charging smarter and greener. CO_2 impact tracking shows how much pollution and trees you save, while Green Points reward eco-friendly charging. Dynamic Pricing adjusts rates fairly based on demand and renewable energy, and automatic session logging keeps all activity transparent for users and analytics.

TKINTER GUI INTEGRATION

A full desktop UI that connects ML + business logic + user profile.

01 Login Panel

- Simple authentication using User ID.
- Creates a profile if user is new.

02 Home Dashboard

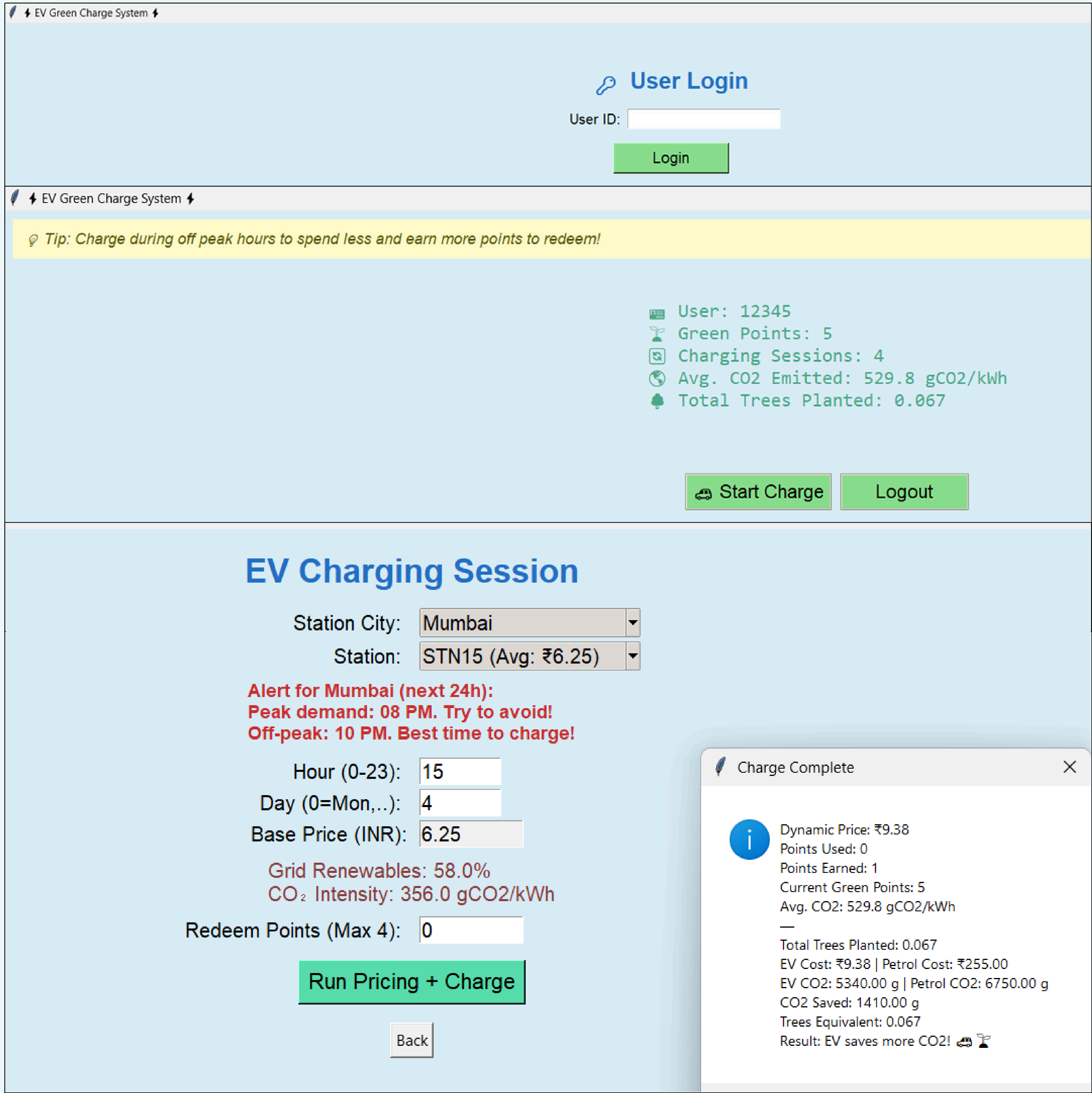
- Shows:
  - Green points
  - Total sessions
  - Avg. CO_2 emission
  - Total trees saved
  - Current badge
- Clean and formatted using custom styles.

03 Charging Screen

- User selects:
- City
- Hour
- Day
- Optimal Station
- Redeemable points
- System fetches:
- Random real-time grid renewable %
- Random CO_2 intensity (200-700 g/kWh)

04 Final Output Popup

- Shows final price
- Environmental impact
- Updated reward status
- Comparison: EV vs Petrol
- All logs automatically stored.



FUTURE SCOPE

SMART AI AND CONNECTED DEVICES

Make charging smarter by predicting demand, adjusting prices automatically, and showing real-time environmental impact using connected sensors and AI.

ROUTE-BASED SMART CHARGING

Integrate Google Maps APIs to suggest optimal charging stops, predict charging availability ahead, and recommend low-carbon routes.

MULTI-STATION LOAD BALANCING

Distribute demand intelligently among nearby stations to avoid local grid congestion, peak overloads, and long wait times.

FEDERATED LEARNING FOR COLLABORATION

Enable multiple stations to share insights and improve predictions without exposing raw customer data.

CONCLUSION

- The system successfully integrates Machine Learning, Time-Series Forecasting, and Clustering to improve EV charging intelligence.
- **Our ML model** provides accurate **charging cost predictions** using real session data.
- **ARIMA forecasting helps anticipate future demand** and supports better grid & station planning.
- **KMeans clustering identifies distinct user** and **charging behavior patterns** for personalized insights.
- The **Dynamic Pricing** Engine adapts charging **cost based on demand**, carbon intensity, and user behavior.
- **CO_2 calculator and tree-equivalent** impact provide clear environmental awareness to users.
- **Green Points reward system encourages eco-friendly charging habits** and long-term behavior improvement.
- **Tkinter GUI offers a user-friendly interface** with login, simulation, dynamic pricing, and rewards.
- **Automated session logging enables long-term analytics**, audits, and future dashboard development.
- Overall, the project provides a complete end-to-end EV charging analytics solution suitable for smart cities, sustainable mobility, and real-world deployment.

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- Kaggle — Electric Vehicle Charge Sessions Data
- Kaggle — Electricity Price Forecasting Dataset

Thank You!

Dynamic pricing makes EV charging smarter, fairer, and greener for everyone.